Principles and Practices of Weed Management

Third Edition

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(2019)

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2019

DEPARTMENT OF AGRONOMY

CSK Himachal Pradesh Krishi Vishvavidyalaya

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Citation
Rana SS and MC Rana. 2019. Principles and Practices of Weed Management - Third Edition. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 166 pages.

Edition

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PREFACE

Weeds are probably the most ever-present class of crop pests and are responsible for marked losses in crop yields. Of the total losses caused by pests, weeds have a major share (30%). They reduce the crop yield and deteriorate the quality of produce and hence reduce the market value of the turnout. Therefore, management of weeds in all agro-ecosystems is imperative to sustain our crop productivity and to ensure the food security to the burgeoning population.

There has been a long-felt need for a teaching manual on Principles and Practices of Weed Management. This manual is a precise account of various theoretical aspects of weed management presented in a simple language suitable for Agron 503 students. The manual has been divided in 5 units. The first unit covers classification and characteristics of weeds, special weed problems including aquatic and parasitic weeds, ecology and physiology of major weeds and ecophysiology of crop-weed competition including allelopathy. In the second unit principles and methods of weed control, concept of integrated weed management, principles of chemical weed control and weed control through bioherbicides are discussed. Third unit constitutes of mode and mechanism of action of herbicides, herbicide selectivity, herbicide combinations, adjuvants and safeners, degradation of herbicides in soils and plants, effect of herbicides in relation to environment and herbicide resistance in weeds and crops. In the fourth unit weed management in major crops and cropping systems, weed shifts in cropping systems and control of weeds in non-cropped situations including grasslands, pastures, tea gardens, orchards and aquatic ecosystem in hills are covered. The fifth unit included cost: benefit analysis of weed management and weed indices. In this edition an exercise has been added at the end of each unit to benefit the students.

With all these varied aspects covered in the manual, we hope this will fulfill the requirement of a much needed standard document on Principles and Practice of Weed Management not only for the students but also for the teachers, scientists and others involved the field of weed management. The authors would welcome additional information and suggestions from students and teachers to improve the manual.

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CONTENTS

UNIT I

Classification and characteristics of weeds, special weed problems including aquatic and parasitic weeds, ecology and physiology of major weeds, ecophysiology of crop-weed competition including allelopathy.

WEED

In natural habitat there are four types of plants: crop plants, wild plants, rogue plants, and weed plants. Crop plants are those which are intensely cultivated by man for his welfare. Wild plants are those which grow voluntarily in nature in an un-controlled way and do not interfere with man's activities. Rogues are off type economic crop plants in same crop fields. **Weeds are those plants which are out of place, unwanted, non-useful, often prolific and persistent, competitive, harmful, even poisonous which interfere with agricultural operation, increase labour, add to costs, reduce yields and detract from comforts of life** (Crafts and Robbins, 1973).

Weeds are defined in many ways, but most definitions emphasize behavior that affects humans. The most basic concept of weed science is embodied in the word 'weed' itself. Each weed scientist has a clear understanding of the term, but there is no universal definition that is accepted by all scientists. The term 'weed' for the plants other than crop in the field, first time was given by Jethro Tull in his book 'Horse Hoeing Husbandry'. Plants, that come up in any land, of a different kind from the sown or planted crop, are weeds (Jethro Tull, 1731). In other words, **weeds are the plants, which grow where they are not wanted**. In 1967 the Weed Science Society of America defined a weed as "**a plant growing where it is not desired**" (Buchholtz, 1967). In 1989 the Society's definition was changed to define a weed as "**any plant that is objectionable or interferes with the activities or welfare of man**" (Humburg, 1989, p. 267; Vencill, 2002, p. 462). The European Weed Research Society defined a weed as "**any plant or vegetation, excluding fungi, interfering with the objectives or requirements of people**" (EWRS, 1986). Although the definitions are clear, they are not accepted by all scientists. These definitions leave their interpretations with people, so they must be the ones to determine when a particular plant is growing where it is not wanted or where it interferes with their activities or welfare. In the *Oxford English Dictionary* (Little et al., 1973) a weed is defined as a "**herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation**."

The human role is again clear because it is we who determine use or beauty and which plants are to be regarded as superior. It is important that weed scientists remember the importance of definitions as determinants of their views of plants and attitudes toward them.

Harlan and de Wet (1965) assembled several definitions to show the diversity of definitions of the same or similar plants (Zimdahl 2007). The array of definitions emphasizes the care weed scientists and vegetation managers must take in equating how something is defined with a right or privilege to control.

Definitions from plant scientists

"A plant out of place or growing where it is not wanted" W.S. Blatchley 1912

"A plant that is growing where it is desired that something else shall grow" A.E. Georgia 1916

"The obnoxious plants are known as weeds" W.W. Robbins et al. 1942

"Those plants with harmful or objectionable habits or characteristics which grow where they are not wanted, usually in places where it is desired that something else should grow" W.C. Muenscher 1946

"Higher plants which are a nuisance" J.L. Harper 1960

"A plant growing where we do not want it" E.J. Salisbury 1961

"A plant growing where it is not desired; or a plant out of place" G.C. Klingman 1961

Definitions by enthusiastic amateurs

"A plant whose virtues have not yet been discovered" R.W. Emerson 1912

"Weeds have always been condemned without a fair trial" F.C. King 1951

Ecological definitions

"Weeds are pioneers of secondary succession, of which the weedy arable field is a special case" A.H. Bunting 1960

"A plant which contests with man for the possession of the soil" W.S. Blatchley 1912

"Opportunistic species that follow human disturbance of the habitat" T. Pritchard 1960

"The cosmopolitan character of many weeds is perhaps a tribute both to the ubiquity of man's modification of environmental conditions and his efficiency as an agent of dispersal" E.J. Salisbury 1961

"A weed is defined as a plant which has, or has the potential to have, a detrimental effect on economic, social or conservation values." (Definition adopted in Western Australia) Western Australia's State Weed Plan

Aldrich (1984) and Aldrich and Kremer (1997, p. 8) offered a definition that does not deny the validity of others but introduces a desirable ecological base. A weed is "**a plant that originated in a natural environment and, in response to imposed or natural environments, evolved, and continues to do so, as an interfering associate with our crops and activities.**" This definition provides "both an origin and continuing change perspective" (Aldrich, 1984). Aldrich wants us to recognize weeds as part of a "dynamic, not static, ecosystem." His definition departs from those that regard weeds as enemies to be controlled. Its ecological base defines weeds as plants with particular, perhaps unique, adaptations that enable them to survive and prosper in disturbed environments. Navas (1991) also included biological and ecological aspects of plants and effects on man in his definition. A weed was defined as "**a plant that forms populations that are able to enter habitats cultivated, markedly disturbed or occupied by man, and potentially depress or displace the resident plant populations which are deliberately cultivated or are of ecological and/or aesthetic interest**." Although all do not agree on precisely what a weed is, most know they are not desirable. Those who want to control weeds must consider their definition.

When the term weed is borrowed from agriculture and applied to plants in natural communities, a verification of negative effect on the natural community should be a minimal expectation. Simple yield affects are not acceptable, but the effects of the presumed weed in a natural community can be estimated in terms of a management goal such as establishment of presettlement conditions, preserving rare species, maximizing species diversity, or maintaining patch dynamics (Luken and Thieret, 1996). Many recognize the human role in creating the negative, often deserved, image. Weeds are detrimental and often must be controlled but only with adequate justification for the site and conditions.

Weeds interface with the utilization of natural resources, harmful, dangerous, prolific, persistent, resistant, competitive, even poisonous, economically detrimental and can grow under adverse climatic conditions. Weeds are a serious threat to primary production and biodiversity. Weeds compete with crop for water, nutrients and light and have been a matter of great concern to the growers. They reduce farm and forest productivity, displace native species and contribute significantly to land and water degradation. The costs of weeds to the natural environment are also high, with weed invasion being ranked second only to habitat loss in causing biodiversity decline. They exhibit allelopathy, competition and parasitism (Hussain, 1980; 1983; Hussain *et al*., 1985; Hussain and Khan, 1987). The different environmental conditions determine the specific weed spectrum, composition and population of each region (Memon *et al*., 2007). The reduction in yield due to weed-crop competition mainly depends on weed species and their densities as well as crop species. As the distribution and infestation intensity of each weed is different, so the extent of crop yield reduction will mainly depend on the number and kind of weeds found in the field (Frisbie *et al*., 1989).

CLASSIFICATION OF WEEDS

There are at least 450 families of flowering plants and well over 350,000 different species. Only about 3,000 of them have been used by humans for food. Fewer than 300 species have been domesticated, and of these, there are about 20 that stand between humans and starvation. There are at least 100 species of great regional or local importance, but only a few major species dominate the human food supply. Only about 15 plants provide most of the food that humans have consumed for many generations.

Twelve plant families include 68% of the 200 species that are the most important world weeds (Holm, 1978). These weeds share certain characteristics, including 1). long seed life in soil, 2). quick emergence, 3). ability to survive and prosper under the disturbed conditions of a cropped field, 4). rapid early growth and 5). no special environmental requirements for seed germination.

They are also competitive and react similarly to crop cultural practices. Weeds are usually defined primarily by where they are and how that makes someone feel about them. The fact that they may have shared characteristics means we may be able to define and classify them based on what their genotype enables them to do. Some characteristics that weeds share are discussed later on in this chapter.

Table 1.1 lists the 12 plant families that include 68% of the world's important weed problems. The Poaceae and Cyperaceae account for 27% of the world's weed problems, and when the Asteraceae are added, 43% of the world's worst weeds are included. Nearly half of the world's worst weeds are in only 3 families, and any 2 of these include over a quarter of the world's worst weeds.

The Poaceae is the family having most weedy species and also the family that includes many of the important crops that feed humans: wheat, rice, barley, millet, oats, rye, corn, sorghum and sugar cane.

About two-thirds of the world's worst weeds are single-season or annual weeds. The rest are perennials in the world's temperate areas, but in the tropics, they are accurately called several-season weeds. The categories *annual* and *perennial* do not have the same meaning in tropical climates, where growth is not limited by cold weather but may be limited by low rainfall. About two-thirds of the important weeds are broadleaved or dicotyledonous species. Most of the rest are grasses, sedges, or ferns. The United States has about 70% of the world's important weeds and they may be classified in different ways.

Table 1.1. Families of the World's Worst Weeds (Holm, 1978)

Family	Number of species	Percent of total		
Poaceae	44	27	43	68
Cyperaceae	12			
Asteraceae	32			
Polygonaceae	8			
Amaranthaceae	7			
Brassicaceae	7			
Luguminosae	6			
Convolvulaceae	5			
Euphorbiaceae	5			
Chenopodiaceae	4			
Malvaceae	4			
Solanaceae	4			
Total	138			

I. Phylogenetic relationships

Weeds are classified by taxonomists and weed scientists the same way as all other plants and species based on phylogenetic (from the Greek *phylo* or *phulon*, meaning "race" or "tribe," plus the Greek *gen*, meaning "be born of" or "become") relationships, or a plant's ancestry.

Phylogenetic keys to plant species, based on ancestry and ancestral similarity, include division, subdivision, class, family, genus, and species. A brief description of a plant key for weed species follows:

Division I—Pteridophyta

Description—Fernlike, mosslike, rushlike, or aquatic plants without true flowers. Reproduce by spores.

Representative families: Salviniaceae, Equisetaceae, Polypodiaceae

Division II—Spermatophyta

Description—Plants with true flowers with stamens, pistils, or both. Reproduce by seed containing an embryo.

Subdivision I—Gymnospermae

Description—Ovules not in a closed ovary. Trees and shrubs with needle-shaped, linear, or scalelike, usually evergreen leaves.

Representative families: Pinaceae, Taxaceae

Almost no weedy species.

Subdivision II—Angiospermae

Description—Ovules borne in a closed ovary that matures into a fruit.

Class I—Monocotyledoneae

Description—Stems without a central pith or annular layers but with woody fibers. Embryo with a single cotyledon. Early leaves always alternate. Flower parts in threes, or sixes, never fives. Leaves mostly parallel veined.

Representative families: Poaceae, Cyperaceae, Juncaceae, Liliaceae, Commelinaceae

Class II—Dicotyledoneae

Description—Stems formed of bark, wood, and pith with the wood between the other two and increasing with annual growth. Leaves net-veined. Embryo with a pair of opposite cotyledons. Flower parts mostly in fours and fives.

Representative families: Polygonaceae, Chenopodiaceae, Convolvulaceae, Asteraceae, Solanaceae

All classified plants have a genus and specific name. By convention, the genus is always capitalized (e.g., *Amaranthus*) and is commonly written in italics or underlined. The species name is not capitalized.

Other common and less systematic classification methods for weeds are based on life history, habitat, morphology, or plant type etc. Knowledge of classification is important because a plant's ancestry, length of life, the time of year during which it grows and reproduces, and its method or methods of reproduction provide clues about management methods most likely to succeed.

II. Based on life span

Based on life span (Ontogeny), weeds are classified as Annual weeds, Biennial weeds and Perennial weeds.

a. Annual Weeds

Weeds that live only for a season or a year and complete their life cycle in that season or year are called as annual weeds. These are small herbs with shallow roots and weak stem. Produces seeds in profusion and the mode of propagation is commonly through seeds. After seeding the annuals die away and the seeds germinate and start the next generation in the next season or year following.

Most common field weeds are annuals. The examples are

a. Monsoon annual e.q. *Commelina benghalensis, Boerhavia erecta*

b. Winter annual e.q. *Chenopodium album*

There are also plants with much shorter life cycles than those mentioned before. These plants are known as ephemeral plants. The word ephemeral means transitory or quickly fading. You may gather from this that the plants live their lives - germinate, produce seeds, flower, and die - quickly. Ephemeral plants are usually classified under three types: spring, desert, and weedy.

The first, spring ephemeral, refers to perennial plants that emerge quickly in the spring and die back to their underground parts after a short growth and reproduction phase. Examples include: spring beauties, trilliums, and harbinger of spring. Desert ephemerals such as the *Arabidopsis thaliana* are plants which are adapted to take advantage of the short wet periods in arid climates. Mud-flat annuals take advantage of short periods of low water. In areas subjected to recurring human disturbance, such as plowing, weedy ephemerals are very short lived plants whose entire life cycle takes less than a growing season. Examples include: *Cardamine hirsuta* and *Cannabis ruderalis*. In each case, the species has a life cycle timed to exploit a short period when resources are freely available.

b. Biennials

It completes the vegetative growth in the first season, flower and set seeds in the succeeding season and then dies. These are found mainly in non-cropped areas e.g. *Alternanthera echinata, Daucus carota.*

(c) Perennials

Perennials live for more than two years and may live almost indefinitely. They are adapted to withstand adverse conditions. They propagate not only through seeds but also by underground stem, root, rhizomes, tubers etc. and hence are further classified into

i. **Simple perennials:** Plants propagated only by seeds. e.g. *Sonchus arvensis*

ii. **Bulbous perennials:** Plants which possess a modified stem with scales and reproduce mainly from bulbs and seeds. e.g. *Allium* sp.

iii. **Corm perennials** Plants that possess a modified shoot and fleshy stem and reproduce through corm and seeds. Eg. *Timothy* (*Phleum pratense*)

iv. **Creeping perennials:** Reproduced through seeds as well as with one of the following.

  a. **Rhizome:** Plants having underground stem – *Sorghum halapense*
  b. **Stolon:** Plants having horizontal creeping stem above the ground – *Cynodon dactylon*
  c. **Roots:** Plants having enlarged root system with numerous buds – *Convolvulus arvensis*
  d. **Tubers:** Plants having modified rhizomes adapted for storage of food – *Cyperus rotundus*

III. Based on ecological affinities

a. Wetland weeds

They are tender annuals with semi-aquatic habit. They can thrive under waterlogged and partially dry condition as well. Propagation is chiefly by seed. Eg. *Ammania baccifera, Eclipta alba*

b. Garden land weeds (Irrigated lands)

These weeds neither require large quantities of water like wetland weeds nor can they successfully withstand extreme drought as dryland weeds. e.g. *Trianthema portulacastrum, Digera arvensis*

c. Dry lands weeds

These are usually hardy plants with deep root system. They are adapted to withstand drought on account of mucilaginous nature of the stem and hairiness. Eg. *Tribulus terrestris, Argemone mexicana.*

IV. Based on soil type (Edaphic)

(a) **Weeds of black cotton soil:** These are often closely allied to those that grow in dry condition. Eg., *Aristolochia bracteata*

(b) **Weeds of red soils:** They are like the weeds of garden lands consisting of various classes of plants. Eg. *Commelina benghalensis*

(c) **Weeds of light, sandy or loamy soils:** Weeds that occur in soils having good drainage. Eg. *Leucas aspera*

(d) **Weeds of laterite soils:** Eg. *Lantana camara, Spergula arvensis*

V. Based on place of occurrence

(a) **Weeds of crop lands:** The majority of weeds infests the cultivated lands and cause hindrance to the farmers for successful crop production. Eg. *Phalaris minor* in wheat

(b) **Weeds of pasture lands:** Weeds found in pasture / grazing grounds. Eg. *Indigofera enneaphylla*

(c) **Weeds of waste places:** Corners of fields, margins of channels etc., where weeds grow in profusion. Eg. *Gynandropsis pentaphylla*, *Calotropis gigantea*

(d) **Weeds of playgrounds, road-sides:** They are usually hardy, prostrate perennials, capable of withstanding any amount of trampling. Eg. *Alternanthera echinata, Tribulus terestris*

VI. Based on Origin

(a) **Indigenous weeds:** All the native weeds of the country are coming under this group and most of the weeds are indigenous. Eg. *Acalypha indica, Abutilon indicum*

(b) **Introduced or Exotic weeds:** These are the weeds introduced from other countries. These weeds are normally troublesome and control becomes difficult. Eg. *Parthenium hysterophorus, Phalaris minor, Acanthospermum hispidum.*

VII. Based on cotyledon number

Based on number of cotyledons it possess it can be classified as dicots and monocots. (a) Monocots Eg. *Panicum flavidum, Echinochloa colona* (b) Dicots Eg. *Crotalaria verucosa, Indigofera viscose*

VIII. Based on soil pH

Based on pH of the soil the weeds can be classified into three categories. (a) Acidophile – Acid soil weeds eg. *Rumex acetosella* (b) Basophile – Saline & alkaline soil weeds eg. *Taraxacum sp.* (c) Neutrophile – Weeds of neutral soils eg *Acalypha indica*

IV. *Based on morphology*

Based on the morphology of the plant, the weeds are also classified in to three categories. This is the most widely used classification by the weed scientists.

(a) **Grasses:** All the weeds come under the family Poaceae are called as grasses which are characteristically having long narrow spiny leaves. The examples are *Echinocloa colonum, Cynodon dactylon.*

(b) **Sedges:** The weeds belonging to the family Cyperaceae come under this group. The leaves are mostly from the base having modified stem with or without tubers. The examples are *Cyperus rotundus, Fimbrystylis miliaceae.*

(c) **Broad-leaved weeds:** This is the major group of weeds as all other family weeds come under this except that is discussed earlier. All dicotyledon weeds are broad-leaved weeds. The examples are *Flavaria australacica, Digera arvensis, Tridax procumbens*

(d) Filamentous, such as *Chara Zeylanica, Nitella hyalina*

X. Based on nature of stem

Based on development of bark tissues on their stems and branches, weeds are classified as woody, semi-woody and herbaceous species.

(a) **Woody weeds:** Weeds include shrubs and under shrubs and are collectively called brush weeds. Eg. *Lantana camera, Prosopis juliflora*

(b) **Semi-woody weeds:** eg. *Croton sparsiflorus*

(c) **Herbaceous weeds:** Weeds have green, succulent stems are of most common occurrence around us. Eg. *Amaranthus viridis*

XI. Based on specificity

Besides the various classes of weeds, a few others deserve special attention due to their specificity. They are, a. Poisonous weeds, b. Parasitic weeds and c. Aquatic weeds.

a. Poisonous weeds

The poisonous weeds cause ailment on livestock resulting in death and cause great loss. These weeds are harvested along with fodder or grass and fed to cattle or while grazing the cattle consume these poisonous plants. Eg. *Datura fastuosa, D. stramonium* and *D. metal* are poisonous to animals and human beings. The berries of *Withania somnifera* and seeds of *Abrus precatorius* are poisonous.

b. Parasitic weeds

The parasite weeds are either total or partial which means, the weeds that depend completely on the host plant are termed as total parasites while the weeds that partially depend on host plant for minerals and capable of preparing its food from the green leaves are called as partial parasites. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites. The typical examples are;

1. Total root parasite – *Orabanche cernua* on Tobacco
2. Partial root parasite - *Striga lutea* on sugarcane and sorghum
3. Total stem parasite - *Cuscuta chinensis* on leucerne and onion
4. Partial stem parasite - *Loranthus longiflorus* on mango and other trees.

c. Aquatic weeds:

Unwanted plants, which grow in water and complete at least a part of their life cycle in water are called as aquatic weeds.They are further grouped into four categories as submersed, emersed, marginal and floating weeds.

1. **Submersed weeds:** These weeds are mostly vascular plants that produce all or most of their vegetative growth beneath the water surface, having true roots, stems and leaves. Eg. *Utricularia stellaris, Ceratophyllum demersum.*
2. **Emersed weeds:** These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. Eg. *Nelumbium speciosum, Jussieua repens.*
3. **Marginal weeds:** Most of these plants are emersed weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water. These weeds vary in size, shape and habitat. The important genera that comes under this group are; *Typha, Polygonum, Cephalanthus, Scirpus, etc.*
4. **Floating weeds:** These weeds have leaves that float on the water surface either singly or in cluster. Some weeds are free floating and some rooted at the mud bottom and the leaves rise and fall as the water level increases or decreases. Eg. *Eichhornia crassipes, Pistia stratiotes, Salvinia, Nymphaea pubescens*.

XII. Based on economic importance

Absolute weeds: Weeds which have no economic value and growing out of their proper place are called absolute weeds i.e. *Euphorbia hirta*, *Amaranthus spinosus*, *Anagallis arvensis* etc.

Relative weeds: Weeds which have some economic importance but are called weeds because these are growing out of their proper place i.e. *Saccharum munja* and *Typha latifolia* are used in cottage industry and *Phalaris*, *Avena ludoviciana*, *Cynodon dactylon* etc. can be used as fodders.

XIII. According to association

Weeds present in crop fields differ in their soil and climatic requirements, cultural requirement, morphology, seed size and food habits. They have intense association with particular climate and crop, thereby they come in particular season and crop. Accordingly on the basis of association weeds are classified in three groups.

A. Season bound weeds: There are three seasons in a calendar year, monsoon, winter and summer. Accordingly, weeds grow in that particular season with disregard to crop species cultivated. There are weeds which are of perennial types but they are considered of particular season weed in which their major vegetative growth period is passed like *Sorghum halepense* is a summer perennial and *Circium arvense* is a winter perennial weed. Annual weeds which come in more than one season are called multi seasonal annual or multi annual weeds. Those weeds which complete their life within a season and propogate by seeds are of four types:

1. **Monsoon annuals (Kharif annuals)** : *Ammania baccifera, Sagittaria Sagittifolia, ludwigia, parviflora, Cyperus difforamis, Echinochloa crusgalli* etc.
2. **Winter annuals (Rabi annuals)**: *Chenopodiumalbum, phalaris minor, Avena fatua Spergula arvensis, Vicia hirsuta, Molilotus alba* etc.
3. **Summer annuals**: *Solanum nigrum, Portulaca oleracea, Argemone mexicana, Tephrosia purpurea* etc.
4. **Multi seasons annuals**: *Echinochoa colonum, Eclipta alba, Phyllanthus niruri* etc.

B. Crop bound weeds or parasitic weeds

Crop bound weeds are also called parasitic weeds. Such weeds are dependent on specific host crop as they get nutrition for their survival and growth from host crop. Accordingly weeds are classified as

1. **Total parasitic weeds**: These weeds are totally dependent on host plants as they take moisture, nutrients and food from host plants e.g. *Orabache* sp. It is usually parasitized tobacco, tomato, carrot, sarson etc..
2. **Semi parasitic weeds**: Those weeds are partly dependent on host plant and partly on their own are called semiparasitic weeds e.g. *Cascuta* sp like *Cuscuta reflexa* and *Cuscuta chinensis* and *Striga sp*. These weeds after germination of host crop seeds germinate and their radicles attach to the roots of host crops. After their germination they produce and synthesize food materials, but they take water and nutrients from the host crops.
3. **Non parasite weeds**: Those weeds which are not dependent on any other plants. These weeds germinate, take nutrients from soil and synthesis their food for themselves e.g. *Cyperus rotundus, Echinochloa sp, Phalaris minor, Chenopodium* album etc.

C. **Crop associated weeds**: The crop associated weeds, like crop bound weeds, are also crop specific, but for different reasons they may be associated with certain crops for one of the following causes.

i) **Need for specific microclimate**: Weeds like *Cichorium intybus* "chicory" and *Coronopus didymus*- "swine cress" require for their best growth shady, cool, and moist habitat which is amply available in crop like lucerne and berseem. Such weeds, therefore, are associated with these crops.

ii) **Mimicry**: *Oryza sativa* var fatua "wildrice" in paddy field and *Avena fatua* "wild oat" and *Phalaris minor* "canary grass" in small grain crops survive because of their similarity in morphology with the host crops. So is true of *Loranthus* in the tea gardens. The resemblance of one organism to another or to an object in its surroundings for concealment or protection from predators is called mimicry. A weed like wild oat tends to grow to the height of winter grains and adjusts its ripening time to the crop over a wide varietal range. This kind of mimicry is called phenotypic mimicry.

Crop mimicry is defined as the phenomenon whereby weeds develop morphological and or biochemical close resemblance to the life history of crop as to be mistaken for the crop and thus evade eradication. A situation where close similarity in appearance occurs between weeds and crops at seedling and vegetative stages is called vegetative mimicry e.g. wild rice (*Oryza longistaminata*) in cultivated rice; wild sorghum (*Sorghum halepense*) in cultivated sorghum; wild sugarcane (*Saccharum spontaneous*) in sugarcane. Seed mimicry is a situation whereby the similarities between weeds and crops is observed in seed weight, size and appearance e.g. similarity in seeds of upland rice and those of itch grass (*Rottboellia cochinchinensis*). Biochemical mimicry is a situation in which a weed develops resistance to a herbicide that has been used.

iii) **Contamination of crop seeds**: Weeds like *Oryza sativa* var. *fatua* (wild rice) in rice, *Phalaris minor* (canary grass), *Avena ludiciana* (wild oat) and *Convolvulus arvensis* (hiran khuri) in wheat , *Cichorium intybus* in berseem mature their seeds almost at the same height and time as that of respective crops. Seeds of these weeds are morphologically similar to associated crop seeds. Thus, they easily contaminate crop seeds at harvest time and cannot separated out by any method.

XIV. According to the site of predominance

i) **Obligate Weeds:** Those species of weeds which grow primarily in the cultivated land and never or rarely in the wild form, e.g. *Chenopodium album, Anagallis arvensis.*

ii) **Facultative weeds:** Those weed species that grow primarily in uncultivated land, e.g. *Argemone mexicana*, *Euphorbia hirta, Opuntia* spp. The facultatine weeds are also called "apophytes"

XV. ACCORDING TO HABITAT

On the basis of habitat weeds are classified broadly in two groups:

A. Terrestrial weeds: These weeds are found in upland soil conditions other than water logged condition. These are further grouped in three categories depending upon their habit and association with soil, climate and with other plants which influence the habit and characteristics of weeds.

i) Weeds of cultivated crops: These weeds grow mainly in cultivated crops like *Chenopodium album, Echinochloa spp, Phalaris minor* etc.

ii) Orchard weeds: The microclomate of orchards being different than the cultivated crop field due to shade, humidity and excessive soil moisture and some of the weed species like *Cannabis sativa, Euphorbia geniculata, Ageragtum conyzoides, Oxalis corniculata* etc. find this type of habitat congenial for their growth and become troublesome.

iii) Weeds of Lawns and Parks: A large number of annual and perennial weeds are found in lawns and parks and deprive the natural beauty. Some common examples are *Imperata cylindrica, Eleusine indica, Desmodium triforum, Setaria intermedia, Medicago denticulata, Poa annua* etc.

B. Aquatic weeds habitat: Aquatic weeds habitat in water. They are of different types, and depending upon their location in water body they are classified as:

i) Floating: (a) Free floating, e.g. *Eichornia crassipes, Pistia stratiotes*

(b) Rooted floating, e.g. *Trapa bispinosa, Ludwigia adscendens*

ii) Submerged, e.g. *Hydrilla verticillata*

iii) Emerged, e.g. *Typha elephantina, Sagittaria sagittifolia*

iv) Amphibious, e.g. *Ranunculus aquatilis, Scirpus supinus*

XVI. According to nature of stem

a. **Erect:** Stem of such weeds stands upright and does not require any support, e.g. *Chenopodium album*, *Panicum repens*, *Melilotus* sp. etc.

b. **Prostrate:** Those weeds instead of being erect have short internodes that bear a crown of leaves borne directly on a root, e.g. *Eleusine indica*, *Digitaria sangunalis*, *Portulaca oleracea* etc.

c. **Twining:** Those weeds, stem will round the support e.g. *Cuscuta* sp., *Ipomoea quamoclit* etc..

d. **Trailing:** Such weeds stems spread on ground, e.g. *Convolvulus arvensis*, *Ipomea pandurata*, *Citrallus vulgaris* etc.

e. **Runner:** Such weeds stem grow horizontally along the ground. Usually there is development of roots at the nodes of stem, e.g. *Cynodon dactylon, Ipomoea bilobba, Launia asplenifolia* etc.

Characteristics of weeds

Weeds are also like other plants but have special characteristics that tend to put them in the category of unwanted plants. Knowledge about these features will help in developing suitable methods for their control by studying their most sensitive stage in their life cycle. Knowing the characteristics of weeds will help in studying the means of their adaptation as well as extent of loss which these weeds can render to human beings.

1. **Weeds have rapid seedling growth and the ability to reproduce when young.** Redroot pigweed (Amaranthus retroflexus) can flower and produce seed when less than 8 inches tall. Crops cannot do either. *Phyllanthus niruri* has faster growth in groundnut.
2. **Quick maturation or only a short time in the vegetative stage**. Ephemerals have lifecycle of 1 month. Canada thistle can produce mature seed two weeks after flowering. Russian thistle seeds can germinate very quickly between 28° and 110°F in late spring (Young, 1991). It would spread more, but the seed must germinate in loose soil because the coiled root unwinds as it pushes into soil and is unable to do so in hard soil.
3. **Dual modes of reproduction**. Most weeds are angiosperms and reproduce by seed. Many also reproduce vegetatively (e.g., Canada thistle, field bindweed, leafy spurge, quackgrass). *Cyperus rotundus* can propagate through tubers.
4. **Environmental plasticity**. Many weeds are capable of tolerating and growing under a wide range of climatic and edaphic conditions. Weeds have the capacity to withstand adverse conditions in the field, because they can modify their seed production and growth according to the availability of moisture and temperature. They

can germinate under adverse soil-moisture conditions, have short period of plant growth, generally grow faster rate and produce seed earlier than most of the crops growing in association. *Rumex spinosus* can germinate in acidic soil

5. Weeds are **often self-compatible**, but self-pollination is not obligatory.
6. **If a weed is cross-pollinated, pollination is accomplished by nonspecialized flower visitors** or by wind.
7. **Weeds resist detrimental environmental factors**. Most crop seeds rot if they do not germinate shortly after planting. Weed seeds resist decay for long periods in soil and remain dormant.
8. **Weed seeds exhibit several kinds of dormancy or dispersal in time** to escape the rigors of the environment and germinate when conditions are most favorable for survival. Many weeds have no special environmental requirements for germination. Weed seeds remain viable for longer period without losing their viability, e.g. annual meadow grass (*Poa annua*) and scarlet pimpernel (*Anagallis arvensis*) remain viable for about 8 years; creeping thistle (*Cirsium arvense*) for 20 years and field bind weed (*Convolvulus arvensis*) for about 20-50 years. *Cyperus rotundus* have 78% viability.
9. **Weeds often produce seed that is the same size and shape as crop seed**, making physical separation difficult and facilitating spread by man. *Cichorium intybus* in berseem. Some weeds resemble morphologically with the crop and are difficult to identify at weeding or hoeing.
10. Some annual weeds produce **more than one seed crop per year**, and seed is produced as long as growing conditions permit.
11. Each generation is capable of producing **large numbers of seed per plant**, and some seed is produced over a wide range of environmental conditions. Most of the weeds especially annuals produce enormous quantity of seeds, e.g. wild oats (*Avena fatua*), produces 250 seeds per plant, whereas wild amaranth (*Amaranthus viridis*) produces nearly 11 million seeds. *Striga juncea* produces 50 lakh seeds/plant ; *Amaranthus viridis* produces 1.78 lakh seeds/plant. It has been observed that among 61 perennial weeds, the average seed-production capacity was 26,500 per plant.
12. **Many weeds have specially adapted long- and short-range seed dispersal mechanisms**. Weed seeds have a tremendous capacity to disperse from one place to another through wind, water and animals including man. Many of times, weed seeds mimic with the crop seeds due to their size and get transported from one place to another along with them. There is formation of special structure for effective dissemination. *Physallis minima* forms balloon structure.
13. **Roots of some weeds are able to penetrate and emerge from deep in the soil**. While most roots are in the top foot of soil, Canada thistle roots routinely penetrate 3 to 6 feet and field bindweed (*Convolvulus arvensis*) roots have been recorded over 10-20 feet deep. Roots and rhizomes are capable of growing many feet per year.
14. **Roots and other vegetative organs of perennials are vigorous with large food reserves**, enabling them to withstand environmental stress and intensive cultivation.
15. **Perennials have brittleness in lower stem nodes or in rhizomes and roots**, and, if severed, vegetative organs will quickly regenerate a whole plant.
16. **Many weeds have adaptations that repel grazing**, such as spines (*Solanum xanthocarpus*), taste, or odor.
17. **Weeds have great competitive ability for nutrients, light, and water** and can compete by special means (e.g., rosette formation, climbing, allelopathy). For example *Echinochloa colona* is most competitive and aggressive in rice.
18. **Weeds are ubiquitous**. They exist everywhere we practice agriculture.
19. **Weeds resist control/eradication**, including resistance to herbicides.

In spite of the anthropomorphic aspects of the definitions of weed and the multiple traits that weeds share, weed scientists have a clear idea of which plants are weeds. It seems that weeds are everywhere in almost every place.

Harmful effects

Weeds have serious impacts on agricultural production. It is estimated that in general weeds cause 5% loss in agricultural production in most of developed countries, 10% loss in less developed countries and 25% loss in least developed countries.

In India, yield losses due to weeds are more than those from pest and diseases. Yield losses due to weeds vary with the crops. Every crop is exposed to severe competition from weeds. Most of these weeds are self-sown and they provide competition caused by their faster rate of growth in the initial stages of crop growth. In some crops, the yields are reduced by more than 50% due to weed infestation.

Weeds compete with crops for water soil, nutrients, light, and space, and thus reduce the crop yields. An estimate shows that weeds can deprive the crops 47% N, 42% P, 50% K, 39% Ca and 24% Mg of their nutrient uptake.

Weeds are also act as alternate hosts that harbor insects, pests and diseases and other micro-organisms. Alternate hosts of some of the pest and diseases

Crop	**Pest**	**Alternate host**
Red gram	Gram caterpillar	*Amaranthus, Datura*
Castor	Hairy caterpillar	*Crotalaria sp*
Rice	Stem Borer	*Echinocholoa, Panicum*
Wheat	Black Rust	*Agropyron repens*
Pearl Millet	Ergot	*Cenchrus ciliaris*
Maize	Downy Mildew	*Sacharum spontaneum*

Some weeds release into the soil inhibitors of poisonous substances that may be harmful to the crop plants, human beings and livestock. Health problems caused by weeds to humans,

Health problem	**Weed**
Hay fever and Asthma	Pollen of *Ambrosia* and *Franseria*
Dermotitis	*Parthenium, Ambrosia*
Itching and Inflammation	*Utrica sp*
African sleeping sickness	Brush weeds
Malaria, encephaliltis and filaria caused by Mosquito	Aquatic weeds like *Pistia lanceolate, Salvinia auriculata*

Weeds reduce the quality of marketable agricultural produce. Contamination of weed seeds of *Datura, Argemone, Brassica* etc., is harmful to human health. Seeds of some weeds present in the produce cause odd odour.

Weeds not only reduce yield but also interfere with agricultural operations. Weeds make mechanical sowing a difficult process and render harvesting difficult, leading to increased expenditure on labour, equipment and chemicals for their removal.

In aquatic environment, weeds block the flow of water in canals, water-transport system and drainage system, rendering navigation difficult. The dense growth of aquatic weeds pollutes water by deoxygenating it and killing the fishes.

Weeds are also a nuisance and a fire hazard along railway lines, roads, right-of- ways, airports, forest and industrial sites.

Beneficial Effects

In spite of all the difficulties caused by weeds, they can offer some beneficial properties, particularly when occurring at low densities. These aspects should be utilized in the farming system, although this may make organic management more complicated than chemical based systems. Some of the potential benefits of weeds are listed below:

- Helping to conserve soil moisture and prevent erosion. A ground cover of weeds will reduce the amount of bare soil exposed helping to conserve nutrients, particularly nitrogen which could otherwise be leached away, especially on light soils.

- Food and shelter can be provided for natural enemies of pests and even alternative food sources for crop pests. The actual presence of weed cover may be a factor in increasing effectiveness of biological control of pests and reducing pest damage.
- Weeds can also be valuable indicators of growing conditions in a field, for example of water levels, compaction and pH.
- Weeds can be an important source of food for wildlife, especially birds. Bird populations have been declining on farmland over the last few decades and leaving weeds as a resource has been shown to help revive bird populations.

Special weed problems including aquatic and parasitic weeds

Weed flora of India is very rich. These plants pose a lot of management problems and adversely affect the productivity besides incurring heavy costs in preventive and damage control measures. It is generally very difficult to distinguish between native and exotic species, as they grow intermixed. Exotic invasive species, however, are usually confined to the areas managed or otherwise influenced by man and his dispersing agencies. Weeds have been classified into the following three categories (Babu, 1977):

i) Category I: - This group comprises of the species, which are thoroughly naturalized and appear to behave as wild plants. These plants are of tropical American origin and are usually obnoxious. They have Napoleonic ambitions to colonize new areas. Members of *Asteraceae, Amaranthaceae, Solanaceae, Malvaceae, Brassicaceae*, etc. belong to this category.

ii) Category II: - This group includes the plants of cultivated origin that have become naturalized or run wild. These weeds represent the members of the families such as *Solanaceae, Cucurbitaceae, Asteraceae, Apiaceae, Brassicaceae, Fabaceae, Convolvulaceae,* etc.

iii) Category III: - Species falling under this category are exclusively cultivated, and also met with as escapes which include members of *Acanthaceae, Caryophyllaceae, Malvaceae, Asteraceae, Poaceae, Amaryllidaceae,* etc.

Similarly based on his studies of the flora of the Garhwal Himalayas, Gaur (*Flora of the District Garhwal, Northwest Himalaya1*: 1999) has categorized weeds of the northwest Himalayas according to their seasonal appearance e.g.

(i) Weeds appearing in the rainy season, and

(ii) Weeds appearing in the winter and spring season.

The weed flora of North-eastern India is very diverse. Weeds of north-east are required to be taxonomically evaluated in terms of their rich genetic and species diversity. Exotic weeds, owing to their aggressive nature can expand their zone of occupancy in quick succession, spread over large tracts, and endanger the natural elements of flora and bring about abrupt changes in floristic composition. With seasonal variations invasive species pass through vigorous reproductive phases without any obstruction and hinder the efforts to eradicate them. Invasive plants have appeared at different times and have always sustained and multiplied at the cost of indigenous species. They have occupied vast areas and have even driven many indigenous species into red data categories. In North-eastern India, there are some recent districts, regional and state level floras in addition to Kanjilal's classic work: *Flora of Assam* but for an accurate and up to date inventorization and taxonomic characterization of weeds, a detailed floristic study is the most desirable proposition. Dutta (*Some Common Weeds of the Tea Estates in North-East India,* 1982) worked on the weed flora of the region but confined himself to the tea estates.

Impact of a few major invasives is explained below

Lantana camara is one of the most obnoxious weeds that has encroached most of the areas under community and reserve forestlands. The outer fragile Himalayas are almost completely encaptured by this rapidly spreading weed. This weed, not only ruins common agricultural and forestlands but also makes shade as well as allelopathy impacts on the regeneration of important forestry species. Due to spread of *Lantana*, the yields of crops and pastures get reduced. The harvesting costs have increased manifolds. Heavy expenditure is incurred for afforestation of lands infested with this weed which requires frequent weeding so as to avoid suppression of young seedlings of planted species. Afforestation cost is also increased due to loss of stand and slower growth rate due to weed competition. *L. camara* is toxic to cattle and cost towards its control was US$70 per hectare (Singh et al., 1996). The economic loss from *Lantana* is estimated to be US$924 million per year.

Parthenium is difficult to control as it seeds prolifically. Seed germinates readily and the plant tolerates a wide variety of conditions. The weed is a menace to agriculture because it has allopathic effect and competes with pastures and reduces their carrying capacity. The weed affects human and animal health by causing respiratory problems, severe dermatitis and tainted milk.

Eupatorium glandulosum is found in the temperate region of the south and the north; ecological disruptions have given way to this weed. This weed spreads fast and checks the regeneration of other species particularly in Western Ghats and has replaced the valued flora at places. It comes in disturbed soils. In most of the goat-travelled paths, it comes up well; that is why it is locally known as '*goat weed*'. Since the plant has no local or commercial use, it has widely spread in denuded and forestlands.

Ulex europaeus represents a fire hazard to private property in the Western Ghats. It invades watersheds, which supply a substantial amount of drinking water. It is threatening agricultural and grazing lands. Thickets of this weed are impenetrable to humans and have persistent spiny litter.

Acacia mearnsii was introduced in Western Ghats particularly in the Nilgiris to provide fuelwood to the rural people to save the shola forests, which were degraded in the past by human activities. It was also planted in the tea gardens to provide shade to the tea plants but now it has covered most of the shola forests and become menace in the Nilgiri Hills. Regeneration of shola forests is effected due to profuse regeneration and invasive nature of this species.

Mikania micrantha is a perennial fast growing weed of Neotropical origin and has become a major menace to the natural forests, plantations and agricultural systems in North-east and South-west India. This weed spreads very fast in areas where canopy is open.

Cytisus scoparius was introduced from European countries in the Western Ghats for ornamental purposes but now it has become menace in the Nilgiri Hills particularly in the shola forests and grazing lands. It reduces the regeneration of shola species and invades on the grasslands, thus decreases the production of grass for the cattle of Nilgiris. This species spreads fast in the areas distributed by forest fires or other biotic interferences.

Euphorbia royleana in the Himalayan zones comes up profusely and has covered thousands of hectares of land. This plant represents a desert environment. Being cactus in habit, it has no use in conserving or making of soil. Similarly, in this zone there are a few other plants viz. *Artemisia vulgaris, Carrisa carander and Dodonea viscosa,* which have spread like weeds and have large areas under their control. *Cannabis sativa* has canvassed most of the deforested and community lands, complicating land management.

Besides the above, unabated free grazing and intense human activities have led the way to many other plant species having no use in supporting ecology and economy of the region. These are *Agave catula, Ageratum conizoides, Ageratum houstonianum, Cassia tora, Clerodendron viscosum* etc.

Mikania micrantha, Prosopis juliflora, Cabomba caroliniana, and *Salvinia molesta* are worth mentioning aliens. Invasive alien weeds are *Lantana camera*, *Chromolaena odorata*, *Eichhornia crassipes, Opuntia dillenii, Mimosa pudica, Lippia geminate*, and *Jaropha gossipifolia* (Viraktamath, 2002). *Parthenium hysterophorus, Phalaris minor* (Diwakar, 2003), *Eupatorium glandulosum, Ulex europaeus, Acacia mearnsii, Cytisus scoparius*, *Opuntia vulgaris, Prosopis chilensis, Euphorbia royleana* (Srivastava and Singh, 2009) are also invasive. Weeds cause an estimated 30% loss in crop production (Singh, 1996) which worth more than US$90 billion per year.

Two prominent invasive alien plants in India are *Eupatorium odoratum* and *L. camara* amongst the World's worst invasives. These weeds originated in the Neotropical region and were introduced into India through the Calcutta Botanical Garden during the last century (Muniappan and Viraktamath, 1993). Other highly invasive Neotropical plants established in India are *M. micrantha*, and *P. hysterophorus. Mimosa invisa* has rapidly expanded its range in the Western Ghats (Ramkrishnan *et al*., 1996). A comprehensive inventory of the invasive alien flora in the state of Uttar Pradesh, India revealed 152 species from 109 genera and 44 families (Singh *et al*., 2010).

The invasive species cause heavy losses to agricultural and forest production, blocking of water bodies, water transport ways, affecting wildlife habitat in the forests and wetlands and commercial activities such as cultivation of medicinal plants etc.

Aquatic weed problems in India

In India, many rivers, irrigation canals, lakes both natural and man made, are choked by the explosive growth of aquatic weeds, resulting in enormous direct losses. Besides different type of algae, the most important representatives of aquatic weeds in India are *Eichhornia* (free floating), *Nymphaea stellata* (rooted floating), *Nelumbo nucifera* (rooted floating), *Hydrilla verticillata* (rooted submerged), *Typha angusta* (emergent), *Saggittaria* sp, *Potamogeton* sp (rooted submerged), *Pistia stratiotes* (free floating) and *Salvinia molesta* (free floating), *Azolla caroliniana*, *Alternanthera philoxeroides*, *Polygonum* sp, *Cyperus* sp etc. Although no precise estimates of the losses caused by aquatic weeds are available but it is estimated that submerged aquatic weeds like *Hydrilla*, *Ottelia*, *Valisnaria*, *Najus*, *Utricularia*, *Chara* etc, caused 50-60% loss of the cultivable water in Assam, Bihar, Madhya Pradesh, Orissa, Uttar Pradesh and West Bengal making them unsuitable for fish culture. Even the cultivation of the water chestnut (*Trapa bispinosa*) for edible purposes in these states is hampered by the presence of aquatic weeds. Eutrophication has led to increasing weed problems in reservoirs. Holm *et al*. (1991) reported that in the Chambal Project in India, submerged aquatic had cut the flow of water by 80% in the canals. Vast areas of lowland paddy in the north eastern parts of India and Kerala state are badly infested with aquatic weeds. While in the north-east, *E. crassipes*, *Chara* sp, *Nitella* sp and algal scams are nuisance, in the coastal Kerala *Salvinia* plays havoc. Irrigation supply to paddy is hindered in about 1.6 lakh ha area in North-eastern India alone. Added to this, several hectares of cultivable food plains are surrendered to noxious aquatic vegetation. Cultivation of *Trapa bispinosa* 'water chestnut' is also abandoned in east India because of water hyacinth and other aquatic weeds in water bodies.

Mostly of fishery tanks and ponds in and around Bangalore and other cities have been badly invaded by water hyacinth. Among the floating weeds, particularly in Punjab, water hyacinth is the main problem. Of the 8 lakh ha of freshwater available in India for pisciculture, about 40% is rendered unsuitable for fish production because of invasion by aquatic weeds. Some of the weeds like *Eichhornia*, *Azolla*, *Nymphaea*, *Nelumbo*, *Nymphoides*, *Hydrilla*, *Vallisneria*, *Potamogeon*, *Najas*, *Muriophyllum*, *Ceratophyllum*, *Typha Utricularia* sp, are problemaric weeds in fishery lakes and tanks of AP, Assam, Haryana, Himachal Pradesh, Jammu and Kashmir, Maharastra, Tamil Nadu and Uttar Pradesh in India. Some of the well known fishery lakes like Barwar, Ramgarh and Guiar lake in Uttar Pradesh, Ansupa lake in Orrissa, Ooty lake in Tamil Nadu, Kollern lake in Andhra Pradesh, Lotak lake in Manipur and the world famous Dal, Nagin and Wular lakes in Kashmir have been largely invaded by the aquatic weeds.

Several irrigation and hydroelectric projects in the country are endangered by infestation of dams and reservoirs with massive growth of aquatic weeds. In a case study, Bisi (1996) calculated huge losses in electricity generation due to aquatic weeds in Chiplima Power house of Hirakund Power System. Aquatic weeds are a great problem in canal systems which have already reduced the designed flow of many of these by 40-50%. The impeded flow of water in canals resulted in forced seppage, water logging and soil salinity. In Kerala state, *Salvinia molesta*, an exotic weed introduced in 1967 has widely distributed in irrigation canals. It is so competitive that it has replaced *E. crassipes* and *Pistia stratiotes* (Joy, 1978). Irrigation supply to paddy is also hindered in about two lakh hectares area due to these weeds in north-eastern states.

The ten most widely spread noxious aquatic weeds in India as revealed from district wise reports are listed in Table 1.2 in order of their incidence.

Table 1.2 Ten most common noxious aquatic weeds in India, arranged in order of decreasing importance from the top, on the basis of assessment of relative preponderance of individual species in different districts.

SN	Species	Nature of weed	Total No. of districts	
			Actual distribution	Causing concern in
1	*Eichhornia crassipes*	Free-floating	98	92
2	*Nymphaea stellata*	Rooted-floating	85	83
3	*Nelumbo nucifera*	Rooted-floating	86	79
4	*Hydrilla verticillata*	Rooted-submerged	87	83
5	*Typha* sp.	Emergent	69	65
6	*Lemnoids*	Free-floating	77	46
7	*Vallisneria* sp	Rooted-submerged	71	40
8	*Potamogeton* sp	Rooted-submerged	66	37
9	*Pistia stratiotes*	Free-floating	78	41

SN	Species	Nature of weed	Total No. of districts	
			Actual distribution	Causing concern in
10	*Salvinia* sp.	Free-floating	60	19

The list is topped by *Eichhornia crassipes*, an alien, which has now become established almost throughout the country (reported form 98 districts). This species is followed by *Nymphaea stellata*, *Nelumbo nucifera* and *Hydrilla verticillata* in extent of distribution and nuisance within the country (more than 85 districts).

Parasitic weeds

Parasitic weeds which are also referred to as Crop-bound, do not produce their own food by themselves and, therefore, necessarily parasitize partially or wholly a crop for their food and survival, e.g. *Cuscuta sp, Orobanche sp, Striga sp, Loranthus longiflorus, Cassytha filiformis*. They remain dependent upon crops and other wild hosts for food. Crop rotation can be of immense use against them, but longer viability in many parasitic weed seeds defies short-term crop rotation measure. Crop-bound weeds because of their large/huge species diversity also infest a large number of crops of economic importance. Unlike autotroph weeds, which affect the crops indirectly by removing nutrients, water from soil or competing with crop plants for space and light, the parasitic weeds affect crop growth directly by sharing/taking away food from the crops. They thus form a parasitic class of weeds based on nutritional habit or nature of competition and may again be classified on the basis of parasitism on roots and shoots in the following ways:

Based on root-parasitism:

a) Total root/holo-root parasite: They take away food from the host-roots and do not have any other source of gathering food. Therefore, they are also called “obligate root-parasite.” For example, *Orobanche sp* (on tobacco, tomato, fababean, chickpea, mustard, etc).

b) Partial root/hemi-root parasite: Initially they depend upon host-roots for their food and living (sub-terranean/under-ground stage in case of *Striga*), but later after emergence from soil, they are green, chlorophyllous and can produce their own food. For example, *Striga hermonthica/asiatica (=lutea*) on sorghum, maize and *Striga gesneroides* on cowpea.

Based on shoot/stem-parasitism:

a) Total stem/holo-stem parasite: They take away food from the host-shoot/stem and do not have any other source of gathering food. Therefore, they are also called “obligate shoot/stem-parasite.” For example, *Cuscuta campesstris/chinensis/epilinum* (on alfalfa, niger and linseed, respectively). Earlier *Cuscuta* was the only parasitic genus of the autotrophic family *Convolvulaceae*. But now-a-days *Cuscutaceae*, a separate family has come into being for this genus.

b) Partial stem/hemi-stem parasite: Initially they depend upon the host-shoot/stem for their food, but later for becoming green and chlorophyllous, can produce their own food. For example, *Loranthus longiflorus* is a green colour plant (on mango and other trees) and *Cassytha filiformis* (on orange, eucalyptus and other trees). *Cassytha filiformis* has circumnutation anticlock-wise like *Cuscuta* but is much greener than *Cuscuta*.

Ecology and physiology of major weeds

(http://www.plantwise.org/knowledgebank/datasheet.aspx?dsid=20367)

The eco-physiology in relation to weeds may cover the following aspects:

1. Ecological characteristics *viz*. frequency of distribution, constancy, population density and biomass per unit area.
2. Reproductive potential and life cycle of weeds. Climatic and soil characteristics of the site.
3. Germination ecology.

The ecology and physiology of few major weeds are presented below:

***Phalaris minor* Retz.(Family gramineae, sub-family Pooideae)**

It is an annual, 30-90 cm tall branched weed appearing during winter in cultivated fields and gardens. Panicle is cylindrical 6 cm long and spikelets laterally compressed. *P. minor* is a winter annual propagated by seeds. It is erect or decumbent, caespitose, more-or-less slender with stems up to 90 cm tall. Leaves long, linear, acuminate; sheath smooth; ligule an oblong hyaline membrane, about 5 mm long (Hooker, 1982; Shukla, 1996). Panicle more-or-less protruding or entirely protruding from the uppermost swollen leaf sheath, ovate to oblong, 5-8 cm long, green; spikelets green, broadly lanceolate on short pedicels, shining, not as conspicuously striped as in P. brachystachys, 4-5 mm long, strongly laterally compressed. Glumes 4-6 mm long, fertile lemma lanceolate about 3 mm long, more or less lustrous; sterile lemma solitary, about 1 mm long. Glumes acute, but not mucronate, with a minutely toothed wing. Hermaphrodite florets with palea villous with applied hairs, and with very small filiform residue of a neutral floret at the base. In the world it is distributed westward to the canaries, South Africa and Australia.

P. minor is a very competitive weed in several winter crops in many Mediterranean countries, the Middle East, India, Pakistan, Nepal, Mexico, Australia and South Africa. Yield losses vary depending on crop, climate and management practices. The losses are maximum in crops of short stature such as chickpea, lentil, peas, etc.

In India, yield losses ranging from 15-50% have been reported (Gill et al., 1978). Cudney and Hill (1979) recorded 40-60% reduction in wheat yield with *P. minor* at 108-915 plants per square metre. Afentouli and Eleftherohorinos (1996) reported 36-39% reduction in wheat yield in Greece with 304 canarygrass plants per square metre.

P. minor has been listed as amongst the top ten weeds in Pakistan (Shad and Siddique, 1996) and in central Greece (Damanakes, 1982). In Spain, several species of *Phalaris* are known to infest wheat and barley in the west Andulasian region, of which *P. paradoxa* and *P. minor* are the most serious (Saavedra *et al*., 1989). The problem has taken a new turn in some countries with reported development of resistance to herbicides. Vast wheat areas in the fertile north-western parts of India are faced with the problem of resistance to isoproturon - the herbicide recommended for its control (Malik and Singh, 1995). An extremely heavy population build-up, in the order of 2000-3000 plants per square metre, is frequently seen. Yield reductions in the region of 60-100% have been reported from these areas. A similar problem, albeit at a lesser intensity, has been documented in Israel (Tal et al., 1996).

***Medicago denticulata* Willd. (Family Legiminosae sub-family Paplionatae) (Fabaceae)**

A nearly glabrous, prostrate or procumbent 15-60 cm long annual; pods flattened, of 2-4 spirals with a double row of spines. It is a common weed in cold season. In the world it is distributed in Orient, Abyssinia, Europe, Japan and China.

***Convolvulus arvensis* L., Bindweed (Family Convolvulaceae)**

A glabrous pubesecent perennial herb, with many ½-3 feet long trailing or twining stems. Fruit is a capsule. It is common weed in gardens, fields and on roadsides. It is distributed in nearly all the temperate and subtropical regions of the world. Herbaceous perennial growing from a very deep root system. Shoots develop from adventitious buds on the deep root system at almost any depth down to 1 m. Above ground, the stems trail or climb by twining. Stems slender, to 1.5 m long, twining anticlockwise, glabrous or finely pubescent. Leaves alternate, petiolate, variable in shape, lanceolate or ovate to narrow-oblong, 1.2-5.0 cm long, acute at the apex, entire but often hastate-sagittate at the base, glabrous or pubescent with scattered crisped hairs. Flowers axillary, solitary or in cymes 2-3 on peduncles subequal to the subtending leaf; bracteoles linear, 2-4 mm long. Sepals free, obtuse, 2.5-4.5 mm long. Corolla funnel-shaped, pentamerous with 5 radial pubescent bands but not divided into distinct lobes, 10-25 mm long, 10-25 mm diameter, white or pink. Stamens 5, inserted on corolla tube. Style single with two oblong stigmas. Ovary two-celled. Fruit a capsule, globular to ovoid with a persistent style base, breaking open irregularly. Seeds usually 4, compressed-globose, 3-5 mm diameter; testa granular, dark-brown or black.

C. arvensis is troublesome as a weed in temperate and mediterranean environments, it is often found in tropical regions but, overall, appears less of a problem there. It is a weed of both agricultural and horticultural crops. It appears to grow best in regions with a moderate to good rainfall and inherently fertile, well drained soils. It will persist in more arid regions and on less fertile soils. It also grows in tropical areas but is susceptible to competition from tall, vigorously growing vegetation in higher rainfall regions of the tropics. It does not generally appear to favour environments that are waterlogged for long periods (although it has been reported as a weed of rice). Annual crops such as cereals and grain legumes appear particularly susceptible to yield loss from *C. arvensis* ranging from 20 to 80% (see e.g. Phillips and Timmons, 1954; Black et al., 1994), but is also widely reported as a troublesome weed in vineyards. It is listed as one of the world's worst weeds by Holm *et al*. (1977).

***Melilotus parviflora* Desf. (Family Leguminosae; sub-family Paplionatae) (Fabadeae)**

An erect much-branched slender glabrous annual 1–2 ft. high. Petioles 12–18 lines. Leaflets obovate-cuneate, 6–9 lines long, finely toothed. Flowers 12–30 in lax short-stalked axillary racemes. Pedicel scarcely any. Calyx 1/2 line deep, the teeth shorter than the tube. Corolla pale yellow, twice the calyx, the standard exceeding the other petals a little. Pod a line long, globose, glabrous, obscurely reticulate-rugose, 1-seeded. Originally a Mediterranean species, now spread over almost the whole world as a weed.

***Lathyrus aphaca* L. (Family Leguminosae; Sub-family Paplionatae) (Fabaceae)**

Lathyrus aphaca is a legume known as the **yellow pea** or **yellow vetchling**. A small branched glabrous annual herb reaching upto 2 feet in height. Leaf wholly transformed into tendril without any leaflet. Fruit, a pod bearing 4-6 seeds. It is a common weed everywhere in the cold season. It is native to southern Europe, parts of Asia, and North Africa. Some consider it to be a weed, particularly when in areas where it is an introduced species, including northern Europe and North America. It acclimates best to dry places, such as sand, gravel, and chalk, and requires a well-drained habitat. It is an annual herb producing yellow pea flowers just over a centimeter wide.

***Asphodelus tenuifolius* Cavan. (Family Liliaceae)**

A. tenuifolius is an erect annual, monocotyledonous herb; root yellowish in young plants and dark brown at maturity, superficially has the appearance of the taproot system of dicotyledons, in fact the ridged and furrowed organ is a hard and compacted bundle of fibrous roots, which may sometimes twist to give a rope-like appearance; leaves numerous, all basal, hollow, slender, gradually acuminate to a point, 10 to 40 cm long, the base sheathing, smooth to minutely hairy; seeming to rise as a 'bunch' from the soil, scapes several, simple, sparse dichotomous branching in upper region, stout, 3 mm in diameter, up to 60 cm long; flowers campanulate, white with pink or purple stripe, in lax racemes; bracteate, pedicellate, short pedicel may be jointed; petals 1.5 cm long in six perianth segments; stamens six; simple, superior, 3-carpelled, 3-loculed ovary; flowering progressing upward in the inflorescence over a period of weeks, normally flowers do not open until late afternoon and unless conditions are dull and cool will close and wither before the next day; fruit, a 3-valved globular capsule, dehiscing at partitions into the cavity, transversely wrinkled, about 3 mm long; seeds 3-angled, blackish, finely pebbled texture, deep irregular dents on face and back.

Yield loss as a result of interference from *A. tenuifolius* is most severe in India and Pakistan. The range of affected crops has been listed. Yield losses of 42% were recorded in chickpea fields infested with *A. tenuifolius* (Tripathi, 1967), and competition from this weed is more severe than that from *Chenopodium album* (Tripathi, 1969). *A. tenuifolius* is an alternative host for the root-rot-causing fungus, *Macrophomina phaseoli* in Pakistan (Anon., 1985), and *Sclerotinia sclerotiorum* has been isolated from *A. tenuifolius* in mustard fields (Rathore *et al*., 1993). Sharma (1977) noted that one gram of seed was fatal to some birds.

***Echinochloa colona* (Junglerice)**

Annual, with fibrous, rather than shallow roots. Culms stout, usually reddish-purple, erect, ascending or decumbent, often branching from the base, often rooting at the lower nodes, 20-60 cm tall, sometimes nodes conspicuously swollen and usually geniculate, compressed, lower internodes often exposed. Sheath 3-7 cm long, compressed, keeled, glabrous, ligule absent; leaf blades light green, sometimes with transverse purple bands, flat, glabrous, elongate, 4-10 cm long, 3-8 mm wide, margins occasionally scabrous, apex acute. Panicle erect or nodding, green or purple-tinged, 5-15 cm long. Racemes numerous, 2-4 cm long, spreading, ascending, sometimes branched, the lower ones up to 1 cm apart, the upper ones crowded. Spikelets green tinged with purple, crowded, arranged in 4 rows, about 3 mm long, rarely with a short point up to 1 mm long. First glume, 1.2-1.5 mm long, 3-nerved, nearly half as long as the spikelet; second glume, 2.5-3 mm long, 7-nerved; the first lemma is similar to the second glume, first palea ovate, ca 2 mm long, glabrous; second lemma, broadly ovate, ca 2 mm long, glossy. Caryopsis whitish, broadly ovate, 1.7- 2 mm long, flat on one side, convex on the other (Wagner et al., 1999). *E. colona* is smaller, branches more at the base and has a more spreading or open type of growth than *E. crus-galli* (Williams, 1956a). Seedlings have rolled leaves with pointed tips. The blades and sheaths are usually, but not always, green. There are no auricles or ligules and stems are circular in cross-section. The lowermost leaf sheath has a few hairs but most other leaf sheaths are smooth. The usually flaccid leaf blade has faint striations, a white midrib and smooth margins, at least in the upper part. Young plants have erect leaves thickened at the base and culms are sometimes flat and spreading (Zimdahl *et al*., 1989). The absence of a ligule, the purplish-tinged leaves and the neatly 4-rowed racemes are characteristic of *E. colona*. *E. colona* is a cosmopolitan weed common in crops (mainly rice, maize and vegetables), gardens, roadsides, disturbed sites, waste areas and pastures. It also grows along waterways, on the margins of lakes and ponds, in swamps and wetlands, and in other damp habitats. It has the potential to invade natural areas and completely outcompete native vegetation. In Australia, the USA, South and Central America, it is ranked among the top environmental weeds (USDA-NRCS, 2014). In Australia, this species has invaded wetter habitats, including endangered swamp tea tree (*Melaleuca tamariscina subsp. irbyana*) thickets (Queensland Department of Primary Industries and Fisheries, 2011).

Echinochloa crusgalli

Annual, coarse, tufted with erect stems or decumbent at the base and rooting at the nodes; 20-150 cm tall. Stems cylindrical in section, glabrous and filled with white pith. Leaf sheaths glabrous to fimbriate at the margin. Leaf blades 5-65 cm long, 0.6-2.2 cm wide; rounded at the base to acute at the tip, rough at the margin, glabrous though often with a few long hairs at the base, no ligule. Inflorescence a terminal panicle, 5-21 cm long, of 5-40 racemes, the longest 2-10 cm often with short secondary branchlets at the base only; with crowded spikelets on one side, main axis angular, with angles scabrous and pilose. Upper spikelets are solitary whereas the lower ones are joined (2-4 together); spikelets hispid, elliptic, 3-4 mm long and usually one-flowered, lower glume third to half as long as spikelet, dull, second glume and lemma as long as spikelet, nerved, nerves are shortly hairy, bristly awn of variable length (0.25-50 mm); seed ovoid, compressed, 1.5-2 mm long. *E. crus-galli* is reported to be among the three most serious weeds of rice in many countries in Asia, and is a major weed in a wide range of crops throughout the tropical and subtropical world (Holm et al., 1991).

Oxalis latifolia

A number of Oxalis species are unusual among dicotyledons in producing scaly bulbs. *O. latifolia* is one of these. The structure of the bulb, 1-2 cm diameter, is complex with two main types of scale which Jackson (1960) refers to as 'membranous' and 'true scales'. Membranous scales are the first to be produced, whether in newly forming bulbils, or at the apex of bulbs resuming growth after dormancy. These scales may or may not produce petioles and leaves from their tips, and have axillary buds which develop into peduncles/inflorescences in larger bulbs, but not in first-year bulbils. After a number of membranous scales have developed, narrower true scales are formed. These true scales have axillary buds which do not develop in the first season but will develop into stolons the following year. At the end of the season, the leaves die down leaving their membranous bases to form a protective layer. When growth resumes, the outermost scales disintegrate, new scales and leaves develop at the apex, while stolons grow out from the axils of the old true scales. Estelita-Teixeira (1982) describes the differences in bulb structure between *O. latifolia*, *O. corymbosa* and *O. oxyptera*. Each bulb produces up to 14 leaves, but with some leaves developing from daughter bulbs, Marshall and Gitari (1988) record up to 45 leaves per plant. There is no stem, other than the short axis of the bulb. The root is a fleshy tuber up to 2 cm in diameter at the top, resembling a small carrot but whitish. Under dry conditions, this root shrinks and contracts, drawing the parent bulb deeper into the soil. In the typical form of *O. latifolia* the bulbils are formed at the end of stolons up to 10 cm long, which may number 30 or more. The leaves, on petioles up to 30 cm long, are glabrous, trifoliate, with individual leaflets broadly fish-tail shaped, 3-6 cm across. The leaflets fold along the midrib at night. The peduncles, about the same length, carry an umbel of 5-12 flowers, each flower 10-20 mm across, erect while open but reflexed before and after. The five sepals each have two orange glands at the tip. The five petals are greenish on the outside, a rich purple inside, changing abruptly to become paler towards the base. *O. latifolia* has the potential for tristyly, having two sets of five stamens of different length but weedy populations are almost invariably short-styled, with medium and long stamens. In Cornwall (UK), Spain, New Zealand and California, USA, atypical forms (sometimes referred to as 'Cornwall type') occur, with bulbils all sessile (no stolons), leaflets much more rounded (less broadly fish-tailed), and flowers distinctly paler in colour (see Young 1958; Esler, 1962; Robb, 1963). At least two different atypical clones occur in Cornwall. These are also short-styled, with the possible exception of one mid-styled population in New Zealand (Esler, 1962).

When seeds are formed, they are orange to dark yellow, about 1 mm long and ribbed. The capsules have the explosive character of *O. corniculata* and seeds may be thrown up to 40 cm (Rivals, 1960). Chromosome number (2n) = 14. Triploid forms are known from Mexico (Holm *et al.*, 1997). Useful review papers on *O. latifolia* include those by Holm *et al*. (1997), Parsons and Cuthbertson (1992) and Marshall (1987).

Holm et al. (1997) record that *O. latifolia* is a weed of at least 37 countries in at least 30 crops. It is listed as a major weed in India, New Zealand, Australia, South Africa and Uganda, particularly in cassava, maize, upland rice, tea, potato, coffee, cereals, sugarcane, orchards and vegetables. It can achieve dominance under certain intensive cultivation systems which remove other competing weeds, and spread of bulbs. Reports on the competitiveness of, and hence yield reducing potential of *O. latifolia* are somewhat contradictory. Atwal and Gopal (1972) recorded 56% reduction in maize yield from uncontrolled *O. latifolia*. However, Thomas (1991) reported no apparent effect on maize yield from populations of 33-50 plants/m² in four successive seasons, when all other weeds had been controlled by a mixture of pre-emergence herbicides. The weed is of undisputed importance in horticultural nurseries where it may infest the produce sold and lead to loss of reputation and occasionally to business closure. O. latifolia is an alternate host of Puccinia sorghi.

***Digitaria sanguinalis* (Large crabgrass)**

Leaf blades 5-15 cm long and 3-12 mm wide. Leaf blade green to purple, both sides with silky, shiny hairs; often reddish with central strip and pale at the margin. Sheath green to reddish violet, with long blister-like hairs, especially at the sheath base. Youngest leaf rolled. Ligule membraneous, white, 1-2 mm long, truncate. Auricles absent. Stem basally prostrate, rooting at the lower nodes, distinctly bent at the lower nodes. Tillers and leaves with some reddish tonalities that increase under unsuitable conditions such as drought and low temperatures (Kissman and Groth, 1993). Inflorescence with 4-10 finger-like spike-like racemes, each 2-16 cm long, not all originating from a single point but with one or more 1-2 cm below the others; spikelets elliptic, plano-convex, about 3 mm long, paired, on short, unequal pedicels; each spikelet has a single fertile floret, lower glume minute, up to 1 mm long, upper glume half to two thirds the length of the spikelet, hairy. Lemmas as long as the spikelet, the lower green, hairy and minutely rough on the nerves towards the tip; upper lemma glabrous, smooth, pale green or light brown (Holm *et al*., 1977; Stucky *et al*., 1980).

After competition from *D. sanguinalis* for 6 weeks and for a full season, *Phaseolus vulgaris* yields were reduced by 28 and 72%, respectively, and leaf area was reduced by 40 and 48%, respectively. Weed competition also resulted in height increases of *P. vulgaris* by 17 and 12%, respectively (Lugo and Talbert, 1989). Six D. sanguinalis: Amaranthus hybridus density ratios (200:0, 150:7.5, 100:15, 50:22 and 0:30 plants/m²) reduced Phaseolus vulgaris yields by 35-53% (Lugo et al., 1994). *D. sanguinalis* is one of the most aggressive weeds in sugarcane in Tucumán, Argentina. Sugarcane suffered most severely from weed competition between 15 and 75 days after sprouting (Lazarte *et al*., 1976). On a red latosol where the major weeds were *Brachiaria plantaginea* and *D. sanguinalis*, the critical period for weed competition was between days 30 and 90 after sugarcane planting (Rolim and Cristoffoleti, 1982). The critical period of weed competition for a maize crop in Argentina was determined in field trials during the period 1974-76. The critical period for competition was from the fourth leaf stage until between the seventh and ninth leaf stages depending on environmental conditions. The weed community was dominated by *Echinochloa colona* and *D. sanguinalis* (Leguizamón and Pedrol, 1978). Yields of silage maize without weed competition were 36.9 kg/plot compared to 21.2 kg/plot when weeds competed for the whole season. The maximum period of grass competition that maize tolerated was 2-4 weeks; competition for moisture was probably a prime factor. Weed grass control was most critical during the first 2-4 weeks after emergence (Vengris, 1978). Five plants per square metre of *D. sanguinalis* reduced sweetcorn yields by 33% (Hartley, 1992).

The critical period of weed competition for a soybean crop was determined in Argentina in 1974-76 (Leguizamón, 1976). Severe yield reductions were detected when weeds, particularly *Echinochloa* spp. and *D. sanguinalis*, emerged in the early stages of crop development and persisted until the seventh trifoliate leaf. A study of *D. sanguinalis* competition in watermelon (*Citrullus lanatus*) showed that, for optimum quality and yield the crop must be kept weed-free between week 0 and week 6 after transplanting (Monks and Schultheis, 1998). The presence of weeds (*Cyperus rotundus*, *D. sanguinalis* and *Eleusine indica*) throughout the life of a radish crop had no significant effect on crop yield (Victoria Filho et al., 1975). Walker et al. (1998) evaluated the competitiveness of *D. sanguinalis* in forage bermudagrass (*Cynodon dactylon*) and found that in late season, *C. dactylon* ground cover was 96% with no weed competition compared with 72% where the weed was present. *Digitaria* also reduced the proportion of *C. dactylon* in the cumulative harvested forage by at least 59%.

Wu et al. (1999) determined the critical period of competition between *D. sanguinalis* and transplanted cotton inter-planted with wheat. The period of weed interference and crop damage, and the critical time of weed-cotton competition were 30-90 days and 30-60 days after transplantation, respectively. For control of the weed using a burn-down herbicide sprayed among the rows, the herbicide must be applied 30 days after cotton transplantation.

In China, Jiang et al. (1997) determined that the economic threshold period for controlling *D. sanguinalis* was 10.6-47.5 days after the emergence of summer maize. There is evidence of allelopathic effects of varieties of *Festuca arundinacea* on *D. sanguinalis* and other species. Extracts were made from 10 g of *F. arundinacea* leaves soaked in 100 ml of water for 24 hours (Peters and Mohammed-Zam, 1981).

***Cyperus rotundus* (Purple nutsedge)**

C. rotundus is a highly variable perennial sedge. Flowering stems are erect, up to 60 cm tall, 3-sided, smooth with swollen bases (basal bulbs). The leaves have a distinct midrib, are linear, usually shorter than the flowering stem, up to 7 mm wide and emerge from a sheath around the shoot base. The inflorescence is a terminal, open umbel subtended by several leafy bracts. Several unequal rays, 2-6 cm long, support 3-8 reddish-brown to purplish-brown, flattened spikelets, 1-2 cm long and 2 mm wide, each with up to 30 glumes, 3.5-4 mm long. Roots are fibrous. Rhizomes are wiry, dark and persistent, connecting a network of daughter shoots and tubers. The tubers are dark brown to black, irregularly shaped and 1-2 cm long when fully grown. Each tuber has an apical bud and several lateral buds. The fruit (often, but erroneously, known as the seed) is a 3-angled achene, 1.5 mm long, dark brown or black.

C. rotundus has been considered as one of the world's worst weeds. It has been reported in more than 90 countries where it grows as a weed infesting at least 52 different crops worldwide (Holm *et al*. 1977). It grows in all types of soils and can also survive high temperatures. *C. rotundus* can be found in a wide variety of habitats including cultivated fields, waste areas, roadsides, pastures, riverbanks, sandbanks, irrigation channels, river and stream shores and natural areas. It is considered a headache for gardeners and farmers because of its insidious and rapid growth and its herbicide tolerance. *C. rotundus* produces an extensive system of underground tubers from which they can regenerate and consequently is very difficult to control once it is established (USDA-NRCS, 2014).

***Cyperus iria* (Rice flatsedge)**

The height of *C. iria* plants varies from 8 to 60 cm. The roots are numerous, short and yellowish-red. The culms are tufted, triangular, glabrous, green and 0.6-3.0 mm thick. The leaves are linear-lanceolate, usually all shorter than the culm, 1-8 mm wide, flat, and scabrid on the margin and major ribs; leaf sheaths are green to reddish-brown, membraneous and envelope the culm at the base. The inflorescence is simple or compound, usually open, 1-20 cm long and 1-20 cm wide, with groups of spikes which are either sessile or on 0.5-15.0 cm long peduncles (rays). Inflorescence bracts (involucre) are leafy, three to five (occasionally seven), the lower one longer than the inflorescence, 5-30 cm long, 1-6 mm wide. The spikes are sessile or almost so, elongate, and rather dense. Spikelets are erect-spreading, crowded, 6-24-flowered, 2-13 mm long, 1.5-2.0 mm wide, golden to yellowish-green.

Glumes are broad-ovate, 1.0-1.6 mm long, golden-brown. There are two or three stamens. The style is 3-branched. The fruit is a small achene (nutlet), 1.0-1.5 mm long, 0.6-0.7 mm wide, obovate, triangular in cross section, dark-brown to almost black; the surface is almost smooth. These descriptions are based on Haines and Lye (1983) and Holm *et al*. (1977). *C. iria* is rated by Holm *et al*. (1977) as one of the three most important weeds of rice in Sri Lanka, India and the Philippines. It is a principal weed in Indonesia and Japan and a common weed in Fiji, Thailand and the USA. It is principally a weed of rice around the world but Holm *et al*. (1977) also noted its occurrence in bananas, cassava, groundnuts, maize, pastures, pineapples, sweet potatoes, tea and vegetables. It is difficult to separate the competitive effects of C. iria from those of other components of the weed flora but the weed caused 40% yield reductions in rice (Ampong-Nyarko and DeDatta, 1991). The costs of controlling *C. iria*, whether manual, mechanical or chemical, are significant. *C. iria* is a host for several pests of rice. In Cuba, it is a host of the rice nematodes *Pratylenchus zeae* and *Hirschmanniella spinicaudata* (Fernandez and Ortega, 1982). *Criconemella onoensis* is a rice nematode which uses *C. iria* as a host in the southern USA. Complete control of the weed is necessary before nematicides (e.g. fensulfothion) can be effective in increasing rice yields (Hollis, 1972).

Arthropod rice pests which use *C. iria* as a host plant include *Scotinophara latiuscula* (Barrion and Litsinger, 1987), *Nisia atrovenosa* (Cruz and Dela-Cruz, 1986), *Lissorhoptrus brevirostris* (Meneses-Carbonell and Carbonell, 1985), *Nymphula depunctalis* (Pillai and Nair, 1979), *Baliothrips biformis* and *B. holorphnus* (Ananthakrishnan and Kandasamy, 1977).

Pathogens of rice that have been reported on *C. iria* include *Pyricularia oryzae* [*Magnaporthe grisea*] (Singh and Singh, 1988), *Rhizoctonia solani* (Gokulapalan and Nair, 1983) and *Acrocylindrium oryzae* [*Sarocladium oryzae*] (Balakrishnan and Nair, 1981). Also the nematode *Pratylenchus zeae* (Waterhouse, 1994).

***Cyperus esculentus* (Yellow nutsedge)**

Erect perennial herb; culms simple with triangular section, growing from perennial, tuber-bearing rhizomes; leaves in three ranks, mostly basal; inflorescence in terminal umbels; umbel subtended by unequal leaf-like brackets varying from 5 to 25 cm long; spikelets yellowish-brown or straw-coloured, 1-3 cm long, of several flowers, flattened, two-ranked; stamens three; style three-cleft; achenes (fruit) three-angled, narrowing gradually from a square-shouldered apex towards the base, about 1.5 mm long, covered with very fine granulation (Holm *et al*., 1977). It propagates by rhizomes, basal bulbs and tubers. This light-bright green perennial sedge grows to about 0.8 m in height. A basal bulb is formed by a swelling of the culm below the soil surface and rhizomes grow out from this basal bulb to terminate in new shoots (under long days over 14 hours long) or underground tubers (under shorter days, less than 14 hours).

C. esculentus behaves as a weed in almost all temperate, tropical and subtropical regions of the world. Once established, it is extremely difficult to eradicate because plants have a stratified and layered root system, with tubers and roots being interconnected. The plant can quickly regenerate if a single tuber is left in place. In its competition for light, water and nutrients it can reduce crop yields and outcompetes native plant species when it grows as an environmental weed. *C. esculentus* also has the potential to grow forming dense colonies which can increase by more than 1m/year. The invasiveness of this species is also high due to its great dispersal capacity. Tubers and seeds can be easily dispersed through agricultural activities, soil movement, by water and wind, and very often as contaminants in crop seeds (Holm et al., 1977; Defelice, 2002; Dodet et al., 2008).

***Alternanthera philoxeroides* (Alligator weed)**

The plant is characterized by dark-green waxy leaves which are lance-shaped and opposite. They are 12-14 cm long and 1.5-2.5 cm wide. The inflorescence is white, ball-shaped, 1.5 cm in diameter and papery (Flanagan, 1991). It does not always set viable seed under field conditions, but reproduces vegetatively from axillary buds at each node (Julien and Broadbent, 1980). One of the main identifying features of alligator weed growing over water is that the stems grow up to 60 cm high and have larger leaves and hollow internodes. On land, stems are shorter and internodes are smaller and much less hollow.

Alligator weed is a problem in 30 countries. It is a serious weed in eight of these and a major weed in the others. In the Sydney basin, Australia, alligator weed is currently threatening the turf industry valued at over $50 million annually. The vegetable industry valued at $150 million annually is also under threat in the Hawkesbury Nepean catchment. The plant can be a problem in rice paddies (Waterhouse, 1993). On land, it invades and competes with pasture plants and this provides a source of further spread. Although it is grazed by cattle in Australia, it is not considered desirable in pasture (Julien and Chan, 1992) and is a declared noxious weed in all mainland states and territories (Parsons and Cuthbertson, 1992) as well as weeds of national significance in Australia (Thorpe, 1999). In China, alligator weed reduce production of rice by 45%, wheat by 36%, corn 19%, sweet potato 63% and lettuce 47%. On an average vegetable production is reduced by 5-15% (www.weeds.org.au/natsig.htm)

Alligator weed mats impede stream flow and lodge against structures thereby promoting sedimentation which contributes to flooding and structural damage. *A. philoxeroides* is one of the greatest threats to rivers, wetlands and irrigation systems in the world. This weed is extremely difficult to control, is able to reproduce from plant fragments and grows in a wide range of climates and habitats, including terrestrial areas. In aquatic habitats alligator weed has deleterious effects on other plants and animals, water quality, aesthetics, vector populations, water flow, flooding and sedimentation. In terrestrial situations, it degrades pasture, turf and crop production producing massive underground lignified root system penetrating up to 50-60 cm deep.

Ecophysiology of crop-weed competition including allelopathy

Eco-physiology is a branch of plant physiology. It deals with the ecological control on growth, reproduction, survival, abundance and geographical distribution of plants. It is well known that all these processes are affected by interaction between plants with their physical, chemical and biotic environment. It can be defined as the study of physiological response of organisms (plants) to their environment. German biologist Emst Haeckel (1969) was first to propose the word Ecology (Greek Oikos – to house or place to live; logous to study). Ecology is defined as the study of the relationship of organisms or groups of organism with their environment. The questions addressed by eco physiologists are derived from ecology in its broadest sense. It also includes questions originating from agriculture, horticulture, forestry and environmental sciences. However, the eco-physiological explanations often require understanding even at a lower level of integration of organisms (i.e. about physiology, biochemistry, biophysics and molecular biology). Eco-physiology also addresses some societal issues like pollution, climate change, conservation of nature etc. Thus a modern eco-physiologist requires a good understanding of both molecular aspects of plant metabolic processes and also functioning of an intact plant in its environment.

Weeds cause greater losses in crop yields than either insects or plant diseases. The weeds reduce the crop yields through (a) competition for growth resources (light, nutrients, water and space) with crops (b) allelopathy, i.e., release of inhibitors from seeds, living plants and plant residues, and (c) acting as an alternate host for insects and disease organisms.

1.Competition

To compete comes from the Latin word competere, which means to ask or sue for the same thing another does. **Competition** in biology, ecology, and sociology, is a contest between organisms, animals, individuals, groups, etc., for territory, a niche, or a location of resources, for resources and goods, mates, for prestige, recognition, awards, or group or social status, for leadership. It is opposite to cooperation. It arises whenever at least two parties strive for a goal which cannot be shared or which is desired individually but not in sharing and cooperation. The few definitions on plant competition are given below:

1. Aspinall and Milthorpe (1959): “the interaction between plants and environment. The plants during growth modify the environment around them and the modified environment in turn influences the growth of the constituent plants.”
2. Bleasdale (1960): “Two plants are in competition with each other when the growth of either one or both of them is reduced or their form modified as compared with their growth or form in isolation.”

Among several interpretations, "plant competition" essentially means a reduction in performance of a given plant species of importance, due to shared use of a limited available resource (Gurevitch *et al*., 2009). Competition between plants is different from the competition between animals. Due to the lack of mobility, the competition among plants apparently is passive, not being visible at the beginning of the development (Floss, 2008). It is known, however, that crops in general terms do not present high competitive ability against weed species, due to the genetic refinement they were submitted to increase the occurrence of desired productive features in detriment of aggressiveness (Silva *et al*., 2007).

According to Grime (1979), as cited in Silva *et al*. (2007), competition is established when neighboring plants use the same resources, and success in competition is strongly determined by the *plant capacity to capture these resources*. Thus, a good competitor has a high relative growth rate and can use the available resources quickly. However, Tilman (1980), cited in Silva et al. (2007), claims that competitive success is the ability to extract scarce resources and to tolerate this lack of resources – essentially to be *more efficient in extracting and using a given resource*. Therefore, in theory, a good competitor could be the *species with least resource requirement* (Radosevich *et al*., 2007).

In agricultural systems, both the crop and weeds grow together in the same area. As both groups usually demand similar environmental factors as water, light, nutrients and CO_2, and usually these resources are not enough even for the crops, the competition is established. Under this situation, any strange plant which emerges at this area will share these limited resources, causing a reduction both in the volume produced by the crops, as well as in the quality of the harvested product (Floss, 2008). Radosevich et al. (2007) classified the environmental factors which determine plant growth in “resources” and “conditions”.

Resources are the consumed factors such as water, CO_2, nutrients and light, and the response of plants usually follows a standard curve: it is small if the resource is less available and maximum at the saturation point, usually declining again in case of excessive availability of the resource (e.g. toxicity due to excessive zinc availability in the soil). Conditions are factors not directly consumed, such as pH and soil density, although they influence directly plant ability in exploring the resources. However, plant competition will only be established when the demand of a given resource by a plant community surpasses the ability of the environment in supplying the demanded level of the given resource (Floss, 2008).

The competition between crops and weed species is critical for the crop in cases where the weed is established together or before the crop (Radosevich, 2007). However, if the crop presents similar competitive ability to the weeds and is capable of establishing itself first, it will cover the soil, preventing access of weeds to light (Silva et al., 2007) – which is one of the most determinant factors for plant establishment (Floss, 2008; Gurevitch et al., 2009).

The competition can be established both among individuals of the same species (intraspecific competition), or among distinct plants (inter-specific competition). There is also the intra-plant competition, where distinct parts of the same plant (leaves, roots, flower buds) vie for photo-assimilates. Based on the previously exposed, in general terms the competitive process among plant species should be faced as follows (Silva et al., 2007):

- Competition is more serious in younger stages of development of the crop, e.g. at the first eight weeks for annual crops;
- Weed species morpho-physiologically similar to the crop are usually the most competitive in comparison to those which differ greatly from the crops;
- A moderate weed infestation in crop fields can be as harmful as a heavy infestation, depending on the moment these weeds are established;
- The competition is established for water, light, CO_2, nutrients and physical space. Weed species can also exudate to soil allelochemicals capable of inhibiting germination and/or growth of other plant species.

When plants are subjected to strong competition in the plant community, the physiological characteristics of growth and development are usually changed. This results in differences in the use of environmental resources, especially the water, which directly affects the availability of CO_2 in leaf mesophyll and leaf temperature, therefore, the photosynthetic efficiency (Procópio *et al*., 2004b).

Competition for Nutrients

Weeds usually absorb mineral nutrients faster than many crop plants and accumulate them in their tissues in relatively larger amounts.

- *Amaranthus* sp. accumulate over 3% N on dry weight basis and are termed as “nitrophills”.
- *Achyranths aspera*, a ‘P’ accumulator with over 1.5% P_2O_5
- *Chenopodium* sp & *Portulaca* sp. are ‘K’ lovers with over 1.3% K_2O in dry matter

Mineral composition of certain common weeds on dry matter basis

Species	**N**	**P_2O_5**	**K_2O**
Achyranthus aspera	2.21	1.63	1.32
Amaranthus viridis	3.16	0.06	4.51
Chenapodium album	2.59	0.37	4.34
Cynodon dactylan	1.72	0.25	1.75
Cyperus rotundus	2.17	0.26	2.73
Rice	1.13	0.34	1.10
Sugarcane	0.33	0.19	0.67
Wheat	1.33	0.59	1.44

- The associated weed is responsive to nitrogen and it utilizes more of the applied ‘N’ than the crop. The ‘N’ uptake by *Echinochloa crusgalli* is more than rice.

Nutrient removal by weeds leads to huge loss of nutrients in each crop season, which is often twice that of crop plants. For instance at early stages of maize cultivation, the weeds found to remove 9 times more of N, 10 times more of P and 7 times more of K.

Competition for water

Plants are powerful pumps extracting water from the soil, and because of this in hot days it is common to see crops submitted to water deficit presenting some degree of wilting, while plants of some weed species are still completely turgid. Usually, the competition for water causes the plant to compete also for light and nutrients (Silva *et al.*, 2007). Several factors influence the competitive ability of a plant in competing for water, highlighting the volume of soil explored (proportional to the volume of the root system), physiological characteristics of the plant, stomatal regulation, osmotic adjustment in roots and hydraulic conductivity capacity of the roots (Floss, 2008).

Some plant species are capable of using less water per unit of dry mass accumulated than others, because they are more efficient in the use of the water (Water Use Efficiency – WUE = amount of dry mass accumulated as a function of water used at the same period). It is possible to infer that plants with higher WUE (more efficient in the use of water) are more productive when submitted to periods of limited water availability, as well as more competitive (Radosevich *et al.*, 2007). However, some weed species may present distinct values of WUE throughout the cycle, being more competitive for water in certain stages of their development (Silva *et al.*, 2007).

Differences in WUE are important in plant aggressiveness, although this is not the only mechanism allowing survival to water competition. The stomatal self-regulation, in terms of stomatal conductance, plays an important role in overcoming water deficit periods.

Competition for light

For some authors, competition for light is not as important as competition for water and nutrients. However, it should be considered that there is an interrelation among these factors (Silva *et al.*, 2007). In fact, researchers are only starting to understand how the plant physiology is related to conditions of competition (Larcher, 2004). When the crop shades completely the soil, there is no competition for light between crops and weed species. For other authors, the genetic improvement of crops allowed these plants to be more efficient in intercepting and using light. As a consequence, plants of crop species present high Light Use Efficiency (LUE) when evaluated alone (Floss, 2008). Probably because of this, competition for light is often not considered in studies of plant competition.

Santos *et al.* (2003) evaluated the LUE of bean and soybean plants and of weed species *Euphorbia heterophylla*, *Bidens pilosa* and *Desmodium tortuosum*, and concluded that crops accumulated more dry mass per unit of light intercepted than any of the weeds studied. These authors also reported that, although the weeds were less efficient than crops in using light, they present high competitive ability in field conditions due to be more efficient in the extraction and use of other resources, like water and nutrients.

It is known that the competition for light is complex and its amplitude is influenced by the plant species, e.g. if the species is native to shaded or sunny environments and if it presents carbon metabolism of the type C_3, C_4 or CAM. The differences between these plant groups are based on the reactions that take place at the dark phase of photosynthesis (Floss, 2008; Gurevitch *et al.*, 2009).

It is common to imagine that C_4 plants are always more efficient than C_3 plants; however, this is true only under certain conditions (Silva *et al.*, 2007). The C_4 plants demand higher levels of energy for producing photoassimilates, because they present two carboxilative systems, and thus need to recover two enzymes for a new photosynthetic cycle. It is known that the relation CO_2 fixed/ATP/NADPH is 1:3:2 for C_3 species and 1:5:2 for C_4 species. This remarks the higher need of energy for photosynthesis in C_4 plants. As all this energy comes from light, if the access to light is reduced, C_4 plants will be less competitive than C_3 species.

On the other hand, the enzyme responsible for carboxilation in C_4 species presents some characteristics like high affinity for CO_2; no oxygenase function; optimal performance at higher temperatures; and no saturation under high light availability. As a function of these and other features, when plants are under high temperatures, light availability and also temporary water deficit, C_4 species are capable of completely overcoming C_3 species, being able to accumulate twice the dry mass per unit of leaf area in the same time interval (Silva *et al.*, 2007).

Competition for CO_2

In relation to CO_2, competitive aspects involving the availability of this gas are usually not considered. However, when the distinct carbon cycles presented by crops and weed species are detailed, it is possible to observe that the CO_2 concentration in the leaf mesophyll, necessary for a given species to properly accumulate dry mass, is distinct. As the efficiency in capturing CO_2 from the air is distinct between C_3 and C_4 species, and also the concentration of CO_2 may vary inside a given mixed plant community, the availability of CO_2 may be limiting for photosynthesis under competition, mainly for C_3 plant species (Silva et al., 2007).

2. Allelopathy

The term allelopathy was first introduced by Hans Molisch in 1937 and refers to chemical interactions among plants, including those mediated by microorganisms. Rice (1984) defined allelopathy as the effects of one plant (including microorganisms) on another plant through the release of chemical compounds into the environment. Since 1960's allelopathy has been increasingly recognized as an important ecological mechanism which influences plant dominance, succession, formation of plant communities, vegetation and crop productivity. It has been related to the problems with weed: crop interference (Bell and Koeppe, 1972), phytotoxicity in stubble mulch farming (McCalla and Haskins, 1964) and in certain types of crop rotations (Conrad, 1927). Rice (1984) indicated that allelopathy contributed to weed seed longevity problem through two mechanisms, (a) chemical inhibitors in the seed prevented their decay by microbes and (b) the inhibitors kept the seed dormant, although viable for many years.

Allelochemicals include mainly the plant secondary metabolites (Levin 1976). They exhibit allelopathic effect either on the growth and development of the same plant or nearby plants species. The term allelochemicals include, (a) plant biochemicals that exert their physiological/toxicological action on plants (allelopathy, autotoxicity or phytotoxicity), (b) plant biochemicals that exert their physiological/toxicological action on microorganisms (allelopathy or phytotoxicity) and (c) microbial biochemicals that exert their physiological/toxicological action on plants (allelopathy and phytotoxicity).

Allelochemicals have mostly negative effects on crop plants such as: (a) delayed or complete inhibition of germination, (b) reduced plant population, (c) stunted and deformed roots and shoots, (d) deranged nutrient absorption, (e) lack of seedling vigour, (f) reduced tillering, (g) chlorosis, (h) wilting, (i) increase susceptibility to disease. However, the main impacts of phytotoxins on crop plants are: (i) inhibition of nitrification and biological nitrogen fixation, (ii) predisposing the plants to diseases and (iii) inhibition or stimulation of germination, growth and yield.

Allelopathy can play a beneficial role in various cropping systems such as mixed cropping, multiple cropping, cover cropping, crop rotations, and minimum and no–tillage systems. The exploitation of allelopathy in agricultural practices as a tool for weed control has shown weed reduction, pathogen prevention and soil enrichment (Kohli et al., 1998).

Ways by which allelopathy can be used to control weeds in cropping systems

In general, the use of allelopathy as a tool to control weeds can be achieved in following five different ways:

Use of crop cultivars with allelopathic properties

The crop cultivars differ in their allelopathic ability and thus superior cultivars can be selected for weed management programs (Wu et al. 1999; Olofsdotter et al. 2002). Differences in allelopathic potential between genotypes has been investigated among accessions (genetical different lines or strains of a species) of barley, cucumber (*Cucumis sativus*), oats, soybean (*Glycine max*), sunflower, sorghum (*Sorghum bicolor*), rice and wheat (Copaja et al. 1999, Dilday et al. 1994, Narwal 1996, Miller 1996,Yoshida et al. 1993, Wu et al. 1998).

In a study on 3000 accessions of *Avena* sp., Fay and Duke (1977) found that four accessions apparently exuded up to three times as much scopoletin (a chemical identified as phytotoxic) as a standard oat cultivar. When one of the accessions were grown in sand culture with wild mustard (*Brassica kaber*), the growth of the mustard was significantly less than when it was grown with an accession that exuded a lower amount of scopoletin. In a field experiment, 1000 accessions of rice were screened for allelopathic activity against the two weedy species, barnyardgrass (*Echinochloa crus-galli* Beauv) and *Cyperus difformis*. Of these, 45 accessions showed allelopathic activity against one of the weeds and five accessions inhibited both species (Olofsdotter et al. 1997). Dilday et al. (2001) evaluated 12,000 rice accessions from 110 countries for allelopathy to ducksalad [*Heteranthera limosa* (S.w.) Willd.] and about 5000 have been assessed for allelopathy to redstem (*Ammannia coccinea*) and barnyardgrass. Results indicated that among them, 145 accessions were allelopathic to ducksalad and redstem and 94 accessions demonstrated apparent allelopathic activity to barnyardgrass.

Many weed species are most susceptible to allelochemicals in the seed and seedling stages. Therefore, the ideal allelopathic cultivar must therefore release allelochemicals in bioactive concentrations before the target weeds grow to old. Knowledge about both the critical developmental stage where the crop starts releasing allelochemicals and the critical sensitive stage of the target weeds is therefore essential (Inderjit and Olofsdotter 1998).

Application of residues and straw of allelopathic crops

Weed suppressive effects of crop residues have been explained by different mechanisms, including initial low nitrogen availability following cover crop incorporation (Dyck and Liebman 1994; Kumar et al. 2008; Samson 1991), mulch effects (Mohler 1996; Mohler and Callaway 1991; Mohler and Teasdale 1993), stimulation of pathogens or predators of weed seeds (Carmona and Landis 1999; Conklin et al. 2002; Davis and Liebman 2003; Gallandt et al. 2005; Kremer 1993), and allelopathy (Chou 1999; Weston 1996).

Allelopathic compounds released from crop residues during decomposition can reduce both emergence and growth of weeds. Allelochemicals can be released either through leaching, decomposition of residues, volatilization or root exudation (Chou 1999). In production systems with no-till or conservation tillage that leave nearly all crop residues on the soil surface, the release of allelochemicals from both the growing plants and during residue decomposition could be advantageous (Kruse et al. 2000).

Barnes and Putnam (1983) reported that rye residue used as mulch reduced total weed biomass by 63%. It was found that disappearance of rye allelochemicals was more closely related to weed suppression than to the disappearance of rye residues. Especially due to the massive production of biomass, rye has the potential to influence the growth of succeeding plant species through the release of allelochemicals from the residue (Barnes et al. 1985).

Wheat residues suppress weeds due to the physical effect and to the production of allelochemicals (Petho 1992). Their allelopathic effect was positively correlated with the total phenolic content in the tissue of the wheat cultivars (Wu et al 1998). Hydroxamic acids have also been identified in shoot and root tissue of wheat.

The residues of barley have also been associated with phytotoxicity (Overland 1966, Lovett and Hoult 1995). Phytotoxic phenolic compounds, including ferulic, vanillic and phydroxybenzoic acids, have been identified in barley (Börner 1960). The two alkaloids, gramine and hordenine have been confirmed to play an important role in the phytotoxic ability of barley (Lovett and Hoult 1995, Overland 1966). In a study, allelopathic compounds released from residues of barley apparently inhibit the emergence of yellow foxtail (*Setaria glauca*) (Creamer et al. 1996).

In another study, the use of sorghum plant tissues as a mulch or incorporated into the soil led to the reduced weed growth in corn field (Mohammadi et al. 2009). This can be attributed to the allelopathic compounds released from the sorghum plant tissues.

Use of an allelopathic crop in a rotational sequence

The entrance of allelopathic crops into the crop rotations can effectively control weeds. In a study, under reduced or no-till condition a considerable reduction in the population of giant foxtail (*Setaria faberii* Herrm.) was occurred when allelopathic soybean-corn-wheat rotation was followed than in corn alone (Schreiber 1992). In a 5–year field study with sunflower (*Helianthus annuus* L.)–oat rotation, the weed density increase was significantly less in sunflower plots than in control plots (Leather, 1983 a, b; 1987). It was found that sunflower plants possess chemicals, which inhibit the growth of common weed species. Macias et al., (1999) reported some sesquiterpene lactones with germacranolide and guaianolide skeletons and heliannuol from different cultivars of sunflower.

In another study, the inclusion of alfalfa in the crop rotation sequence significantly decreased the interference of weeds in the next crops (Entz et al. 1995). Ominski et al. (1999) conducted a survey in 117 fields in Manitoba, Canada, and found that rotation with alfalfa can effectively reduce the interference of wild oat (*Avena fatua* L.), Canada thistle (*Cirsium arvense* L.), wild mustard (*Brassica kaber* L.) and catchweed bedstraw (*Galium aparine* L.) in the succeeding cereal crops. Therefore, it can be concluded that the inclusion of alfalfa in crop rotation can be an efficient tool in an integrated weed management program. However, climatic and economic conditions are important limiting factors which can notably influence the regional crop rotation scenarios.

Application of allelochemicals or modified allelochemicals as herbicides

A promising way to use allelopathy in weed control is using extracts of allelopathic plants as herbicides (Dayan, 2002; Singh et al., 2005). Because biosynthesized herbicides are easily biodegradable, they are believed to be much safer than synthesized herbicides (Rice, 1984, 1995; Dayan et al., 1999; Duke et al., 2000). Duke et al. (2000) discussed that natural compounds have several benefits over synthetic compounds. For example, natural compounds may have novel structure due to diversity of molecular structure. This diversity is because synthetic chemists have been biased toward certain types of chemistry. They have had almost no interest in water-soluble compounds. Unlike a high proportion of synthetic pesticides, natural compounds are mostly water-soluble and non-halogenated molecules. Natural products relatively have short half-life and therefore considered safe of environmental toxicology standpoint (Duke et al., 2002). Although, allelochemicals have the potential to be explored as natural herbicides, but prior to using them as herbicides, the following questions should be considered (Bhowmik and Inderjit 2003):

1. At what minimum concentration does each compound have phytotoxic activity?
2. Whether the compound is accurately separated and correctly identified?
3. What is the residence time and fate of the compound in the soil environment?
4. Does the compound influence microbial ecology and physicochemical properties of the soil?
5. What is the mode of action of the compound?
6. Has the compound any adverse effect on desired crops?
7. Whether the compounds are safe from health standpoint?
8. Whether the large production of the compound at commercial scale is economical?

Plant chemicals associated with allelopathic activity have been reported in most cases to be secondary metabolites from shikimic acid, acetate, or terpenoid pathways (Rizvi and Rizvi 1992; Vokou 2007). Some of the natural products exploited as commercial herbicides are triketone, cinmethylin, bialaphos, glufosinate and dicamba. The compounds having potential herbicidal activity but not commercially used are sorgoleone, artemisinin and ailanthone (Bhowmik and Inderjit 2003).

Sorgoleone is an allelochemical of sorghum which constitutes more than 80% of root exudates composition (Nimbal et al., 1996a; Czarnota et al., 2003). This compound inhibited the evolution of O_2 during photosynthesis in potato (*Solanum tuberosum* L.) and in common groundsel (*Senecio vulgaris* L.) (Nimbal et al. 1996a). Nimbal et al. (1996b) carried out a study on sorgoleone using triazine-susceptible potato and redroot pigweed thylakoids. Sorgoleone was a competitive inhibitor of atrazine binding sites. Sorgoleone also inhibited the photosystem II electron transport reactions (Gonzalez et al., 1997).

However, sorghum shoots produce higher amounts of cynogenic glucosides whose phenolic breakdown products inhibit plant growth (Einhellig and Rasmussen, 1989; Weston et al., 1989; Se´ne et al., 2001). In a study, Mohammadi et al. (2009) reported that the spray of sorghum shoot extract (Sorgaab) reduced weed infestation in corn field.

Artemisinin, a sesquiterpenoid lactone is an allelochemical of annual wormwood (*Artemisia annua* L.). It has been shown to inhibit the growth of redroot pigweed, pitted morning glory (*Ipomoea lacunosa* L.), annual wormwood and common purslane (*Purtulaca oleracea* L.) (Duke et al., 1987). Duke et al. (1987) concluded that artemisinin is a selective phytotoxin with herbicidal activity similar to cinmethylin (Bhowmik, 1988).

Ailanthone an allelochemical of *Ailanthus altissima* L. exhibited a strong herbicidal activity when sprayed on soil before the seed germination. It, however, also had dramatic effects when sprayed onto seedlings after their emergence from soil (Bhowmik and Inderjit 2003). However, most of allelochemicals indicate a poor performance under field conditions compared to laboratory conditions. Moreover, many allelochemicals exhibit rapid dissipation under natural situations and thus fail to give desired results (Singh et al. 2003). Therefore, further studies are needed to enhance performance and stability of allelochemicals under field conditions.

Modification of crops to enhance the allelopathic effect

Breeding of crops for allelopathic ability by using the methods like screening and biotechnology is another promising strategy for efficient weed control. Just as crop plants are bred for disease resistance, crop plants can be bred to be allelopathic to weeds common to specific regions (Rice, 1984, 1995; Jensen et al., 2001; Wu et al., 2000, 2003; Olofsdotter et al., 2002; He et al., 2004). Allelopathic effect against a broad spectrum of weeds has been proposed as a valuable character of an allelopathic crop and the possibility of inserting resistance genes towards one or several weeds as part of a breeding strategy of a crop has been mentioned (Olofsdotter et al. 1997).

Genetic modification of crop plants to improve their allelopathic properties and enhancement of their weed-suppressing ability has been suggested as a possibility (Kruse et al 2000). Use of biotechnological transfer of allelopathic traits between cultivars of the same species or between species has also been proposed (Chou 1999, Macias 1995, Macias et al. 1998, Rice 1984).

Several researchers have suggested improvement of allelopathic properties of crop cultivars by traditional breeding or by genetic manipulation. For example, there has been significant progress in isolating rice allelochemicals (Rimando et al., 2001) and locating genes controlling allelopathic effects of rice (Jensen et al., 2001). These researchers identified quantitative trait loci (QTL) associated with the rice allelochemicals against barnyardgrass. This is an important step toward breeding allelopathic rice varieties. It was found that 35% of the total phenotypic variation of allelopathic activity of population was explained by four main effect QTLs situated on three chromosomes.

In wheat, the control of hydroxamic acid accumulation seems to be multigenic involving several chromosomes. Chromosomes of group 4 and 5B are apparently involved in the accumulation of hydroxamic acids (Niemeyer and Jerez 1997).

In barley, a gramine synthesis gene has been detected on chromosome 5 (Yoshida et al. 1997). Moharramipour et al. (1999) reported that one or two genes control the synthesis of gramine. DIBOA is a hydroxamic acid compound which has been found in wild *Hordeum* species by Barria et al. in 1992 and the production of DIBOA by cultivated barley could possibly be achieved by transferring genetic material from wild barley species (Gianoli and Niemeyer 1998).

Duke et al. (2000) suggested that biotechnology may eventually allow for the production of highly allelopathic crops through the use of transgenes to increase allelochemical production to levels that effectively manage weeds without herbicides or with reduced herbicides input. However, it has been stated by Wu et al. (1999), that even though genetic manipulation seems promising, it might be more feasible to select for crop cultivars with improved allelopathic properties using conventional breeding methods, because of the strict regulation and public concern about transgenic crops.

Exercise

Tick the correct answer

Q.1. *Commelina benghalensis* bearing short-lived blue coloured flowers is a
a).**Monocot** b). Dicot c). Spermatophyte d). Pteridophyta

Q.2. The most systematic method for classifying weeds is based on
a).Morphology b). Life history c). Habitat d). **Phylogenetic**

Q.3. Simple perennials are reproduced by
a).Rhizomes b). Tubers c). Corms d). **Seeds**

Q.4. The first prominent instance of biochemical mimicry based crop associated weed under Indian perspective is
a).*Saccharum spontaneous* in sugarcane b). ***Phalaris minor* in wheat** c). Wild rice (*Oryza longistaninata*) in rice d). Itch grass (*Rottboellea cochinchinensis*) in upland rice

Q.5. A weed with a trailing stem
a).***Convolvulus arvensis*** b). *Digitaria sanguinalis* c). *Cuscuta* sp d). *Cynodon* sp

Q.6. A weed with a balloon structure for effective dissemination
a).***Physalis minima*** b). *Avena fatua* c). *Phalaris minor* d). *Amaranthus viridis*

Q.7. A weed having spines as adaptations that repel grazing
a).*Solanum nigrum* b). ***Solanum xanthocarpus*** c). *Parthenium* d). *Ageratum*

Q.8. Which of the following causes itching and inflammation
a).*Ammannia baccifera* b). *Solanum nigrum* c). ***Urtica* sp** d). *Lantana camara*

Q.9. Cultivation of water chestnut (*Trapa bispinosa*) is abandoned in India due to
a).*Lantana camara* b). ***Eichhornia*** c). *Mikania micrantha* d). *Acacia mearnssi*

Q.10. *Eichhornia crassips* is a representative of
a).**Free floating** b). Rooted floating c). Rooted submerged d). Emergent

Q.11. The partial root parasite
a).*Cuscuta* b). *Loranthus* c). ***Striga*** d). *Orobanche*

Q.12. A weed with a funnel shaped corolla
a).*Medicago denticulata* b). *Vicia sativa* c). ***Convolvulus arvensis*** d). *Scirpus sp*

Q.13. A sedge with rhizomes
a).*Commelina obliqua* b). ***Cyperus rotundus*** c). *Scirpus* sp d). *Eleocharis*

Q.14. A lowland rice sedge
a).*Cyperus iria* b). *Cyperus difformis* c). *Cyperus esculentus* d). **All**

Q.15. The ‘condition influences’ directly plant ability in exploring resources
a).**Soil density** b). Soil CO_2 c). Soil N d). Soil water

Q.16. Hans Molish is associated with

a).Competition b). Eutrophication c). Allelomediation d). **Allelopathy**

Q.17. The natural product explored as commercial herbicide

a).glufosinate b). dicamba c). cinmethylin d). **all**

Q.18. Man associated with 'Horse Hoeing Husbandry'

a).Zimdahl Robert L. b). Molish c). **Jethro Tull** d). Aspinall and Milthorpe

Q.19. Dryland weeds usually have

a).deep root b). hairyness c). Mucilaginous stem d). **all**

Q.20. A weed poisonous to animals and human beings

a).***Datura metal*** b). *Ammannia baccifera* c). *Chenopodium* d). *Urtica* sp

Q.21. Off type economic crop plants in same crop fields say barley plants in wheat fields are called

a). Crop plants b). Wild plants c). **Rogue plants** d). Weed plants

Q.22. The plant family includes many of the important crops and having most weedy species

a). Cyperaceae b). **Poaceae** c). Asteraceae d). Leguminosae

Q.23. About two-thirds of the important weeds are

a).Grasses b). **Broad-leaved** c). Sedges d). Ferns

Q.24. A family having almost no weedy species

a).Equisitaceae b). Malvaceae c). **Taxaceae** d). Juncaceae

Q.25. A weed with flower parts mostly in threes or sixes and never fives

a).***Avena ludoviciana*** b). *Polygonum alatum* c). *Chenopodium album* d). *Convolvulus*

Q.26. A weed with flower parts mostly in fours and fives

a).*Cyperus iria* b). *Phalaris minor* c). *Equisetum arvense* d). ***Polygonum alatum***

Q.27. Based on ontogeny the weeds are classified as

a). **Annual, biennials** etc b).Monocots, dicots etc c). Native, exotic etc d). Relative, absolute

Q.28. A partial stem parasite

a). *Cuscuta chinensis* b). *Striga lutea* c). ***Loranthus longiflorus*** d). *Orobanche cernua*

Q.29. a floating weed

a). *Uticularia stellaris* b). *Nelumbium speciosum* c). *Typha* d). ***Eichhornia crassipes***

Q.30. A winter perennial weed

a). ***Circium arvense*** b). *Sorghum halepense* c). *Lantana camara* d). Wild rose

Q.31. A summer perennial weed

a). ***Sorghum halepense*** b). *Circium arvense* c). *Avena* sp d). *Polypogon monspelensis*

Q.32. A weed associated with berseem

a).***Cicorium intybus*** b). *Phalaris minor* c). *Avena* d). *Polypogon*

Q.33. A twining weed

a).*Ipomoea pandurata* b). *Citrallus vulgaris* c). ***Cuscuta*** sp d). *Convolvulus arvensis*

Q.34. A weed with maximum seed production potential per plant

a).*Avena fatua* b). ***Amaranthus viridis*** c). *Xanthium strumerium* d). *Solanum nigrum*

Q.35. A weed resembling morphologically with the crop

a).*Phalaris* b). *Avena* c). *Echinochloa* d). **All**

Q.36. A weed act as alternate host of rice stem borer

a). *Sacharum spontaneum* b). *Cenchrus ciliaris* c). ***Echinochloa*** d). *Amaranthus*

Q.37. A weed induce itching and inflamation

a).***Urtica* sp** b). *Parthenium* c). *Ambrosia* d). *Pistia*

Q.38. Which of the following is known as a goat weed

a). *Ulex uropaeus* b). *Parthenium* c). ***Eupatorium glandulosum*** d). *Mikania micrantha*

Q.39. An invasive Neotropical plant established in India

a).*Mikania micrantha* b). *Parthenium hystophorus* c). *Lantana camara* d). **All**

Q.40. Presence of aquatic weeds hamper the cultivation of

a).*Trapa bispinosa* b). Makhana c). Rice d). **All**

Q.41. A very competitive winter weed

a). ***Phalaris minor*** b). *Echinochloa* c). *Amaranthus* d). All

Q.42. A leguminous weed

a).*Medicago denticulata* b). *Melilotus parviflora* c). *Lathyrus aphaca* d). **All**

Q.43. Which of the following is called purple nutsedge

a). *Cyperus esculentus* b). *Cyperus difformis* c). *Cyperus iria* d). **None of these**

Q.44. Rice flatsedge is which of the following

a). ***Cyperus iria*** b). *Cyperus haspan* c). *Cyperus rotundus* d). *Cyperus esculentus*

Q.45. Alligator weed is the common name for

a).*Eclipta alba* b). ***Alternanthera phloxeroides*** c). *Parthenium hystophorus* d). Mikania

Q.46. The consumed factor of the environment

a).**Nitrogen** b). pH c). Soil density d). None of these

Q.47. A factor not directly consumed although influences plant ability in exploring the resources

a). CO_2 b). Potassium c). **pH** d). None of these

Q.48. A 'K' lover

a). *Poa annua* b). *Achyranthus aspera* c). ***Chenopodium*** sp d). None of these

Q.49. The term allelopathy was introduced by

a). Rice (1984) b). **Hans Molish (1937)** c). Conrad (1927) d). Bell and Koeppe (1972)

Q.50. Artemisinin has been shown to inhibit the growth of which of the following

a). Redroot pigweed b). Pitted morning glory c). Common purslane d). **All**

Fill in the blanks

1. The ___________ is the family having most weedy species as well as many crops.
2. According to Holm (1978), three plant families *viz.* ____________, ____________ and ____________ include 43% of 200 species that are most important world weeds.
3. The array of definitions of weeds given by plant scientists, ecologists and _______________________ emphasizing the care weed scientist must take in equating how they are defined with a right or privilege to control.
4. Classification based on ______________ is the most widely used method of classifying weeds as it may be used to select herbicides.
5. A weed having no economic importance is referred to as _____________ weed.
6. Based on specificity, weeds are classified as ____________, _________________ and ____________.
7. __________________ is the most important crop bound weed of tobacco, tomato, carrot and sarson.
8. Dual mode of reproduction means reproduction by ______________ as well as through ______________ ________________.
9. Weeds are ______________________ that they exist everywhere we practice agriculture.
10. Several irrigation and hydroelectric projects in the country are endangered by infestation of dams and reservoirs with massive growth of _______________________.
11. Among the ten common noxious aquatic weeds in India, ______________________________ an alien, topped the list.
12. __________ is a partial root parasite on Sorghum and maize.

Key

1.Poaceae 2. Poaceae, Cyperaceae and Asteraceae 3. Enthusiastic amateurs 4. Morphology 5. Absolute 6. Poisonous, parasitic and aquatic 7. Orobanche sp 8. Seed, vegetative propagules 9. Ubiquitous 10 aquatic weeds, 11. *Eichhornia crassipes* 12. Striga

Define/explain the following

Eco-physiology; Sedge; Competition; Allelopathy; Environmental plasticity; Prostrate; Terrestrial; Obligate weed

Define weeds based on a desirable ecological base and classify them based on phylogenetic relationships.

Give a comprehensive view of aquatic weed problems in India.

How enthusiastic amateurs defined weeds? Classify the weeds based on life cycle and specificity.

What do you mean by competition? Discuss ecophysiology of crop-weed competition.

How weeds are classified based on morphology and association
What is crop-weed interference? Discuss the ways allelopathy can be used to control weeds
How ecologists think about weeds? Enlist the ways weeds are classified. Discuss the most widely used classification by the weed scientists.
Discuss the ecological consequences weeds pose on the environment. Discuss the impacts and control of *Lantana*, *Parthenium* and *Alternanthera*.
How competition is different from allelopathy? Discuss the approaches allelopathy can be exploited in weed management.
Give five ways in which plants generally called weeds can be beneficial. Five ways they can be detrimental.
Define a weed. Why might there be disagreement about whether a plant is weed or not?
What is the difference between summer annuals and winter annuals? Give three examples of each.
What is the difference between a biennial and a winter annual? Name two biennials.
How do you distinguish between grasses and sedges?

UNIT II

Principles and methods of weed control, concept of integrated weed management, principles of chemical weed control, weed control through bioherbicides.

Principles and methods of weed control

Principles of Weed Control

Weed control is the process of limiting weed infestations so the crops could be grown profitably and other activities of man conducted efficiently. The main aim of weed control is to manage the vegetation on land and water bodies in such a way as will encourage the growth of plants beneficial to humans and will suppress the remaining unwanted plants. Indiscriminate application of control measures against plants is not the objective of weed control.

Weed eradication is the complete removal of all live plant parts and seeds from an area. It is an expansive adventure since it costs more than that of the land. Besides complete elimination of all vegetation is not wanted as many of them are useful. Eradication of some noxious weeds such as *Cuscuta, Xanthium* and *Lantana* can be done. Eradication should start when the weeds are small and limited in growth and spread.

Concept of weed management instead of control is important. Weed control aims at putting down the weeds already present. Weed management is a system approach whereby whole land use planning is done in advance to minimize the invasion of weeds in aggressive forms and give crop plants a very strong competitive advantage over the latter. The systems approach is called integrated weed management (IWM). Build up of previously minor species (perennials) into dominant levels because of repeated use of the same method to control existing dominant species (annuals), increasing concern over pesticide effects on human health and the environment and development of resistant weeds are the main forces behind adoption of IWM. IWM is the management system of weed populations aiming to keep infestation levels below those causing economic injury by combining any two or more of preventive, cultural, chemical or biological methods. The definition implies that IWM is largely a decision making process involving 1) when to apply control measures with use of critical thresholds and 2) what combination will provide best control at greatest profits.

The long term objective of IWM is to avoid or reduce any adverse environmental impact of control methods and to prevent build up of any one weed species.

Pre-requisite of successful weed management programme

One must gain knowledge of the biology of weeds under attack before choosing a system for their control. The nature of weed problems must be surveyed in the target area. Weed control measures must be planned for the whole farm and not just against weeds in a field. Weed control system must follow up programme of weed prevention measures.

For successful control, one has to consider the following points:

1. Habits of weed plants: A xerophytes weed (E.g. *Alhagi camelorum*) thriving under dry & arid conditions will die if fields are flooded with water. Similarly weeds which thrive under marsh or ill drained condition of soil can be controlled by improving drainage.
2. Life cycle of the weed: Annuals & biennials can be controlled effectively if the land is cultivated before seedling stage of weeds. Perennials require deep ploughing to dig out rhizomes, bulbs, etc. vegetative part by which they propagate.
3. Susceptibilities: Some weeds are susceptible to certain chemicals while others are not. E.g.: Dicots are susceptible to 2, 4-D while monocots are not, hence 2,4-D is used to control broad leaved weeds in monocot crops.
4. Dormancy period: While controlling dormancy weeds, period is to be considered as they have long dormancy period.
5. Resistance to adverse conditions without losing viability: Some weed seeds have hard seed coats which enable them to remain for a long time without losing their viability, hence they should be controlled before seed formation.
6. Methods of reproduction: Weeds propagate either by seeds, vegetative parts or by both. Seeded weeds should be removed or smothered before seed formation. Vegetatively propagated weeds should be exposed to sun heat to dry & die like rhizome, bulbs, stolons, etc. by deep ploughing. Frequent cultivation leads to destroy green leaves & thereby exhaust the food reserves & starve the plants may have to be restored too. In weeds propagated by both mechanical & chemical methods may have to be followed.

7. Dispersal of seeds: Weeds can be controlled or kept in check if the ways in which different weed seeds disseminate are known and counter measures are undertaken.

Methods of weed control

Weed management is the combination of the techniques of prevention, eradication, and control to manage weeds in a crop, cropping system, or environment. Weed managers recognize that a field's or area's cropping history, the grower's management objectives, the available technology, financial resources, and a host of other factors must be combined to make good management decisions. Complete weed control in a crop may be the best decision in some cases, but it is not automatically assumed to be the goal. Maintenance of a weed population at some level in a cropping system may be the most easily achievable and financially wise goal for a weed management program. Weed prevention, control, eradication, and management are different concepts, and each uses and combines technologies differently. Controlling weeds in cropped and non-cropped lands may involve a wide range of techniques. Nevertheless, virtually all weed control methods may be classified into one or more of five main categories viz. preventive, cultural, mechanical, biological and chemical.

Preventative Weed Control

Prevention of invasion is the best strategy to combat weeds. Preventative weed control refers to any control method that aims to prevent weeds from being established in a cultivated crop, a pasture, or a greenhouse. A good weed management program includes vigilance or watchfulness. The good weed manager can identify weed seeds, seedlings, and mature plants, and has a management program for each crop and field and appropriate follow-up programs. The good manager is ever watchful for new weeds that may become problems and whenever possible emphasizes prevention rather than control.

Several preventive practices can be included in management programs:

1. Isolation of introduced livestock to prevent spread of weed seeds from their digestive tract.
2. Use of clean farm equipment and cleaning of itinerant equipment, including combines, cultivators, and grain trucks.
3. Cleaning irrigation water before it enters a field.
4. Mowing and other appropriate weed control practices to prevent seed production on irrigation ditch banks.
5. Inspection of imported nursery stock for weeds, seeds, and vegetative reproductive organs.
6. Inspection and cleaning of imported gravel, sand, and soil.
7. Special attention to fence lines, field edges, rights-of-way, railroads, and so on as sources of new weeds.
8. Prevention of deterioration of range and pasture to stop easy entry of invaders such as downy brome (Mack, 1981).
9. Seed dealers and grain handlers should clean crop seed and dispose of cleanings properly.
10. Cleanings should be heated or ground to prevent seed dispersal.
11. Fields should be surveyed regularly to identify new weeds.
12. When identified, small patches of new weeds should be treated to prevent growth and further dispersal.

The first rule for weed prevention and the first step of any good weed management program is the purchase and planting of clean seed. Each country regulates transport and sale of seeds in foreign and interstate (but not intrastate) commerce.

Cultural

Cultural weed management techniques are of immense importance in crops where other weed management options are limited or not available. Cultural weed management is an important part of nearly all weed management systems, even when it is not recognized. They should be included in weed management programs although they should not be regarded as solutions to all weed problems. Similarly, despite the outstanding success of herbicides, absolute reliance on them to solve all weed problems is economically and environmentally unfeasible. Cultural weed control refers to any technique that involves maintaining field conditions such that weeds are less likely to become established and/or increase in number. The techniques of cultural weed control are well known to farmers and weed scientists. In fact, they are employed regularly but often are not consciously attempted to manage weeds. Planting a crop is a sure way to reduce growth because the crop interferes with the weeds. It is a fundamental method of weed management, but most often cultural weed control just happens rather than occurring as a planned addition to weed management programs. Examples of cultural weed control would be crop rotation, optimum date of sowing, plant density, planting pattern/crop architecture, selection of quick growing varieties, avoiding overgrazing of pastures or rangeland, using well-adapted competitive forage species, stale seed bed or dab system, proper water management, method of fertilizer application and maintaining good soil fertility.

A. Crop competition

These methods of cultural weed management include conscious use of crop interference, use of cropping pattern, intercropping, soil amendments, and no or minimum tillage.

Weed scientists have investigated the relative competitiveness of crop cultivars. As reported by Mohler (2001) "The role of crop genotype in weed management has received growing attention over the past 30 years." The reports indicate that there has been attention but the perennial weeds do well in perennial crops such as alfalfa. Sudangrass, planted in dense stands, can compete effectively against many, but not all, weeds.

Crops can be favoured by knowing and using the effect of row width and crop seeding rate. Khan et al. (1996) showed that spring wheat yields were as great or greater when early seeding or a double seeding rate was used as a substitute for a post-emergence herbicide to control foxtail species. Early and middle seeding dates favoured the increase of green foxtail over yellow foxtail, whereas late seeding favoured yellow over green. Spring wheat competing with foxtail had a higher yield when the seeding rate was 270 kg/ha (twice the normal rate) than when it was 130 or 70 (1/2 normal rate) kg/ha unless the seeding was late. Yenish and Young (2004) demonstrated that seeding rate of winter wheat in Washington had a consistent effect on wheat yield. Yield was about 10% higher when the seeding rate was 60 as opposed to 40 seeds per meter of row when jointed goatgrass was the competing weed. Tall wheat varieties competed best. Early, high-seeding rates increase crop density and biomass early in the season and this suppresses weed growth. Seeding wheat at higher than normal rates in Alberta, Canada, improved performance of herbicides used to control wild oats (O'Donovan *et al.*, 2006). Increasing wheat seeding rate from 75 to 150 kg/ha reduced wild oat biomass up to 18% and the soil seed bank up to 46% even when herbicides were not used. On average, wheat yield improved 19% and net economic return 16% with the higher seeding rate.

Decreases in weed growth have been observed in narrow (about 8 inch) versus wide (about 30 inch) row spacing in several crops. For example weed growth was reduced 55% in peanuts (Buchanan and Hauser, 1980) and 37% in sorghum (Wiese et al., 1964). Varying row width uses the principles of plant population biology to achieve competitive interactions that favour the crop.

Research is proceeding in the midwestern United States to devise narrow row production techniques for soybeans. When these are combined with minimal tillage and the right herbicides, yield is maintained or increased, soil erosion is reduced, and excellent weed management is obtained. Row spacing is not always an effective weed management technique. Esbenshade et al. showed that row spacing had little effect on burcumber emergence or control in corn (2001a) and soybean (2001b). Tharp and Kells (2001) showed that corn yield was not affected by row spacing and corn population, and row spacing did not influence weed emergence following glufosinate application. Common lambsquarters' biomass was reduced as corn row width was reduced from 76 to 38 cm spacing. In Minnesota, narrow rows (51 vs. 76 cm) did not affect late season weed density, but corn grain yield increased in two of three years (Johnson and Hoverstad, 2002). Other work showed a significant reduction in weed density by careful selection of early-maturing corn hybrids planted in narrow (38) versus wide (76 cm) rows (Begna et al., 2001). Combining narrow rows and high population density increased corn canopy light interception 3 to 5%, decreased light available to weeds, which produced 5 to 8 times less biomass. In contrast, Norsworthy and Oliveira (2004) suggested that increasing corn population in the row might be a more effective strategy to reduce weed competition than decreasing row width. They found light interception and the critical period for weed control were similar in narrow-row (48 cm) and wide-row (97 cm) corn, and the end of season weed biomass was similar.

An interesting study of the effect of soil amended with residue of the weed wild radish showed that the competitiveness of tomato and bell pepper with yellow nutsedge was enhanced by the weed residue compared to soil with no residue (Norsworthy and Meehan, 2005). This work illustrates the previously suspected but undemonstrated potential of weed residue in weed management and crop competitiveness.

Intercropping is a common, small-scale farming system among farmers of the developing world. The main reasons for mixing crops or planting in close sequence are to maximize land use and reduce risk of crop failure. Intercropping maintains soil fertility, reduces erosion, and may reduce insect problems (Altieri et al., 1983).

Intercropping also gives greater stability to yield over seasons and provides yield advantages over single crop agriculture (Altieri, 1984). The National Agricultural Library published a useful bibliography of citations on green manure and cover crops (MacLean, 1989). The positive and negative effects of Brassica cover cropping systems have been reviewed by Haramoto and Gallandt (2004).

It is claimed (Altieri et al., 1983; Moody and Shetty, 1981) that one reason for intercropping is weed suppression, but other than work in Nigeria (Chikoye et al., 2001), there has been little experimental evidence to support this conclusion (Shaw, 1982). Similarly, there is little evidence that intercropping requires less weed control. It is assumed that intercropping saves labour because weeding is less critical, and some operations such as planting a second crop and weeding the first can be combined (Norman, 1973). Intercropping's effectiveness for weed control depends on the species combined, their relative proportions, and plant geometry in the field. All reports recommend additional weeding with intercropping, and weeds can often be worse than in sole crops (Moody and Shetty, 1981). Successful use of inter-seeded cover crops in vegetables has been limited by their tendency to inadequately suppress weeds or to suppress weeds and the crop. For example, winter rye sown in broccoli was successful only when sown at high density, in locations or seasons with low soil temperatures (e.g., spring), and when combined with other weed management methods (Brainard and Bellinder, 2004). When these conditions were not met, rye was often detrimental to weed management and reduced broccoli yield. Rye sown as a cover crop in soybean reduced total weed density and biomass compared to no cover crop. However, costs were higher and the rye cover crop system was less profitable than soybean grown without a cover crop where weeds were controlled with conventional technology (Reddy, 2003).

Several cover crops were compared in the moist savanna regions of Nigeria (Ekeleme *et al*., 2003). Weed density was negatively correlated with percent ground cover of five legume cover crops. Only one, lablab (hyacinth bean), produced adequate ground cover and good weed suppression in all locations independent of varying duration, distribution, and amount of rainfall. Others were successful in high-rainfall regions. Readers must note the variation between rainfall regions. The same variation will be observed across the regions of the United States or Europe. No system will be developed that will work equally efficiently in all regions. Other work with cover crops in Nigeria has been quite successful. For example, 12 months after planting corn, cassava, or a corn/cassava intercrop plots with cover crops had 52 to 71% less cogongrass (a hardy, difficult to control perennial weed) and 27 to 52% more corn grain yield at three locations in Nigeria (Chikoye *et al*., 2001). The cover crops were centro, cowpea, hyacinth bean, egusi melon, tropical kudzu, or velvetbean all known as tropical food crops (cowpea and egusi melon) or green manure crops. Higher crop yield was a result of one or a combination of three things: reduced weed competition from the cover crop, a mulching effect that conserved soil moisture and prevented weed growth, and a contribution of nitrogen from the leguminous cover crops. It has been demonstrated that cover crops such as hairy vetch can improve corn and soybean productivity, and, when they are combined with reduced rates of environmentally benign herbicides, will minimize the requirements for herbicides (Gallagher *et al*., 2003).

Annual intercrops can enhance weed suppression and crop production compared to sole crops. Studies in Canada with wheat-canola and wheat-canola-pea intercropping demonstrated that intercropping tended to provide greater weed suppression compared to sole cropping; there was a synergism of weed suppression among the intercrops compared to any sole crop (Szumigalski and Van Acker, 2005). Studies of intercropping do not confirm that any plant grown with a crop will always provide adequate weed control. Intercropping is a common practice in many agricultural systems, and these systems should be studied to develop complementary plants, control soil erosion, and prevent or reduce weed growth. It is undoubtedly true that plants that are not crops are classified by most farmers in the developed world as weeds. Other farmers classify noncrop plants in a way that judges their potential use or their effects on soil and crops. Western farmers see noncrop plants as weeds, but subsistence farmers have a different understanding of the use and value of plants that are neither crop nor weed.

A variation on intercropping is the intentional growth of spring-seeded smother plants for weed management. The intent is to eliminate the plants after the crop has grown and is a better competitor and before the smother plants become competitive, as intercrops often do. Berseem clover, four species of medic, and yellow mustard were planted immediately after corn and soybean planting in a 25 cm band over the crop row. All species achieved 45% or greater ground cover within 10 weeks of seeding. Yellow mustard grew most rapidly, and it and sava medic gave greater weed suppression than other species. When the medic was killed 30 DAP, it reduced weed suppression but did not increase corn yield compared to season long presence (Buhler et al., 2001).

Research on these alternative, generally nonchemical systems of weed management is continuing as environmental concerns, sustainability questions, and debate over long-term efficacy of present weed management and crop production systems intensifies. They are alternative systems not panaceas. Weeds will adapt and change as weed management systems change, just as they have adapted to herbicides. Weeds will always be a part of agriculture.

B. Planting date and population

The trend in crop production is early planting to optimize yield. Yield is increased because crops have a longer growing season and photosynthesize for more days (Barrett and Witt, 1987). Early planting provides a competitive edge to adapted crop cultivars. Early-season establishment of a crop, such as corn, provides it an advantage compared to yellow nutsedge, a warm-season weed (Ghafar and Watson, 1983). The competitive advantage could be due to the weed's light requirement for growth and to shading by the crop that emerged first. Choice of planting date should be considered part of integrated weed management. Planting date of any crop plays a role, as illustrated by a 60% reduction in kochia population when proso millet was planted June 1 rather than May 15, although millet yield was not affected (Anderson, 1988). Planting date can also play a role in crop choice. Longspine sandbur emerges in late May and June in Colorado and flowers in late July. The seed, in its bur, reduces the value of hay. Foxtail millet is planted in early June and, when harvested as hay in late August (Lyon and Anderson, 1993), will be contaminated with the burlike seed if longspine sandbur is present. Oats can also be grown for hay when planted in early April and harvested in late June, before the longspine sandbur seed develops. The oat hay will not be contaminated with the burlike seed.

Sunflower and safflower are grown as oil crops in the US Great Plains states. Safflower is planted in early April and sunflower in early June. Because of its early planting, over 70% of weed seedlings emerge within 10 weeks of planting safflower. These weeds are easily controlled by tillage or herbicides, and sunflower is planted in a more weed-free field after mid-June (Anderson, 1994). Early planting requires weed control for longer periods. Late planting is usually preceded by tillage that destroys emerged weeds and reduces their population in the crop. Advantages gained by later planting are often outweighed by decreased crop yield over a shorter growing season.

In Minnesota, delaying soybean planting until early June instead of early May permitted the use of preplant tillage to control early germinating weeds (Gunsolus, 1990). This reduced maximum soybean yield potential 10%. When corn planting was delayed from the normal time in the beginning of May until after May 25, maximum yield potential was reduced by 25% (Gunsolus, 1990). The same study also showed rotary hoeing for weed control when either crop was young reduced corn plant stand up to 10% but did not affect soybean stand. In Minnesota, a 10% loss in corn stand reduced final yield 2% but did not affect soybean yield. This small set of data illustrates the complexity of agriculture; extrapolations cannot be made between crops and certainly not between regions. Sweeping generalizations are rare.

Khan *et al*. (1996), in a different kind of study about planting date, reported that crop management practices related to planting date could substitute for herbicide use to control foxtail species in wheat. Spring wheat yields in North Dakota were equal to or greater when early seeding or a doubled seeding rate was substituted for postemergence foxtail control with an acceptable herbicide. Yield of spring wheat was greater with a high seeding rate (240 lb/A) than with normal (116 lb/A) or low (62 lb/A) seeding rates for early (late April to mid-May) or midseason (mid- to late May) seeding but not for late (early to mid- June) seeding. It is interesting to note how seeding date in this work affected certain weeds. Early and middle seeding dates favoured the relative increase of green foxtail, and the late date favored yellow foxtail. In weed management, as in ecology, no one can do just one thing.

Planting date is often dictated by considerations other than weed management. Similarly, plant population is dictated by agronomic studies that have shown the population that gives the best yield. Populations are also determined by row-spacings required by planting, cultivating, and harvesting machines. Increasing crop plant populations can often decrease weed density and growth. Wiese et al. (1964) showed over 50 years ago how row width and seeding rate interacted to reduce competition from weeds in grain sorghum in Texas (Table 2.1). With 25 cm rows, yield loss from weeds was lower with the higher of two seeding rates. This relationship remained true until rows were 102 cm wide.

Table 2.1. Effect of Row Width and Cultivation on Yield of Grain Sorghum (Wiese et al., 1964)

Row width (cm)	Seeding rate (kg/ha)		Grain yield (kg/ha)	Yield loss (%)
		Weedy	Hand weeded	
25	5.6	3326	4861	31
	11.2	4188	5466	23
51	5.6	3125	5152	39
	11.2	3987	4715	16
76	5.6	3237	5365	40
	11.2	3606	5029	28
102	5.6	3058	4491	32
	11.2	3203	4637	31

C. Companion cropping

Cover crops or living mulches (Akobundu, 1980b) can be used as intercrops or companion plants to suppress weeds (Liebman, 1988, 1989; Shetty and Krantz, 1980). Appropriate weed control practices, for many farming systems, must consider the need to maintain soil fertility and prevent erosion, and open row crops are inimical to these needs. Akobundu (1980a) developed integrated low- or no-tillage weed management systems, compatible with more than one crop plant in a field that reduced herbicide use, fertilizer requirements, and soil erosion. Combinations of a legume or Eugusi melon and sweet potato with corn showed that the companion crops or living mulches maintained corn yield, contributed to nitrogen supply, suppressed weed growth, and reduced soil erosion. Groundnut, centro, and wild winged bean have been used as living mulches with corn. Living mulches incorporate organic mulch, no-tillage, and weed control. Centro and wild winged bean grew so vigorously that a growth retardant had to be applied to bands over corn rows to gain a growth advantage for corn (Akobundu, 1980b). In unweeded no-till plots, corn grain yield was 1.6 t/ha, whereas with conventional tillage it was 2.3 t/ha. Corn yield in unweeded, live mulch plots averaged 2.7 t/ha. Yields were not different, and live mulch plants did not reduce yield; they were complementary, not competitive. Further studies (IITA, 1980) verified these results.

Clover has been grown successfully with corn and has reduced weed growth (Vrabel *et al*., 1980). Crimson clover and subterranean clover were the most promising cover crops in cucumbers and peppers in Georgia and contributed to effective management of diseases, nematodes, and insects (Phatak *et al*., 1991). Sweet corn in a living mulch of white clover had high yields in early years but lower yields later because a contact herbicide used over the corn row allowed invasion of perennial weeds that were not suppressed by white clover (Mohler, 1991). A dead rye mulch decreased weed biomass and did not decrease corn yield (Mohler, 1991). A living mulch of spring planted rye reduced early season biomass of common lambsquarters 98%, large crabgrass 42%, and common ragweed 90%, compared to unmulched controls. Barnes and Putnam (1983) also reported that the age of rye when it was killed with herbicides was important to the subsequent emergence of yellow foxtail and lettuce.

Companion cropping can be a good weed control technique, but research is needed to determine how appropriate it may be in specific situations. Limited evidence supports the contention that it can provide weed competition, build soil organic matter, reduce soil erosion, and improve water penetration (Andres and Clement, 1984). In some climates when spring soil moisture is limiting, cover or companion crops can deplete moisture and be detrimental to crops in spite of weed control advantages. Companion crops may also have to be killed before a crop is planted or they become competitors.

In Pennsylvania, crownvetch, a legume, was tried as a living mulch in a no-tillage corn (Cardina and Hartwig, 1980; Hartwig, 1987). Crownvetch is difficult to establish, but once established, it provides soil erosion control, improved fertility through reducing nutrient loss via erosion, and by contributing nitrogen and weed control. Weed control must be supplemented with herbicides that will not kill the crownvetch. The system is amenable to rotation of corn with other crops. Work in Ohio demonstrated use of hairy vetch for weed management. Unsuppressed hairy vetch reduced weed biomass in corn 96% in one year and 58% in another. When corn was planted in late April into hairy vetch in the early bud stage of growth, corn yield was reduced up to 76%. Hairy vetch competition was reduced or eliminated when corn was planted into hairy vetch in mid- or late-bloom in May or early June. Because of the shortened growing season and competition from hairy vetch, corn planted in

May into untreated hairy vetch yielded similarly to corn planted in the no-cover crop, weed-free check. Use of the contact, nonresidual herbicide glyphosate to kill vetch and eliminate competition with corn was helpful with early and midbloom planting but not with late planting because of the lack of continuing weed control.

In Wisconsin, spring planted winter rye has been a successful living mulch for weed control in soybean (Ateh and Doll, 1996). A system employing just rye for weed control reduced weed shoot biomass from 60 to 90% over three years. Rye worked best for weed control and did not reduce soybean yield when weed density was low and ground cover from the mulch and soil moisture were adequate for growth. Rye interference with soybean was minimal if rye was killed within 45 days after soybean planting.

Other successful companion crops have been low-growing plants such as cowpea and mungbean in India (Shetty and Rao, 1981). Seed costs of companion plants and expected competition to the primary crop were offset by the value of companion plant yield, a more permanent soil cover (less erosion), reduced nitrogen fertilizer requirement, and reduced cost of hand weeding. Attempts have also been made to try different cover crops to manage noxious weeds such as cogongrass in India, Malaysia, Nigeria, and Kenya (Vayssierre, 1957). The smothering effect of velvetbean on cogongrass in corn was equivalent to 1.8 kg/ha of glyphosate but less than that of imazapyr at 0.5 kg/ha in Nigeria (Udensi et al., 1999). The work suggests that planting velvetbean to manage cogongrass may be a “better alternative for farmers without the resources to purchase herbicides.”

Another example of a weed used to gain interspecific competition is the use of azolla as a weed control technique in lowland rice. *Azolla pinnata*, a free floating fern, has been used in Asian rice culture because of its symbiotic relationship with *Azolla anabaena*, a nitrogen-fixing blue-green algae. This symbiotic relationship can contribute up to 100 kg of nitrogen/ha. A second use of azolla is for weed control due to the competitive effect of an azolla blanket over the surface of paddy water.

When azolla is used, some farmers can grow rice without the addition of nitrogen fertilizer. Success of the azolla technique depends on the ability of the farmer to control water supply and on the weed species present. Perennial weeds such as rushes and annuals with strong culms (e.g., barnyardgrass) are not suppressed and must be controlled in other ways. Many other weeds are controlled well.

Azolla has been successful but cannot be universally recommended because there is an increase in labour (skill) to manage it. Some land must be devoted to supplying a continuing source of inoculum of azolla for paddies, and azolla may complicate other pest problems. In fact, azolla may become a weed. An interesting twist in companion cropping is the use of genetic engineering to make a companion crop self-destruct. A potential problem with companion cropping is that the companion may become a competitor if it is allowed to grow too long or if it becomes too large. Herbicides or tillage may then be required to eliminate (control) the companion crop. Stanislaus and Cheng (2002) tried to design a cover crop that would self-destruct in response to an environmental cue. If self-destruction could be achieved, no supplemental herbicide or tillage would be required after the cover crop had completed the task of early weed control. They incorporated a heat-shock-responsive promoter to direct expression of the ribonuclease *Barnase*, which is extremely toxic to cells. The heat-shock-responsive promoter very effectively caused heat-regulated plant death and was sufficient to kill the transgenic plants. They concluded that although work with temperature sensitivity showed its potential, that temperature may not be the best factor to study. Temperature is not a completely reliable environment factor (it is not always hot). Therefore, self-destruction based on photoperiodic sensitivity is a more promising research area.

D. Crop rotations

Crop rotation is done for economic, market, and agronomic reasons. Some weeds associate with certain crops more than with others. Barnyardgrass and junglerice are common in rice. Wild oat is common in irrigated wheat and barley but almost never occurs in rice. Nightshades are common in potatoes, tomatoes, and beans, and kochia and lambsquarters are frequent in sugarbeets. Dandelions are common in turf but not in row crops, although without management, dandelions can increase in row crops and in pastures and long-term hay crops such as alfalfa.

These associations occur because of similarity in crop and weed phenology (naturally occurring phenomena that recur periodically, e.g., flowering), adaptation to cultural practices (e.g., tillage, mowing, irrigation), similar growth habits (e.g., time to mature or to reach full height), and perhaps of most importance, resistance or adaptation to imposed weed control methods. When one crop is grown in the same field for many years (monoculture), some weeds, if they are present in the soil seed bank, will be favored, and their populations will increase. Weed-crop associations are not accidental and can be explained. Associations can be changed by rotating crops, altering time of planting, or changing weed control methods. Annual grass weeds can be reduced in small grain crops by growing corn in the rotation and using herbicides selective in corn plus cultivation to control the grasses when corn is grown. The same herbicides and cultivation cannot be used in small grain crops.

A good rotation includes crops that reduce weeds that are especially troublesome in succeeding crops. Removal is accomplished by competition or through use of different weed control techniques in different crops. In Canada, yellow foxtail populations in flax were highest when flax followed oats, lowest after flax, and intermediate after wheat, corn, and sorghum (Kommedahl and Link, 1958). Sugarbeets grown after beans in Colorado were always more weed-free than sugarbeets grown after sugarbeets, barley, or corn (Dotzenko et al., 1969). Beans are cultivated well, and intensive chemical weed control is practiced. The number of weeds was highest where corn preceded sugarbeets and lowest with beans. Barley was intermediate.

In many places, barley is planted in spring before soil temperatures are ideal for germination of most annual weeds. Beans, on the other hand, are planted in late spring, and tillage can be used to destroy most summer annual weeds.

Ball and Miller (1990) showed that weed species composition varied with cropping sequence among rotations of corn for three years, pinto beans for three years, or two years of sugarbeets followed by one year of corn (Figure 10.4). Hairy nightshade seed bank population increased after three years of pinto beans, green foxtail increased after three years of corn, and the sugar beet-corn sequence caused an increase in kochia. Ball and Miller attributed the differences to the herbicides used in each cropping sequence. Crop cultivation, land preparation time and method, and time of planting and harvest may also favor some weeds and discourage others.

Crop rotation regularly changes the crop in each field, soil preparation practices, subsequent soil tillage, and weed control techniques. All of these affect weed populations, and while crops are not commonly rotated to control weeds, the effect of rotation as a determinant of weed problems must be recognized.

Different cropping systems affect weed populations and favour or deter some species. This is observed in vegetable crops where intensive cultivation and weed control are regularly practiced, and weed populations can be reduced (Roberts and Stokes, 1965).

Long-term studies to determine the effect of different cropping sequences on the population dynamics of winter wild oat (Fernandez-Quintanilla et al., 1984) showed that continuous winter cereal cropping (with or without herbicides) increased the winter wild oat soil seed bank from 26 to 80% per year. With spring barley the soil seed bank declined 10% per year. When sunflower was a summer crop or a 12-month fallow was included in the rotation to prevent new seed production, the soil seed reserve declined 57 to 80% annually. There was a great reduction in the size of the soil seed bank of winter wild oats if the cropping program was other than continuous winter cereals (Fernandez-Quintanilla et al., 1984).

Crop rotation has significant effects on the soil seed bank. A 35-year study at two locations in Ohio showed that crop rotation was a more important determinant of soil seed density than moldboard plowing, chisel plowing, or no-tillage, although the two were related (Cardina et al., 2002). Initial seed density was highest with no tillage and declined as tillage intensity increased. The research showed how weed species' composition of the soil seed bank changed in response to crop rotation and soil management and provides leads on how complex plant communities are assembled and endure.

E. Fertility manipulation

Manipulation of soil fertility solely to manage weed populations is virtually unknown. However, as is true of most soil manipulations, fertility affects weeds. Walters (1991) suggests that most weeds can be controlled by simple manipulation of soil nutrient levels. His claims are supported by abundant anecdotal evidence but not by any planned, peer-reviewed scientific research. Nevertheless, they should not be dismissed as idle speculation. Farmers fertilize to maximize yield and attain greater assurance of crop success and profit. They do not fertilize or withhold fertilizer to manipulate weed populations.

Fertilizer is added to improve crop yield, but weeds are often more competitive with crops at higher nutrient levels (DiTomaso, 1995). When weed density is low, added fertilizer, particularly nitrogen, increases crop yield and makes a crop a more vigorous competitor with weeds. But when weed density is high, added nutrients favor weed over crop growth. DiTomaso (1995) summarized much of the literature on this subject.

An excellent illustration of the potential of fertility manipulation as a method to change plant populations is the Park Grass Experiment at the Rothamstead Agricultural Experiment Station in England. The official title of the experiment is "The Park Grass Experiment on the effect of fertilizers and liming on the botanical composition of permanent grassland and on the yield of hay." The work was started in 1856 by Sir John B. Lawes, the son of the manor and founder of Rothamstead as an agricultural research center, and J. H. Gilbert. In many ways, the experiment continues in its original form and is the longest ecological study in the world. The ecological insights were reviewed by Tilman et al. (1994).

In unlimed plots amended with a complete fertilizer with nitrogen primarily as ammonium sulfate, a pure stand of common velvetgrass has developed. It was selected out of the original mixture solely by fertility manipulation and lack of lime. It has one of the heaviest hay yields of any plot, but the hay is unpalatable. With complete fertilizer and lime, plots have one of the heaviest hay yields and a very diverse flora, including orchard grass and meadow foxtail. In unlimed plots amended with ammonium sulfate and no phosphorus, the vegetation is completely different from either of the preceding. If potassium is absent, dandelions are absent because they flourish only with potassium and a pH above 5.6.

In winter wheat, downy brome was least responsive to nitrogen applied during fallow (Anderson, 1991). Nitrogen applied during winter wheat's growing season increased downy brome growth and decreased wheat yield. When crop season rainfall was only 70% of normal (21 vs. 62 mm), nitrogen fertilization reduced wheat yield 12 to 20%.

Competition for nutrients is not independent of competition for light and water. The complexity and opportunity of fertility manipulation are well illustrated in work by Liebman (1989) and Liebman and Robichaux (1990). They demonstrated improved weed control because of differing nitrogen use efficiency of crops and weeds. With no added nitrogen, total crop seed yield was identical for the long-vined Century or short-vined Alaska pea cultivars. Century's yield was 45% greater than Alaska's under these conditions. Adding nitrogen dramatically increased barley yield and reduced yield of Alaska peas. Barley can compete for the added nitrogen and Alaska cannot, but the latter cultivar does well with no added N. The seed yield of white mustard increased with nitrogen fertilization, and it was much more competitive with short-vined Alaska than with long-vined Century peas. Results of this study were supported by greenhouse research in Canada that showed that green foxtail grown under low nitrogen required approximately six times as much nicosulfuron for control as plants grown under high nitrogen (10 times higher). Higher doses of four herbicides were required to achieve 50% reduction in biomass of redroot pigweed, but there was no similar affect on velvetleaf (Cathcart et al., 2004).

Further evidence of the potential role of soil fertility in weed management is in studies done in Alabama (Hoveland et al., 1976). Soils with low potassium were dominated by buckhorn plantain and curly dock. Soils with low soil phosphorus were dominated by showy crotalaria, morningglory, coffee senna, and sicklepod. The shoot and root growth of several weeds increased with added phosphorus, but the magnitude of the response varied among species. With increasing phosphorus, 17 weed species increased shoot biomass more than wheat and 19 increased shoot biomass more than canola (Blackshaw et al., 2004). The studies that have been done clearly show that manipulating soil nutrient status can change weed populations, and fertility manipulation should be regarded as a potential weed management technique.

Mechanical

These methods are most common non-chemical method of weed control. Mechanical weed control refers to any technique that involves the use of farm equipment to control weeds. These methods are as old as agriculture. Tillage, handweeding and mowing are most often used mechanical control techniques. These methods are distinguished into a) mechanical b) manual. Physical method of weed control utilizes manual energy, animal power or fuel to run the implements that dug out the weeds. The hand hoe first animal drawn implement was invented by Jethro Tull in 1731. Implements used vary from simple hand tools to multiple tractor drawn implements.

Hand weeding

It refers to removal of weeds either manually or by using tools like khurpi or sickle, when weeds grow upto some extent. It is effective against annuals and biennials and controls only upper portion of the perennial. In order to reduce soil seed bank, this method should be practiced before flowering and seed setting stage of weeds. Higher labour is required and is tire some.

Hand hoeing

Hoe has been the most appropriate and widely used weeding tool for centuries. Taking out the weeds with the help of khurpi or hand hoes or wheel hoes is more time saving method than hand pulling. Hoeing by cutting the crown part gives proper control. The time of hoeing is very critical and should not be too early or too late but crop should be kept weed free at the critical stage of crop growth. Annuals and biennials can be effectively controlled. *Convolvulus arvensis* which has shallow root system can be controlled. This method is very safe but labour intensive and very expensive. Hand hoeing can be done in all row-sown crops may be solid drill or widely sown.

Spudding

1. dig up or cut (plants, especially weeds) with a small spade.
2. make the initial drilling for (an oil well).

Spudding involves hand weeding and hand hoeing added by a sharp edged sickle. It is most common in rice.

Sickling

Sickling is also done by hand with the help of sickle to remove the top growth of weeds to prevent seed production and to starve the underground parts. These methods are useful for control of tall growing grasses. Sickling is especially useful in irrigation and drainage channels and where undulating topography is present.

Cutting/slashing

Cutting is the topping/cutting of the weeds little above ground level. It is done with help of axes and saws. It is mostly practiced against brushes and trees. In aquatics, under water weed cutters are used. Slash means cutting with a wide sweeping movement typically using a knife or sword.

Mowing

It is cutting of uniform growth from the entire area up to the ground level. It is useful more in non-cropped areas than cropped areas. It is very effective method of cutting excessive growth of undesirable plants from lawns, playgrounds, roadsides, orchards and from non-cultivated areas. Mowing improves aesthetic value of an area. This method is effective against erect and herbaceous annual weeds. However, perennials re-sprout from rootstock and needs repeated cutting to exhaust the food reserve. This methods apart from controlling weeds, enriches the soil by adding organic matter.

Digging

Digging is useful for patch or spot control of obnoxious / perennial weeds. Digging is very useful in the case of perennial weeds to remove the underground propagating parts of weeds from the deeper layer of the soil. They can be eliminated by digging with crowbar or Pick axe etc. For large areas, it is not desirable because it is costly and labour oriented.

Dredging

This is used to control aquatic weeds growing in shallow ditches. Dredging refers to mechanical pulling of aquatic weeds along with their roots & rhizomes from the mud.

Chaining

Very big and heavy chain is pulled over the bottom of a ditch with tractors along with embankments of ditch. With rubbing action of chain weeds can be fragmented and collected by nets and hooks.

Burning

It is cheapest method to eliminate the mature unwanted vegetation in non-cropped areas and range lands. Coagulation of protoplasm occurs with which plant dies.

Flaming

It is the momentary exposure of green weeds to as high as $1000^{O}C$ from flame throwers to control in row weeds. Sometime weeds are desiccated with high pressure steam. Flaming and steaming are used in western countries for selective weed control in wider row sown crops like cotton, soybean and fruit orchards. Dodder is also controlled by flaming in lucerne.

Searing

Repeated application of flame to above ground parts destroyed the root system and plant dies.

Microwave irradiation

Microwaves (MW) are non-ionizing electromagnetic waves with a frequency range of 300 MHz $<f<$300 GHz and wavelength range of 1 m $<\lambda<$1 mm (Banik et al., 2003). Interest in the interaction of MW energy with biological systems dates back to the twentieth century (Ark and Parry, 1940). In 1924, Antonin Gosset was the first to explore the bio-stimulation effect of MW energy, when he, along with his co-worker, used high-frequency electromagnetic waves to treat tumors in plants with no injury to the plant (Bren, 1996). MW absorption is primarily influenced by the dielectric and roughness properties of the load (Ulaby et al., 1978).

The absorption of MW energy projected into the soil can be affected by numerous unknown factors (Nelson, 1996a). The propagation of MW energy through soil depends on the soil's gravimetric (θ_g) and volumetric (θ_v) moisture content (Nelson, 1996a), bulk density (Dobson et al., 1985), organic matter content (O'Neil and Jackson, 1990), texture (Brodie et al., 2009), and specific heat.

Pre-emergence MW irradiation of soil may potentially minimize weed establishment (Brodie et al., 2012b; Davis et al., 1973; Nelson, 1996b; Sartorato et al., 2006; Wayland et al., 1973). It can also destroy the reproductive parts of weed plants and their seeds that are covered with soil at a depth of several centimetres (Brodie et al., 2007; Diprose et al., 1984). Wayland et al. (1973) treated wheat and radish seeds *in situ* at 25 mm depth and 6.5% soil moisture content. They found that MW was lethal to seeds with a threshold energy density of 10 J cm^{-2}. Increases in energy density were more effective at reducing the germination percentage of seeds than increases in exposure time for some species. Davis et al. (1971) conducted an experiment to evaluate the effects of MW irradiation on the seedling survival percentage of twelve crop and weed species. They found that seedlings germinated for 48 h showed no survival after a short exposure to MW energy and concluded that the susceptibility of young seedlings to MW heating was highly correlated with moisture content and energy absorption. Menges and Wayland (1974) compared post-emergence herbicides (methazoal, propachlor, and perfluidone) with MW treatment at energy densities of 45 to 720 J cm-2 for weed suppression in an onion crop. They reported that MW irradiation (360 J cm-2) significantly inhibited weed establishment. Additionally, minimum crop injury was noted with MW (18%) compared to herbicide application (85%). Barker and Craker (1991) explored the effects of MW on oats and weed seeds in soil at different moisture levels. They concluded that seed susceptibility to MW treatment depends on the soil temperature, and temperatures of 75°C to 80°C significantly inhibited the germination of weed seeds.

Bigu-Del-Blanco et al. (1977) treated two-day-old maize seedlings with MW energy at a frequency of 9 GHz and energy density of 10 to 30 mW cm^{-2} for periods of 22 to 24 h. They reported that longer MW exposure time, even at very low energy densities, significantly dehydrated the maize plants and retarded their growth. In contrast, research on fleabane and paddy melon concluded that a short exposure (≤5 s) of high-intensity MW (2 kW) was enough to dehydrate the plants (Brodie et al., 2012a). Therefore, MW treatment in agricultural systems has potential to substitute for the hazardous, toxic, and environmentally unsafe chemicals used for weed management (Brodie et al., 2012b; Sartorato et al., 2006; Wayland et al., 1978). Khan et al. (2017) evaluated the effects of pre-emergence MW irradiation of soil for subsequent weed management, germinated through the seedbank, in a direct-seeded rice crop under field conditions. The projection of 560 J cm^{-2} of MWenergy into the soil gave a temperature gradient of 80°C to 90°C in the top 5 to 6 cm, which induced a 70% to 80% reduction in weed establishment through the soil seedbank compared to the untreated control. Therefore, a 34% increase in the grain yield of rice (9.0 t ha^{-1}) was achieved compared to the non-MW scenario (6.7 t ha^{-1}). Microwave-based weed control could be effective in managing herbicide-resistant weed biotypes in cropping systems.

Soil Solarization

It is also called solar soil heating. It is effective against weeds which are produced from seeds. It doesn't involve any tillage of the field. It involves covering the soil with transparent very thin polyethylene (PE) (plastic) sheets of 20-25mm film during hottest part of summer months for 2-4 week. This increases the temperature by 10-12 ^{o}C over unfilmed control fields. Then weeds seeds are desiccated which are present at top 5 cm soil depth Eg: *Phalaris minor, Avena* and broad leaved weeds controlled by solarization. *Melilotus* sp. possessing hard seed coat has been found resistant to solarization treatment.

Cheeling

An implement called cheel (spade like implement with very long handle) with which weeds and soil can be racked up. It is generally practiced in tea plantations.

Tillage

Tillage is done for preparing good seedbed ideals for the seeds to germinate, conservation of soil moisture & weed control. Tillage removes weeds from the soil resulting in their death. There are different implements which can be used of this purpose such as cultivation, disc harrows, mould board plough, deep chiseler etc. Tillage may weaken plants through injury of root and stem pruning, reducing their competitiveness or regenerative capacity: Pre plant tillage helps in burying the existing weeds. Bring the seeds to the soil surface for germination and their subsequent destruction by suitable secondary tillage implements. Post plant tillage (row cultivation) helps in mixing of manures and fertilizers & control of weeds, soil and water conservation.

Mulching

Principle is exclusion of sunlight from environment. Black or white polythene sheets and natural materials like paddy husk, ground nut shells, saw dust etc. are used as mulching material. The thickness of organic mulch should be enough to cut off light (i.e. 10-15 cm).The efficiency of polythene sheet is more (more polythene) if it is applied in continuous sheet rather than in particle farm. It is effective against annual weeds and perennial weeds like *Cynodon dactylon* and *Sorghum halepense.* Mulching is used in high value crops like coffee and tea plantations by using guatemala grass (*Tripsacum laxum*) and citronella grass (*Cymbopogan sp*)

Flooding

Flooding kills weeds by excluding oxygen from their environment. It is a worldwide crop husbandry method of controlling weeds in rice fields. Flooding is very effective method for controlling annual weeds requiring aerobic conditions and many perennials like *Cynodon dactylon* and *Sorghum halepense*.

Inter-cultivation

This method is very widely adopted in wider row sown crops such as maize, cotton, sugarcane and pigeonpea. Inter-cultivation is done with bullocks or with tractor by adjusting the distance between tines. In rice inter-cultivation is performed in standing water. This method is effective for controlling later flushes of weeds in large area. To make the method effective the weeds near the vicinity of crop plants are removed manually. However, the crops with lateral spread of roots suffer due to root injury. Even the spread of plant diseases may also takes place as in potato.

Biological

Biological weed control refers to any technique that involves the use of natural enemies (insects, disease organisms, herbivorous fish, other animals and competitive plants) of weed plants to control the germination of weed seeds or the spread of established plants. This is a rapidly expanding area of weed control with many examples. Examples of biological weed control include sheep to control tansy ragwort or leafy spurge, cinnabar moth and the tansy flea beetle to control tansy ragwort, the chrysolira beetle to control St. John's Wort, and the use of goats to control brush weeds on rangelands.

Quality of bioagents: They must be host specific, adjust to field environment, easy to multiply and attack flowers or seeds of weeds or bore into the stem.

Limitations: After feeding the host plant the insects may move to economical plants. For rearing insects large scale laboratory and different types of substrates are required. Biological method is a costly method a lot of investment is required for screening of desirable predator. Isolation of desired area which we want to keep off the insect is not possible. Examples of biological control of weeds:

Parthenium hysterophorus: The beetle namely *Zygogramma bicolorata* provides biological control of this weed during rainy season.

Cyperus rotundus: *Bactra verutana* a shoot boring moth was reported to control this weed in USA, India and Pakistan.

Chemical

Chemical weed control refers to any technique that involves the application of a chemical (herbicide) to weeds or soil to control the germination or growth of the weed species. In economic terms, chemical control of weeds is a very large industry and there are scores of examples of chemical weed control products. Common examples of chemicals used to control weeds in forages are 2,4-DB; EPTC; bromoxynil; and paraquat.

The idea regarding control of weeds with herbicides started when Boardex mixture which was sprayed to cure a particular disease of wheat in Europe and it showed killing of broadleaf weeds. Similar types of reports regarding control of broadleaf weeds with copper sulphate were published by Bolley (1908) from USA, Schulty (1909) from Germany and Bonnet from France. Similarly Robate (1917) in France conducted experiments with copper sulphate, ferrous sulphate and sulphuric acid to control weeds. Later on efficacy of more inorganic salts such as sodium arsenate, sodium chloride, potassium chlorate, sodium borate, potassium borate etc was reported. During 1941, Pokorny in USA reported synthesis technique of 2,4-D. Zimmernam and Hitchcock from

USA during 1942 reported use of 2,4-D as growth regulators. Hammer and Tukey (USA) during 1944 reported that higher concentrations 2,4-D can act as herbicide. Nutman and Blackman from England confirmed these findings during 1945. So the history of weed science dates back to the use of 2,4-D on commercial scale for the control of broadleaf weeds from cereals. Later on, the introduction of triazine, S. ureas, carbamates, dinitroanilids and other new molecules brought a revolution in herbicide use against weeds in different crops. As compared to mechanical method, chemical weed control has many advantages such as, 1) elimination of early crop weed competition, effective control of morphologically similar, intra-row and problematic weeds, ensure method, holds good in problem soils, in-situ killing of weeds, no injury to roots, tillage can be minimized and economical method. However, lack in application technology, weed resurgence/resistance, herbicide drift, pollution hazards, no chance for succeeding crop on crop failure, use as insecticides by mistake, no antidote available and chemical crop war are limitations of chemical weed control.

Concept of Integrated Weed Management

The concept of integrated weed management (IWM) has been around for several decades and practiced by some, but only in the last few years has this concept become popular. IWM has been defined as: "The use of all suitable weed control methods to keep weed populations below the economic injury level. Methods include cultural practices, use of biological, physical, and genetic control agents, and the selective use of herbicides". In other words, IWM involves utilizing a combination of control strategies which will hopefully result in the most effective control of the target pest species. Integrated weed management includes all practices that enhance a crop's competitive ability and decrease weeds' ability to reduce yield.

The term effective control, for most agencies and organizations refers to both the economics of the control effort and the effectiveness or mortality success of control strategies used. Five control strategies have been defined that are important components to consider in "war on weeds": cultural, biological, physical, genetic and chemical, through the selective use of herbicides (NPS, Weed Mgmt. 1990). The term "biological control" has historically meant the use of insects to control noxious weeds. Since most noxious weeds are exotics, most biological control agents are insects which naturally evolved with the weed species in it's native land. Usually the insect is specific to a particular weed species and usually impacts the plant through defoliation of the leaves or boring into the root/ vascular system of the plant. This type of control can occur with adult insects, their larva or both. Recently, researchers have been experimenting with the use of plant pathogens (diseases) and livestock grazing control. Biological control can be effective but usually requires long periods of quarantine, can be quite expensive and have limited effectiveness.

The use of cultural control methods primarily refers the prevention of noxious weed infestation through the modification or elimination of land use practices by humans which may indirectly cause or aid in the spread of noxious weeds. There are generally five aspects to cultural control, which include: 1) prevention, 2) livestock manipulation, 3) wildlife manipulation, 4) soil disturbance activities and 5) public uses.

The use of physical control is a control strategy commonly used on target species and often serves as the "foundation" of the integrated weed management effort. Physical control usually falls under three categories: 1) manual control, which can be as simple as hand pulling of the weed species (seedlings or mature herbaceous weeds generally) to eliminate individuals and reduce the seed source for usually very small infestations, to using hand tools like a hoe, loppers or a machete; 2) mechanical control, which involves the use of power tools (chainsaws/ clearing saws) and heavy equipment (tractors & bulldozers); 3) Control via fire, which is normally achieved through the use of prescribed burns. However, "let burn" designations for specific plant communities during wildfire situations can be an opportunity to explore when controlling target species. Resulting burns will usually achieve some level of mortality of the target species though very rarely eliminates the entire problem, but allows for access in to the vegetative stand for secondary treatment with mechanical and chemical control methods.

For the majority of weed infestations, the selective use of herbicides is necessary to accomplish the objectives of the control effort. The use of herbicides, in conjunction with cultural and mechanical control methods, usually results in the most effective levels of control of the weed (Egan et al 1993). The decision to selectively use herbicides requires a comprehensive planning effort and is site, as well as species specific. There are five important questions that must be answered when considering the use of herbicides as an element to an integrated control approach: 1) what herbicides are effective in producing a high level of mortality with a minimal need for re-treatment; 2) what are the effects of the herbicide on nontarget species, including residual effects of the herbicide to the soil; 3) what is the most effective and cost-efficient mode of application; 4) are properly trained personnel available to apply the herbicide; and 5) are there local, state or federal restrictions for the use of a particular herbicide.

The concept of IWM, as discussed above, refers to the "classic" understanding of IWM: the integrated use of cultural, physical, biological and chemical control strategies to contain or eradicate a population of noxious weeds. There are "other" aspects of IWM which may have been overlooked in the previous discussion, especially those related to weed infestation on open rangelands. Integrated weed management on rangelands involves the use of several control techniques in a well-planned, coordinated, and organized program (Sheley 1995). In Sheley's article, he discusses the need for inventory as the first phase of IWM. The goal is to determine and record the weed species present, the size of the area infested, the density of the infestation, whether other rangelands are under threat of invasion, soil and range types affected and other site factors pertinent to successfully managing weed-infested rangelands.

Planning and implementation is the second phase of IWM (Sheley 1995). Planning is the process by which problems and solutions are identified and prioritized, and an economic plan of action is developed to provide direction for implementing the control program. Implementing an IWM plan includes: 1) preventing weed encroachment into uninfested rangeland; 2) detecting and eradicating new weed introduction; 3) containing large-scale weed infestations; 4) controlling large-scale infestations using an integrated approach; 5) revegetation of control sites when and where appropriate; 6) Adoption of the proper range management practices (cultural control) in conjunction with the development of a weed management program; and 7) Monitoring and evaluation of the IWM plan itself. Monitoring and evaluation are the keys to determining if weed and/or grazing management plans are meeting plan objectives and are the prime determining factors used in altering IWM plans.

Principles of chemical weed control

Herbicides are important tools for controlling weeds. It is important to understand the effects and limitations of those used for control of noxious weeds. Herbicides are categorized as selective or non-selective. Selective herbicides kill a specific type of plant, for example, 2,4-D kills only broadleaf plants. Herbicides are also selective based on the rate of which they are used. Non-selective herbicides such as glyphosate will kill all plants that come into contact with it.

Once the decision has been made to utilize herbicides as the method for control of noxious or nuisance weed species; there are 3 basic principles that need to be fundamentally addressed for successful applications. These standard principles are:

- Proper herbicide choice for the target species of concern
- Proper timing of herbicide application(s)
- Proper “consistent” application technique
- Additional site conditions/factors may also need to be considered to assure the most effective herbicide application out comes such as; soil type, slope, existing vegetation (target and non-target plants). Contact a local weed management professional for technical assistance.

The herbicide industry continues to improve upon its products and new and improved herbicides are coming out each year, as well as generics. **No one herbicide will control all species of weeds, so it is important to select herbicides based on the weeds present in a field.** All noxious weeds can be treated and managed by herbicides. Always calibrate the sprayer for the best possible application.

When designing a weed control program based on herbicide use, consider soil type, tillage practices, crops (current and following), weed problems, and overall farming operations. Herbicides are often combined to control more weed species, reduce carryover, or reduce crop injury. Some weeds are not controlled by any of the currently available selective herbicides, and require specialized application of nonselective herbicides. Good herbicide performance depends upon the weather, soil conditions, and accurate application.

Soil-applied herbicides have traditionally been the mainstay of herbicide programs. Preplant and preemergence herbicides have the advantage of eliminating early competition between crops and weeds. However, research has shown that weeds will not reduce crop yields if controlled within 4 to 6 weeks after emergence. Postemergence herbicides are comparable to soil-applied herbicides in effectiveness and economics if applied within this time period. Some weeds are better controlled by soil-applied herbicides, while others are more susceptible to postemergence herbicides. Consider combining soil-applied and postemergence herbicides for maximum control of some populations of weed species.

Control of weeds through bioherbicides

A **bioherbicide** is a biologically based control agent for weeds. Bioherbicides may be compounds derived from microbes such as fungi, bacteria, viruses, or protozoa; or phytotoxic plant residues, extracts or single compounds derived from other plant species. In the industry, bio-herbicides and other bio-pesticides are often referred to as "naturals". When the active ingredient used is a fungus, the product is called a mycoherbicide.

Almost every agricultural pest has at least one naturally occurring enemy that will reduce its population. Bioherbicides utilize such naturally occurring enemies, rather than depending on man-made chemicals. This can be important because agents of biological control ordinarily have many fewer, and much milder, effects on the environment than do synthetic chemicals. What is more, they tend not to lead to the public health problems that chemicals are associated with. These two advantages of biological control agents, including bioherbicides, do not however mean that they need not also be subjected to careful tests for environmental and public health safety.

Plant pathogens can be used to control weeds in a similar way to chemical herbicides. Bioherbicides can be applied in many ways, e.g. as aerial sprays, through 'cut and paste' application or in a powder applied to the soil.

In contrast to the fungi typically used in classical biological control, the pathogens exploited as mycoherbicides are often native to the area where they are utilized, and do not need to be specially imported. Under natural conditions disease epidemics occur and damage plants from time to time, but the potential of these fungi is frequently limited. For example, the environment is not always conducive to good disease development and the pathogen may be limited in its dispersal capabilities. The inundative approach, where these fungi are turned into mycoherbicides, allows people to overcome some of these constraints and create disease epidemics when and where they want.

After application the fungi do not usually persist at high levels for long and have often returned to background levels 1–2 years later. This means that, like other herbicides used to kill plants, bioherbicides often need to be reapplied.

The pathogens used in inundative control often need not be as highly host specific as classical biological control agents because their use can be restricted to certain areas.

History of bioherbicides

Mycoherbicide research to control agricultural and environmental weeds began in the 1940s. The earliest experiments simply involved moving indigenous fungi between populations of target weeds (e.g. the fungus *Fusarium oxysporum* used against prickly pear cactus (*Opuntia ficus-indica*) in Hawai'i, before the release of the *Cactoblastis cactorum* moth).

In the 1950s the Russians mass-produced the spores of *Alternaria cuscutacidae* and applied them to the parasitic weed dodder (*Cuscata* spp.). In 1963 the Chinese mass-produced a different fungus (*Colletotrichum gloeosporioides* f. sp. *cuscutae*) for the same weed. They called their mycoherbicide 'LuBao' and an improved formulation is still in use today. Since then more than 100 bioherbicide projects have been undertaken worldwide, but only a small percentage of these have resulted in commercially available, registered products. It should be borne in mind that the chemical industry routinely screens thousands of inorganic compounds to find a single commercially feasible new chemical herbicide.

Formulation is often the stumbling block when difficult to get living organisms to behave predictably and reliably in the field given the variety of conditions they encounter. Mixtures that look promising in laboratory trials often prove unsatisfactory in the field. It can take many years of experimentation to develop a workable formulation.

Each country has its own rules regarding registration, and meeting the requirements can be an expensive and complex process (e.g. it took 5 years to register BioMal®).

Commercialization can also be difficult, especially if the target market is small and the product extremely effective (if the product does not need to be reapplied, its market gets smaller).

Benefits of bioherbicides over other herbicides

Because the plant pathogens used in bioherbicides usually occur naturally in the areas where they are utilized, they tend to be less harmful to the environment than chemical herbicides. The fungi are often more selective in their mode of action so the risk of damage to other plants is reduced. Bioherbicides are, as a rule, less toxic to people and animals than chemical herbicides.

Bioherbicides that have been registered and their current status, October 2008

Where and When	Product and Pathogen	Target weed	Status
USA: 1960	*Acremonium diospyri*	Persimmon (*Diospyros virginiana*) trees in rangelands	Status unknown
China 1963	Lubao: *Colletotrichum gloeosporioides f. sp. Cuscutae*	Dodder (*Cuscata* sp.) in soybeans	Probably still available
USA:1981	DeVine®: *Phytophthora palmivora*	Strangler vine (*Morrenia odorata*) in citrus orchards	Status unknown, may no longer be marketed
USA: 1982	Collego™: *Colletotrichum gloeosporioides f. sp. Aeschynomene*	Northern joint vetch(*Aeschynomene virginica*) in rice & soybeans	Not produced or distributed since 2003, but rice producers are showing renewed interest
USA: 1983	CASST™: *Alternaria cassia*	Sickle pod & coffee senna (*Cassia* sp.) in soybeans & peanuts	No longer available due to lack of commercial backing
USA: 1987	Dr BioSedge: *Puccinia canaliculata*	Yellow nutsedge (*Cyperus esculentus*) in soybeans, sugarcane, maize, potato& cotton	Product failed due to uneconomic production system & resistance in some weed biotypes, no longer available
Canada: 1992	BioMal®: *Colletotrichum gloeosporioides f. sp. Malvae*	Round-leaved mallow (*Malva pusilla*) in wheat, lentils & flax	No longer commercially available but made on request
South Africa: 1997	Stumpout™: *Cylindrobasidium leave*	Acacia species in native vegetation & water supplies	Still available for sale, though demand has declined due to lack of advertising. May be taken up by "Working for Water"
Netherlands: 1997	Biochon™: *Chondrostereum purpureum*	Woody weeds, e.g. black cherry (*Prunus serotina*) in plantation forests	Available until end of 2000. Marketing/production stopped due to low sales & regulatory concerns
Japan: 1997	Camperico™: *Xanthomonas campestris pv poae*	Turf grass (*Poa annua*) in golf courses	Probably commercially available
South Africa: 1999	Hakatak: *Colletotrichum acutatum*	*Hakea gummosis* & *H. sericea* in native vegetation	Never registered, but will be produced on request
USA: 2002	Woad Warrior: *Puccinia thlaspeos*	Dyers woad (*Isastis tinctoria*) in farms, rangeland, waste areas, & roadsides	Registered, but never commercially available due to lack of commercial backer. Once registered, the fungus was spread by researchers.
Canada: 2004	Chontrol™ = Ecoclear™:	Alders, aspen & other hard-woods in rights of way & forests	Commercially available

Where and When	Product and Pathogen	Target weed	Status
	Chondrostereum purpureum		
Canada: 2004	Myco-Tech™ paste: *Chondrostereum purpureum*	Deciduous tree species in rights of way & forests	Commercially available
USA: 2005	Smolder: *Alternaria destruens*	Dodder species: in agriculture, dry bogs & ornamental nurseries	Only just registered. Company planning to do more field trials & then market it in 2007
Canada: 2007	Sarritor: *Sclerotinia minor*	Dandelion (*Taraxacum officinale*) in lawns/turf	Commercially available

Steps in developing a bioherbicide

1. Check that a bioherbicide product is needed and that there is sufficient industry and commercial backing to proceed.
2. Look for suitable pathogens (if not already known).
3. Identify highly pathogenic (disease- causing) isolates that produce no or few toxins, and are unlikely to damage non-target species.
4. Develop an efficient way of mass-producing the pathogen and ensuring stability and shelf life.
5. Determine the optimum conditions for infection and disease development.
6. Check that the pathogen can be used in a manner that will minimise any harmful effects.
7. Develop an appropriate formulation and application technology.
8. Test in the field and improve formulation if necessary.
9. Obtain registration for the product, and market and distribute product.

Exercise

Define/explain the following

a. Bioherbicides
b. Soil solarization
c. Inter-cultivation
d. Companion cropping
e. Mulching

Comment on the following

a) Weed management is a system approach
b) One year's seeding seven years weeding
c) Complete elimination of weeds is neither economical nor warranted
d) Prevention is better than cure
e) Application of same herbicide/weed control practice is beset with problems of development of resistance/tolerance
f) Biological control can be quite expensive and have limited effectiveness
g) Preparing weed inventory must be the first phase of IWM
h) It is important to select herbicides based on the weeds present in the field
i) An understanding of herbicides mode of action is essential for herbicide effectiveness
j) Combination approach is very common in intensive agriculture
k) Maintenance of a weed population at some level may be the most easily achievable and financially wise goal for a weed management program.
l) Microwave heating of soil may potentially minimize weed establishment
m) Perennials can be eliminated by digging in small area only

What do you mean by weed control? How is it differentiated from weed management? Discuss the principles of weed control.
Discuss the concepts of integrated weed management. Also throw light on principles of chemical weed control.

Tick the correct answer

1. Successful weed management is based on
   a).Knowledge on weed biology b). Survey on the nature of weed problem c). Whole farm planning d). Removal of weeds before flowering
   i. a & b ii. b & d iii. c & d iv. **All**
2. A system approach based on whole land use planning
   a).Weed eradication b). Weed control c). Weed prevention d). **None**
3. Weed control aims to putting down weed infestation
   a).**Already present** b). a + future infestations c). b + introduction from the adjacent fields d). Combining the available techniques in the optimum level
4. Eradication is possible in following weed situations
   a).*Ageratum conyzoides* b). *Phalaris minor* c). *Parthenium hysterophorus* d). ***Lantana***
5. Besides providing N Azolla is used for weed control in
   a).Wheat b). **Rice** c). Castor d). Linseed
6. Azolla pinnata is
   a).**a fern** b). an algae c). a gymnosperm d). an angiosperm
7. Spudding involving hand weeding/hoeing added by a sharp edged sickle is most common in
   a).Wheat b). Sugarcane c). Sesame d). **Rice**
8. Dredging is most effective treatment for controlling
   a).Parasitic weeds b). *Lantana* c). Agrestals d). **Aquatic weeds**
9. Flooding is an effective strategy to control
   a).***Avena ludoviciana*** b). *Sorghum halepense* c). *Cynodon dactylon* d). All e). None
10. Bioagent for controlling *Parthenium hysterophorus*
    a).*Bactra verutana* b). ***Zygogramma bicolorata*** c). *Chrysolira* d). Flea beetle
11. The first rule of weed prevention
    a).Regular survey to identify new weeds b). Destruction of weeds before they set seed c). **Clean seed** d). Clean farm equipments and irrigation water
12. A companion crop
    a).Hairy vetch b). Winter rye c). Cowpea d). **All**
13. A farming practice influencing weed floristic diversity
    a).Fertility manipulation b). Crop rotation c). Intercropping d). **All** e). None
14. Practices using direct radiant energy of the sun
    a).**Soil solarization** b). Micro-waves c). Flaming d). All
15. Post-plant tillage helps in
    a).Mixing of manures b). Control of weeds c). Soil and water conservation d). None e). **All**
16. Flooding – a worldwide crop husbandry method of controlling weeds in
    a).Maize b). Sugarcane c). Buckwheat d). **Rice** e). None
17. Inter-culture with bullocks in standing water
    a).**Rice** b). Sorghum c). Pearlmillet d). all
18. The first chemical shown to have herbicidal activity
    a).2,4-D b). **Bordeux mixture** c). Paraquat d). 2,4- DB
19. The herbicidal activity of 2,4-D at the first time was reported by
    a).Hammer and Tukey (1944) b). **Zimmernam and Hitchcock (1942)** c). Nutman and Blackman (1945) d). None
20. a latest herbicide family
    a).Triazines b). Dinitroanilines c). **Sulfonyl ureas** d). Growth regulators
21. The effective control of morphological similar *Phalaris minor* in wheat is achieved with

a).2,4-D b). Glyphosate c). Metsulfuron - methyl d). **Isoproturon**

22. Which of the following gives effective control of *Phalaris minor* in wheat
    a).Hand weeding b). Inter-cultivation c). Flaming d). **Clodinafop-proparygyl**
23. Integrated weed management practices that
    a).Enhance crop competitive ability b). Decrease weeds ability to reduce yield c). Practices that eliminate weeds from an area d). **Both a and b** e). Both a and c
24. The first phase of IWM as per Sheley
    a).Integrated use of different methods b). Planning and implementation c). **Inventorization** d). Monitoring and evaluation
25. Selective post-emergence herbicide
    a).**2,4-D** b). Glyphosate c). Paraquat d). All
26. A non-selective contact herbicide
    a).Glyphosate b). **Paraquat** c). 2,4-D d). None
27. A soil applied herbicide
    a).Glyphosate b). Paraquat c). 2,4-DB d). **Fluchloralin**
28. A 'Natural amongst the following
    a).**Devine** b). Glyphosate c). Potassium chloride d). 2,4-D
29. A mico-herbicide
    a).BT b). **Collago** c). NPV d). Zygogramma
30. Application of bio-herbicides
    a).Aerial sprays b). Cut and paste c). Soil application d). **All**
31. Dab system is successful practical strategy in limiting future weed infestation in
    a).Xerophytic environments b). Rainfed areas c). Water-logged areas d). **Irrigated areas**
32. Flaming and steaming are successful practical weed control tools in
    a).Asian countries b). **Western countries** c). African countries d). Japan
33. The practice that directly hit soil weed seed bank in minimizing future weed infestation
    a).Microwave irradiation b). Soil solarization c). Stale seed bed d). **All** e). None
34. A practice where one or two flushes of weeds are destroyed before seeding a crop
    a).Cheeling b). **Stale seed bed** c). Searing d). None
35. A practice that does not necessarily involve tillage
    a).Summer ploughing/hot weather cultivation b). Stale seed bed c). **Soil solarization** d). None
36. Soil solarization increases soil temperature by
    a).**10-12 °C** b). 3-4 °C c). 15-16 °C d). 20-22 °C
37. The condition intensifies the spread of perennial propagules of weeds after being exposed by tillage
    a).Hot weather b). **Rainfall** c). High light intensity d). High wind
38. Which is the 'odd one' based on mimicry
    a).Wild rice in rice b). Wild sorghum in sorghum c). Wild sugarcane in sugarcane d). **Itch grass in upland rice**
39. C_4 weed
    a).*Avena fatua* b). *Lolium temulentum* c). ***Sorghum halepense*** d). *Phalaris minor*
40. The environment friendly weed control method
    a).**Biological** b). Physical c). Chemical d). None
41. To devitalize weed seeds in manure, the composting temperature must be in which of the following range
    a).35-50 °C b). 50-65 °C c). **65-90 °C** d). 90-105 °C
42. Main objective of weed control is
    a). Encourage growth of crop plants b). Suppress unwanted plants c). Discriminate application of control measures d). **All**
43. An expensive venture costing more than that of land
    a). Weed prevention b).Weed management c). **Weed eradication** d). Weed control
44. An approach concerns with putting down the weeds already present
    a). Weed eradication b). Weed management c). **Weed control** d). Weed prevention
45. A xerophyte weed

a). *Scirpus supinus* b). *Monochoria vaginallis* c). ***Alhagi camelorum*** d). *Ammannia baccifera*

46. Weed management is the combination of the techniques of
    a). Prevention and eradication b). Prevention and control c). Control and eradication d). **All**
47. Ever watchfulness of the new weeds that may become problem emphasizes
    a).Eradication b). Control c). **Prevention** d). None
48. Always an important part of weed management even though not recognized
    a). Handweeding b). **Cultural techniques** c). Control techniques d). Tillage
49. A living mulch to suppress weeds
    a).Crownvetch b). Winter rye c). Azolla d). **All**
50. Barnyard is a common weed in which of the following
    a). **Paddy** b). Linseed c). Rye d). Gram
51. Most effective strategy to reduce population of crop associated weeds
    a). Rotating crops b). Altering planting time c). Changing control methods d). **All**
52. Dandelions are
    a). Mg lovers b). Fe lovers c). Ca lovers d). **K lovers**
53. A weed grown under no or low N, requires ______ herbicide (dose) than it is grown under higher N
    a).**More** b). Less c). No d). Similar
54. Most common non-chemical method of weed control
    a).Stale seed bed b). **Mechanical methods** c). Biological d). Bio-technological
55. The first animal drawn hoe was invented by
    a).Hammer and Tukey (1944) b). Zimmernam and Hitchcock (1942) c). Nutman and Blackman (1945) d). **Jethro tull (1731)**
56. A method used to control aquatic weeds
    a).**Dredging** b). Digging c). Dibbling d). Drowning
57. Repeated application of flames to above ground weed parts is called
    a).Flaming b). **Searing** c). Burning d). None
58. A weed found resistant to solarisation treatment
    a).*Phalaris minor* b). *Avena fatua* c). ***Melilotus* sp** d). *Lolium temulentum*
59. A weed management strategy based on exclusion of sunlight from environment
    a).Flaming b). **Mulching** c). Flodding d). Solarization
60. *Zygogramm bicolorata* provides control of
    a).***Parthenium hysterophorus*** b). *Lantana camara* c). *Ageratum conyzoides* d). *Cyperus rotundus*
61. *Cyperus rotundus* is controlled by
    a).Alachlor b). Glyphosate c). *Bactra verutana* d). **All**
62. History of weed science dates back to commercial use of ________
    a).Glyphosate b). Paraquat c). **2,4-D** d). None
63. A post-emergence herbicide
    a).Glyphosate b). Paraquat c). 2,4-D d). **All**
64. LuBao has its origin in
    a).Spain b). USA c). **China** d). Britain
65. Devine is associated with
    a).***Phytopthora palmivora*** b). *Alternaria cassia* c). *Colletotrichum gloeosporoides* d). *Puccinia thlaspeos*
66. The major stumbling block in bioherbicide technology
    a).Suitable pathogen b). **Formulation** c). Mass production d). Registration

UNIT III

Mode and mechanism of action of herbicides, herbicide selectivity, herbicide combinations, adjuvants and safeners, degradation of herbicides in soils and plants, effect of herbicides in relation to environment, herbicide resistance in weeds and crops.

Mode and mechanism of action of herbicides

Herbicides kill plants by disrupting an essential physiological process. This is accomplished by the herbicide specifically binding to a single protein for many herbicides. The target protein is referred to as the herbicide "site of action." Herbicides in the same family generally have the same site of action. The symptoms observed on weeds sprayed with herbicides express the mode of action (MOA). In other words, the mechanism by which a herbicide kills a plant is known as its "mode of action (MOA)". For example, triazine herbicides interfere with photosynthesis by binding to the D_1 protein involved in photosynthetic electron transfer. Thus, the site of action for triazines is the D_1 protein, whereas the mode of action is the disruption of photosynthesis. An understanding of herbicide mode of action is essential for diagnosing crop injury or off-target injury problems and for designing weed management programs with a low risk of selecting for herbicide- resistant weed populations. Knowing a herbicide MOA is important to understand how to use a herbicide most effectively.

In herbicide R&D, when new chemicals are screened experts carefully observe the detail and timing of the appearance of symptoms to gain clues as to the MOA. Full understanding a MOA may take years of research by plant physiologists, biochemists, molecular biologists and many other scientific disciplines. The more that is known about MOA, the more safely and effectively herbicides can be used.

Mode of action in detail

Most often, herbicides have MOAs which mean that a target enzyme no longer functions properly, or at all. This is usually because the herbicide molecule has distorted the enzyme molecule in some way. Shape is crucial to enzyme function. Enzymes are 'catalysts'. They provide a platform for a specific chemical reaction which they are not directly part of and which would not happen effectively without them. 'Knocking-out' an enzyme with a herbicide has two main effects with various consequences:

- Component chemicals for the reaction accumulate and may be directly or indirectly damaging.
- Absence of the reaction's product will restrict growth, either through starvation of key building blocks or because the reaction makes chemicals which normally protect the plant.

As plants have evolved, slight differences in their biochemical systems for carrying-out physiological processes have arisen. Sometimes a gene with DNA coding for a particular enzyme or other herbicide target will have mutated in some species so that variations in that enzyme exist which may differ by only one or two amino acids out of thousands. This small change will still allow plants to grow successfully, but it may mean that herbicides with a MOA involving this enzyme will only be effective on one type and, therefore, on a particular group of species.

Gene mutations are responsible for one sort of herbicide selectivity based on MOA. Herbicides such as fluazifop-p-butyl inhibit the enzyme Acetyl Coenzyme A Carboxylase (ACC-ase) and selectively control grass weeds in broad-leaved crops like soybeans or oilseed rape (canola). The enzyme carrying out the same function in broadleaved weeds and crops is slightly different and not affected by the herbicide. On the other hand, glyphosate is a non-selective herbicide with a very wide weed control spectrum because it inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, a fundamentally important enzyme very similar in all plants.

Mutations are also one way in which weed resistance to herbicides can occur. Rare individual plants which have a mutated enzyme may not be susceptible to a herbicide which is generally effective on that species. An outbreak of weed resistance occurs when such an individual is allowed to reproduce and comes to dominate the weed population in a field. Ensuring that herbicides with different MOAs are used helps to avoid weeds becoming resistant.

The other main type of selectivity and weed resistance occurs when one group of plants can metabolize a herbicide rapidly enough to avoid any damage.

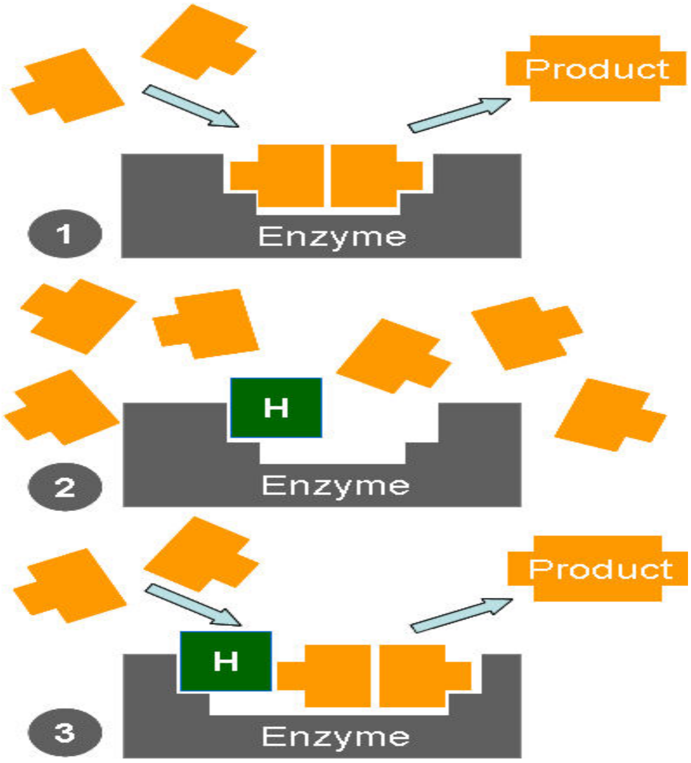


Fig. 3.1. 1) shows an enzyme functioning normally. In 2) a herbicide is stopping biochemicals coming together to form the usual product. As a result the plant is starved of the product and potentially damaging building blocks accumulate. 3) shows an enzyme which has mutated so that even when the herbicide is present the reaction can continue. Either the herbicide is selective to species with this type of enzyme, or an individual plant with this mutation could reproduce to establish a population of resistant weeds.

Several other types of herbicide MOA exist. Some affect photosynthesis in various ways to ultimately divert the flow of energy from sunlight. Instead of being incorporated into chemical energy stores it ends up in very destructive 'free radicals' based on oxygen. These destroy membranes and desiccate leaves. Another large group, the first selective herbicides to be discovered, mimic plant hormones – the chemical messengers that control growth and development. Another group affect cell division by, for instance, disrupting the mechanism by which chromosomes are arranged in a cell as it prepares to divide in two. Others herbicides have more general chemical effects which are hard describe as specific MOAs, or where very little has been discovered about the MOA. These are generally older products which have been superseded.

Classifying modes of action

Herbicide MOAs can be classified by the plant process affected, eg photosynthesis, cell division or specific enzyme targets. This often reflects the practical uses of herbicide products. For instance, those affecting photosynthesis are applied post-emergence and are often fast acting; those affecting cell division are often pre-emergence herbicides affecting germinating seeds; and some enzyme targets will determine patterns of weed control spectrum and selectivity depending on whether the enzyme is fundamental to the growth of all plants or whether it is confined to, say, grasses or broadleaved weeds.

However, there are always significant exceptions to these general rules and their particular chemistry may mean that they move in plants and soil differently. These factors determine selectivity, whether they are contact or systemic herbicides, and whether they can be used pre-emergence, post-emergence, or both.

A more detailed classification is required for managing weed resistance.

1. MOAs involving photosynthesis

Four types of herbicides primarily affect photosynthesis. Paraquat and its sister herbicide diquat are the only members of the first type. When the energy in sunlight is captured by chlorophyll it is transferred in a flow of electrons through 'Photosystem I'. Paraquat diverts this flow resulting in the production of highly reactive free radicals which very quickly destroy cell membranes, spilling the contents, and appearing as yellowing and desiccation. This happens within hours in bright sunlight because of the high levels of energy running rampant. Almost all green plants are affected by paraquat making it a broad-spectrum, non-selective herbicide.

The second type blocks the transfer of energy through 'Photosystem II'. Herbicides of this type ('PS II inhibitors') bind to a protein involved in the transfer chain, reducing its effectiveness. This causes some diversion of electrons with similar, but slower, results to paraquat and slows growth because of less energy for photosynthesis. Triazines like atrazine and ureas like chlortoluron are both PSII inhibitors, but have slightly different MOAs because they bind to the protein concerned in different places.

A third type, the protoporphorinogen oxidase (PPO) inhibitors, interfere with an enzyme involved in producing chlorophyll and other large molecules important in photosynthesis. Without new chlorophyll leaves yellow and photosynthesis slows. However, unused building blocks of chlorophyll accumulate and react with oxygen to form reactive free radicals which are especially destructive to broadleaved species.

The fourth type of photosynthesis inhibitor prevents the production of leaf pigments called carotenoids. These are familiar as the colours of autumn when green chlorophyll has degraded. Carotenoids have roles in protecting chlorophyll from being destroyed by more light energy than it can process. Herbicides in this category have several different targets, but all result in treated weeds being bleached white.

For simplicity, a fifth type can be added. This has a single commercial member, glufosinate. Although it is an enzyme inhibitor, it indirectly affects photosynthesis; its faster appearing symptoms are due to membrane destruction resulting in desiccation.

Mode of Action	**Effect on Weeds**
Photosystem I (PSI) inhibition	• Photosynthesis is affected leading to destruction of cell membranes; the specific effect is much faster than other desiccators • Leaves quickly yellow and desiccate especially fast in bright sunlight • Very broad spectrum of weeds controlled; foliar application only; inactivated and immobilised on contact with soil; unique to paraquat and diquat
Photosystem II (PSII) inhibition	• Photosynthesis is affected leading to destruction of cell membranes, but more slowly than by other desiccators • Leaves yellow and desiccate from tips, edges and between veins • Pre- and post-emergence application with soil residual effects; weed spectrum and crop selectivity vary; several different types including: triazines (eg atrazine), ureas (eg isoproturon); nitriles (eg bromoxynil)
Protoporphyrinogen oxygenase (PPO) inhibition	• Rapid desiccation of all green tissue on contact from foliar sprays • Systemic with slower action when entering through roots • Biased to broadleaved weed control in various crops, eg fomesafen
Carotenoid biosynthesis inhibition, eg 4-hydroxyphenyl-pyruvate-dioxygenase (HPPD)	• Leaf pigments cannot be made or protected and so degrade • Shoots are bleached white • Pre- and post-emergence application to different target weeds and crops depending on product, eg mesotrione, clomazone, norflurazon
Glutamine synthetase	• Causes accumulation of ammonia which destroys cell membranes and stops photorespiration and photosynthesis through starvation of amino donors • Shoots yellow and desiccate, but more slowly than by paraquat • Controls a broad spectrum of young weeds from foliar sprays only; unique to glufosinate

2. MOAs targeting other enzymes

In this group, the primary effects are to starve weeds of the essential products normally made by the enzymes affected. The appearance of symptoms is usually slow and depends on how conducive the environment is for plant growth. The ACC-ase inhibitors particularly affect growing points at shoot tips, while the ALS inhibitors and glyphosate have more general effects due to the ubiquity of the amino acids they deplete.

MOA	Effect on Weeds
Acetyl CoA carboxylase (ACC-ase) inhibition	• Stops plants making the fatty acids important in cell membranes • Growth stops within hours; leaves turn yellow, then purple, brown and die over many days; roots and rhizomes may also be killed • Post-emergence control of grass weeds in broadleaved crops, eg fluazifop-p-butyl
Acetolactate synthase (ALS) inhibition	• Stops plants making amino acids leucine, isoleucine, valine, so many proteins can't be made • Growth stops within hours, stunting shoots and roots; leaves yellow and die over day to weeks • Control a broad spectrum of weeds in many different crops; post-emergence or pre-emergence, eg sulfonylureas and imidazolinones
EPSP synthase	• Plants stop making amino acids phenylalanine, tryptophan, tyrosine, so are starved of many proteins • Growing points in shoots and roots die, leaf chlorophyll degrades, yellowing and exposing purple pigments, stunting; slow in cool climates • Foliar application only, inactive in soil; unique to glyphosate

3. Other MOAs

Generally less is known about the detail of these other MOAs.

MOA	Effect on Weeds
Cell division disruption	• Cells cannot divide for various reasons • Stunting of emerging seedlings • Pre-emergence application towards grass weed control, eg metolachlor (chloracetamides), pendimethalin (dinitroanilines)
Seedling growth inhibitors	• Various types (eg some prevent the waxy cuticle from forming) but tissues do not develop normally • Act on new shoots which fail to emerge properly and roots are stunted • Soil applied for pre-emergence weed control mainly of grass weeds in cereals, eg triallate
Synthetic auxins	• Hormonal effects on plant growth and development • Twisting of stems and curling of leaves within hours, yellowing, browning • Post-emergence control of broadleaved weeds in cereals, eg 2,4-D

Selectivity

Different plant species respond differently to same herbicide and same plant species respond differently to different herbicides. This is a foundation for phenomenal achievement in modern chemical vegetation (weed) management where objective is to kill weeds and retain others at the same time and place. But selectivity is unwanted within weed species of mixed population. This resulted in buildup of the tolerant species.

The differential response of plants to the herbicide is called selectivity of herbicide. In other wards herbicides harm or kill weeds whereas crop plants are not affected due to selectivity. The fundamental principle is that more toxicant should reach the site of action in active form inside the target plants than in the non target plants. The selective mechanism may occur due to following aspects:

1) Differential rate of absorption of herbicides.
2) Differential rate of translocation of herbicides.
3) Differential rate of deactivation of applied herbicides.
4) Protoplasmic resistance to the specific herbicide

Differential absorption of herbicides

In the tolerant wild cucumber (*Sicyos angulatus*), 2, 4-D absorption was so slow that it kept pace with its metabolism easily than the susceptible cultivated cucumber (*Cucumis sativus*), thus was tolerant. Similarly, bigleaf maple (*Acer macrophyllum*) was tolerant to amitrole due to its faster absorption while, bean and lucerne plants were susceptible due to slow absorption of the herbicide by them. Under field conditions, differential absorption of herbicides may occur due to 1) difference in morphology and growth habit of plant species, 2) timing in application of herbicides by different methods, 3) use of antidotes and adsorbents to prevent herbicide absorption by non target plants, and 4) difference in ability of herbicide formulations to contact with non target plants. The selectivity may be due to one or combination of processes.

A) Differences in morphology of plants

Certain morphological features such as narrow upright leaves, corrugated (or) finally ridged leaf surfaces, waxy leaf surface and pubescent leaves allow limited retention of aqueous herbicides on their foliage. Pea, onion, sugarcane, cabbage and colocasia posses the above morphological features. Here the herbicide bounce off as droplets from their foliage or small area may be wetted. C rops like wheat and sugarcane are protected by herbicide sprays by covered growing point. The limited spray retention provides resistance against selective contact herbicides without any wetting agents.

With translocated herbicides, limited spray retention is not of much help in protecting the non-target plants from herbicide injury. Post emergence application of bromoxynil and ioxinyl controlled many broad leaved weeds in wheat crop due to limited spray retention. Like-wise selectivity of nitrofen in case of rice and *Brassica* is due to differential wetting. In recent years importance of limited wetting of crop plants as a factor in herbicide selectivity has diminished.

B) Differences in growth habit of plants

Shoot growth difference: When crop rows have a clear advantage in height over the inter row weeds, directed spraying of herbicides is a common method of achieving selective control of weeds. Herbicide mulches are used in standing crop rows for affecting selective control of germinating weeds.

In slow germinating crops like potato and sugarcane, weeds often establish themselves even before crop emergence; hence they are controlled selectively by spraying a contact herbicide before more than 10% of the crop plants are seen over the ground.

In more advanced stages of crop growth, sometimes specific weed sp may grow much above the crop height. In crops like spinach and Egyptian clover, these tall weeds may often completely hide the crop plants. In the USA. herbicide-laden wax bars have been employed successfully for the control of tall weeds in wide row crops. In the closely sown crops a low volume application of a contact herbicide can be used. In lawns and gardens shoots of nutsedge and other erect weeds can be selectively wiped with herbicides from either with herbicide- laden wax bars (or) clothed stick dipped in concentrated herbicide solution.

Root growth differences: When herbicides are applied to soil, differences in the growth habit of underground parts of weeds and crop plants become important in determining their selective absorption. In general weeds seeds germinate from top 1.25-1.5 cm of soil, whereas many crop seeds are planted 5 to 7.5 cm deep. When a recommended pre-emergence herbicide is applied on the soil surface, and the soil moisture conditions are suitable to leach it to about 2.5 – 3 cm soil depth, it is readily available for absorption to the germinating weeds. Crop plants that grow their roots beyond 5 cm depth obviously avoid herbicide absorption and escape phytotoxicity. This is the basic principle of selectivity of most of the pre-emergence herbicides. Basic principle of selectivity of pre emergence herbicide is a function of herbicide structure, formulation and rate besides soil texture, organisms and inorganic colloids and rain fall.

When any of these factors is unfavorable herbicide may either injure the crops (or) poor weed control is seen. Sometimes, both these adverse effects may occur together when the phenomenon is called 'reverse selectivity'. Selectivity of mollinate between rice and *E. colona* due to differences in crown root initiation levels of two grasses. CRI is close to surface in *E. colona* but in rice CRI is below the soils surface in herbicide free zone. Selecitvity of trifluralin in wheat and green foxtail (*Setaria viridis)* is due to differences in coleoptilar nodes, irrespective of depth from which it is germinated (*S. viridis*); it is within 1 cm of the soil surface whereas in wheat it is much deeper.

C) Use of adsorbents and antidotes (Induced selectivity)

(a) Adsorbents: These are the materials having ability to adsorb herbicides which are placed near crop seed. Activated charcoal is strong absorbent of 2,4-D, EPTC, 2, 4, 5-T, propham, propachlor, pyrazon, trifluralin, chloramben, diuron, butachlor, simazine etc. When a germinating seed is surrounded by a layer of activated charcoal, then seed is prevented from absorption of soil applied pre-emergence herbicides. Mostly in horticultural crops activated charcoal is placed dibble over the crop seeds. Activated charcoal is first used as an adsorbent of 2,4-D. In transplanted horticultural crops, roots of seedlings are dipped in a charcoal before transplanting. Seed pelleting with charcoal has been developed in recent years using gum/ PVA (poly vinyl acetate) for increasing the selectivity of ETPC to maize and cowpea, and of chloramben, butachlor and EPTC to rice.

(b) Antidote (safener): Safeners are chemicals discovered to antagonize phytotoxicity of specific herbicides to specific plant species. Safeners prove successful against herbicides which inhibit cell division. **Otto –L-Hoffman –father of safeners** as early as in 1948 observed antagonism of 2,4-D to 2,4,6-T on tomato plants. By 1969, he discovered and reported **NA** (1, 8 Naphthalic anhydride) as highly successful safener of EPTC and butylate in maize. Effective dose is 0.5g per kg seed. It should be applied as seed dress. Later maize specific safener of EPTC and butylate, namely **R-25788** (N, N - dially 1-2, 2, dichloroacetamide) was discovered. The dose of the soil applied R-25788 is 0. 6 kg/ha. It has further been found an antidote of metachlor, alachlor in protecting maize seedlings. A seed coating has been found to provide protection to cultivated oat against pre-emergence alachlor and maize and sorghum against perfluidone and diclofop.CGA-43089 provide safety to sorghum against metalachlor by seed treatment @1-1.5 kg per ha.

Use of granules: The granules filters through crop foliage leaving very little for absorption, then settle over ground where the weeds will absorb and has low leach ability. The important desirable character of herbicide granules is low leach ability in soils. Eg. Chlorpropham, Dinoseb, diuron and nitrofen.

Differential rates of translocation of herbicides

Plants can translocate herbicide through the plant as much herbicide it absorbs. When equal amounts of herbicides are absorbed by plants and weeds but translocation rates are different. For example 2,4, 5-T is more toxic to *Cucumis trigonus* than 2,4-D because it was translocated much more rapidly than the latter compound inside plants. Like-wise differences in the selectivity between sugarcane (tolerant) and beans (susceptible) to 2,4-D was on the basis of its slow translocation in sugarcane and rapid translocation in beans. Always faster translocation does not mean quick killing. In certain cases it will help the plants is escaping specific herbicide action. For instance, diphenamide selective to *Convolvulus arvensis* because it translocated the herbicide very rapidly from shoots to the roots where it gets metabolized very rapidly than in *Avena sativa* (it fails to transmit very rapidly from roots to shoots). Soybean has bean found tolerant to oxyflourfen due to its slow absorption.

Differential rates of deactivation of herbicides

Selectivity is primarily a function of differential rate of deactivation. Herbicide selectivity is governed not only by differential absorption & differential translocation but also due to differential rates of deactivation of herbicides by the target and the non target plants. A tolerant plant species deactivates the herbicide molecule rapidly, whereas a susceptible species deactivates it slowly. This deactivation may be a process of i) metabolism ii) Reverse metabolism iii) conjugation.

Reverse metabolism is important mode of herbicide dissipation. Conversion of active herbicide to inactive form is metabolism where as conversion of inactive to active herbicide form is reverse metabolism.

a. Metabolism:

It involves a change in molecular structure of applied herbicides inside the plants yield on phytotoxic compounds. Eg. *Ribes nigrum* is susceptible to 2,4-D. (It metabolises the 2% of herbicide applied in 96 hours). Whereas *Ribes sativum* is tolerant to 2,4-D (metabolizes 50% of applied amount within 96 hours).

Selectivity of terbacil between *Mentha piperata* (tolerant) and *Ipomea hederaceae* (susceptible). *Mentha piperata* metabolised the herbicide rapidly and shown temporary fall in photosynthesis but in *Ipomea hederaceae* herbicide persisted for long time to inhibit photosynthesis. Rice is tolerant to bensulfuron due to rapid metabolism inside the plant.

b. Reverse Metabolism (inactive to active)

This is an enzymatic beta oxidation process. Intermediate chemical compounds are more Phytotoxic than original Compounds (parent compounds). Even number carbon ω Phenoxy Alkanoic acid compounds (2,4-DB, MCPB) these are non toxic but in plants they are converted to 2,4-D, MCPA (these are more toxic). This is due to enzymatic oxidation occurs in non-leguminous plants. But in legumes like lucerne, berseem, peas and clovers lack B-oxidation tolerant to 2,4-DB and MPCB.

c. Conjugation

Coupling of intact herbicide molecule with some plant cell constituents in living plants. Tolerance of grasses and *Convolvulus arvensis* to 2,4-D, this conjugate with glucose and form glucoside, ß- D glucose ester of 2,4-D. Binding of 2,4-D on certain protein films in tolerant graminaceous members eg.Sugarcane. It takes toxic herbicide concentration out of the main stream and makes tolerant. In Soybean chloramben- translocate rapidly to roots and conjugated with glucose molecules forming N-glucosyl chloramben and an unknown compound Chloroamiben –X.

In apple, maize and certain millets atrazine and simazine are deactivated by conjugation. Enzyme responsible for conjugation in maize is glutathione–S-Transferase. This catalyses conjugation of simazine with reduced glutathione to form S- Glutathion and chloride ion released during this process. Like- wise propanil selective to rice (tolerant); phytotoxic to *Echinocloa colonum* (susceptible) due to an enzyme called arylacylamine amidohydrolase content in leaves. In Barnyard grass the enzyme is less by 1/60 th as that in rice. In rice, leaves able to hydrolyze propanil to non phytotoxic compounds 3,4-dichloro aniline and propionic acid.

Differential protoplasmic resistance

Protoplasm of different plant species differing in withstanding abnormal deficiencies or excess constituents that may be induced in the presence of some specific herbicide molecules. Eg. Plant show tolerance to dalapon can withstand pantothenic acid deficiency and resist precipitation of cell protein. Buffering mechanism of protoplasm of plants is affected differently by different herbicides. Eg. Tolerance of mustard, groundnut and cotton to trifluralin and nitriles is due to their inherent protoplasmic resistance. Tolerance of rice plants to molinate is due to protoplasmic tolerance.

MULTIFACTOR HERBICIDAL SELECTIVITY IN PLANTS (Multi modes of selectivity)

a. Selectivity of linuron against parsnip in comparison to tomato was due to lower absorption rates and lower pace of metabolism in the parsnip.

b. Selectivity of flurodifen between resistant peanut and susceptible cucumber was found to be due to limited translocation from roots to leaves as well as more rapid metabolism of herbicide that reach the peanut leaves before it could enter the chloroplast. In cucumber flurodifen translocation was fast but its metabolism was slow.

c. Wheat is tolerant to ioxynil and bromaxynil due to limited spray retention, **s**low translocation and rapid metabolism. Limited spray retention is the first line defense.

d. Distribution of herbicide molecules within the plant is also important factor in the selectivity. Perfluidone and picloram accumulate at the site of action in susceptible plants and equally distributed in tolerant plants. In cotton plant lysigenous glands and trichomes hold high concentrations of triazines and substituted ureas lowering the concentration at the site of action.

Other selectivity components

Even if a plant posses some mechanisms to exhibit tolerance to a given herbicide but two important aspects that are to be considered are.

(I) Rate of herbicide

(II) Stage of the plant at the time of application in inducing selectivity

Rate of herbicides

1. It is important to consider how much and when to apply in obtaining the desired volume of weed control.
2. Under rates improve selectivity to crops at the cost of satisfactory weed control.
3. Over rates decreases the selectivity and cause variable crop injury.
4. In physiologically selective herbicides, range of selective rates is much greater than that is needed for effective weed control. Narrow in case of other herbicides.
5. Most of herbicides loose selectivity at over rates at 0.5-1 kg/ha
6. Some of herbicides like Dicamba and metamitron loose selectivity even by few grams per ha.

Growth stage of crops plant

There are herbicide susceptibility as well as tolerance stages. Except few herbicides which can be applied irrespective of crop stages e.g. simazine in maize and propanil in rice. In most cases at different stages of growth, plants respond differently to a given herbicide. 2, 4-D is selective to winter grains at first 3-6 leaf stage and dough stage. In other stages malformations like onion leafing, missing spikelet ear, rat tail ear occurs. In barley- malting quality is decreased by applying 2, 4-D at susceptible stages.

Herbicide combinations

Applying two or more herbicides simultaneously, either using prepackage mixtures or by mixing different herbicide products before the application, is a very common approach in intensive agriculture (Hatzios & Penner, 1985; Green, 1989; Zhang *et al.*, 1995). This is because the application of a single herbicide, even though may provide good control of certain weeds, is often inadequate for satisfactory and cost effective weed control. Furthermore, many herbicides have a narrow spectrum of weed control; whereas, other herbicides do not show the same efficacy against all weeds of their spectrum of control when applied at the recommended rates. Given that weed flora normally consists of many species with varying levels of herbicide sensitivity, more herbicide applications should be often performed or additional measures for weed control should be additionally adopted. This, however, increases the cost of weed control and consequently the cost of crop production.

Mixtures of selected herbicides offer several advantages over the use of a single herbicide, including (a) a reduction in production cost by saving time and labour, (b) a reduction in soil compaction by eliminating multiple field operations, (c) an increase in the spectrum of weeds controlled or an extension of weed control over a longer period of time, (d) an improvement in crop safety by using minimum doses of selected herbicides applied in combination rather than a single high dose of one herbicide, (e) a reduction in crop or soil residues of persistent herbicides by using minimum doses of such herbicides, and selected herbicides (Hatzios & Penner, 1985).

The use of tank mixtures with two or more herbicide partners presupposes that the combined herbicides behave and act independently (the presence of each one does not affect the activity of the other). In this case, the activity of the applied combination can be easily predicted as the sum of activities of each single herbicide of the mixture when these herbicides are applied separately. In some cases, however, interactions between companion herbicides may significantly modify the biological behaviour of each single herbicide in the mixture. These interactions often result in a reduction or an increase of the activity of the combined herbicides compared with activities when each one of them is applied alone. Practically, the optimum herbicide combinations would be those that exhibit enhanced activity on target weed species and decreased toxicity on crops (increased selectivity). This, however, is difficult to predict since the behaviour of each single herbicide in the mixture is often affected by the presence of the other(s) and the activity of the mixture may also vary considerably depending on plant species, growth stage, and environmental conditions.

The objective of this paper was to summarize important aspects on the most common interactions that take place between herbicides from the use of tank mixtures. Thus, the most important types and mechanisms of interactions as well as various factors that may affect the behaviour of herbicide mixtures are discussed.

Types of herbicide interactions. The result of an interaction between two or more herbicides after their application in mixture may be additive, synergistic, or antagonistic (Fig. 3.2). In the first case, the activity of the mixture is equal to the sum of the activities of all herbicides in the mixture when these herbicides are applied separately. In the second and the third case, however, the activity of the mixture is greater or lower, respectively, than the sum of the activities of all herbicides in the mixture when these herbicides are applied separately (Hatzios & Penner, 1985; Green, 1989). It is obvious that in the case of antagonism, where the activity of the mixture is reduced, greater application rates of the affected herbicide are required, whereas in the case of synergism, where the activity of the mixture is enhanced, application rates can be reduced.

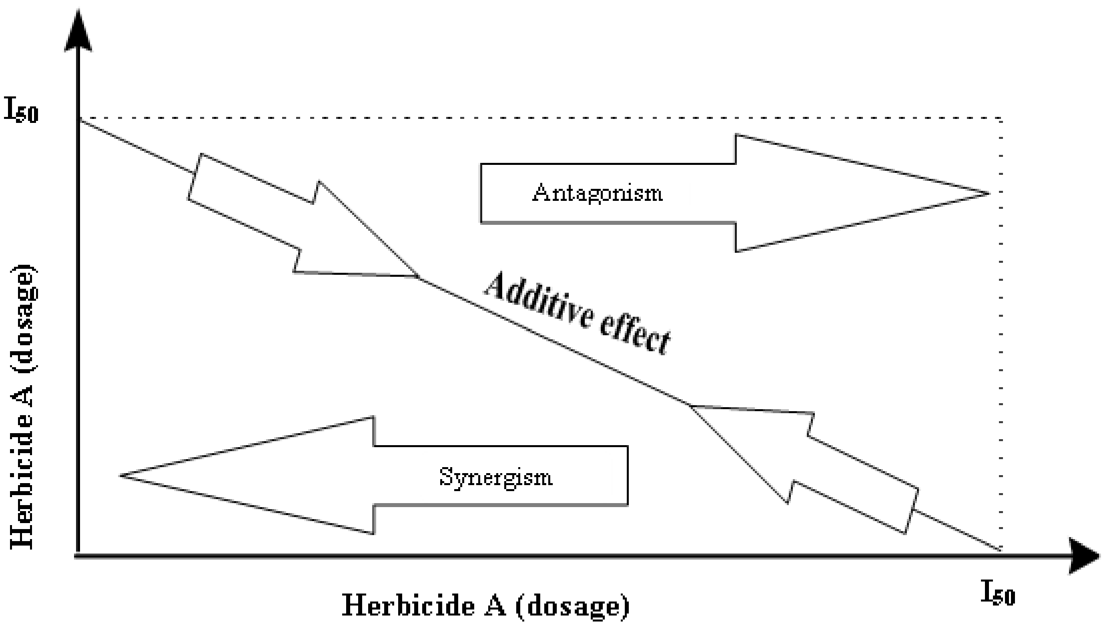


Fig. 3.2. Schematic presentation of herbicide interactions (ID_{50} = rates of herbicides, applied alone or in mixture, for a 50% weed control) (modified from Green, 1989)

Antagonistic interactions in herbicide mixtures often cause significant problems in weed control. For example, the application of pyrithiobac in mixture with fluazifop-P has been reported to reduce the efficacy of fluazifop-P on large crabgrass (*Digitaria sanguinalis*) (Ferreira *et al.*, 1995). Similarly, the application of tribenuron in mixture with diclofop has been reported to reduce the efficacy of diclofop on wild oat (*Avena fatua*) (Baerg *et al.*, 1996). It is obvious that such herbicide combinations should be avoided. Antagonistic interactions, however, may be considered beneficial when they reduce herbicide activity on crops. For example, according to Deschamps *et al.* (1990), mixtures of fenoxaprop with MCPA showed reduced toxicity of fenoxaprop on wheat and barley compared with fenoxaprop applied alone. Furthermore, mixtures of thifensulfuron with bentazon showed reduced toxicity of thifensulfuron on soybean compared with thifensulfuron applied alone (Hart & Roskamp, 1998; Lycan & Hart, 1999). Therefore, such herbicide combinations appear desirable unless antagonism on weeds also occurs.

Synergistic interactions may be particularly beneficial when they result in more effective control of troublesome weeds. For example, Flint and Barrett (1989a) found that mixtures of glyphosate with 2,4-D were more effective on field bindweed (*Convolvulus arvensis*) compared with separate applications. Similarly, Scott *et al.* (1998) found that mixtures of sethoxydim with dimethenamid were more effective on johnsongrass (*Sorghum halepense*) compared with separate applications. It is obvious that such herbicide combinations are particularly useful for more effective weed control. Synergistic interactions, however, may cause significant problems when they result in increased herbicide activity on crops. For example, mixtures of ethametsulfuron with haloxyfop, fluazifop, fluazifop-P, quizalofop, and quizalofop-P may cause phytotoxicity and yield losses in *Brassica napus* and *Brassica rapa* (Harker *et al.*, 1995). Furthermore, mixtures of thifensulfuron (sulfonylurea) with imazethapyr (imidazolinone) may cause phytotoxicity in soybean resistant to sulfonylureas (Simpson & Stoller, 1996).

Mechanisms of herbicide interactions. Interactions in herbicide mixtures can occur prior, during, or after application of the mixture. This means that herbicides may interact physically or chemically in the spray solution or biologically in the plant. Mechanisms of interactions in herbicide mixtures can be broadly grouped into four categories: biochemical, competitive, physiological, and chemical (Hatzios & Penner, 1985; Green, 1989; Zhang *et al.*, 1995). According to this classification, interactions between herbicides in mixtures may be attributed to a) changes in the amount of an herbicide that reaches its site of action through absorption, translocation or metabolism caused by the presence of the other herbicide, b) interaction at the site of action between the combined herbicides where one herbicide of the mixture affects the binding of the other at its site of action c) interaction between combined herbicides that produces opposite effects on the same physiological process of the plant or synergizes the overall effect, and e) chemical reaction between the combined herbicides that leads to formation of inactive complex or an increase in the rate of metabolism (Hatzios & Penner, 1985; Green, 1989; Zhang *et al.*, 1995). The aforementioned mechanisms have not been fully documented in many cases. This is because of the great complexity in the study of such interactions since the occurrence of interactions may be a result of two or more mechanisms.

Factors affecting herbicide interactions. The type and the extent of interactions depend primarily on properties of the combined herbicides (chemical group, absorption, translocation, mechanism of action, pathway of metabolism). In general, antagonism has been found to occur three times more often than synergism regardless of the species or the herbicides in which is recorded (Zhang *et al.*, 1995). Synergism has been found to occur more frequently in mixtures where the companion herbicides belong to the same chemical group (Fig. 3.3A). These herbicides normally have similar chemical structure, the same mechanism of action, and similar pathway of metabolism. The high frequency of antagonism in such herbicide mixtures could be attributed in plant inability to metabolize simultaneously two or more herbicides. Antagonism, unlike synergism, has been found to occur more frequently in mixtures where the companion herbicides belong to different chemical groups (Fig. 3.3B). These herbicides normally have different chemical structure, different mechanism of action, and different pathway of metabolism. This is because these herbicides probably have a greater chance to interact at the site of action (enzyme or physiological process) or to react chemically and form an inactive complex.

The point of entrance and the mobility of the combined herbicides into the plant may affect significantly the behaviour of the herbicide mixture. In particular, when the combined herbicides enter into the plant through the same point (root or foliage) then the presence of one herbicide in the mixture may reduce the absorbed amount of the other and consequently can reduce its efficacy (Flint & Barrett, 1989b; Wanamarta *et al.*, 1989; Hart & Wax, 1996; Culpepper *et al.*, 1999; Damalas & Eleftherohorinos, 2001). Furthermore, the translocated amount of an herbicide to its site of action can be reduced by the presence or the concomitant translocation of another herbicide into the plant (Aguero-Alvarado *et al.*, 1991; Hart & Penner, 1993; Ferreira *et al.*, 1995, Baerg *et al.*, 1996; Hart, 1997; Damalas & Eleftherohorinos, 2001). On the contrary, the chance of such interaction is significantly reduced when only one herbicide in the mixture is translocated; whereas, the other is not (Zhang *et al.*, 1995). A similar trend with aryloxyphenoxypropionate and cyclohexanedione herbicides was observed using data from previous studies; members of both herbicide families were found to be affected more when mixed with systemic rather than contact broadleaf herbicides (Damalas & Eleftherohorinos, unpublished data).

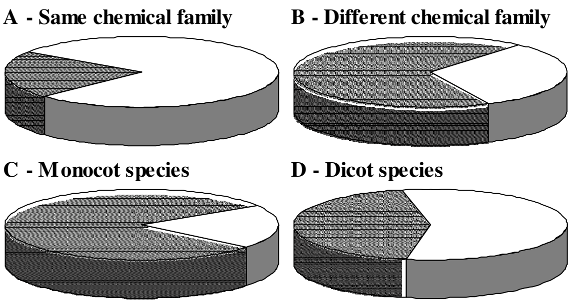


Fig 3.3. Frequency of antagonistic (z) and synergistic ({) interactions after simultaneous application of herbicides belonging to the same (A) or different (B) chemical groups and applied either on monocotyledons (C) or dicotyledons (D) (modified from Zhang *et al.*, 1995)

Antagonistic interactions may sometimes be attributed to increased metabolism of an herbicide because of the presence of another herbicide. For example, studies of Jacobson *et al.* (1985) and Shimabukuro *et al.* (1986) showed that the reduced efficacy of diclofop on various species after application with hormone herbicides such as 2,4-D resulted from an increase in its metabolism (formation of complex in the carboxylic group) because of the presence of 2,4-D.

The type of interactions between companion herbicides may depend on target plant species. For example, the combination of acifluorfen and bentazon showed an increased efficacy against common lambsquarters (*Chenopodium album*) and velvetleaf (*Abutilon theophrasti*) but reduced efficacy against jimsonweed (*Datura stramonium*) and red root pigweed (*Amaranthus retroflexus*) (Sorensen *et al.*, 1987). Moreover, the combination of herbicides that inhibit acetolactate synthase (ALS) (e.g. imazaquin, chlorimuron) with herbicides of the diphenyl-ether group (e.g. acifluorfen, fomesafen) showed increased efficacy on prickly sida (*Sida spinosa)* but reduced efficacy on common cocklebur (*Xanthium strumarium*) (Wesley & Shaw, 1992).

The growth stage of weeds may often affect the extent of interactions between combined herbicides. Liebl and Worsham (1987) observed that the post-emergence application of chlorsulfuron and diclofop decreased efficacy of diclofop on italian ryegrass (*Lolium multiflorum*) and the effect was more severe when the application was performed at the three-leaf growth stage than at the two-leaf growth stage. This may be attributed to reduced detoxification ability from the younger plants and also to their thinner cuticle that probably allowed retention, absorption, and translocation of greater amounts of the applied herbicides.

The post-emergence application of various graminicides in mixture with one or more broadleaf herbicides to broaden spectrum of control often results in reduced efficacy of graminicides (Vidrine, 1989; Holshouser & Coble, 1990; Grichar, 1991; Vidrine *et al.*, 1995; Damalas & Eleftherohorinos, 2001). This is the most common case of herbicide interaction reported in the literature and it has been observed in a great number of herbicide combinations on various grass species. Antagonistic interactions between graminicides and broadleaf herbicides are probably due to morphological and physiological differences between grasses and broadleaf weeds. Broadleaf weeds have meristems at the top of the plant; whereas, grasses have them at the base. This difference probably affects absorption and mainly translocation of the foliar applied herbicides particularly the systemic ones that are translocated and accumulated at the meristematic tissues of the plant where they act. Data of the literature show clearly that the simultaneous application of various graminicides with certain broadleaf herbicides limits considerably graminicide absorption by foliage and translocation to the meristematic tissues. This has been confirmed by the results of Zhang *et al.* (1995) who found that the frequency of antagonistic interactions was four times greater than synergistic interactions in grasses (Fig. 3.3C); whereas, the corresponding frequencies were almost equal in broadleaf weeds (Fig. 3.3D). It is worth mentioning that almost 80% of the interactions that has been observed in species of the family Poaceae (grasses) refer to cases of antagonism (Zhang *et al.*, 1995).

It is evident from all the above that many factors may affect the behaviour of herbicide mixtures. Many of the observed interactions are not fully understood at the physiological and biochemical levels and it is possible that more than one mechanisms are involved.

ADJUVANTS

An adjuvant is any material added to a herbicide spray solution that modifies or enhances the action of that solution. Many herbicides already contain adjuvants as part of their formulations. Some of these formulations can be used directly whereas others need to be applied in conjunction with one or more adjuvants. There are over 3,000 adjuvants available for use. These can be grouped into three general types of adjuvants, including activators, spray modifiers and utility modifiers.

Activators increase the activity of herbicides by modifying certain herbicide characteristics, including particle size of the herbicide spray, distribution of the spray on the plant, spray viscosity, evaporation rate, rate of herbicide uptake or solubility of the herbicide in the spray solution. Activators can be either nonionic (producing little or no ionization in water) or ionic (having a positive or negative charge). It is generally recommended that a cationic (positively charged) herbicide should not be used with an anionic (negatively charged) adjuvant (and vice versa) because oppositely charged compounds could react, diminishing the effects of the herbicide. Most activators have no charge and thus can be mixed readily with any herbicide. There are three categories of activators including surfactants, wetting agents and oils.

Surfactants primarily influence the ability of herbicides to penetrate the leaf's waxy cuticle. Emersed and floating aquatic plants develop waxy cuticles similar to terrestrial plants, whereas submersed plants do not. Most herbicides are prepared in a solution of water. Water is a chemically polar material and thus can be repelled by the waxy surface of leaves. Activators reduce the surface tension of water on plants, and allow the herbicide formulation to wet leaf surfaces and enter into the plant.

Wetting agents increase the ability of water to displace air or liquids from the leaf surface, allowing it to be wet by the herbicide. (Surfactants also have wetting properties but they vary in the degree of wetting they provide.) Wetting agents help spread the solution more evenly over the leaf.

Oils are usually marketed at a concentration of about 80% oil/20% surfactant and are added to water to increase the retention time of a solution on leaves, allowing for an increase in herbicide uptake.

Spray modifiers influence the delivery and placement of spray solution. They confine or alter the characteristics of the spray solution. They include thickening agents (i.e., invert emulsions and polymers), stickers, spreaders, spreader-stickers and foaming agents, which reduce herbicide drift and allow for more exact placement of the herbicide.

Thickening agents modify the viscosity of formulations to reduce or control drift, aid in dispersal and promote sinking. Inverts and polymers are two types of thickening agents commonly used in aquatic herbicide applications.

Invert emulsions are mixtures of inverting oil and water, having a mayonnaise-like appearance on the water surface and a snowflake-like appearance under the water surface. Depending on their solubility, herbicides dissolve in either the oil or water component. The adjuvant/herbicide emulsion sticks to leaves and stems of plants, thus reducing drift and increasing herbicide contact time with plants.

Polymers are long-chain carbon molecules which are up to 40,000 carbons in length, forming a thick mucus-like material which helps to break the surface tension of water and enhance sinking of herbicides. Higher molecular weight polymers are generally formulated as an emulsion and are used as sinking agents. Lower molecular weight polymers are usually formulated as solutions and are used for drift control. Polymers are not very effective in water with a flow rate of greater than 3 cm/sec. as the herbicides/adjuvant mixtures may be washed off leaves before effective contact time is achieved.

However, polymers are effective in still waters.

Stickers are made of vegetable gels, resins, mineral oils, vegetable oils, waxes or latex polymers. They promote the sticking of a spray to the sprayed surface. Stickers are usually used for application of fungicides and insecticides rather than herbicides.

Spreaders are blends of primarily nonionic surfactants used for spreading and sticking a spray to plant leaves. They are not as cost-effective as most surfactants but they can increase the effectiveness of some herbicides.

Spreader-stickers are combinations of the above two materials which provide additional retention of herbicide in wet conditions. These adjuvants are more expensive than surfactants and are not used very much in herbicide applications but they are used with fungicides and insecticides.

Foaming Agents are surfactants which are used with specialized spray applicators to create foam for reducing drift and evaporation. These agents are used infrequently for drift control of herbicide applications.

Utility Modifiers are rarely used in aquatic plant control. The addition of modifiers to a herbicide formulation expands the range of conditions (e.g., pH, hardness, etc.) under which a formulation can be used. Types of modifiers include emulsifiers, dispersants and stabilizing agents (including buffering agents and anti-foam agents). Buffering agents and anti-foam agents are used for aquatic plant management. Buffering agents are used to increase the dispersion or solubility of herbicides in alkaline or acid waters used in making up an herbicide solution. Anti-foam agents are mostly silicone-based and are used to eliminate foam in the spray tank, especially useful when mixing herbicides with soft water which usually creates a foaming problem. (above information adapted from: Aquatic Plant Identification and Herbicide Use Guide, 1988; Langeland, 1991)

COMMONLY USED ADJUVANTS

Table 3.1 contains a partial listing of adjuvants used with aquatic herbicides.

Toxicity
The toxicity of adjuvants is not as well characterized as the toxicity of herbicides. Very commonly, a study of the toxicity of a herbicide focuses on the active ingredient in the herbicide and neglects to consider the toxicity of adjuvants used during application of that herbicide. Part of the reason for the limited toxicity information of adjuvants is that the regulation of adjuvants is not very rigorous.

Table 3.1. Commonly Used Adjuvants

Name	Type	Action
Big Wet (E,F)	Activator	nonionic/anion spreader, wetting agent, penetrant
Cide-Kick (E,F,S)	Activator	nonionic wetting agent, activator, penetrant
Cide-Kick II (E,F,S)	Activator	nonionic wetting agent, activator, penetrant
Ortho X -77 Spreader (E,F)	Activator	nonionic spreader, activator
Asgrow "403" Invert Emulsifier (E,F,S)	Spray modifier-invert	invert emulsion, drift control, reduce evaporation, increase droplet spreading and penetration, resist wash off
Bivert (E,F,S)	Spray modifier-invert	invert emulsion, chemical encapsulating, suspending agent, deposition and retention agent, reduce drift and washoff
I'vod Invert ing Oil (E,F,S)	Spray modifier-invert	invert emulsion, drift control, reduce evaporation, increase droplet spreading and penetration, resist wash off. (Dilution with #2 diesel oil or water required.)
Spra -Mate Invert Emulsion (E,F,S)	Spray modifier-invert emulsion	invert emulsion, drift control, reduce evaporation, increase droplet spreading and penetration, resist wash off (Dilution with #2 diesel oil or xylene required.)
Visko-Rhap (E,F,S)	Spray modifier-inverting oil	invert emulsion, reduce drift. (Can be diluted with #2 fuel oil or kerosene, if necessary)
Nalquatic (S)	Spray modifier-polymer	improve sinking, herbicide confinement and contact properties
Nalco-Trol (E)	Spray modifier-polymer	drift control, developed for Rodeo (glyphosate), diquat and 2,4 -D; sinking agent for Hydrothal 191 (endothall)
Nalco-Trol II (E,S)	Spray modifier-polymer	sinking agent developed for Hydrothol 191 (endothall) and drift control for RODEO (glyphosate)
Poly Control	Spray modifier-polymer	drift control, sticking agent, nonionic
Poly Control 2 (S)	Spray modifier-polymer	drift control, sticking agent, nonionic
Submerge (S)	Spray modifier-polymer	sinking agent, contact confinement of herbicides (manufactured in both anionic and nonionic forms)

E - emersed plants; S - submersed plants; F - floating plants; (Aquatic Plant Identification and Herbicide Use Guide, 1988)

Herbicide Safeners

Herbicide safeners (herbicide antidotes), are chemical agents that increase the tolerance of monocotyledonous cereal plants to herbicides without affecting the weed control effectiveness. The use of safeners offer several benefits to agricultural weed control. Safeners may allow:
(1) the selective chemical control of weeds in botanically related crops;
(2) the use of nonselective herbicides for selective weed control;
(3) the counteraction of residual activity of soil-applied persistent herbicides such as triazines in crop rotation systems;
(4) an increase in the spectrum of herbicides available for weed control in "minor" crops;
(5) an expansion and extension of the uses and marketability of generic herbicides;
(6) the elucidation of sites and mechanism by serving as useful biochemical tools.
The commercial viability of safener concept is indicated by the growing number of herbicide-safener products available on the pesticide market. With the use of safeners, difficult weed control problems can be addressed and without safeners, many herbicidally active substances could have never been applied for weed control.
1,8-naphthalic anhydride (NA) patented by Hoffmann has been considered as the most versatile safener showing less botanical and chemical specificity than other safeners developed later. NA protected cereals as seed treatments against various herbicide chemistries. NA was reported to be mildly phytotoxic to maize (chlorosis

and growth inhibition) under some growing conditions. One problem in treating seeds with safeners prior to planting is that phytotoxicity can increase as the time the safener is exposed to the seed increases. With NA, the phytotoxicity to the crop increases with increased time the safener is in contact with the seed during storage. This problem has thus far prevented NA from being introduced to the commercial market.

The introduction of dichloroacetamide derivatives developed as safeners against thiocarbamates and chloroacetanilides was a breakthough in the history of the safeners since these compounds can be applied to the soil in preplant incorporated (PPI) or preemergence (PRE) technology in prepackaged tank mixture with the herbicide. Generally, prepackaged herbicide-safener mixtures offer several advantages over seed safeners. First of all, the manufacturer controls all components of the formulation secondly, the farmers buy and use a single and reliable product which allows a wider selection of crop cultivars. Dichlormid exhibited a remarkable degree of chemical and botanical specificity in protection of maize against thiocarbamates such as EPTC, butylate, vernolate but the safener was less protective to maize against chloroacetanilides.

Table 3.2. Structure, logP and application of some important safeners

Chemical class	Name	logP	Herbicide	Crop	Appl. method
Anhydride	1,8–Naphthalic anhydride (NA)	2.54	Thiocarbamates	Maize	Seed–treatment
Dichloro–acetamide	Dichlormid	1.84	Thiocarbamates Chloroacet-anilides	Maize	PPI, PRE
	Furilazole	2.12	Acetochlor Halosulfuron-methyl	Maize	PRE
	AD–67	2.32[b]	Acetochlor	Maize	PRE
	Benoxacor	2.69	Metolachlor	Maize	PRE
Oxime ether	Cyometrinil	1.56	Chloroacet–anilides (metolachlor)	Sorghum	Seed–treatment
	Oxabetrinil	2.76	Chloroacet–anilides (metolachlor)	Sorghum	Seed-treatment
	Fluxofenim	2.90	Chloroacet-anilides (metolachlor)	Sorghum	Seed–treatment
Thiazole carboxylic acid	Flurazole	3.64[b]	Alachlor	Sorghum	Seed–treatment
Dichloromethyl-ketal	MG–191	1.35[b]	Thiocarbamates Chloroacet-anilides	Maize	PRE
Phenyl–pyrimidine	Fenclorim	4.17	Pretilachlor	Rice	PRE
Urea	Dymron	2.70	Pyributicarb Pretilachlor Pyrazosulfuron–ethyl	Rice	PRE, POST
Piperidine–1–carbothioate	Dimepiperate	4.02	Sulfonylureas	Rice	POST
8–Quinolinoxy–carboxylic esters	Cloquintocet–mexyl	5.03	Clodinafop–propargyl	Cereals	POST
1,2,4–Triazole–carboxylate	Fenchlorazole–ethyl	4.52	Fenoxaprop–ethyl	Cereals	POST
Dihydropyrazole–dicarboxylate	Mefenpyr–diethyl	3.83	ACCase inhibitors Sulfonylureas	Wheat, Rye, Triticale, Barley	POST
Dihydroisoxazole–carboxylate	Isoxadifen–ethyl	3.88[b]	ACCase inhibitors Sulfonylureas	Maize Rice	POST
Arylsulfonyl–benzamide	Cypro–sulfamide	2.09[b]	Isoxaflutole	Maize	PRE, POST

[i] - [a] Safeners used as racemic mixtures are indicated by *R*/*S* in their structures. [ii] - [b] Log P values unavailable were calculated by ALOGPS 2.1 program available online at www.vclab.org/articles/cite.html.

Degradation of herbicides in soil and plants

Millions of tonnes of pesticides are applied annually; however, less than 5% of these products are estimated to reach the target organism, with the remainder being deposited on the soil and nontarget organisms, as well as moving into the atmosphere and water (Pimental and Levitan 1986). The length of time that a herbicide remains active or persists in the soil is extremely important as it relates to the length of time that weed control can be expected. To a certain degree persistence is a desirable property. Herbicides are claimed to persist in the soil as long as their herbicide activity against weeds is wanted. Persistence exceeding this degree is called undue persistence. Also, residual activity is important as it relates to phytotoxic after-effects that may prove injurious to succeeding crops or plantings.

Herbicides are lost from the soil either by physical removal of the unchanged molecule or by degradation. The availability and thus activity, to plants and other organisms, is related to their concentration in the aqueous and/or vapour phases. Seven factors affect the persistence of a herbicide in the soil;

Physical removal: adsorption on the soil colloids, leaching, plant uptake and volatility,

Degradation: chemical decomposition, micro-organism decomposition, and photodecomposition,

Adsorption of Herbicide by the Soil

Herbicides tend to leave the soil solution and are adsorbed by clay and organic matter particles making the herbicide unavailable for uptake by the weed.

Research has shown that:

- Soils high in organic matter require relatively large amounts of pre-emergence and soil sterilant herbicides for weed control.
- Soils high in clay content require more herbicide than sandy soils for pre-emergence or soil sterilant weed control.
- Soils high in organic matter and clay content tend to hold the herbicides for a longer time than sands. The adsorbed herbicide may be released so slowly that the chemical is not effective as a herbicide.

Runoff and Leaching

Runoff moves herbicides in surface water, either mixed in the water or bound to soil particles. The amount of herbicide runoff depends on the grade or slope of the field, the type of soil, the amount of rainfall (especially close to the time of application) and properties of the herbicide. For example, a herbicide applied to a saturated clay soil is highly susceptible to runoff. Established vegetation or plant residues reduce runoff.

Herbicide runoff is greatest when heavy rainfall occurs shortly after application. No-tillage, minimum-tillage and soil incorporation reduce runoff. Surface grading, drainage ditches and dikes, and the use of border vegetation can help reduce herbicide movement into surface water.

Leaching is the movement of herbicides through the soil into groundwater. Several factors influence leaching, including water solubility of the herbicide, soil structure and texture, and persistence of herbicide adsorption to soil particles. If a herbicide is strongly adsorbed to soil particles, it is less likely to leach, regardless of its solubility, unless the soil particles themselves move with the water flow. Leaching occurs in any direction (downward, upward, sideways).

The extent to which a herbicide is leached is determined principally by:

- Solubility of the herbicide in water.
- Amount of water passing through the soil.
- Adsorptive relationships between the herbicide and the soil.

In general, those herbicides which are completely water-soluble are most easily leached. Salts of 2,4-D are water-soluble and leach readily through porous, sandy soils whereas esters of 2,4-D are low in solubility and do not leach easily.

Herbicides have been known to move upward in the soil. If water evaporates from the soil surface, water may move slowly upward. The water may carry with it soluble herbicides. As the water evaporates, the herbicide is deposited on the soil surface.

Plant Uptake

The uptake of herbicides by plant roots results in their removal from the environment; hence, reduced concentrations in the soil. **Absorption** is the process by which plants and microorganisms take up chemicals. Once absorbed, most herbicides are degraded within plants. Residues may persist inside the plant or be released back into the environment as the plant decays.

Volatility

Volatilization occurs when a solid or a liquid turns into a gas. A pesticide in a gaseous state can be carried away from the treated area by air currents. This is called vapor drift. Unlike the drift of sprays and dusts that can sometimes be seen during application, vapor drift is invisible.

Avoid applying volatile herbicides when conditions favor volatilization, such as temperature inversions. Herbicide labels usually mention the potential for volatility of herbicides. Volatilization can sometimes be reduced through the use of low volatile formulations or soil incorporation of the herbicide.

Herbicides may evaporate and be lost to the atmosphere as volatile gases. The volatile gases may or may not be toxic to plants. The volatile gases may drift to susceptible plants such as those from the ester forms of 2,4-D causing injury to susceptible crops such as tomatoes or grapes. Eptam, Eradicane and Treflan are examples of volatile herbicides which must be incorporated into the soil immediately following application to prevent loss of herbicide to the atmosphere.

Rain or irrigation water applied to a dry soil will usually leach the herbicide into the soil, or aid in its adsorption by the soil particles. Once adsorbed by the soil, the loss by volatility is usually reduced.

Degradation is, generally, the major route for herbicide dissipation from soil. Herbicide is, gradually, transformed by degradation into series of intermediate metabolites, until the molecule is completely broken down. The intermediate metabolites are particularly important because they can have biological activity, toxicity characteristics and persistence which are different from those of the initial compounds. Degradation is possible in three ways: enzymatically (microbial), photochemical and chemical.

Micro-Organism Decomposition

The principal micro-organisms in the soil are algae, fungi, actinomyces, and bacteria. They must have food for energy and growth. Organic compounds of the soil provide this food supply, except for a very small group of organisms that feed on inorganic sources. Microbial degradation occurs when microorganisms such as fungi and bacteria use a herbicide as a food source. Conditions that favor microbial growth include warm temperatures, favorable pH levels, adequate soil moisture, oxygen and fertility. Adsorbed herbicides are more slowly degraded because they are less available to some microorganisms. Micro-organisms use all types of organic matter, including organic herbicides. Some chemicals are easily decomposed (easily utilized by the microorganisms), whereas others resist decomposition.

Chemical Decomposition

Chemical degradation is the breakdown of a herbicide by soil processes not involving a living organism. Adsorption of the herbicides, soil pH, soil temperature and moisture influence the rate of degradation. Some herbicides are more rapidly degraded on low pH soils. Chemical decomposition destroys herbicides through interaction with the soil constituents of oxygen, hydrogen or water. Hydrolysis (interaction with water), for example, is responsible for inactivating atrazine in the soil.

Photodecomposition

Photodegradation is the breakdown of herbicides by the action of sunlight. Herbicides applied to foliage or the soil surface may be broken down by exposure to light. Soil incorporation can reduce herbicide exposure to sunlight. Ultraviolet light from the sun decomposes many herbicides applied to the soil surface. Some herbicides such as fluchloralin and trifluralin are recommended for soil incorporation as they break down readily when exposed to sunlight.

The metabolic fate of pesticides is dependent on abiotic environmental conditions (temperature, moisture and soil pH), microbial community or plant species (or both), pesticide characteristics (hydrophilicity, $pK_{a/b}$, K_{OW}, etc.), and biological and chemical reactions. Abiotic degradation is due to chemical and physical transformations of the pesticide by processes such as photolysis, hydrolysis, oxidation, reduction, and rearrangements. Further, pesticides may be biologically unavailable because of compartmentalization, which occurs as a result of pesticide adsorption to soil and soil colloids without altering the chemical structure of the original molecule. However, enzymatic transformation, which is mainly the result of biotic processes mediated by plants and microorganisms, is by far the major route of detoxification.

Metabolism of pesticides may involve a three-phase process (Table 3.3) (Hatzios 1991; Shimabukuro 1985). In Phase I metabolism, the initial properties of a parent compound are transformed through oxidation, reduction, or hydrolysis to generally produce a more water-soluble and usually a less toxic product than the parent. The second phase involves conjugation of a pesticide or pesticide metabolite to a sugar, amino acid, or glutathione, which increases the water solubility and reduces toxicity compared with the parent pesticide. Generally, Phase II metabolites have little or no phytotoxicity and may be stored in cellular organelles. The third phase involves conversion of Phase II metabolites into secondary conjugates, which are also nontoxic (Hatzios 1991). In leafy spurge (*Euphorbia esula* L.), examples of Phase III metabolism are the conjugation of the *N*-glycoside metabolite of picloram with malonate and the formation of a gentibioside from the picloram glucose ester metabolite (Frear et al. 1989) (Fig 3.4). There are fundamental similarities and differences between plant and microbial pesticide metabolism.

Table 3.3. Summary of the three phases of pesticide metabolism (adapted from Shimabukuro 1985).

Initial Characteristics	Properties	Phase I	Phase II	Phase III
Reactions	Parent compound	Oxidation, hydrolysis, reduction	Conjugation	Secondary conjugation or incorporation into bio- polymers
Solubility	Lipophilic	Amphophilic	Hydrophilic	Hydrophilic or insoluble
Phytotoxicity	Toxic	Modified or less toxic	Greatly reduced or non- toxic	Nontoxic
Mobility	Selective	Modified or reduced	Limited or immobile	Immobile
Bioavailability[a]	***	***	**	* Or unavailable

[a] ***, Readily absorbed in GI tract of animals; **, less absorption; *, limited absorption.

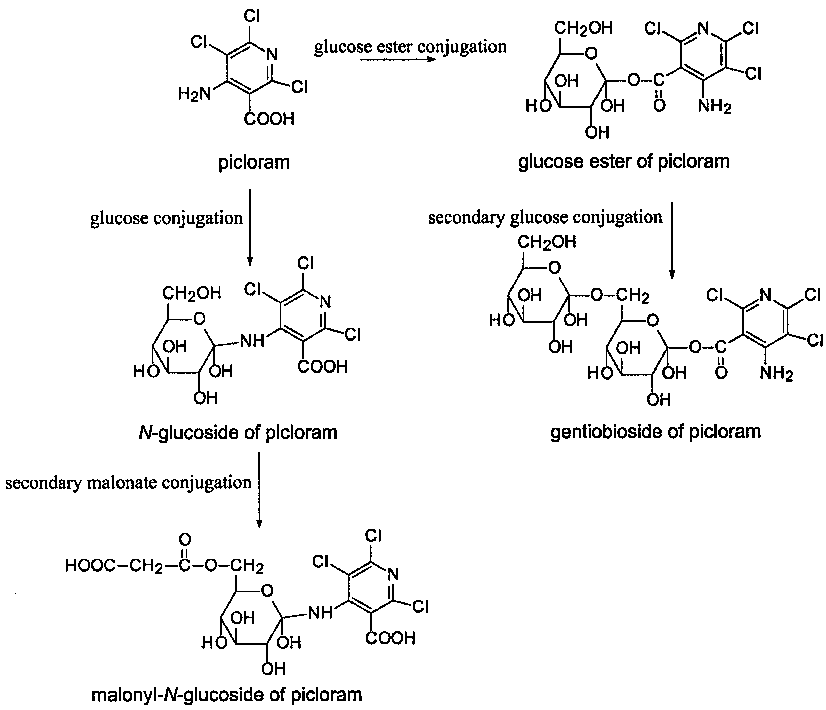


FIG 3.4. Conjugation and secondary conjugation of picloram in leafy spurge (*Euphorbia esula* L.) as proposed by Frear et al. (1989).

Primary Metabolism

Oxidative Transformations

Reactions by Cytochromes P450

Oxygenation is the most frequent first step in the bio-transformation of pesticides and other organic xenobiotics. Many of these reactions are mediated by oxidative enzymes, e.g., cytochrome P450s, peroxidases, and polyphenol oxidases. The most extensively studied oxidative enzymes in plants and animals are the P450s, which are the most important enzymes in Phase I pesticide metabolism (Barrett 2000). Cytochrome P450s are hemethiolate proteins that have been characterized in animals, plants, bacteria, and filamentous fungi. In plants, bacteria, and fungi, P450s produce many secondary metabolites including plant growth regulators, isoprenoids, and alkaloids. Cytochrome P450s are encoded by a superfamily of genes designated as *CYP,* which have highly conserved residues around the heme portion of the protein (Barrett 2000). The first plant P450 gene was sequenced in 1990 (Bolwell et al. 1994), and presently, more than 500 P450 plant genes have been described (Barret 2000). P450 genes occur in clusters in the genome (Frey et al. 1997). Regulation and expression of P450s are not well understood in plants or microorganisms mainly because of the very low quantities of P450 enzymes usually present in these cells, particularly if the organism has not been ex- posed to physiochemical, physiological, or xenobiotic stress.

Cytochrome P450s often catalyze monooxygenase reactions, usually resulting in hydroxylation, according to the following reaction: RH 1 O_2 1 NAD(P)H 1 H^1 ROH 1 H_2O 1 $NAD(P)^1$. However, there are many other P450- mediated reactions including dehydration, dimerization, deamination, dehydrogenation, heteroatom dealkylation, epoxidation, reduction, and C–C or C5N cleavage. P450s are divided into three classes. Class I P450s are flavin adenine dinucleotide (FAD) or flavin mononucleotide (FMN) dependent, and reduced nicotinamide adenine dinucleotide phosphate (NADPH) requiring P450s that are usually mi-crosomal membrane-bound proteins in plants and filamentous fungi. Bacteria and nonfilamentous fungi class I P450s are in soluble form (van den Brink et al. 1998). Class II P450s are similar to those in class I, but they are found only in bacterial and animal mitochondria. Class III P450s are located in plant plastids and do not require auxillary redox partners.

Agrochemicals can influence cytochrome P450 systems by acting as effectors, thereby modifying pesticide metabolism, or by modulating overall metabolism of an organism. These effects can increase or decrease physiological activities, which may affect growth and development. Pioneering work on P450-mediated herbicide metabolism in plants was conducted using the phenylurea herbicides, particularly chlortoluron. On the whole-plant level, wheat (*Triticum aestivum* L.) seedlings exposed to chlortoluron and known cyto-chrome P450 inhibitors (e.g., piperonyl butoxide or 1-aminobenzotriazole) were injured more than plants treated with chlortoluron alone (Cabanne et al. 1987; Gaillardon et al. 1985). Similar results were observed using plant cell suspension cultures, where a P450 inhibitor, tetcyclacis, reduced chlortoluron metabolism (Canivenc et al. 1989). Direct evidence that xenobiotic metabolism was mediated by P450s was obtained through experimentation with plant microsomal preparations. Using microsomal preparations from several plant species, it was shown that chlortoluron was metabolized to two metabolites by at least two different P450 enzymes (Mougin et al. 1990). Since that time, a number of P450-mediated phenylurea-metabolizing genes have been characterized (Robineau et al. 1998; Shiota et al. 1996; Siminszky et al. 1999).

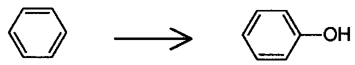
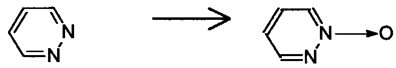
Mougin et al. (2001) demonstrated that the fungicide fenpropimorph was metabolized to an oxygenated metabolite in wheat seedling microsomal preparations. Increased metabolism occurred when seeds were pretreated with naphthalic anhydride, a chemical safener that enhances cytochrome P450 levels. Further, oxidation of fenpropimorph in wheat seedling microsomes was inhibited when the preparations were exposed to carbon monoxide, which binds to the heme portion of the P450 molecule instead of oxygen, thereby blocking enzymatic reactions. These authors sug-gested that fenpropimorph metabolism is P450-mediated.

Other researchers have used microsomes to demonstrate that the mechanism of resistance to several dissimilar herbicide chemistries in blackgrass (*Alopecurus myosuroides*) (Menendez and De Prado 1997) and rigid ryegrass (*Lolium rigidum*) (Preston et al. 1996) was based on enhanced P450-mediated metabolism. Herbicide resistance mediated by P450s may arise via two scenarios: (1) mutation of an existing P450, allowing increased binding and metabolism of the herbicide or (2) increased activity of existing P450s (Barrett 2000). In the future, researchers will no doubt continue to focus on isolating and characterizing plant P450 genes associated with pesticide metabolism. With a better understanding of P450 genes and their regulation, it may be possible to manipulate the crop plant system to increase herbicide tolerance.

Peroxidases, Phenoloxidases, and Related Oxidoreductases

Plants and microorganisms produce a wide range of oxidative enzymes (e.g., peroxidase, polyphenoloxidase, laccase, and tyrosinase) other than P450s that catalyze the polymerization of various anilines and phenols (Dec and Bollag 2001). For example, peroxidase-mediated pesticide transformations in plants that function similar to P450s include decarboxylation, sulfur oxidation, *N*-demethylation, ring hydroxylation, and aromatic methyl group oxidations (Lamoureux and Frear 1979) (Table 3.4). In plants, peroxidase enzymes often function in Phase III metabolism, e.g., formation of bound residues. Horseradish (*Amorocia lapathifolia* Gilib.) roots contain large quantities of peroxidase. Horseradish root tissue has been used to remove 2,4-dichlorophenol from water and was more effective in contaminant removal than the purified peroxidase enzyme (Dec and Bol lag 2001).

Table 3.4. Three phases of pesticide metabolism, with pesticide examples and nonspecific chemical reactions

Phase	Reaction	Example pesticide	Non-specific example of the chemical scheme
I	Oxidation		pesticide + O_2 → pesticide-O + H_2O
	aryl/alkyl hydroxylation	chlortoluron	
	O-dealkylation	ethametsulfuron	$R-OCH_3 \rightarrow R-OH$
	N-dealkylation	ethametsulfuron	$R-NHCH_3 \rightarrow R-NH_2$
	oxidative deamination	metribuzin	$R-NH-NH_2 \rightarrow R-NH_2$
	sulfoxidation	prometryne	$R-S-CH_3 \rightarrow R-S(\rightarrow O)-CH_3$
	nitrogen oxidation	credazine	
	Reduction		
	nitroreduction	trifluralin	$R-NO_2 \rightarrow R-NH_2$
	Hydrolysis		pesticide + H_2O → pest-OH + H-icide
	ester	diclofop-methyl	$R-C(=O)-O-CH_3 \rightarrow R-C(=O)-OH$
	amide	propanil	$R-NH-C(=O)-CH_2CH_3 \rightarrow R-NH_2$
	nitrile	cyanazine	$R-C\equiv N \rightarrow R-C-O-NH_2$
II	Conjugation		pesticide + molecule to conjugate → pesticide-conjugate
	glucose		
	O-glucoside	metribuzin	R—OH → R—O—glucose
	N-glucoside	flumetsulam	$R-NH_2$ → R—N—glucose
	glucose ester	2,4-D	$R-C(=O)OH$ → R—C(=O)—O—glucose
	amino acid	2,4-D	$R-C(=O)-OH$ → R—C(=O)—O—NH—CH(COOH)—CH_2—COOH
	glutathione	atrazine	
III	Secondary conjugation		pesticide-conjugate + molecule to conjugate → pesticide-conjugate-conjugate
	glucose	picloram-glucose	R—N(H)—glucose → R—N(H)—glucose—glucose
	malonate	metribuzin-glucose	R—N(H)—glucose → R—N(H)—glucose—malonate

White rot fungi (*Phanerochaete chrysosporium*) offer high potential for xenobiotic transformation because they possess free radical–based lignin degrading systems (lignin peroxidase and manganese-dependent peroxidases) that can degrade a wide range of pollutants such as polychlorinated biphenyls (PCBs) and nitroaromatic explosives (Barr and Augst 1994). In most instances, polymerization products have reduced toxicity compared with the substrate (Dec and Bollag 2001), whereas polymerization of 3,4-dichloroaniline (propanil metabolite) by soil microorganisms results in the formation of carcinogenic tetrachloroazobenzene (Pothuluri et al. 1991) (Fig 3.5). Generally, polymerization products are considered to be unextractable humic components (Dec and Bollag 2000).

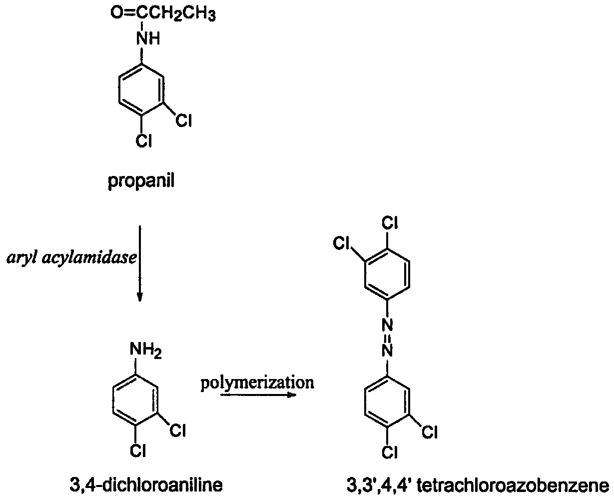


Fig 3.5. Amide hydrolysis of propanil by aryl acylamidase in plants and microorganisms and polymerization of 3,4-dichloroaniline to 3,3',4,4' tetrachloroazobenzene by microbial peroxidases.

Oxidative Nitroaromatic Transformations

In microorganisms as opposed to plants, numerous enzymes from many different pathways are capable of oxidizing nitroaromatic compounds (Table 3.5), and in many cases the enzymes have been purified, and the genes cloned and sequenced (Zablotowicz et al. 2001). Oxidative reactions that transform various nitroaromatic compounds from several genera of aerobic bacteria have been described (Kadiyala and Spain 1998; Leung et al. 1997; Za- blotowicz et al. 1999). In bacteria, monooxygenases, flavin monooxygenases, and dioxygenases are generally involved in the initial oxidation of nitroaromatic pesticides, e.g., 2,4- dinitrophenol can be metabolized by these three enzymes (Cassidy et al. 1999) (Fig 3.6). Depending on the compound, nitrite can be released before, or after ring cleavage. The flavin monooxygenase from *Sphingomonas* strain UG30 is responsible for initial nitrite removal from the herbicide 4,6-dinitrocresol, but not dinoseb (4,6-dinitro-*o*-*sec*-butyl- phenol), because of the steric hindrance caused by the bulky butyl group of dinoseb (Zablotowicz et al. 1999). Overall, these diverse microbial nitroaromatic degradative pathways allow for ring hydroxylation, ring cleavage, and subsequent mineralization of several xenobiotics (e.g., nitrobenzene, nitrobenzoic acid, nitrophenols, and nitrotoluene) (Zablotowicz et al. 2001).

Hydrolytic Transformations

Hydrolytic enzymes cleave bonds of a substrate by adding H or OH from H_2O to each product. There are many hydrolytic enzymes that are capable of metabolizing a variety of substrates, particularly those containing amide, carbamate, or ester functional groups (Table 3.4). These enzymes may be compartmentalized or extracellular, and reactions strate specificities, thereby allowing degradation of a variety of pesticides.

Ester hydro- lysis is commonly carried out by esterases and to a much lesser extent by lipases and proteases. Microbial and plant esterases have a characteristic GLY-X-SER-X-GLY motif (Brenner 1988). The SER acts as a nucleophile, enabling ester bond cleavage (Cygler et al. 1995). Often, herbicides such as fenoxaprop-ethyl, diclofop-methyl, and 2,4-DB are esterified to increase absorption and selectivity. In plants, the ester bond is metabolized, forming the acid, which is usually more phytotoxic (Table 3.4). Depending on the herbicide, de-esterification also can result in immediate herbicide detoxification, as is the case with thifensulfuron-methyl (Brown and Kearney 1991) in certain plant species.

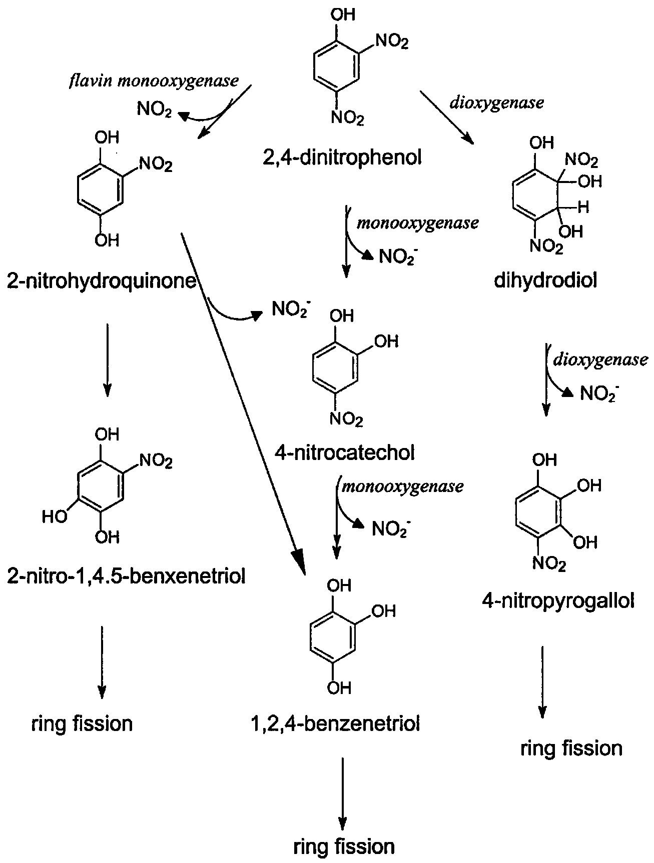


Fig 3.6. Biotransformation of 2,4-dinitrophenol by dioxygenase, *O*-nitro- phenol-monooxygenase, or pentachlorophenol-flavin monooxygenase char- acterized in *Spingomonas* sp. UG30 (Cassidy et al. 1999).

Several authors have shown microbial-based ester hydrolysis of diclofop-methyl (Gaynor 1992) and fenoxaprop-ethyl in soil (Köcher et al. 1982; Smith and Aubin 1990) by mixed bacterial consortia (Gennari et al. 1995), and by pure cultures or cell-free extracts (Hoagland and Za- blotowicz 1998; Zablotowicz et al. 2000). Four types of esterases have been characterized in *Pseudomonas fluorescens*, each differing in protein structure, cellular localization, and substrate specificity (Choi et al. 1990). Although many microbial esterases have been cloned and sequenced, few have been tested for pesticide hydrolysis.

Atrazine was traditionally considered to be moderately persistent in soil; however, in the past several years many bacterial strains representing several genera have been isolated that can completely mineralize atrazine (Sadowsky and Wackett 2001). These authors have suggested that a unique operon of genes encoding for *s*-triazine degradation has evolved in areas where this herbicide has been used extensively. The gene regions encoding the first three enzymes of atrazine degradation have been isolated and characterized from Pseudomonas *sp.* strain ADP (Boundy-Mills et al. 1997; de Souza et al. 1995, 1996; Sadowsky et al. 1998). This bacterium mineralizes high concentrations (500 mg L21) of atrazine under both growth and non-growth conditions, using the herbicide as the sole nitrogen source (Man- delbaum et al. 1995). The *atzA* gene encodes atrazine chlorohydrolase, which dechlorinates atrazine hydrolytically to the nonphytotoxic metabolite hydroxyatrazine (Figure 4). The next step in the degradation pathway is hydrolytic removal of the aminoethyl group from hydroxyatrazine by the *atzB* gene product, hydroxyatrazine ethyl amidohydrolase. Finally, the *atzC* gene encodes for another amidohydrolase that converts *N*-isopropylammelide to cyanuric acid. Martinez et al. (2001) have recently sequenced the complete catabolic plasmid from strain ADP and have identified three additional genes *atzD, atzE,* and *atzF* encoding for cyanuric acid amidohydrolase, biuret hydrolase, and allophanate hy- drolase. Thus the total genetic basis for the complete atra- zine metabolism in strain ADP has now been identified. Many soil bacteria have the capability to mineralize cyanuric acid (Cook 1987; Cook and Hutter 1981; Erickson and Lee 1989; Korpraditskul et al. 1993). Five other atrazine-degrading bacteria with *s*-triazine–degrading genes have been identified with ≥ 99% homology to *atzABC* from *Pseudo- monas* sp. strain ADP, suggesting that horizontal transfer of atrazine degradation genes may have occurred recently (de Souza et al. 1998a, 1998b). In fact, in *Pseudomonas* sp. strain ADP, the three *atz* genes are on a self-transmissible plasmid pADP-1 (de Souza et al. 1998b). Many lines of evidence suggest the ability of microorganisms to mineralize *s*-triazines developed after the first use of these herbicides in the mid-1950s (Sadowsky and Wackett 2001). In contrast to bacteria, atrazine and other *s*-triazines are metabolized in plants via *N*-dealkylation by cytochrome P450s, hydrolytic dehalogenation, or displacement of chlorine with glutathione (GSH) (Lamoureux et al. 1998) (Table 3.4). In micro- organisms, there have been no reports of GSH conjugation resulting in dechlorination of *s*-triazines (Zablotowicz et al. 1994).

Propanil is the most widely studied pesticide with regard to amide hydrolysis. Rice (*Oryza sativa* L.) is tolerant to propanil because of high levels of aryl acylamidase, which cleaves the amide bond and is the basis for crop selectivity (Frear and Still 1968). Aryl acylamidases are widely distributed in plants, bacteria, fungi, and algae (Hoagland and Zablotowicz 2001). After 35 yr of use, mainly for rice production, propanil-resistant barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] has developed and is quite widespread throughout many rice-producing regions of the world (Carey et al. 1995b; Hoagland and Zablotowicz 2001). Propanil resistance is due to enhanced hydrolysis by aryl acylamidase in resistant barnyardgrass (Carey et al. 1995a, 1997) and resistant jungle-rice (*Echinochloa colona*) biotypes (Leah et al. 1994). In several plant species, experiments with propanil analogs (i.e., different ring chloride locations and alkyl chain length, etc.) revealed that generally propanil was the preferred aryl acylamidase substrate (Frear and Still 1968; Hoagland 1975, 1978; Hoagland and Graf 1972). Synergistic interactions can occur when propanil is mixed with any of several agrochemicals (e.g., carbamate and organophosphorus insecticides, and the herbicides anilofos, pendimethalin, and piperophos) (Frear and Still 1968; Matsunaka 1968; Norsworthy et al. 1999). Synergism of propanil and the insecticide carbaryl was the result of competitive inhibition with aryl acylamidases (Bowling and Hudgins 1966; Frear and Still 1968); however, the mecha- nisms of propanil synergism with other agrochemicals have not been fully characterized. Likewise, certain agrochemicals, e.g., carbamates, can inhibit the hydrolysis of propanil in soil and water by inhibiting microbial aryl acylamidase activity (Kaufman et al. 1971).

Table 3.5. Comparison between plant and microbial pesticide metabolism.

Biotransformation	Plants	Microorganisms
General pesticide metabolism	Detoxification	Mineralization
Oxidation	P-450 mediated	Not generally P-450 mediated, Mediated by various oxidoreductases
P-450 oxidation	Microsomal membrane bound	Soluble form, not membrane bound
Hydrolytic transformation	Predominantly via esterases, amidases, aryl acylamidases, and nitrilases	Greater enzyme diversity
C–P bond cleavage	None known	Diverse C–P lyases and hydrolytic enzymes
Aromatic nitro-reductive processes	Nitroreductases GSH[a] conjugation	Nitroreductases, No GSH conjugation
Reductive dehalogenation	None known	Halo-respiration
Conjugation	With sugar and amino acids Compartmentalized or sequestered GSH conjugation	With xylose, methyl, or acetyl groups Conjugates formed extracellularly No known GSH conjugation

[a] Abbreviation: GSH, glutathione-*S*-transferase

The substrate specificity of microbial aryl acylamidases varies even more considerably than that of plant aryl acy- lamidases. For example, in some *P. fluorescens* strains, the substrate range is limited to the acylanilide pesticides (Hoag- land and Zablotowicz 1995), but *Bacillus sphaericus* has a wide substrate range, including acylanilide, phenylcarba-mate, and substituted phenylurea pesticides (Engelhardt et al. 1973). Many microbes are capable of amide hydrolysis of propanil (Fig 3.5). In one study, 37% of 97 bacterial isolates collected from soils and rice flood water of the Mississippi Delta (an area where propanil has been widely used) were capable of hydrolyzing propanil (Hoagland and Zablo- towicz 1995). Aryl acylamidases have been purified from several bacterial genera including *B. sphaericus* (Engelhardt et al. 1973), *P. fluorescens* (Hammond et al. 1983), *Pseudomonas pickettii* (Hirase and Matsunaka 1991), *Pseudomonas aeuruginosa* (Riley and Behal 1971), *Nocardia globerula* (Yoshioka et al. 1991), and a coryneform-like bacterium (Mochida et al. 1993). These enzymes range in size from 52.5 to 127 kDa and differ with respect to the subunit aggregation, i.e., some are monomers, dimers, or tetramers. All amidase proteins have a characteristic hydrophobic GLY- GLY-

SER-SER motif.

Organophosphorus pesticides are hydrolyzed by micro-organisms and have been extensively studied in *Pseudomonas diminuta* (Chaudhry et al. 1988; McDaniel et al. 1988) and *Flavobacterium* sp. (Mulbry and Karns 1989). Hydrolysis, oxidation, and glutathione biotransformations of organo- phosphorus pesticides appear to be equally important de- toxification mechanisms in plants (Lamoureux and Frear 1979). In plants and bacteria, there is limited literature on the role of phosphatases and sulfatases in pesticide metab- olism (Hoagland and Zablotowicz 2001). However, there is evidence that sulfatases in the fungi *Trichoderma harzianum* (Katayama and Matsumura 1993) and *P. chrysosporium* (Kullman and Matsumura 1996) hydrolyze the insecticide endosulfan. Nitrile hydrolysis is the main route of metabolism of bromoxynil in wheat (Buckland et al. 1973) and of cyanazine in wheat and potato (*Solanum tuberosum* L.) (Benyon et al. 1972a, 1972b) (Table 3.4). Hydrolysis of the nitrile group produces an amide moiety that is converted to carboxylic acid, which may be subsequently decarboxylated. In contrast to plants, several bacteria species hydroxylate the cyano group of bromoxynil (Cullimore and Kohout 1974; McBride et al. 1986). Hydrolysis of the carbamate moiety of phenylcarbamate pesticides is common in animals and soil microorganisms but not in plants. In plants, the major metabolic route for the phenylcarbamate pesticides CIPC (Still and Mansager 1972, 1973) and IPC (Dyer and Wright 1959) is aryl hydroxylation and conjugation, rather than hydrolysis of the carbamate moiety (Table 3.4).

Generally, there is more known about xenobiotic hydrolysis in microorganisms than in plants. However, the precise physiological role of many hydrolytic enzymes is not known. There is a need to further understand the mechanism and regulation of hydrolytic enzymes (Hoagland and Zablotow- icz 2001).

Aromatic Nitroreductive Processes

Generally, nitroaromatic compounds are transformed differently in plants in comparison with microorganisms. For example, the major metabolite of trifluralin in peanut (*Arachis hypogaea* L.) is *N*-depropylated trifluralin, whereas in sweet potato (*Ipomoea batatas* L.), the monoamino-derivative of trifluralin is predominant (Probst and Tepe 1969) (Figure 5). In contrast, trifluralin is transformed via nitroreductase by microbes (Lusby et al. 1980). In plants, glutathione conjugation of pentachloronitrobenzene occurs concomitant with the removal of Cl or NO_2 (Lamoureux and Rusness 1980; Rusness and Lamoureux 1980) (Figure 6). Although glutathione-mediated displacement of the nitro group of aromatic compounds has been described in plants, it has not been reported in microorganisms.

In bacteria, three pathways of reductive metabolism of nitroaromatics have been characterized: aromatic nitroreduc-tion, partial nitroreduction, and hydrogenation (Zablotow-icz et al. 2001). Reductive metabolism of nitroaromatic xe- nobiotics is mediated by nitroreductase enzymes found in aerobic and anaerobic bacteria, and several genera of fungi (Zablotowicz et al. 2001). Nitroreductases are flavoproteins that use NAD(P)H as reducing equivalents, require FMN/FAD as cofactors, and have varying sensitivities to O_2 con- centrations. Some bacteria contain multiple aromatic nitro- reductase isozymes (Bryant et al. 1981; Kinouchi and Oh- nishi 1983). It is sometimes difficult to separate biological and chemical xenobiotic reductions because reduction of aromatic nitrogroups, e.g., trifluralin and diphenyl ether her- bicides, may be coupled with anaerobic reduction of humic acids or iron reduction (Oyamada and Kuwatsuka 1989; Probst and Tepe 1969). The conversion of the herbicide acifluorfen to aminoacifluorfen is a common example of an aromatic nitroreduction reaction (Table 2) catalyzed by bacteria under aerobic (Andreoni et al. 1994) and anaerobic (Gennari et al. 1994) conditions, as well as in *Enterobacter cloacae* and *P. fluorescens* cell-free extracts (Zablotowicz et al. 1997). Aminoacifluorfen is susceptible to sorption and in- corporation into soil humic material (Locke et al. 1997; Zablotowicz et al. 1997). There is potential to develop transgenic crops that express a bacterial nitroreductase gene to metabolize diphenyl ether herbicides, thereby providing crop tolerance to these herbicides (Zablotowicz et al. 2001).

Numerous bacteria are capable of partial nitroreduction, resulting in NH_3 release and subsequent ring cleavage. Par- tial nitroreduction pathways are catalyzed by a nitroreduc- tase that reduces the nitro moiety to a hydroxylamino group, followed by further molecular rearrangement catalyzed by a hydroxylaminolyase, forming the hydroxyl amino derivative. Although bacterial partial nitroreduction of several xenobi- otics including *p*-nitrobenzoate (Groenewegen and de Bont 1992; Groenewegen et al. 1992) and nitrobenzene (Nishino and Spain 1993) has been demonstrated, partial nitroreduc- tion of pesticides has not been reported. In bacterial partial reductive hydrogenation reactions, the nitroaromatic com- pound is used as the sole carbon or nitrogen source (Lenke and Knackmuss 1992; Lenke et al. 1992).

Carbon–Phosphorus Bond Cleavage Reactions

Organophosphonates used as pesticides, antibiotics, lubricants, and flame retardants have a carbon-to-phosphorus (C–P) bond, which does not undergo photochemical, hydrolytic, thermal, or chemical degradation (Freedman and Doak 1957). However, many organophosphonate compounds do not persist in the environment because of microbial degradation. Currently, it is believed that plants do not possess the ability to break the C–P bond of organo- phosphonates, and relatively little is known about fungal organophosphonate metabolism (Bujacz et al. 1995; Sobera et al. 1997; Zboinska et al. 1992). However, degradation of C–P bonds has been extensively studied in bacteria. For instance, a gene cluster designated *phn,* consisting of 17 genes from *Escherichia coli*, is responsible for the degradation of a wide range of phosphonates and is likely to encode for a C–P lyase (Chen et al. 1990; Kim et al. 1993; Metcalf and Wanner 1991; Wackett et al. 1987; Wanner and Boline 1990; Wanner and McSharry 1982; Wanner and Metcalf 1992). The enzyme(s) responsible for direct cleavage of or-ganophosphonate C–P bonds is known by the general name C–P lyase. The ability of C–P lyase to degrade a wide variety of chemically diverse phosphonates is quite striking (Kafar-ski et al. 2001). However, the precise mechanism of C–P lyase is not fully understood. It is hypothesized that alkane- phosphonate biodegradation occurs by two different path-ways in which either organophosphonyl (Avila and Frost 1988; Cordeiro et al. 1986; Frost et al. 1987) or organo- phosphoranyl (Avila and Frost 1989; Wanner and Boline 1990) radicals are formed.

With regard to herbicides, the two-carbon phosphorus bond (C–P–C) of glufosinate is difficult to cleave, and although glufosinate is metabolized in soils, it is not known if the C–P–C bond is broken (Tebbe and Reber 1988). In contrast, many researchers have reported the microbial mineralization of glyphosate in the environment (Cheah et al. 1998; Krzysko-Lupicka and Orlik 1997; Malik et al. 1989; Nomura and Hilton 1977; Ruepple et al. 1977; Sprankle et al. 1975; Zaranyika and Nyandoro 1993) by gram-negative and gram-positive bacteria (Quinn et al. 1989; Ternan et al. 1998), under both anaerobic and aerobic conditions and with no lag phase of degradation (Cheah et al. 1998; Sprankle et al. 1975; Torstensson and Aamisepp 1977). Numerous bacterial strains can use glyphosate as the sole P source without mineralizing it. However, only an *Achromobacter* strain and a *Streptomyces* sp. were able to use glyphosate as the sole carbon or nitrogen source via C–P bond cleavage and formation of sarcosine constitutively in pure culture (Barry et al. 1992; Obojska et al. 1999). This research indicates that a consortium of microbial species may be required for glyphosate mineralization or that gly- phosate is metabolized by fastidious bacteria (Forlani et al. 1999; Kafarski et al. 2001). Two main pathways of glyphosate C–P bond cleavage have been characterized (Ghis-alba et al. 1987; Hallas et al. 1988; Quinn et al. 1989; Ternan et al. 1998); however, neither reaction has been solely used for generating commercially viable genetically engineered glyphosate-tolerant crops. In one pathway, initial cleavage of the C–P bond yields inorganic phosphorus and sarcosine, and the latter is further converted to glycine and a C_1-unit. In the second case, glyphosate oxidoreductase (GOX), a well-characterized 46.1-kDa flavoprotein, cleaves glyphosate into glyoxylate and aminomethylphosphonic acid. Aminomethylphosphonic acid is further degraded by a C–P lyase.

Pesticide Conjugation Reactions

Carbohydrate and Amino Acid Conjugation

Hall et al. (2001b) recently defined pesticide conjugation as the "metabolic process whereby an exogenous or endogenous natural compound is joined to a pesticide or its metabolite(s) facilitating detoxification, compartmentalization, sequestration, and/or mineralization." Conjugation of pesticides often involves utilization of existing enzymatic machinery and is therefore called a cometabolic process. Glucose conjugation to pesticides occurs primarily in plants, resulting in several metabolites including *O*-, *S*-, and *N*-glucosides, glucose ester, gentibioside (e.g., 6-*O*-b-D-gluco- pyranosyl-D-glucose), and malonyl-glucose conjugates (Table 3.4). The most common glucose conjugates are *O*-glucosides because pesticide oxidation reactions form hydoxyl groups, which are suitable sites for glucose conjugation.

Differential conjugation of 2,4-D imparts differences of susceptibility in wheat and some broadleaf species. Many susceptible broadleaf weeds produce glucose ester metabolites, which are readily susceptible to hydrolysis, yielding phytotoxic 2,4-D. Conversely, 2,4-D–tolerant wheat rapidly produces amino acid conjugates and *O*-glucosides (Table 3.4), which are stable nonphytotoxic metabolites that are not easily hydrolyzed. Amino acid conjugation occurs primarily in plants and is very common. Most of the research on amino acid conjugation of pesticides has been conducted on 2,4- D. Twenty amino acids have been found to conjugate with 2,4-D (Andreae and Good 1957; Feung et al. 1971, 1974, 1975).

Uridine diphosphate–glucosyl (UDPG) transferase, an enzyme involved in cellulose biosynthesis, mediates pesticide–glucose conjugation (Klambt 1961) and pesticide–glucose ester conjugation reactions (Mine et al. 1975). As mentioned above, glucose esters of pesticides are cleaved by esterases, often resulting in the release of the pesticide (Frear et al. 1978). However, the addition of a second glucose molecule to the glucose ester produces a gentiobiose conjugate (Hodgson et al. 1973), which is not readily hydrolyzed. Other complex sugar conjugates in addition to gentibioside (two glucose molecules) are glycosides (a glucose and one other sugar, such as arabinose) (Frear 1976).

Pesticide–sugar conjugates can undergo further conjugation with malonate via reaction with malonyl CoA (San-dermann et al. 1997), a common reaction in higher plants (Lamoureux and Rusness 1986). In tomato (*Lycopersicon es-culentum* L.), the herbicide metribuzin is conjugated to glucose, which is subsequently conjugated to malonate, forming the *N*-malonyl–glucose conjugate (Frear et al. 1985). A range of UDPG transferase activity within various tomato cultivars confers differential tolerance of these cultivars to metribuzin (Smith et al. 1989). Furthermore, increased metribuzin phytotoxicity in all the cultivars was noted under low light conditions (da Silva and Warren 1976). It was speculated that under low light conditions less glucose and UDPG were produced, thereby reducing conjugation and elevating herbicide phytotoxicity (Frear et al. 1983).

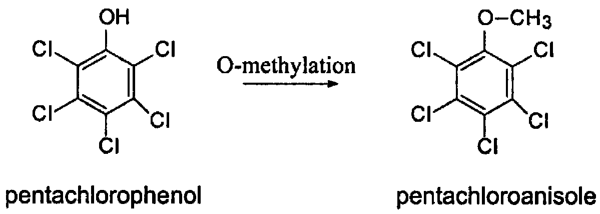


Figure 3.7. Conjugation of pentachlorophenol by microorganisms.

Microbial Pesticide Conjugation

Microbial pesticide conjugation reactions include xylosylation, alkylation, acylation, and nitrosation and can occur intra- or extracellularly. During fungal degradation of lignin, carbohydrates are generated, but toxic phenols are also concomitantly released. These phenols are extracellularly conjugated to xylose as a detoxification mechanism. Fungi use the same process to extracellularly conjugate 2,4-D and 2,4,5-T with xylose (Reddy et al. 1993).

Fungi generally biotransform pesticides and other organic xenobiotics by inducing minor structural changes to the pesticide, rendering it nontoxic (Bollag 1972; Cerniglia 1992). The biotransformed pesticide is released into the soil, where it is susceptible to further metabolism by bacteria. Both fungi and bacteria use methylation as a conjugation reaction to detoxify xenobiotics. For example, formation of *O*-methylated pentachlorophenol by fungal cultures of *Trichoderma virgatum* (Iwan 1976; Joshi and Gold 1993) and many gram-positive and gram-negative bacteria (Häggblom 1990; Suzuki 1983) results in a less toxic, but more recalcitrant, pentachloroanisole (Fig 3.7). *Phanerochaete chrysosporium* methylates chlorophenoxyacetic acid via a manganese–lignin peroxidase, which is an extracellular degrading enzyme system (Joshi and Gold 1993; Lamar and Dietrich 1990; Valli and Gold 1991).

Pesticide conjugation via microbial acylation with acetate or formate is also common. Phenols and anilines in soil, which are typical breakdown products of phenylacylanilides, phenylcarbamates, and substituted phenylurea pesticides, are often acylated by fungi. For example, the herbicide meto- bromuron is metabolized by microbes to 4-bromoaniline, which is metabolized to 4-bromoacetanilide (Tweedy et al. 1970).

Nitrosation is a process mediated by bacteria, wherein nitrite reacts with a secondary amine to form a nitrosamine derivative (Alexander 1999; Suzuki 1983). Nitrosamines can be generated by both enzymatic and nonenzymatic processes (Suzuki 1983). Certain pesticides are converted to secondary amines, e.g., dimethyl and dimethylamines, when metabolized in soil (Tate and Alexander 1974).

Plant Glutathione Conjugation Reactions

Glutathione (g-L-glutamyl-L-cysteinylglycine [GSH]), commonly present in the reduced form, is ubiquitously distributed in most aerobic organisms. Homoglutathione (g-L- glutamyl-L-cystein-b-alanine), a GSH analog, occurs in several legume species (Macnicol 1987). Although GSH con- centrations vary during plant development (Hausladen and Alscher 1993; Rennenberg 1982; Rennenberg and Brunold 1994), GSH is found in relatively high concentrations in most plant tissues (Rennenberg 1982). Glutathione is phloem mobile (De Kok et al. 1986) and is degraded by carboxypeptidases and transpeptidases in the cytoplasm and vacuoles (Steinkamp and Rennenberg 1985). Generally, GSH synthesis is limited by availability of cysteine and hence by the concentration of sulfate ions.

Nonenzymatic GSH conjugation may be important for the metabolism of several herbicides (Rozman and Klaassen 1996). For example, increased GSH concentrations protected wheat from fenoxaprop injury (Romano et al. 1993; Tal et al. 1995). This reaction was considered nonenzymatic because glutathione *S*-transferase (GST) activity in these plants was low (Tal et al. 1995). However, enzymatic conjugation of xenobiotics with GSH via GSTs is more common than nonenzymatic conjugation.

Glutathione-*S*-transferases are homo- or heterodimer, multifunctional enzymes located in the cytosol, which catalyze the nucleophilic attack of the sulfur atom of GSH by the electrophilic center of the substrate (Armstrong 1994; Marrs 1996; Rushmore and Pickett 1993; Tsuchida and Sato 1992). More than 50 plant GST gene sequences from 13 plant species have been published (Dixon et al. 1998a, 1998b; Droog 1997; Marrs 1996; Wu et al. 1999). Com- pared with other plant and bacterial species, corn (*Zea mays* L.) GST gene enzyme systems have been the most exten- sively studied (Cole et al. 1997; Frova et al. 1997; Marrs 1996; Sommer and Böger 1999; Timmerman 1989). X-ray crystallography revealed that the N-terminus of this dimeric enzyme is highly conserved and binds GSH at the G-site (Neuefeind et al. 1997a, 1997b; Reinemer et al. 1996; Zajc et al. 1999). The less conserved C-terminal is an a-helix that binds substrates, including herbicides, at the H-site (Neuefeind et al. 1997a, 1997b; Reinemer et al. 1996; Zajc et al. 1999). These two binding domains are kinetically in- dependent (Marrs 1996; Zajc et al. 1999). Recently, a new phylogenetic plant GST classification system was proposed by Dixon et al. (1997, 1998a, 1998b) and Droog (1997) that consists of four classes (I to IV).

In plants and animals, regulation mechanisms and the catalytic function of GST enzymes have been highly conserved during evolution (McGonigle et al. 1997). Some GSTs are constitutively expressed in certain tissues, but GST regulation can be modified by agrochemicals, including herbicide safeners and synergists. It is hypothesized that plant GST gene promoters have multiple regulatory elements that respond differently to specific or more general stress-related signals (Droog 1997). Class I corn GSTs have safener responsive elements, designated by an ATTTCAAA nucleotide sequence (Jepson et al. 1999). Moreover, GSTs probably have common mechanisms of signal transduction to activate gene expression; e.g., all active oxygen species may affect a common transduction pathway during oxidative stress (Low and Merida 1996; Tenhaken et al. 1995).

The role of GSTs and GSH in plants encompasses several major functions. The first is the metabolism of secondary products, including cinnamic acid (Edwards and Dixon 1991) and anthocyanins (Marrs et al. 1995). A second function is regulation and transport of both endogenous and exogenous compounds, which are often GS-X tagged for compartmentalization in the vacuole or cell wall (Hatzios 2001). This is a particularly important aspect for herbicides (Marrs 1996), anthocyanins (Marrs et al. 1995), and indole-3-acetic acid (Bilang and Sturm 1995; Jones 1994). Protection against oxidative stress from herbicides, air pollutants (Sharma and Davis 1994), pathogen attack (Dudler et al. 1991; Taylor et al. 1990), and heavy metal exposure (Hagen et al. 1988; Kusaba et al. 1996) is a third function. Glutathione conjugates and their terminal metabolites are stored in the vacuole or bound to the cell wall (Blake-Kalff et al. 1997; Schrö der 1997). Glutathione conjugate pumps in the tonoplast membrane carry GSH conjugates across the membrane (Gaillard et al. 1994; Li et al. 1995a, 1995b; Marrs 1996; Martinoia et al. 1993). In the vacuole, peptidases release the glutathionyl moiety (Schröder 1997).

Glutathione-*S*-transferases in plants were first studied be-cause of their ability to detoxify herbicides (Lamoureux et al. 1991; Marrs 1996). Glutathione-*S*-transferase–based herbicide metabolism imparts herbicide selectivity in several plant species (Cole et al. 1997; Lamoureux and Rusness 1989, 1993; Lamoureux et al. 1991; Marrs 1996; Timmer-man 1989; Zajc et al. 1999). Many herbicide families, in- cluding sulfonylureas, aryloxyphenoxypropionates, triazinone sulfoxides, and thiocarbamates, are susceptible to GSH conjugation (Cole et al. 1997). Furthermore, there is a positive correlation of both GSH levels and the activity of spe-cific GST enzymes with the rate of herbicide conjugation and detoxification (Breaux 1987; Breaux et al. 1987; Farago et al. 1993). For example, the resistance of a velvetleaf (*Abutilon theophrasti* Medicus) biotype to atrazine was the result of an enhanced rate of GSH conjugation (Anderson and Gronwald 1991; Gray et al. 1996; Plaisance and Gronwald 1999).

To study GST substrate specificity, Sommer and Böger (2001) purified four recombinant N-terminal 6ЗHis-tagged corn GST isoforms, using an *E. coli* expression system. The recombinant GST isoforms included GST types I, II, III, and IV, with subunits of 29/29, 27/29, 26/26, and 27/27 kDa, respectively. Substrate specificity for each of the four isoforms was different and was based on subunit specificity. For example, GST isoforms with a GST29 subunit could readily conjugate 1-chloro-2,4-dinitrobenzene, whereas isoforms with GST27 subunits had their greatest metabolic activity on thiadiazoliodine and metazachlor. Moreover, the GST27 subunit had metabolic activity on endogenous hy-droperoxides such as linolenic acid and cumene hydroper-oxide. These results suggest that certain GSTs function through peroxidase activity, to protect the plant from oxidative stress. Based on metabolism levels reported in the literature, the 63His-tag expression in *E. coli* does not seem to affect GST isoform substrate specificity and is therefore a convenient system to study GST-mediated herbicide metabolism (Sommer and Böger 2001).

Bacterial Glutathione Conjugation Reactions

Compared with plant GSTs, few bacterial GSTs have been characterized at the biochemical level. It is thought that bacterial GST–mediated herbicide metabolism is important because herbicide metabolites with thiol, thioester, and sulfoxide moieties have been identified in soil (Feng 1991; Field and Thurmann 1996). The role of bacterial glutathione conjugation has been demonstrated in the dechlorination of chloroacetamide herbicides, e.g., alachlor (Zablotowicz et al. 1994, 1995) and metolachlor (Hoagland et al., 1997), and the ether bond cleavage of the herbicide fenoxaprop-ethyl (Hoagland and Zablotowicz 1998). Glu- tathione-*S*-transferases that function as reductive dehalogenases from *Sphingomonas* strains are involved in the dechlorination of pentachlorophenol and lindane (Vuilleumier 2001). In spite of a few well-characterized degradation schemes, little is known about bacterial GST regulation and function (Vuilleumier 2001). Most of the knowledge about bacterial GSTs is based on genomic analysis. Many gene sequences with homology to corn GSTs have been identified within bacterial genomes; however, there is a need to dis- criminate and determine enzyme function at the biochemical level.

Two messages become clear from bacterial genomic research (Vuilleumier 2001): (1) there is a large set of GST- homologous genes, which vary in size and content in bacteria and (2) certain GST-classified genes are associated with operons and gene clusters involved in xenobiotic dehalogenation. In *E. coli* and *P. aeruginosa* genomes, there are 8 and 17 GST-like genes, respectively (Vuilleumier et al. 1999). In both organisms, only four of the GST-like genes have _40% homology with known plant and mammalian GSTs at the protein level. The *P. aeruginosa* genes, however, have greater sequence similarity to known biodegradation GST genes, even though the physiological roles of these genes are unknown (Vuilleumier 2001). Nevertheless, known bacterial GSTs have structural similarities to plant and mammalian GSTs despite the extensive variation in sequences (Nishida et al. 1998; Prade et al. 1998; Rossjohn et al. 1998).

The bacterial GST dehalogenases thus far identified include dichloromethane dehalogenase (Cai et al. 1998; Leis- inger et al. 1994; Vuilleumier and Leisinger 1996; Vuilleumier et al. 1997), tetrachlorohydroquinone reductase involved in pentachlorophenol metabolism (McCarthy et al. 1996), and 2,5-dichlorohydroquinone reductive dehalogenase involved in lindane degradation (Nagata et al. 1999). An unusual function of a GST enzyme from a *Rhodococcus* strain is the ability to open the epoxide ring during the degradation of isoprene and chlorinated ethenes (van Hylck- ama et al. 1998). This GST enzyme was purified and the *iso1* gene cloned and characterized (van Hylckama et al. 1999). Similarly, a human GST has been characterized that acts as both an isomerase and a dioxygenase in aromatic ring opening (Tong et al. 1998a, 1998b). This suggests that bacterial GST dehalogenases also may act as isomerases and dioxygenases in aromatic ring opening (Armengaud and Timmis 1997; Fuenmayor et al. 1998; Milcamps and de- Bruijn 1999; Vuilleumier 2001; Werwath et al. 1998). There are many unanswered questions regarding bacterial GST–mediated xenobiotic metabolism, GST regulation, as well as GSH–conjugate uptake, excretion, and toxicity. Moreover, there is potential for using bacterial GSTs in bio- remediation and biodetoxification; however, further research is required to fully understand the function and substrate specificity of bacterial GSTs (Vuilleumier 2001).

Formation of Bound Pesticide Residues

Pesticides (mainly conjugated pesticides) are often bound to plant cell walls. Bound pesticide residues are generally considered as those that cannot be extracted with aqueous and organic solvents. However, a more precise definition has been provided by Skidmore et al. (1998):

> "A bound xenobiotic residue is a residue associated with one or more classes of endogenous macromolecules. It cannot be dissociated from the natural macromolecule using exhaustive extraction or digestion without signifi- cantly changing the nature of the associated endogenous macromolecules."

When studying bound-pesticide residues using radiolabeled pesticides, it is important to differentiate the bound residue containing the labeled xenobiotic or its metabolite from the "natural label." Natural labeling occurs when $^{14}CO_2$ is released from the mineralized pesticide and is incorporated into the plant cell wall. Natural labeling in plants has been observed with several pesticides (Sandermann et al. 1983).

Furthermore, it is important to know the precise position of the label on the pesticide molecule so that the site of pesticide incorporation into the cell wall can be determined (Sandermann et al. 2001). Digestive treatment with different enzymes such as cellulase, collagenase, pepsin, amylase, and proteases can aid in identifying the nature of pesticide incorporation. On the basis of reports in the literature, it appears that xenobiotics are incorporated randomly into different cell wall components (Sandermann et al. 2001); however, little is known about the type of linkages involved in this binding.

There is concern about the bioavailability of bound pesticides from plant residues. *Phanerochaete chrysosporium* mineralized bound chloroaniline and 2,4-dichlorophenol, indicating that these compounds may become bioavailable (Arjmand and Sandermann 1985). The ability of animals to release xenobiotics bound to plant residues is unknown. Experiments using a "simulated stomach" demonstrated that pesticides were released from plant residues, but only when high concentrations of bound pesticide residues were used (Sandermann et al. 1990). In comparison, only low concentrations of bound pesticide residues are typically present in plant residues (Sandermann et al. 2001). However, the biological relevance of typically low concentrations of bound pesticide residues is not known. Presently, the U.S. Environmental Protection Agency requires no characterization of bound pesticide residues if concentrations are less than 0.05 ppm of the parent equivalents or 10% of the total pesticide residue. If concentrations exceed these levels, determination of the bioavailability based on "simulated stomach" experiments is required. The toxicological nature and bioavailability of bound xenobiotic residues requires continued research to fully assess its impact on human health and the environment (Sandermann et al. 2001).

Bioremediation and Pesticide Metabolism in the Rhizosphere

The ligninolytic fungus *P. chrysosporium* oxidizes the insecticide lindane by a putative cytochrome P450 enzyme (Mougin et al. 1996, 1997). There is potential to exploit *P. chrysosporium* along with other indigenous microflora to mineralize lindane or convert it to volatile metabolites. Bio- remediation of lindane-contaminated soil with *P. chrysospor- ium* is possible. The advantages of using filamentous fungi for bioremediation include the following: (1) fungi are in direct contact with solid, liquid, and vapor portions of the soil, (2) fungi are capable of transforming a large number of structurally dissimilar compounds, (3) fungi are able to withstand toxic effects of many xenobiotics, and (4) fungi release metabolites, making the metabolites available for further degradation by other microorganisms (Mougin et al. 2001).

Use of Enzymes in Bioremediation

Bioremediation is the use of microorganisms, plants (often called phytoremediation), or biologically active agents to degrade, sequester, or conjugate environmental pollutants. Advantages of bioremediation include ease and timing of application, ability to target specific pollutants, decreased sludge volume, and decreased ecological hazard. There is potential to use enzymatic treatment in bioremediation, and this technology is currently at the laboratory stage of development (Alexander 1999). Advantages of enzymatic treatment over microbial bioremediation include (1) no acclimation phase, (2) use over a wider range of environmental conditions (pH, moisture, temperature), (3) effectiveness at high and low pollutant concentrations, (4) movement of enzymes readily into soil micropores and their protection from inactivation, and (5) little effect of inhibitors of mi- crobial metabolism on enzymes (Dec and Bollag 2001; Nan- nipieri and Bollog 1991). The disadvantages of enzymatic treatment in bioremediation include the high cost of isola- tion and storage, the difficulty in maintaining enzyme stability, the requirement for expensive cofactors, and the lack of xenobiotic mineralization (Dec and Bollag 2001).

The use of isolated enzymes to metabolize pesticides is not new (Engelhardt et al. 1973; Kearney and Kaufman 1965; Mulbry and Karns 1989). For example, enzymes from crude *Pseudomonas* cell extracts immobilized on glass beads, hydrolyzed 95% of parathion (10 to 250 ppm) from waste- water (Barik and Munnecke 1982). The same enzyme prep- aration hydrolyzed parathion at 2,500 ppm in soil and was also effective in hydrolyzing other organophosphate insec- ticides (triazophos, diazinon, and fenitrothion) (Munnecke 1976). Microbial enzymes with potential for pesticide metabolism include oxidoreductases, hydroxylases, amidases, and esterases. However, enzymatic treatments are not ideal for complete xenobiotic mineralization because mineralization usually requires many enzymes and several cofactors such as NAD(P)H and FAD. Oxidoreductases, such as laccase, tyrosinase, and horseradish peroxidase, can be used to decontaminate soil and water. These enzymes oxidize the substrate to free radicals, which are susceptible to chemical coupling, forming oligomers (Suflita et al. 1981). For example, oligomer formation reactions can take place between humic acid and xenobiotics, resulting in the polymerization of the substrate to soil, as was observed with 2,4-dichloro- phenol (Sarkar et al. 1988). In another experiment, horse- radish root tissue and hydrogen peroxide (an electron acceptor) decontaminated water containing 850 ppm of 2,4- dichlorophenol and other chlorinated phenols (Dec and Bollag 1994). Depending on the concentration of hydrogen peroxide, up to 100% of the contaminants were removed by polymerization. Furthermore, horseradish root tissue contributed to the irreversible binding of 2,4-dichlorophen- ol to soil (Flanders et al. 1999).

For enzymatic treatment to be effective in bioremediation, the enzymes must be stabilized. The most effective way to stabilize enzymes is by immobilization. Immobilization can be accomplished by enzyme linkage to organic or inorganic solid supports by adsorption on solid surfaces such as glass, entrapment in polymeric gels, encapsulation, or in- termolecular cross-linking (Bickerstaff 1997). Although preparing supports can be time-consuming and expensive, the support can generally be reused. Enzymatic treatment holds great promise in bioremediation of contaminated soil and water.

Pesticide Degradation in the Rhizosphere

Chemicals released by plants may enhance xenobiotic degradation, and it may therefore be beneficial to use plants in the remediation of contaminated soils (Crowley et al. 2001). There are three general mechanisms by which the rhizosphere may act to enhance cometabolism of anthropogenic contaminants (Crowley et al. 2001). First, the rhizosphere may allow selective enrichment of degrader organisms that have densities too low to significantly degrade xenobiotics in root-free soil (Crowley et al. 1997; Jordahl et al. 1997; Nichols et al. 1997). Second, the rhizosphere may enhance growth-linked metabolism or stimulate microbial growth by providing a natural substrate when the concentration of xenobiotics is low or unavailable (Alexander 1999; Haby and Crowley 1996). Finally, the rhizosphere is rich in natural compounds that may induce cometabolism of xenobiotics in certain microorganisms that carry degradative genes or plasmids. This may permit initial degradation of xenobiotics that would otherwise be unavailable as carbon sources.

Rhizosphere effects on xenobiotic biotransformation have been studied for a variety of compounds, although the mechanisms by which certain plants enhance biodegradation are still poorly understood (Crowley et al. 1997). Differences in plant tolerance to phytotoxic compounds in soils may be related to the plants' ability to induce microorganisms that will detoxify these xenobiotics in the soil environment (Crowley et al. 2001). Research on phytoremediation, through trial and error, has focused on densely rooted, fast- growing grasses and plants, such as *Brassica* sp., with fine root systems. Mulberry (*Morus alba* L.) and poplar (*Populus deltoides*) trees have been used successfully in the phytoremediation of chlorophenols and chlorinated solvents such as trichloroethylene (TCE) (Stomp et al. 1993).

Salicylic acid, flavonoids, and monoterpenes are structurally analogous to many anthropogenic compounds in that they are small, mobile chemicals that are amenable to cellular uptake and may interact through signal transduction pathways to induce the production of specific degradative enzymes (Crowley et al. 2001). For example, salicylic acid was used in tomato fields in irrigation water to promote rhizosphere bacterial growth (Colbert et al. 1993). Salicylic acid is an effective inducer of many different enzymes that may be involved in the cometabolism of xenobiotics such as polyaromatic hydrocarbons (PAHs) and PCBs (Crowley et al. 2001). Degradation of PAHs and PCBs probably evolved in a modular fashion by gene operon recruitment (Williams and Sayers 1994). The salicylic acid–inducible toluene monooxygenase gene, *TOM,* was isolated from *Burkholderia cepacia* (Shields et al. 1995) and introduced into *P. fluorescens* (Yee et al. 1998). The rhizosphere of wheat was inoculated with this transformed *P. fluorescens*, resulting in enhanced degradation of TCE (Yee et al. 1998).

Pseudomonas putida G786 hydroxylates the terpenoid camphor (Bradshaw et al. 1959) by a monoxygenase $P450_{CAM}$ located on a plasmid (Rheinwald et al. 1973). Other P450 enzymes have been implicated in terpene degradation; however, it appears that terpene-induced P450s do not have broad substrate specificity (Crowley et al. 2001). Plants have been used in the phytoremediation of PAH- contaminated soils (Reilley et al. 1996; Schwab et al. 1995), suggesting the involvement of rhizosphere microorganisms in PAH degradation (Trower et al. 1988). A microbial community–based approach may be useful for screening different plant chemicals to find inducers of xenobiotic-degrading enzymes (Crowley et al. 2001).

Reductive Dehalogenation in the Rhizosphere

Reductive dehalogenation is the only significant mechanism for the breakdown of halogenated aromatic, aliphatic, and heterocyclic compounds like PCBs, TCE, hexachloro- benzene, and halogenated pesticides such as heptachlor and aldrin (Barkovskii 2001). Reductive dehalogenation enzymes have broad substrate specificities. There are two principal mechanisms of RDE. The first process is cometabolic RDE, which yields no energy for the organism. The second mechanism is halorespiration, where organohalides act as terminal electron acceptors and adenosine triphosphate is generated (Griffith et al. 1992). In cometabolic RDE, organohalides are not used as terminal electron acceptors. Generally, an- aerobic respiration is relatively inefficient in that electrons produced during substrate oxidation lose energy in the electron transport chain. In cases of excess substrate, high-energy electrons, "hot electrons," accumulate, creating a redox potential imbalance. However, microbes may gain protection from "hot-energy" electrons by halo-scavenging, there- by providing an advantage to microbes that conduct halo- respiration (Barkovskii 2001).

In theory, certain microsites within the rhizosphere are favorable (anaerobic conditions, low redox potentials, and available electron acceptors) for RDE thus fascilitating the transformation of halogenated compounds (Barkovskii 2001). Although O_2 does not inhibit RDE (Criddle et al. 1986; Häggblom et al. 1989; Steiert and Crawford 1986; van den Tweel et al. 1987), RDE is generally an anaerobic process. Spatial and temporal heterogeneity in O_2 distribution in the rhizosphere environment usually (but not always) provides microbes with localized environments that are an- aerobic and have low redox potential, thereby favoring RDE reactions (Barkovskii 2001). Moreover, most of the terminal electron acceptors, such as nitrate

(Haider et al. 1987), ferric iron (Frenzel et al. 1999; Wang and Peverly 1999), sulfate (Blaabjerg and Finster 1998), CO_2 (Frenzel et al. 1999; Ro- den and Wetzel 1996), and quinones (Barkovskii et al. 1994, 1995), are abundant in the rhizosphere. The addition of quinones can enhance both the capacity and the rate of microbial reduction of contaminants (Barkovskii and Adriaens 1998; Barkovskii et al. 1995; Lovley et al. 1996). In RDE, quinones and semiquinones provide reducing power and protons, which transfer excess electrons to organohalides.

The bioavailability of hydrophobic contaminants determines the rate of xenobiotic transformation and mineralization. For example, the rhizosphere may increase the bioavailability of lipophilic polyhalogenated aryl halide contaminants (Banks et al. 1999; Erickson et al. 1995; Fan et al. 1997; Ferro et al. 1994; Hustler and Marschner 1994; Nardi et al. 1997) otherwise unavailable for RDE. Concomitantly, the bioavailability of the hydrophilic intermediates of organohalide degradation will decrease, thus reducing further degradation (Kreslavski et al. 1999; Walton et al. 1994). Further research is needed to fully characterize the role of the rhizosphere in halide degradation and the biotransformation of xenobiotics.

Effect of herbicides in relation to environment

After a herbicide is applied, whether pre-plant incorporated, pre-emergence, or post-emergence, inside a polyhouse/structure, or to any other site, it has been introduced into the environment. Applicators need to ask themselves a few important questions:

1. Will the herbicide remain where it was applied or will the pesticide become mobile in the environment?
2. How long will the herbicide remain viable or effective?
3. What effect could the herbicide have on non-target plants, animals, or other things in the environment?

To answer these questions, you must understand how herbicides move in the environment and the chemical properties that control movement. There are four basic chemical characteristics that control herbicide/pesticide movement in the environment: solubility, adsorption, persistence and volatility.

Solubility is a measure of the ability of a pesticide to dissolve in a solvent, usually water. The greater the solubility, the more readily the pesticide dissolves. Pesticides that are easily dissolved in water can move with water. Highly soluble pesticides are more likely to move through the soil and into groundwater or into surface waters, causing harm to unintended sites, plants and animals, including humans.

Adsorption is the ability of a pesticide to bind with soil particles. Adsorption occurs because the pesticide has an electrical attraction to the surface electrical charge of a soil particle, generally organic matter or clay particles. A pesticide that adsorbs to soil particles is less likely to move from the application site.

Persistence is the ability of a pesticide to remain in its original form, active and viable, before breaking down chemically to become inactive. A common measure of persistence in chemicals is referred to as the half-life. Half-life is the time it takes for half the original amount of chemical applied to break down. The longer the reported half-life of a chemical or pesticide, the more persistent the chemical or pesticide is in the environment. Sometimes, persistent pesticides are desirable because they will provide long-term pest control and reduce the need for repeated applications. However, persistent pesticides can also cause later problems to unintended sites, plants, animals or humans if the persistent pesticides are also mobile in the environment. If you are using a persistent pesticide, it is very important to prevent unintended consequences due to improper handling, drift, runoff, erosion or leaching.

Volatility is a measure of the tendency of a pesticide to turn into a gas or vapour. Some pesticides are more volatile than others. Pesticides tend to volatilize more readily when temperatures are high, winds are high, and relative humidity is low at the application site. Pesticide movement as a gas or vapour is also known as "drift" and will be discussed in the next section.

Pesticide degradation occurs in three basic ways:

- Microbial action: chemical breakdown or degradation of pesticides by soil microorganisms, such as fungi, bacteria, etc.
- Chemical degradation: Breakdown of pesticide chemical components by inorganic methods (not by living organisms).

- ➢ Photodegradation: breakdown of pesticide chemical components by reaction with sunlight. This is why many pesticide application instructions require incorporation of the pesticide in the soil, away from direct sunlight.

How do Pesticides Move in the Environment?

Pesticides can move in the air, in water, and through the soil resulting in environmental damage and exposure to nontarget plants and animals. Applicators are responsible for damages resulting from off-target pesticide movement.

Pesticide Drift

Pesticide drift is the movement of pesticides through the air away from the intended target site. When pesticide drift occurs, it can damage crops and expose humans, domestic animals and wildlife. Drift can contaminate soil and water.

Pesticide movement in water usually is the result of either **runoff** from the application site to an unintended site or water body or **leaching** from the soil by water, moving outward and/or downward in the soil. This can cause unintended harm to plants or animals or contaminate surface water or groundwater.

Movement on or in objects includes such things as:

- Pesticide **residues** on equipment or clothing used by pesticide applicators. These residues can affect unintended plants, wildlife, livestock, pets and people.
- Pesticides that have adsorbed on soil particles that are subsequently moved to an unintended site by wind or water **erosion**.
- Pesticide **residues** on plants that are removed from site. This may be as plant parts, feed, seed or other plant-based products.
- Pesticide **residues** on or in animals that are treated by pesticides and moved to a new site. The residues can be in the meat, milk or fiber used by man, on their fur or skin, in their feces or other waste products, etc. Minimizing pesticide movement and subsequent unintended application and damage is part of the pesticide applicator's job.

Types of Pesticide Drift

There are two types of drift: vapor drift (chemical volatility) and particle drift.

Vapor drift is the movement of pesticide vapors from the target area, carried by air.

Particle drift is the movement of small spray droplets or dust from the target area, carried by air.

Factors Affecting Drift

Many factors influence the amount of particle spray drift. Of primary concern are **spray droplet size** and **wind velocity,** as they are the cause of most of the problems associated with spray drift.

Temperature influences the volatility of pesticides.

The size of the spray droplets determines how fast the droplets fall and how far the pesticide might drift. Small, lightweight droplets fall more slowly and have more time to drift.

As droplet size increases, the potential for drift decreases.

The greater the wind speed during a pesticide application, the greater the risk of pesticide drift.

Consider wind direction when planning a pesticide application. Do not apply pesticides when the wind is blowing towards a susceptible crop, water body or other sensitive site.

Winds are generally calmer in early morning or early evening. These are better times of day to apply pesticides.

Low relative humidity and/or high temperature increase the evaporation rate of spray droplets.

Spray drift is usually greater from aerial applications than from ground applications.

Proper nozzle selection helps maintain uniform application by controlling both the amount of pesticide applied and the size of the pesticide droplets.

Spray pressure influences the size of the droplets formed. Increased pressure produces smaller droplets, which are more susceptible to drift.

Pesticide Contamination and Water Resources

Pesticides can contaminate surface water and groundwater from both point sources and nonpoint sources.

Chemicals on the ground surface can become groundwater contaminants if they are carried downward by recharge water.

Leaching is the term for transport of pesticides downward or sideways through soil.

The risk of Groundwater contamination is greater when pesticides are applied to gravelly or sandy soils.

The closer the water table is to the land surface, the greater the possibility of contamination.
Runoff and erosion moves pesticides into surface water bodies, such as streams or lakes.

Protecting Water Resources

Preventing Groundwater contamination is the pesticide applicator's responsibility.
Always read, understand and follow directions and precautions on the product label.
Use pesticides only when and where necessary and only in amounts adequate to control pests.
There are both civil and criminal penalties for using pesticides in a manner inconsistent with label directions.
Read, understand and follow the information and instructions on the pesticide label regarding disposing of pesticides and storing pesticides safely.
Maintain records of pesticide applications, as required.
Additional Groundwater protection methods, such as timing of irrigation, avoiding irrigation runoff and regularly inspecting and maintaining water wells, can help prevent groundwater contamination.

Chemigation

Chemigation is the application of agricultural chemicals, both pesticides and fertilizers, through a sprinkler system.
Chemigation has the advantage that the correct amount of chemical can be applied to the crop at the appropriate time, the application is inexpensive, convenient, and field access is unnecessary.

Pesticide Effects on Non-Target Organisms

The effects of pesticides on non-target organisms may involve direct and immediate injury or may be due to the long-term consequences of environmental pollution. Valuable non-target plants, bees and other beneficial insects, pets, livestock, and wildlife may be affected.
Phytotoxicity refers to plant injury caused by exposure to a chemical. Phytotoxic injury can occur on any part of a plant's roots, stems, leaves, flowers or fruits.
Most phytotoxic injuries are due to herbicides that are persistent at the site of application. Persistent products may also injure succeeding crops.
Damage to crops or other plants in adjacent areas is most often due to drift, although damage may sometimes be a consequence of surface runoff, particularly from sloping areas.
Apply pesticides in the evening or early morning, when bees are not actively foraging. Beneficial insects, other than bees, can also be harmed by pesticides. Survey the insect population and use caution when applying pesticides.
Keep pets out of treated areas during applications and cover pet food and water bowls.
Applying a pesticide to a forage crop that is not listed on the label and then feeding the forage to livestock may result in illness or death of the animals.
Pesticides can affect wildlife in many ways. They may kill wildlife, weaken wildlife, kill their food source or interfere with reproduction.
Lethal effects are those that cause death directly by exposure to pesticides.
Sublethal effects are those that do not kill outright, but those that interfere with survival and reproduction.
Bioaccumulation or bioconcentration is the accumulation of persistent pesticides in the bodies of animals.
Biomagnification is the accumulation of persistent pesticides in increasing concentration in animals as it moves up the food chain.
Any application method or farming practice that allows considerable drift or runoff is potentially harmful to wildlife.
Remember, if you use pesticides, you are responsible for knowing if an endangered or threatened species or their habitat may be affected by pesticide use in your area.

Herbicide resistance in weeds and crops

Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild type. In a plant resistance may occur naturally due to selection or it may be induced through such techniques as genetic engineering. Resistance may occur in plants as the result of random and infrequent mutations; there has been no evidence to date that demonstrates herbicide induced mutations. Through selection, where the herbicide is the selection pressure, susceptible plants are killed while herbicide resistance plants survive to reproduce without competition from susceptible plants. If the herbicide is continually used, resistant plants successfully reproduce and become dominant in the population.

Types of resistance:

Multiple resistance is the phenomenon in which a weed is resistant to two or more herbicides having different mechanisms of action. An example would be a weed resistant to sulfonylurea herbicides (ALS inhibitors) and glycines (EPSP synthase inhibitors). Multiple resistance can happen if a herbicide is used until a weed population displays resistance and then another herbicide is used repeatedly (without proper resistance management) and the same weed population also becomes resistant to the second herbicide, and so on. Multiple resistance can also occur through the transfer of pollen (cross-pollination) between sexually compatible individuals that are carrying different resistant genes.

Cross resistance occurs when the genetic trait that made the weed population resistant to one herbicide also makes it resistant to other herbicides with the same mechanism of action. An example would be a weed resistant to imidazolinone herbicides (ALS inhibitors) and sulfonylurea herbicides (also ALS inhibitors). Cross resistance is more common than multiple resistance, but multiple resistance is potentially of greater concern because it reduces the number of herbicides that can be used to control the weed in question.

Incidence and History of Herbicide Resistance

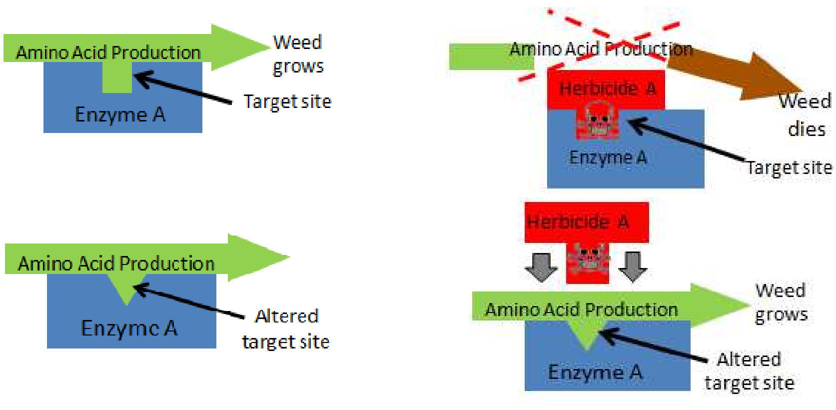
The first reported case of herbicide resistance in the United States was reported in the 1950's. Field bindweed resistant to 2,4-D was reported in Kansas in 1964, and common groundsel resistant to triazine herbicides was discovered in Washington in 1970. Beginning in the 1980's, the number of reported resistant biotypes began increasing rapidly in the U.S. and worldwide. Resistance to one or more of 25 herbicide families has been observed in more than 65 weed species in the U.S.

Mechanisms of Herbicide Resistance

What occurs within a resistant plant that allows it to survive after an herbicide application? What characteristics do the resistant plants possess that the susceptible plants lack? The four known mechanisms of resistance to herbicides are:

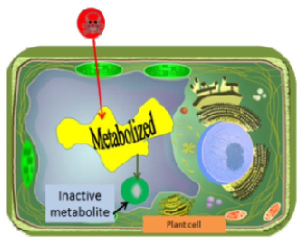
1. **Altered target site:**

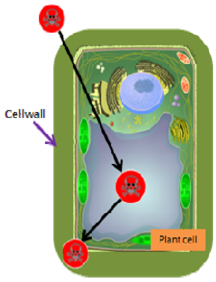
An herbicide has a specific site (target site of action) where it acts to disrupt a particular plant process or function (mode of action). If this target site is somewhat altered, the herbicide no longer binds to the site of action and is unable to exert its phytotoxic effect. This is the most common mechanism of herbicide resistance.



2.Enhanced metabolism:

Metabolism within the plant is one mechanism a plant uses to detoxify a foreign compound such as an herbicide. A weed with the ability to quickly degrade an herbicide can potentially inactivate it before it can reach its site of action within the plant.



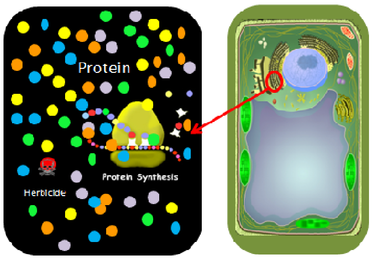


3. Compartmentalization or sequestration:

Some plants are capable of restricting the movement of foreign compounds (herbicides) within their cells or tissues to prevent the compounds from causing harmful effects. In this case, an herbicide may be inactivated either through binding (such as to a plant sugar molecule) or removed from metabolically active regions of the cell to inactive regions, the cell wall, for example, where it exerts no effect.

4. Over-expression of the target protein:

If the target protein, on which the herbicide acts, can be produced in large quantities by the plant, then the effect of the herbicide becomes insignificant.



Prevention and management

Any management action that reduces the selection pressure for resistance will reduce the rate of resistance evolution. Crop rotation is one of the best tools for preventing resistance. Rotation to another crop allows the grower to use both chemical and non-chemical control methods. Manipulation of planting time, the competitiveness of the crop, cultivation techniques, hand weeding, and application of herbicides with different target sies all are possible in a crop rotation system.

Strategies to delay herbicide resistance

Weed management strategies that discourage the evolution of herbicide resistance should include the following:

- Herbicide rotation
- Crop rotation
  - Plant to a crop having a different season of growth
  - Plant to a crop having different registered herbicides
  - Plant to a crop for which there are alternate methods of weed control
- Monitoring after herbicide application
  - Check for weedy patches in patterns consistent with application problems
  - Hand weed patches that are not in patterns consistent with application problems.
- Non-chemical control techniques
  - Cultivate
  - Hand weed. A 90% or greater rate of weed removal reduces the chances that a resistance plant will produce seed.
  - Mulching with both synthetic and organic materials.
  - Solarise the soil.
- Short residual herbicides
- Certified seed
- Clean
  - Use a power washer or compressed air to remove seeds.

Strategies to manage herbicide resistance weeds

To keep herbicide-resistance weeds under control, incorporate following strategies into the weed management plan:

- Herbicide rotation
- Fallow tillage
- Close cultivation
  - Monitor hand weeding crew to insure more that 90% removal of weeds in the crop row.
- Prevention of weed seed spread through use of clean equipment

- Enter the field with resistance plants last.
- Use a power washer or compressed air to remove seeds.

- Monitoring the initial evolution of resistance by recognizing patterns of weed escapes typical of resistant plants
    - Watch for small weed patches that spear in the same place in the next crop.
    - Watch for weed patches that do not have a regular shape that woild indicate a herbicide application problem.
- Control of weeds suspected to herbicide resistance before they can produce seed.

Herbicide Resistant Crops

Herbicide resistance is the major trait that has been engineered into crops. The problem to weed resistance to herbicides has provided an invaluable opportunity for visionary scientists to develop crops resistant to previously non-selective herbicides. HRCs (herbicide-resistant crops) can be classified as **non-transgenic** (traditional genetic methods of selection of resistance traits) and **transgenic** (genetically engineered). Non-transgenic HRCs were developed using conventional breeding techniques. The first such example is triazine resistant canola that was developed through a breeding programme in 1984. Thereafter, various methods such as microspore selection, seed mutagenesis, pollen mutagenesis, tissue culture, cell selection, and transfer from a weedy relative have been used for generating non-transgenic HRCs.

Genetic engineering of herbicide tolerance

Before the emergence of plant genetic engineering, options for selective crop protection against herbicides were limited. Specific herbicides could be used in the crops that were naturally resistant to the herbicide. In rare cases, resistance could be induced in crop varieties through mutations. For example, monocots are naturally resistant to triazine and hence triazine could be used as selective herbicide in monocot crops to control dicot weeds. Developments in plant genetic engineering and knowledge of biochemical action of herbicides on plants spurred innovative approaches to engineer crops to withstand herbicides. These strategies usually involve isolation and introduction of a gene from another organisms, mostly bacteria, which is able to overcome the herbicide-induced metabolic blockage. For example, tolerance to the herbicide glufosinate (Basta) is conferred by the bacterial gene *bar*, which metabolizes the herbicide into a non-toxic compound. Glyphosate (another most popular herbicide) resistance is achieved by the introduction of either *Agrobacterium* gene *CP4* that codes for a glyphosate-insensitive version of the plant enzyme, EPSP-synthase, or *gox* gene from *Achromobacter*, which codes for glyphosate oxidoreductase in the breakdown of glyphosate. A number of other genes have been identified that can alleviate the herbicide action through various ways (such as detoxification, sequestration, etc.) and thus confer resistance to the plants carrying them. Thus genetic engineering technology has made it possible to tailor crop varieties to resist specific herbicides by introducing relevant genes. Consequently, the range of selective herbicides has now greatly expanded, wherein specific genotypes and varieties can be conferred resistance rather than generic crops displaying resistance to specific herbicides. These developments have provided the herbicide companies new opportunities to promote their herbicides through development and marketing of genetically engineered HRCs.

Worldwide use of transgenic crops

Transgenic crops were first introduced in the 1990s. According to a 2010 database maintained by a non-profit environmental risk assessment institution, 60% (87 of 144) of all transgenic/biotechnological events reported involved herbicide resistance traits (CERA, 2010). All herbicide resistance traits that had regulatory approval did not result in commercialization and sales. In 2003, 67.7 million were planted to transgenic crops (both herbicide and insect resistance) in the world (Dill, 2005) and by 2010, the area increased to 148 million ha (James, 2010).

By 2012, 84.6% of all genetically modified (GM) crops worldwide carried herbicide resistance traits (144 mil. ha). Herbicide-resistant (HR) crops occupy about 59% of the 170.3 million hectares under GM cultivation globally, with GM crops with stacked traits (basically herbicide and insect resistance) covering 25.6%.

The cumulative area planted to transgenic crops from 1996 to 2010 exceeded 1 billion ha. An unprecedented 87 – fold increase in transgenic crop hectarage, from 1.7 million ha in 1996 to 148 million ha in 2010, makes transgenic crop technologies the most widely accepted in crop husbandry. Since 1996, the only year to year double digit (10%) growth in transgenic crop area was for 2009 to 2010. While the number of countries that planted transgenic crops increased to 29 in 2010 from 25 in 2009, the top ten countries each grew more than 1 million ha for the first time. Of the 29 countries growing transgenic crops 19 were developing and 10 were developed.

Among the HRCs, soybean was the most dominant transgenic crop in 2010, occupying 73.3 million ha or 50% of global are planted to transgenic crops. Among the traits, herbicide resistance remained the most planted trait. In 2010, herbicide resistance crops: soybean, maize, canola, cotton, sugarbeet and alfafa accounted for 61% (or 89.3 million ha) of the global transgenic area (148 million ha). Stacked traits are increasingly becoming important for weed control and economic reasons. In 2010, eight of 11 countries planted stacked trait crops were developing nations.

While 29 countries planted commercialized transgenic crops in 2010, an additional 30 countries, totaling 59 have granted regulatory approvals for transgenic crops import for food and feed use and for release into the environment since 1996. The global value of the transgenic seed market alone was valued at $11.2 billion in 2010 with commercial biotech maize, soybean grain, and cotton valued at an estimated $150 billion for 2010 (James, 2010).

Exercise

Tick (√) the correct choice

Q.1. The symptoms on weeds sprayed with herbicides express the ___________
a). Mechanism of action b). **Mode of action** c). Phytotoxicity d). None

Q.2. Crop or off target herbicide injury can be diagnosed after having an understanding of herbicides ________
a). Mechanism of action b).Translocation c). **Mode of action** d). None

Q.3. Glyphosate inhibit the enzume
a). ACC-ase b). **EPSP synthase** c). Protoporphyrinogen oxygenase d). Glutamine synthatase

Q.4. Fluazifop-p-butyl inhibit which of the following enzymes
a). **Acetyl COA carboxylase** b). ALS c). HPPD d). EPSP synthase

Q.5. Cell division disruption is brought about by which of the followings
a). Triazines b). Phenoxys c). Ureas d). **Chloracetamides**

Q.6. Hormonal effect on plant growth and development such as twisting of stems and curling of leaves are brought about by
a).Triallate b). **2,4-D** c). Metolachlor d). Pendimethalin

Q.7. An inhibition of PS-I is caused by
a). Glyphosate b). Clomazone c). **Paraquat** d). Glufosinate

Q.8. A photosystem II inhibitor
a).**Isoproturon** b). Paraquat c). 2,4-D d). Mesotrione

Q.9. Carotenoid biosynthesis inhibition is brought about by which of the following
a). Glufosinate b). **Tembotrione** c). Bromoxynil d). Paraquat

Q.10. Sulfonyl ureas bring about inhibition of which of the followings
a). **ALS** b). ACC-ase c). EPSP synthase d). Glutamine synthetase

Q.11. Which of the following are protected from herbicide sprays by covered growing points
a). Arhar & moong b). **Wheat & sugarcane** c). Rapeseed & Mustard d). Peas & beans

Q.12. In slow germinating crops, where weeds emerge before the germination of the crops, selective post-emergence control can be achieved with which of the following
a).Thiobencarb b). Atrazine c). **Paraquat** d). Pendimethalin

Q13. The weeds which grow tall above the crop height are controlled using
a).herbicide laden wax bars b). cloth stick dipped in herbicide solutions c). Rope-wick applicator d). **All**

Q.14. Selectivity of molinate between rice and *Echnochloa colona* is due to differences in
a).**Crown root initiation levels** b). Coleoptiler nodes c). Selective absorption d). None

Q.15. Father of safeners

a).**Otto-L-Hoffman** b). J.I. Rodales c). Hans Molisch d). Eve Walfour

Q.16. 1,8 Naphthalic anhydride, a highly successful safener of EPTC and butylate in maize was discovered in

a).1949 b). **1969** c). 1989 d). 2007

Q.17. Herbicide safener interaction is

a).Synergistic b). **Antagonistic** c). Additive d). Enhancement

Q.18. The effective dose of NA is

a).2.5 g/kg seed b**). 0.5 g/kg seed** c). 5 g/kg seed d). 10 g/ kg seed

Q.19. Which of the following is a safener

a).R-25788 b). CGA 43089 c). NA d). **All**

Q.20. Induced selectivity is designated to the use of

a).Herbicide combinations b). **Adsorbents** c). Surfactants d). None

Q.21. Induced selectivity we may refer to the use of which of the following along with herbicides

a).Safeners b). Adsorbents c). **Both** d). None

Q.22. Sugarcane is tolerant to 2,4-D because of its

a).Rapid translocation b). **Slow translocation** c). Rapid metabolism d). Conjugation

Q.23. Selectivity of atrazine and simazine in maize is due to

a).Metabolism b). Reverse metabolism c). **Conjugation** d). Rapid translocation

Q.24. Arylacylamine amidohydrolase is responsible for selectivity of

a).**Propanil to rice** b). Atrazine in apple c). Simazine in maize d). 2,4-D to grasses

Q.25. Glutathione S transferase is responsible for conjugation of

a).Propanil in rice b). 2,4-D in grasses c). **Simazine in maize** d). None

Q.26. Wheat is tolerant to ioxynil and bromoxynil because of

a).Limited spray retention b). Slow translocation c). Rapid metabolism d). **All**

Q.27. 2,4-D is selective to winter grains at

a). 1-2 leaf stages b). **3-6 leaf stages** c). 7-10 leaf stages d). flowering stage

Q.28. Interactions in herbicide mixtures can occur

a). Prior to application b). During application c). After application d). **All**

Q.29. Major interaction in herbicide mixture is

a). biochemical b). physiological c). competitive d). **All**

Q.30. Synergism is more common in mixtures where the companion herbicides belong to

a). **Same group** b). Different group c). Different structure d). Different metabolism

Q.31. Almost 80% of the herbicide combination interaction in poaceae refers to cases of

a). Synergism b). Additive c). **Antagonism** d). Enhancement

Q.32. An adjuvant used to adjust the acidity of the spray solution

a).Stenching agents b). Wetting agents c). non-ionic agents d). **Buffering agents**

Q33. Adjuvants are used to modify

a).Herbicide acidity b). Application characteristics c). to improve shelf life d). **All**

Q.34. Activator adjuvants include

a).Emulfifier b). Dispersants c). Co-solvents d). **None**

Q.35. Surfactants are

a).Utility modifiers b). Spray modifiers c). Both d). **Activator adjuvants**

Q.36. Preferentially which class of surfactants be used to increase herbicide activity

a).Anionic b). Cationic c). Both d). **Non-ionic**

Q.37. The solvent used for solublising 2,4-D (acid form), the other water insoluble herbicide is

a).**Polyethylene glycol** b). Xylene c). Lanolin d). Methyl chlloride

Q.38. Drift susceptible spray droplets diameter is which of the following

a). 750 μ and less b). 500μ and less c). 250 μ and less d). **150 μ and less**

Q.39. To reduce drift which of the following is used

a).Invert emulsion b). Thickening agent c). Particulating agents d). **All**

Q.40. Dichlormid exhibited specific protection of maize against which of the following

a).Bipyridilliums b). **Thiocarbamates** c). Triazines d). Ureas

Q.41. Splitting of molecule through the addition of water is called

a).Hydroxylation b). **Hydrolysis** c). Ring hydroxylation d). Beta-oxidation

Q.42. The degradative phase of herbicide molecules
a).**Chemical degradation** b). Volatilization c). Ring hydroxylation d). Beta-oxidation

Q.43. Pathways by which long chain carbon segments are degraded by removing 2 carbons for each cycle of the pathway
a).Deamination b). Dealkyloxylation c). Both d). **Beta-oxidation**

Q.44. The organisms have caused herbicides to degrade are
a).fungi b). Bacteria c). Algae d). **All**

Q.45. The breakdown of a herbicide in the absence of a living organism
a).Photodecomposition b). Chemical decomposition c). **Both** d). Volatilization

Q.46. An example of chemical decomposition
a).Oxidation b). Reduction c). Hydrolysis d). **All**

Q.47. The adsorptive capacity for cationic herbicides in descending order
a). Clay>sand>silt>OM b). Sand>silt>clay>OM c). **OM>clay>silt>sand** d). Silt>sand>clay>OM

Q.48. A herbicide that volatilize and still possesses herbicidal activity in which of the following physical forms
a). Liquid b). Solid c). **A gas** d). a and b

Q.49. First reported case of herbicide resistance in the 1950s was in the
a). Japan b). UK c). **US** d). Canada

Q.50. The method used for generating non-transgenic HRCs
a). Microspore selection b). Pollen mutegenesis c). Cell selection d). **All**

Q.51. Tick the correct answer

1. Paraquat is associated with inhibition of which of the following
a).**PSI** b). PSII c). PPO d). HPPD
2. Symptoms where shoots/leaves are bleached white are caused due to
a).Atrazine b). Glufosinate c). **Tembotrione** d). Fluazifop-p-butyl
3. Herbicides inhibiting Acetolactate Synthase (ALS) associated with making of leusine, isoleucine and valine
a).Ureas b). **Sulfonylureas** c). Chloracitamides d). Bipyridilliums
4. Mode of action of isoproturon
a).**PSII inhibition** b). ACCase inhibition c). Glutamine synthatase inhibition d). Cell division inhibition
5. Foundation for phenomenal achievement in modern chemical weed management
a).Safeners b). Adjuvants c). **Selectivity** d). Herbicide combinations e). None
6. Which of the formulations has low leach ability in soils
a).EC b). WP c). **Granules** d). WSC
7. An enzymatic beta-oxidation process
a).Conjugation b). **Reverse metabolism** c). Translocation d). Metabolism
8. In case of combined application of herbicides, application rate can be reduced in which of the following interaction
a).Antagonistic b). **Synergistic** c). Additive d). None
9. Mixture of glyphosate with 2,4-D on field bindweed had interaction of the type
a).**Synergistic** b). Antagonistic c). Additive d). Enhancement
10. The odd one amongst the following
a).**Adjuvants** b). Activators c). Spray modifiers d). Utility modifiers
11. The odd one amongst the following
a).Surfactants b). **Activators** c). Wetting agents d). Phytobland oils
12. Physical removal/loss of herbicides
a).**Adsorption** b). Hydrolysis c). Deamination d). Dealkylation
13. Deactivation of herbicides in the plant system
a).Conjugation b). Accumulation c). Secretion d). **All** e). None
14. In the development of transgenics, tolerance to herbicide glufosinate is conferred by which of the following
a).**bar** b). CP4 c). gox d). All e). None

Q.52. Explain/define the following

Mechanism of action; Carotenoid biosynthesis inhibition; Selectivity; Safener; Reverse metabolism; Antagonistic effect; Surfactant; Invert emulsions; Buffering agents; undue persistence; Conjugation; Half-life; Adsorption; Sublethal; Biomagnification; Cross-resistance; Sequestration; Tolerance; Transgenic; Herbigation

Q.53. What do you mean by site of action of herbicides? How is it differentiated from mode of action of herbicides? Classify mode of action of photosynthesis inhibitors.

Q.54. Discuss types and mechanism of herbicide interactions. Also elucidate the factors affecting herbicide interactions.

Q.55. Discuss types and mechanism of herbicide resistance. Also give an account on prevention of herbicide resistance in weeds.

Q.56. What do you mean by selectivity? Discuss mechanism of selectivity based on differential rate of deactivation of herbicides.

Q.57. Discuss the fate of herbicides in the environment.

Q.58. What do you mean by genetic engineering of herbicide tolerance? Give an account of worldwide use of transgenic crops.

Q.59. What are adjuvants? Classify them based on their type of action.

Q.60. What do you mean by chemical selectivity? Describe the selective mechanism of herbicides due to differential rate of translocation of herbicides.

Q.61. Comment on the following

1. There are herbicide susceptibility as well as tolerance stages.
2. Soils high in clay content require more herbicide than sandy soils for pre-emergence or soil sterilant weed control
3. The limited spray retention provides resistance against selective contact herbicides while in case of translocated herbicides, it is not of much help in protecting the non-target plants from herbicide injury.
4. Esters of 2,4-D do not leach easily.

UNIT IV

Weed management in major crops and cropping systems, weed shifts in cropping systems, control of weeds in non-cropped situations including grasslands, pastures, tea gardens, orchards and aquatic ecosystem in hills.

Weed management in major crops and cropping systems

Rice

Throughout the world, it is impossible to produce rice economically without a well planned weed management programme. Weed problem persists because of the inability to cope with their great reproductive capacity and massive recycling potential. Another problem is the shift in the weed species as a consequence of the control measures applied. As there are many kinds of weeds with varying germination periods and highly differing life cycles, weed management requires an integrated approach based on through knowledge of biology and ecology of the species.

Yield losses due to weeds vary with system of rice culture (direct or transplanted), variety, plant population, fertilizer applied, duration and time of application, weed species, amount of weed growth, season, ecology and climatic conditions. Weed competition is more in direct seeded rice. Further, competition from weeds is greater when rice is seeded into dry soil than when it is wet seeded or transplanted. Reduction in yield to the tune of 34% in transplanted rice, 45% in direct seeded low land rice and 67% in upland rice are reported. Weed competition in direct seeded rice is greatest during the first three weeks. The critical period for weed free condition for higher productivity is reported to be 30 – 35 days in transplanted rice where as direct seeded low land and upland condition the weed free period ranges from 40-60 days. Estimating losses in the absence of any weed control is unrealistic because almost all farmers follow some kind of control. Therefore, a comparison between weeded and unweeded plots over states the additional benefits of weed control. A more realistic approach is to compare the added benefits from additional weeding compared with farmers weed control method (Moody 1983). In direct seeded rainfed (upland) rice weeds emerge simultaneously with crop leading to early competition. In transplanted rice, flooding and puddling destroy existing weeds before transplanting and new flush of weeds establish after 2-3 weeks of planting, thus enabling rice seedlings to establish well and withstand subsequent weed competition (Rao 2000). Thus the weed problem is more under upland rice conditions than in flooded lowland rice.

The weed flora of rice depends on the rice ecosystem and the management practices. The major weeds normally observed in rice crop are grasses which includes *Echinochloa colonum, E. crusgalli, Eleusine indica, Setaria glauac, Cynodon dactylon*, the sedges *Cyperus rotundus and Fimbristylis sp.* and the broadleaved weeds and aquatic weeds *Trianthema portulacastrum, Cynotis axillaries, Digeria arvensis, Euphorbia hirta, Phyllanthus niruri, Eclipta alba and Chara sp.* In general, grasses and sedges dominate weed spectrum.

Cultural management

Manual weeding is the most widely used method of weed control in rice which is however, difficult, time consuming and often costly. Hand pulling is the common method of weed control in nurseries. Similarity between grassy weeds and rice crop, especially during early stages poses problems for manual weeding. Intercultivation between two rows of crop by a rotary weeder is useful, time saving and more economical than manual weeding. Preparatory tillage is an effective means of destroying the existing weed growth. Flooding and puddling is an added advantage in lowland rice weed management. Intensive puddling starting 15-20 days ahead of transplanting and continuous land submergence eliminated the need for any weed control method in lowland rice (Reddy and Hukkeri 1980). Soil compaction to a bulk density around1.8 g cc^{-1} was very effective for minimizing weed infestation in direct seeded lowland rice. However, the final yield was not comparable with that of direct seeded puddle rice due to stunted rice growth with soil compaction.

Use of herbicides

When labour is scarce and expensive, use of herbicides may be cheaper and effective. Time of application depends on the stage of weed growth at which they are very effective in suppressing their growth and relative susceptibility of the rice crop to the herbicide used.

Nursery: Controlling weeds at the nursery level itself is rewarding. Application of butachlor (0.75-1.0 kg/ha) or thiobencarb (1.5-3.0 kg/ha) or pretilachlor + safener (sofit) (0.75 kg/ha), anilofos (0.25-0.5 kg/ha) at 4-7 days before or after sowing through ponded water where as oxadiazon (0.5-0.75 kg/ha) or cyhalofop butyl (clincher)

0.1 kg/ha on 8th day after sowing result in effective control of weeds. Bispyribac 20 g/ha at 14 – 15 days to control G + BLW + S.

Upland Rice

In upland drilled rice suitable pre-emergence herbicides are cyhalofopbutyl 0.06-0.07 (G), metsulfuron 0.03-0.06 kg/ha (BLW), where as oxadiazon 0.6 to 1.5, butachlor 1-1.5, oxadiargyl 0.09 kg/ha at 7-8 days, quinclorac 0.187-0.375, dithiopyr (crabgrass) 0.18 kg/ha to control grasses and broad-leaved weeds. Pretilachlor 0.75 kg/ha control grasses, broad leaved weeds and sedges also.

Post emergence herbicide to control G + BLW is propanil (3-4 kg ai/ha) effective at 2-3 leaves stage. 2,4-D @ 0.5 -1.0 kg a.i /ha effective to control established broad leaved weeds. In addition to this for broad leaved weed control ethoxysulfuron (sunrise) @ 0.03 kg a.i/ha (75 g/ha) is applied at 20 days. Chlorimuron-ethyl and metsulfuron at 0.03-0.06 and 0.004 kg/ha, respectively, are used to control broad- leaved weeds. Fenoxaprop-p-ethyl (puma super) 0.05-0.075 kg/ha is effective to control both grasses and sedges. Broad spectrum weed control can be achieved by pretilachlor 0.75 and pyrazosulfuron ethyl 0.025 kg/ha.

There may be some varietal differences in rice in respect of their tolerance to the recommended herbicides. For instance, ADT-36 and ADT-38, PY-3 varieties of rice in Tamilnadu and HPU-845 and HPU-846 in Himachal Pradesh have been found to susceptible to butachlor because of their very low α-Amylase content. Similarly cv. IR-50 has been reported susceptible to oxyflourfen because of its very low chlorophyll content.

Low land /transplanted rice

Pre- emergence application of butachlor 1.5-2, anilophos 0.25-1.0, oxadiargyl 0.07- 0.125, clomazone 0.2-0.25 and acetachlor 0.10-0.15 kg/ha to control grasses and broad-leaved weeds. Where as 2,4-D easter G (0.8-1.2 kg/ha) controls sedges and broad-leaved weeds and chlorimuron-ethyl (0.01 kg/ha) to control BLW. Herbicides should be applied 4-7 DAT. The field should not be drained till 7 days to obtain satisfactory weed control.

Post-emergence herbicides are effective at 4-6 weeks after transplanting. The field should not be drained before the application of post emergence herbicide. Fenoxaprop-P-ethyl 0.075-0.120, cyhalofop-butyl 0.06-0.75 kg/ha to control grasses and ethoxysulfuron 0.02 kg/ha for BLW should be applied 10 DAT. Cinosulfuron (0.02 kg/ha) used as pre and post emergence herbicide to control grasses and broad leaved weeds. Where as 2,4-D and MCPA (0.75-1.5 kg/ha) used to control sedges and broad leaved weeds.

For controlling unwanted algal growth in the rice fields copper sulphate and copper oxychloride @ 8-10 kg/ha have been used since long time. But now more effective products like brestan -60 (0.07-1.7 kg a.i /ha) and potassium azide are available for this purpose.

Integrated Weed Management (IWM)

IWM involves the concept of multiple tactics of weed management, maintenance of weed population below economic injury level and conservation of environment quality. A successful IWM strategy has the principles of enhancing farmer's profitability, environmental protection and responsiveness to consumer preference.

Weeds vary so much in their growth habit and life cycle under different ecosystems and growing seasons that no single method of weed management can provide efficient weed control. Continuous use of one method of control creates problems of buildup of weeds that are tolerant to that particular method of weed control. Similarly shift in weed flora from annual grasses to sedges in transplanted rice and appearance of resistant biotypes due to continuous use of some herbicides has been reported (Mukhopadhyay 1996). Table 4.1 illustrates importance of long term strategies to minimize weed problems through weed management than with weed control.

Table 4.1. Difference between weed control and weed management (Kon 1993)

Structure	Weed control	Weed management
Goal	Maximize crop yield and profits	Optimize long term farm productivity
Objectives	Eradicate weeds from crops.	Maintain weeds below level of significant competition with crop
Approach	Use one or two of the easiest, most effective methods suited to the	Balance the best available methods suited to the farming system

Structure	Weed control	Weed management
	crop	
Action	Employ full tillage technology, apply full rate of herbicides	Employ minimum tillage, minimum effective rate of herbicide and integrated agronomic practices to increase competitive ability of the crop.
Outputs	Near perfect elimination. High crop yield	Substantial reduction of weed pressure, optimum farm profit.
Application	Wide geographical regions	Adapted to specific locations/areas.

Major components of IWM are

- Monitoring of weeds, weed shifts, appearance of resistance weeds and introduction of new weeds.
- Emphasis on ecological, biological and biotechnological methods for environmental safety.
- Low cost agronomic technology for weed management in IWM system.
    - Stale seed bed
    - Balanced fertilizer use
    - Higher plant population
    - Intercropping/relay cropping
    - Supplemental herbicide use at maximum possible rate.

Monitoring of weeds

Systematic monitoring of weeds would help to device effective ways to tackle current emerging problems of weed shifts. Similarly, appearance of propanil resistant biotypes of *Echinochloa* sp in rice has become a problem.

Ecological control

Attacking ecological weak points of weeds during field operations such as ploughing, water management, crop season and crop rotation can minimize the weed problem considerably. Ploughing causes change in perpendicular distribution of weed seeds with the soil and inhibits their emergence, especially annual weeds which emerge from soil surface layer.

Ploughing: In perennial weeds, ploughing is effective to control emergence in weed species whose propagules are formed at relatively shallow position within the soil as *Eleocharis acicularis*, *Sagittaria pygmea* and *Cyperus secrotinus*.

Water management: Weed suppressing ability of standing water has long been recognized. Growth of broadleaf aquatic weeds such as *Monochoria vaginalis* is suppressed at saturation or field capacity, while growth of low moisture requiring grasses *Echinochloa crusgalli* is suppressed at greater (25 cm) water depth (Moody 1991). Water management can substitute for weeding in transplanted rice. Grasses can be eliminated if continuous 10-15 cm submergence is maintained throughout the crop period. In much of northeast India, rainfed transplanted rice does not have much competition from grass weeds due to standing water during monsoon season.

Crop rotation: Rotating lowland rice with an upland crop to control moisture-loving weeds is an effective weed control method. The population of *Scirpus maritimus* increases with continuous cropping of lowland rice but decline when the rice is rotated with an upland crop. Similarly, population of *Cyperus* and *Echinochloa* sp can be considerably brought down by rotating rice with an upland crop.

Biological control

Biological control using insects, fish, snails and pathogens is gaining importance to reduce the input of herbicides. In India, biological control of aquatic weeds has shown promising results as indicated below:

Weed	Biocontrol agent	Place of release
Alternanthera	*Cassida* sp	Southern states
Philozeroides	*Cassida syritica*	Southern states
Pistia stratiotes	*Namagana pectinicoris*	Kerala
Salvania molesta	*Cryto salviniae*	Kerala
	Myrothecium rovidium (Fungal	Bangalore

Weed	Biocontrol agent	Place of release
	pathogen)	
Ludwigia adscendens	*Haltica carculca* (beetle)	Bangalore
	Nanophyes sp (beetle)	Bangalore
Cyperus rotundus	*Athespacuta cyperi* (weevil)	Bangalore
	Bactra minima (Stem borer)	Bangalore
	B. venoane (stem borer)	Bangalore

Biotechnology in weed control

The microbial toxins and alleochemicals could be manipulated to produce commercial herbicides. Bioherbicides Collego and biolopas are used for controlling grass and broadleaved weeds in rice. In India, bioherbicides for weed control have not yet developed to the extent of practical application.

Agronomic practices

Agronomic measures, necessary for higher yields, are at the same time are directed at preventing mass multiplication of weeds.

Stale seedbed technique: It involves the removal of successive flushes of weeds before sowing rice. Weeds that germinate after land preparation are destroyed mechanically, manually or chemically. In mechanical or manual method, soil disturbance should be as shallow as possible.

Crop stand: Closer the spacing or higher the seed rate for rice, better it can compete with weeds due to its smothering effect on weeds.

Fertilizer management: N application should be timed to prevent weed proliferation and yet to obtain maximum benefit from the applied fertilizer. Application at early growth stage may intensify weed problem. With dry seeded rice, basal application should be delayed until weeds are removed. In lowland rice, N top dressing after weeding is desirable for minimizing weed growth and increasing N use efficiency.

Intercropping and relay cropping: intercropping upland rice with groundnut, soybean, or green gram minimizes weed density leading to yield advantage. A pulse crop is usually broadcast as relay crop into standing rice crop 10-15 days before harvest. As soon as rice crop is harvested the pulse crop cover the field in dry season and suppress the weed growth.

Cultivars: high yielding dwarf cultivars are less competitive against weeds than traditional cultivars. For rainfed areas, heavy tillering varieties of medium stature may be better suited than semidwarf varieties.

Herbicides

Herbicides should be used as a supplement and at lower rate as possible by proper selection of the chemical, timing and method of application. Fast degradable, low dose, high efficiency with little toxicity to environment namely sulfonylurea herbicides (7-10 g/ha) are as effective as standard herbicides like butachlor, oxadiazon, anilophos etc for use in transplanted rice. Non chemical methods of weed control when integrated with one manual weeding are as effective as standard rice herbicides at different ecosystems throughout the country.

Management of wild rice in rice

Several species of the genus *Oryza* behave like a weed even though they share most of the features of the cultivated varieties. They are undesirable, above all, because their seeds can easily shatter before crop threshing and remain dormant in the soil for a long period of time. Weedy rice varieties are usually very similar to commercial varieties, both as regards plant morphology and tolerance to herbicides. Because of their high competitive ability, these weeds can remarkably affect rice yields.

The effective control of weedy rice cannot be based on one single practice, but should rely on complex management programme based on an appropriate combination of preventative, cultural, mechanical, chemical and genetic means (Vidotto *et al.* 2001) (Table 4.2). Preventative practices, which include the use of weedy rice-free seed and clean equipment, are the starting point for a successful application of other means of control. Of the cultural practices, rotation is frequently the best way of reducing severe weedy rice infestation. In continuous rice cultivation, an

effective control of the weed can be obtained by applying the stale seed bed method to stimulate weed germination and by destroying the seedlings through harrowing or with herbicides.
The spread of weedy rice seeds can be successfully prevented in crop post-planting both by panicle cutting or the localized application of systemic herbicides, but these measures should be aimed more at preventing the infestations from becoming worse, rather than reducing them.
The introduction of herbicide-resistant varieties offers rice growers a good opportunity to manage weedy rice and other weeds, even though its success depends on how well the cultivation strategies can avoid the transfer of resistance genes to weeds.

Table 4.2. Main weedy rice control strategies and methods

Control strategy	Control method
Preventative	Certified seed
	Cleaning of machinery
Cultural	Rotation
	Soil tillage
	Stale seed bed preparation
	Water management
	Rice variety
	Hand weeding
Mechanical	Before rice planting
	After rice planting
Chemical	Before rice planting
	After rice planting
Genetic	Rice varieties tolerant to total herbicides

Detail of chemical weed control
The close anatomical and physiological similarity to the crop makes the control of weedy rice plants with selective post-emergence herbicides very difficult. The most successful management technique is based on herbicide application before crop planting, both before and after emergence of these weeds.
Several antigerminative herbicides such as chloroacetamides, thiocarbamates and dinitroanilines applied alone or in mixtures with other herbicides proved to be effective on weedy rice before its emergence (Khodayari *et al.* 1987; Griffin and Harger, 1990; Noldin *et al.* 1998,). Good control of these weeds (often higher than 75 percent) can be obtained in European rice conditions with pretilachlor and dimethenamid used alone or in combination at 1.5 kg ha^{-1} and 0.48 kg ha^{-1}, respectively (Ferrero and Vidotto, 1999). To avoid any phytotoxicity risks, both herbicides need to be applied at least 25 days before rice planting.
The main thiocarbamate herbicides that are used to control weedy plants are molinate and butylate (Smith, 1981; Fisher, 1999; Garcia de la Osa and Rivero, 1999). Both products are applied in pre-planting and need to immediately be incorporated into the soil to avoid volatilisation. According to the experiments carried out by CIAT in Central and South America, the best results can be achieved by applying molinate at 7.2 kg ha^{-1} and butylate at 4.2 kg ha^{-1} with seed protectants such as oxabetrinil at 1.5 g kg^{-1} and flurazole at 2.5 g kg^{-1} (Smith, 1992).
In continued flooded monocultures, an effective management of weedy rice is often achieved through the application of the stale seed bed technique followed by spraying of the graminicides or total herbicides once the weeds have reached the 2-3-leaf stage at least (Vidotto *et al.* 1998). The most frequently applied graminicides are dalapon (about 12 kg a.i. ha^{-1}), clethodim (0.2 kg ai ha^{-1}) and cycloxydim (0.6-0.8 kg ai ha^{-1}). Other wide spectrum herbicides are glyphosate (1-1.5 kg ai ha^{-1}), glufosinate ammonium (0.5-0.7 kg ai ha^{-1}), paraquat (0.8 kg ai ha^{-1}) and oxyfluorfen (0.8 kg ai ha^{-1}). Graminicides are highly effective even at early stages of the weeds while total herbicides have to be applied on more developed plants. Delaying the treatment to a more advanced growth phase of the weeds implies the planting of very early and sometimes low-yielding varieties.
Chemical control in crop post-planting should only be considered as a 'salvage' operation and mainly relies on difference in size or growth stage between weedy rice and commercial rice. This practice prevents the infestation from becoming worse thanks to the grain shattering, but has no influence on the weed-crop competitive relationships.
Weedy rice that has grown taller than rice can be treated with foliar systemic herbicides such as glyphosate or cycloxydim, at 20 and 5% concentrations, respectively, by using wick/wiper applicators. This equipment wipes the herbicide over the top of the weeds and, owing to the difference in height between these plants and the crop, prevents contact with the desirable vegetation. Wick/wiper applicators are usually made up of a frame with a rope,

sponge or carpet which can absorb the herbicide solution and wipe it onto the weed (Stroud and Kempen, 1989). They can be mounted on self-moving machines, the front of a tractor or hand-held equipment. The results of the treatments carried out with this equipment on semi-dwarf varieties at the beginning of the weedy plant flowering showed a higher than 90% germinability reduction of the weed seeds (Balsari and Tabacchi, 1997; Ferrero and Vidotto, 1999). This percentage concerned only the seeds of the weed panicle that come in contact with the wiping equipment. About one-third of the panicles in the experimental field escaped the treatment as they were equal to or lower in height than the crop. The seeds of the escaped panicles, on one hand, can feed the soil seed bank, but on the other, can select short biotypes for the following years that can no longer be controlled with this equipment.

The seed viability of weedy rice can be affected by spraying maleic hydrazide at the heading stage of these plants (Noldin and Cobucci, 1999). To avoid negative effects on the yield and seed viability, commercial rice plants have to be earlier and to have reached the milky-stage. The use of this growth regulator has been approved in Brazil and is being tested in several countries in South America.

Wheat

The weeds reduce grain yield up to 10-70% and competition is during first 30-60 days after sowing the crop. In India, *Phalaris minor* in moisture retentive and *Avena fatua* in light soils are the biggest threats to wheat production (Gupta 1998). Besides *Phalaris minor* and *Avena fatua, Lolium temulentum, Lolium rigidum; Polypogon monspeliensis* and *Poa annua,* have threatened wheat production in Asian and African countries. In some areas perennial weed *Cynodon dactylon* is noxious in wheat field. The common broad leaved are: *Chenopodium album, Chenopodim murale, Fumaria sp, Vicia sp, Melilotus alba*, *Lathyrus sp. Anagalis arvensis*, *Carthamus oxycantha and Circium arvense.*

Cultural Management

Grass weeds such as *Phalaris* and *Avena* sp are difficult to identify from wheat during early stages. Closer row spacing for wheat (22.5 cm) or broadcast seeding does not permit inter-cultivation. As such manual weeding is the only option. Hand weeding twice at 4 and 6 weeks after seeding because of narrow row spacing is recommended. In heavy soils, it is very slow and costly operation.

Use of herbicides

Several herbicides are used in conjunction with good crop husbandry to control specific weeds.

Pre emergence: Diuron and linuron 0.5 -1.0 kg/ha are effective to control grasses, broad leaved weeds, where as linuron is effective to control sedges also. Pendimethalin and trifluralin 1.0 & 0.5 -1.0 kg/ha are effective to control grasses and broad leaved weeds.

Post emergence: Sodium and amine salts of 2,4-D and MCPA @ 0.75 kg -1.0 kg a.e /ha should be sprayed at CRI for dwarf wheat varieties, where as for tall varieties 40-50 day after sowing that is at active tillering stage or 5-6 leaf stage @ 2.0 kg a.e /ha of sodium and 1.5 kg a.e/ha of amine form and 0.75 kg a.e/ha of easter form. Irrigation should be given before sowing. It is to avoid the leaching of herbicide to the crop roots. The roots of grain crops are very sensitive to the phenoxy herbicides. Recently fluroxypyr (0.1-0.3 kg/ha) has been found a very good substitute for 2,4-D for broad leaved weed control. At hard dough stage 2,4-D and MCPA employed to destroy the late weeds like *C. oxycantha; C. arvense,* to prevent grain contamination. To control difficult broad leaved weeds like *Gallium*, *Anthemis*, *Stellaria,* and *Matricaria* terbutryn 0.75 kg – 1.0 kg /ha and sulfonylurea 0.07 kg/ha are applied .

Post emergence control of *P. minor and A. fatua* can be achieved by either isoproturon 0.75 kg/ha (15-20 DAS) or methabenzthiazuron 0.75-1.5 kg/ha. Isoproturon can be used as pre and post emergence herbicide. Metoxuron 1.5 kg/ha and bromoxymil and ioxynil @ 26 to 56 g/ha against broad leaf weeds (2-leaf to full tillering stage).

Alternate herbicides for control of isoproturon resistance P. minor

Metribuzin @ 0.245-0.315 kg/ha as pre & post and sulfosulfuron @ 0.025-0.050 kg/ha herbicides are effective for both grass and broad leaved weeds. Whereas fenoxaprop- P- ethyl (0.062-0.12 kg/ha) and mesosulfuron-methyl (0.01-0.030 kg/ha), and tralkoxydim (0.35-0.4kg/ha) control grasses like *P. minor* and *A. fatua* than broad leaved weeds.

The other herbicides are clodinafop 0.03-0.05 kg/ha at 30 DAS, chlorsulfuron 0.03-0.04 at 30 DAS, metsulfuron 0.004 kg/ha + isoproturon 0.75 kg/ha at 15-20 DAS and isoproturon 0.75 kg/ha + 2,4-D 0.4-0.5 kg/ha. *Poa annua*, an annual grass is becoming problematic in wheat (Gupta 1998) after the spray of clodinafop as it is ineffective against this weed (Rana et al 2016). It has been reported susceptible to sulfonylurea herbicides at 0.28-0.70 kg/ha at early growing stage.

The following herbicides can be used for weed control in intercropping systems:

Cropping system	Herbicides
Wheat + mustard	Pendimethalin or oxyfluorfen (pre)
	Isoproturon
Potato + wheat	Isoproturon or pendimethalin (pre)
Wheat + chickpea	Pendimethalin + isoproturon (pre)

Barley

Wheat and barley are two *rabi* cereals. As such, wherever soil and environment are not ideal for wheat, as a cereal crop, barley is the only option. Weeds are usually, controlled by hand weeding within a month after sowing. Herbicide use is uncommon. If necessary, a herbicides recommended for weed management in wheat crop can be applied for weed control in barley crop also.

Maize

Maize crop is sensitive to weed competition during early growth period due to slow growth in the first 3-4 weeks. Critical period of weed competition is upto 40-45 DAS. Maize yield was reduced as much as 25-80%. Weeds associated with maize are *Echinochloa colona*, *E. crussgalli*, *Panicum dichotomiflorum, Cyperus rotundus, Cyperus esculentus, Cynodon dactylon, Celosia argentia, Commelina benghalensis, Phyllanthus niruri and Amaranthus viridis.*

Cultural methods

Wider row spacing for maize is convenient for weeding between the rows with bullock or tractor drawn implements. Weeds within the rows can be removed by manual weeding. One or two inter-cultivations with implements followed by manual weeding can effectively control the weeds. It should be started with 15 cm crop whorl height and continue up to 60 cm crop height. There should not be any inter-cultivation after flowering to avoid damage to maize crop. Selective crop stimulation may be an important practice to minimize weed infestations.

Use of herbicides

Herbicides which can prevent weed establishment during the first 6 weeks are very useful in maize.

Pre-plant incorporated

Trifluralin 0.8-1.20 kg/ha, butylate 4.0-6.0 kg/ha and EPTC 2.0-4.0 kg/ha provide season long control of nutgrass and many annual weeds.

Pre-emergence

Pre-plant incorporation of butylate or EPTC 3-4 kg/ha, (G + BLW) mixed with 0.5 kg/ha of atrazine or simazine controls nut grass and many annual grasses. Treat the seed with NA or add R25788 to spray tank. EPTC formulation containing R25788 is available in the market. Butylate should not be used on high pH soils.

Pre-emergence application of atrazine & simazine @ 1-2 kg/ha effectively controls grasses and broad leaved weeds. In dry conditions, where less moisture in field occurs, atrazine is preferred over simazine. Atrazine herbicide can be applied at any stage of crop i.e pre (or) post emergence as it dissolves easily in water.

Alachlor and metolochlor 1-2 kg/ha as pre-emergence are effective against annual grasses but these are weak on broad leaf. Pendimethalin 1-1.5 kg /ha is effective for control of grasses, broad leaved weeds and sedges.

Other pre-emergence herbicides which can give good control of mixed weed spectrum include acetachlor 1.5-2.0 kg/ha + safener, dimethenamide 0.8-1.6 kg/ha, oxyfluorfen 0.25-1.0 kg/ha, imazaquin 50-70 g/ha, halosulfuron 70-80 g/ha + safener, fluchloralin 1 kg/ha, oxadiazon 0.5-0.75 kg/ha, terbutryn 1-2 kg/ha and trifluralin 1.5-2.0 kg/ha.

Combinations of atrazine + alachlor or atrazine + pendimethalin are more effective on a spectrum of weeds including grasses and broadleaved weeds. A tank mix of 0.42 kg alachlor/ha + 0.25 kg atrazine/ha + 5% phytobland oil emulsion can be used to broaden the spectrum of weed control.

Post emergence

2,4-D or MCPA (0.25- 0.5 kg/ha) used as directed spray between 8 and 25 cm whorl height stage of crop to control the broad leaved weeds. Atrazine shows good post activity when tank mixed with phytobland oil and applied at 2 to 4 leaf stage. Other herbicides are metsulfuron 0.30-0.50 kg/ha, nicosulfuron 30-50 g/ha, primsulfuron 20-40 g/ha, prosulfuron 15-30 g/ha and flumiclorac 30-60 g/ha. Tembotrione 125-150 g/ha with or withour surfactant is very effective post-emergence herbicide in maize for controlling a large number of weeds. Tembotrione was first launched as a maize herbicide in 2007 by Bayer Crop Science (Gatzweiler *et al*. 2012). Tembotrione inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) efficiently in numerous weed species. HPPD is an enzyme of the biosynthetic pathway that converts tyrosine to plastoquinone and tocopherol. Plastoquinose is a cofactor for the phytoene desaturase, a component of the carotenoid biosynthetic pathway. The depletion of plastoquinone levels by inhibition of HPPD results in depletion of carotenoids and an absence of chloroplast development in emerging foliar tissue which then appears bleached and stunted (Hawkes 2007). As carotenoids play key role in photosynthesis and in photo-protection there is clear involvement of light in the expression of herbicidal activity of HPPD inhibitors.

Sorghum

The environment in which sorghum is grown favours germination and growth of weeds. Sorghum crop is a poor competitor when young and always have competitive edge. Weed seed germinate 2-3 days earlier than the sorghum seed since the weed seed will be in the soil, ideal for germination, before the sorghum seed is sown. Seedling growth of sorghum at the establishment is much slower than weed growth. The weed species usually associated with sorghum are: *Solanum nigrum*, *Lucus aspera*, *Cyperus rotundus*, *Cynodon dactylon*, *Phyllanthus niruri*, *Sorghum halepense*, *Digera arvensis*, *Dactyloctenium aegypticum*, *Celosia argenetena*, *Digitaria sanguinalis*, *Euphorbia hirta* and *Eleusine indica*.

The critical period of crop weed competition is 15 – 45 days after sowing. Reduction in grain yield of sorghum due to weeds varies from 15-40% depending on the intensity of infestation.

Cultural management

Off season tillage (harrowing, deep ploughing) can considerably bring down the weed population leading to optimum sorghum yield. Deep ploughing could reduce the weed growth by 50% and increased grain yield by 35% (Bhan et al 1998). Since row spacing for sorghum is wide enough for intercultivation, harrowing between the rows can minimize the weed problem. However, hand weeding is necessary for intra-row weed control. Working blade harrow twice followed by one hand weeding resulted in grain yield of 2.5 t/ha as against 1.7 t/ha with no harrowing and hand weeding. Off-season tillage, inter-row harrowing and hand weeding when judiciously combined, there may not be any necessity for chemical weed control. Harrowing and other field operations are often not possible when the crop is too tall to permit such operations. Hence, cultural operations early in the season are very essential.

Use of herbicides

Trifluralin 0.75-1.0 kg/ha is pre-plant incorporated herbicide. Atrazine and simazine at 0.5-1.0 kg/ha, propazine 1-1.5 kg/ha, tributrin 0.75-1.50 kg/ha, alachlor 1.0-1.5 kg/ha, isoproturon 0.75-1.5 kg/ha, metolachlor 1.5-2.0 kg/ha, and pendimethalin 1-1.5 kg/ha are effective as pre-emergence.

2,4-D 1 kg/ha is a versatile post emergence herbicide to control broad leaved weeds. It is also used to prevent Striga. The other post emergent herbicides are metribuzin 0.75-1.50, halosulfuron 30-40 g/ha and prosulfuron 15-30 g/ha.

Striga control

Striga litura (witch weed) is the common root parasite on sorghum. Stimulating germination of seed in the soil and destroying by tillage after they germinate can effectively control Striga. Crop rotation with legumes or other trap crops which produce chemical stimulant necessary for *Striga* seed germination but not parasitized by the witch weed and catch crop, which stimulate germination but parasitized by the weed, offer effective control. Trap crops helps to germinate *striga* seeds but makes *striga* not to form hostoria. Cotton, soybean, cowpea, chickpea, sunflower, groundnut and pigeonpea are effective trap crops. Catch crops are sorghum, maize and millets to reduce seed bank in the soil.

Pre-plant incorporation of fenac 1.0 -1.5 kg /ha or 2,3,6-TBA is effective against striga control. Pre-emergence herbicides simazine, atrazine and propazine can give effective control of this problem weed. Post emergence application of 2,4-D 1.0 kg/ha as at 5th week after sowing is more effective.

Pearlmillet

Like sorghum, pearlmillet is rainfed crop in arid and semiarid regions. Weed species of pearlmillet are the same as that in rainfed sorghum crop. Weed competition is acute during early stages of pearlmillet when the crop growth is relatively slow. Critical period of weed competition is upto 35 days after seeding. Instances of grain yield loss upto 60% due to unchecked weed growth are common.

Cultural management

Due to wider row spacing (30-45 cm), local intercultivation implements can be used for minimizing weed growth. Weeds within the row can be removed by hand weeding. Two inter-cultivations, 15 and 30 days after seedling emergence with one hand weeding around 20 or 35 days after seeding is adequate to minimize the losses due to weeds. In situations where intercultivation and manual weeding is not possible, use of herbicides is the only option for weed control.

Use of herbicides

The effective herbicides are atrazine (0.5-1.0 kg/ha), simazine (1.0-1.5 kg/ha), pendimethalin (0.75-1.5 kg/ha), tebutryn and propachlor (1-2.0 kg/ha) for light soil, and norea (1.0-2.0 kg/ha) and fluometuron (1.0-1.50 kg/ha) for heavy soils. Pre-emergence pendimethalin gives good preventive control of a wide spectrum of weeds without affecting pearlmillet. A follow up of 2,4-DEE (0.25-0.5) controls most of the late emerging broadleaf weeds and some annual grasses. As pearlmillet is sensitive to most herbicides, mixing a safener could increase the margin of selectivity to them.

Fingermillet

Intercultivation with tined implements improves considerable wed infestation. Two to three such intercultivations coupled with hand weeding, generally suffice to keep the weed population under threshold under rainfed conditions. Weed problem is greater in drilled or broadcast crop under dryland conditions than transplanted irrigated crop. The critical stage for crop-weed competition is between 20 and 35 days after sowing. In rainfed crop, first weding should be completed within 3 or 4 weeks of seeding. Both transplanted and direct seeded crops need two or three intercultivations and one hand weeding. Even when herbicides are used for weed control, intercultivation is necessary to provide favourable environment in root zone. Pre-emergence nitrofen (0.5-1.0 kg/ha) has been recommended for sole finger millet crop. Pendimethalin (0.75-1.50 kg/ha) as pre-emergence application can give good control of a wide spectrum of weeds. Post emergence application of 2,4-DEE (1.0-1.50 kg/ha) is effective against broadleaf weeds.

Foxtail millet

Rainfed foxtail is usually sown by drilling with adequate row spacing for using intercultivation implements. Two to three intercultivations followed by one hand weeding is adequate to minimize the losses due to weeds. Critical period of crop-weed competition is 20 to 35 days after sowing. First intercultivation should be before 20 DAS and the second before 35 days after sowing. Herbicides are not, generally, used for weed control in foxtailmillet.

Chickpea

Weeds are problematic both in rainfed and irrigated chickpea because of its short growing nature. Weed problem is severe under irrigated than in rainfed conditions. Weed problem in rainfed crop can be minimized with inter-cultivation since the crop is drilled with a row spacing of 30-45 cm. The herbicides effective against weeds in chickpea are: fluchloralin 0.5-1.0 kg/ha and trifluralin 0.50-0.75 kg/ha as pre plant incorporation; bentazon (1.0-1.5 kg/ha), pendimethalin (0.50-1.5 kg/ha), isoproturon (1.0-1.25 kg/ha), metolachlor (1.0-1.5 kg/ha), and oxadiazon (0.5-1.0 kg/ha) as pre-emergence. Preemergence application of pendimethalin 0.50 kg/ha + imazethapyr 50 g/ha is an effective treatment. Quizalofop-ethyl 0.04-0.05 kg/ha is an effective post-emergence treatment to control annual grasses. In several situations, integrated weed management appears to be more economical and effective. Use of pre-emergence herbicides followed one hand weeding 45 DAS appears to be effective against all the weeds leading to economic chickpea production under different situations.

Greengram and blackgram

Weed are major problem in rainy and postrainy season greengram as compared with summer irrigated crop. Critical period of weed competition varies from 30-40 DAS. Yield reduction is upto 50%. Due to wider row spacing of about 30 cm there is scope for intercultivation using local blade harrows. A single hand weeding around 40 DAS can remove weeds within the row.

Two such inter-cultivations may be required at 15 and 30 days after seeding. Alternatively, two weeding during the first 35 DAS may be given for effective control of weeds. Herbicide use may prove uneconomical due to low yield levels of greengram/blackgram under rainfed situations. If the row spacing and soil condition does not permit intercultivation and hand weeding, use of herbicides is the only option. Any of the herbicides can be used against weeds in these crops:

Pre-plant incorporation of pendimethalin or fluchloralin 0.75-1.00 kg/ha or pre-emergence application of alachlor 1.5 kg/ha or pendimethalin 1.0 kg/ha or linuron 0.75 kg/ha, acetachlor 1.0 kg/ha or imazethpyr 0.1 kg/ha or premix imezethapyr + pendimethalin 800-900 g/ha (Singh et al. 2016) to control grasses and broad leaved weeds or Post-emergence application of fluazifop-P-butyl 0.25-0.375 kg/ha or clodinafop-propargyl 0.375-0.75 kg/ha, or quizalofop-ethyl 0.5-1 kg/ha for control of grasses.

Cowpea and Horse gram

Weed management is almost similar to that of other pulses.

Lentil

Lentil crop is poor competitor due to slow initial growth. The first 45-60 DAS is the critical period of weed competition. Hand weeding at 30 and 60 DAS is the traditional practice. Pre-emergence herbicides such as prometryn (1.0-1.5 kg/ha) and pendimethalin or premix imezethapyr + pendimethalin 1.0 kg/ha (Chandrakar et al 2016) can effectively control the weeds in lentil crop. However, herbicide use is not economical under several situations due to low yields.

Pigeonpea

Pegeonpea has characteristically slow initial growth rate making it less competitive with weeds. Reduction in yield could be upto 90% if weeds are not controlled in time. Some of the common weeds with pigeonpea are *Cyperus rotundus*, *Echinochloa* sp, *Celosia argentia*, *Digitaria* sp, *Commelina benghalensis*, *Amaranthus* sp, *Phylanthus niruri* and *Euphorbia* sp.

In traditional production system, intercropping is able to reduce weed infestation by 50-70%. Intercropping of maize and sorghum can suppress weeds for longer period. With short season pigeonpea, fast growing cereals are unsuitable intercrops. However, low stature crops such as cowpea, green gram, blackgram, groundnut and soybean as smother crops can minimize the weed problem. Short season pigeonpea can take advantage of high plant density even when grown as sole crop. Critical period for weed competition is first 40-60 days. For short season pigeonpea, the first 30 days appear critical, although this period may vary with the genotype and time of sowing.

Being a long duration crop it requires 2-3 hand weedings (25 and 45 DAS). It is drought tolerant crop and herbicidal recommendations are not economical. However, a number of herbicides have been found useful for pigeonpea systems.

Fluchloralin 1.0 kg/ha is used as pre-plant incorporation. Pre-emergence application of pendimethalin 0.75-1.0 kg/ha or alachlor (1-1.5 kg/ha) or metolachlor 1.0-1.50 kg/ha, oxadiazon 0.75-1.0 kg/ha or prometryn 1.0 kg/ha are used to control grasses and broad leave weeds.

Post-emergence application of quizalofop-ethyl 0.04-0.05 kg/ha for control of annual grasses. Paraquat 1.0 kg/ha can be used to control weeds that have already germinated at the time of sowing. There is no toxic effect even when it is applied 4 weeks after sowing. It is a common experience that herbicides are slightly inferior to hand weeding in pigeonpea. It is therefore suggested to give a hand weeding at 40-45 days after sowing in herbicide applied fields. Marginal superiority of Oxadiazon and pendimethalin have been indicated, since they are effective for longer period than other recommended for weed control in pigeonpea.

Soybean

First 6 to 7 weeks after seeding is the critical period for crop-weed competition. Clean cultivation is therefore, essential during the critical period.

Cultural management

Since soybean is sown in rows, bullock drawn harrows can be used for controlling the weeds. Tow inter-cultivations, first at 20-30 DAS and the second around 45 DAS along with manual weeding can maintain the soybean field weed free for economic yield.

Use of herbicides

A wide range of soil and foliage applied herbicides provides moderate to excellent control of a wide range of weeds

infesting soybean crop. Among pre-plant incorporated herbicides fluchloralin 1.0-1.5 kg/ha, acetochlor 1.0-1.50 kg/ha, vernolate 1.5-2.5 and trifluralin 0.75-1.0 kg/ha are important. Alachlor 1.5-2.0 kg/ha, clomazone 0.75-1.50 kg/ha, metriuzin 1.0-1.50 kg/ha, chlorimuron ethyl 4-8 g/ha, metolachlor 1.0-1.5 kg/ha, trifluralin 1.5-2.0 kg/ha, lactofen 1.0-1.5 kg/ha, oxyflurofen 0.5-1.0 kg/ha and imazethapyr 0.10-0.50 kg/ha are important pre-emergence herbicides.
Combinations of trifluralin and alachlor or triallate 1.0-1.5 kg/ha applied PPI is the best for season long weed control. Pre-emergence combination of pendimethalin 0.5-0.75 kg/ha and imazethapyr is also equally effective for weed free environment.

Groundnut

Weed problem is severe in early stage of groundnut because of its slow growth. The competition is from both grasses and broad-leaf weeds. The important weed flora is *Cyperus rotundus*, *Digitaria sanguinalis*, *Chloris barbata*, *Commelina benghalensis*, *Cynodon dactylon*, *Celosia argentia*, *Amaranthes viridis*, *Cleome viscose*, *Portulaca oleracea*, *Trichodesma indicum*, *Boerhavia diffusa* and *Eclipta alba*. Critical period for weed growth is 20-45 DAS. Losses are as high as 70%. When once pegging begins (40 DAS), there should not be any disturbance to pegs through manual or mechanical weeding.

Cultural management

Most common methods of weed control in groundnut are hand weeding and harrowing. Line spacing with a row spacing around 30 cm facilitates working with different types of bullock drawn implements. Intercultivation usually start around 10 days after emergence and continue upto 35 days after sowing at 10 days interval till pegging begins. Weeds within the rows are removed by hand weeding. Hand weeding is done twice first around 20 DAS and the second about 35 DAS. There should not be any intercultivation or hand weeding from 40 DAS.

Use of herbicides

Cultural methods alone may not provide complete weed free environment for groundnut crop and repeated cultural practices may be costly or labour may not be available for timely weeding. Under such situations, herbicide use is the only option. Any of the herbicides are effective against many weed species:

Pre-plant incorporation of fluchloralin 1-2 kg/ha or nitralin 0.5-1.0 kg/ha or pendimethalin 1.0-1.50 kg/ha or pronamid 1.5-2.5 kg/ha or trifluralin 0.5-1.0 kg/ha or metolachlor 1.5-2.0 kg/ha or imazethapyr 50-70 g/ha. These herbicides can be pre-plant incorporated or pre-plant surface. They will be effective only if rains or irrigation follow their application. Herbicides can be applied about 5 days before crop emergence.

Pre-emergence application of pendimethalin (2 kg/ha) or alachlor 1.5-2.0 kg/ha or metolochlor (0.75-1.0 kg/ha) or butachlor (1.0 kg/ha) or nitrofen (2-4 kg/ha) or oxadiazon (1-2 kg/ha) or oxyflourfen 0.25-0.50 kg/ha or prometryn 0.5-1.0 kg/ha. A mixture of oxadiazon and dinoseb each at 1.7 kg/ha gives excellent control of weeds besides reducing stem rot in groundnut.

Post-emergence application of fluazifop (0.125 – 0.250 kg/ha) 30-40 days after sowing groundnut against grasses especially C*ynodon dactylon,* imazethpyr 0.75 kg/ha for control of mixed growth of grasses and BLW and quizalofop-ethyl 0.4-0.5 kg/ha for control of annual perennial grass weeds.

Rapeseed and mustard

Brassicas are fast growing crops and are rarely infested with more than one flush of weeds. First 30 to 45 DAS is the critical period for crop-weed competition.

Cultural management

Initial weed growth can be effectively controlled with intercultivation in row planted brassicas. In a broadcast crop, one manual weeding within three week after seeding is adequate to check the weed growth. Therefore, weeds are smothered by fast growing brassicas.

Use of herbicides

Herbicide use in brassicas is limited because of their smothering effect on weeds. When required, herbicides can replace intercultivation or hand weeding. Pre or post-emergence treatment with nitrofen (1.5-2.0 kg/ha) or fluorodifen (1.5-2.0 kg/ha) at 2-3 leaf stage can effectively control the weeds in brassicas. Fluchloralin 0.5-0.75 kg/ha as pre-plant incorporated is also effective. Isoproturon 0.75-1.0 kg/ha both as pre-plant incorporated or pre-emergence and oxadiazon 0.5-0.75 and pendimethalin 1.0 kg/ha as pre-emergence are also effective for weed control in brassicas.

Sesame

Sesame is sensitive to weed competition during the first 15-25 DAS. A minimum of two weeding, one after 15 DAS and another 35 DAS are required to keep the field relatively weed free. Row seeded crop facilitates use of blade harrows for inter-cultivation. Inter-cultivation 15 and 35 DAS followed by one hand weeding keep the field free of weeds.

Use of herbicides

Herbicides use especially under rainfed conditions is very limited due to low yield, which may not compensate for the cost of herbicides. If necessary, alachlor 1.0 kg/ha or thiobencarb 2.0 kg/ha can be used as pre-emergence spray for effective control of weeds. Use of pre-herbicides followed by one hand weeding around 30 DAS is the most appropriate way of weed management in sesame.

Sunflower

It can be grown in all seasons. It is grown in rice fallows. Competition from weeds is more severe during early stage of crop growth. The critical period of crop weed competition is 4-6 weeks after sowing.

Cultural management

Sunflower is sown in rows wide enough to permit inter-cultivation using different blade harrow. Two inter-cultivations at 15 days interval commencing from 15 DAS and one hand weeding between the two inter-cultivations can effectively check the weed growth in sunflower.

Use of herbicides

Pre-plant incorporation of trifluralin 1 kg/ha or fluchloralin 1.0 1kg/ha to control grasses and broad leaved weeds. Pre-emergence application of pendimethalin (0.75-1.0 kg/ha), metolachlor1.0 kg/ha, alachlor 1.0-2.0 kg/ha, oxyfluorfen 0.25 kg/ha and butachlor 1-1.5 kg/ha to control grasses and broadleaved weeds.

Post-emergence application of fluazifop-P butyl 0.25 kg/ha 21- 25 DAS to control grasses.

Linseed

Linseed crop due to its slow initial growth, is a poor competitor with weeds. The critical period for weed competition is the first 30 DAS.

Cultural management

Adequate tillage prior to seeding can minimize the weed infestation. If the seed is drilled with rows spaced 30 cm apart, two inter-cultivations at 20 and 35 DAS with manual weeding is ideal to minimize the loss due to weeds.

Use of herbicides

In general herbicides for weed control in linseed may not be economical due to poor crop yield under rainfed conditions. If necessary, fluchloralin 1-1.50 kg/ha, pendimethalin 1.0-1.50 kg/ha or alachlor 1.0-1.50 kg/ha or isoproturon 1.0 kg/ha can be used for weed control in linseed crop.

Safflower

Safflower cannot compete with weeds upto 60 DAS. Since safflower is largely cultivated as an intercrop, the component crop acts as cover crop to suppress the weed growth.

Cultural management

Since, safflower is planted in wide rows (45-60 cm) intercultivation implements (harrows) can be used for weed control. Two harrowing at 25-30 and 45-50 DAS, depending on the length of rosette period and one manual weeding between can effectively check the weed growth.

Use of herbicides

Use of herbicides is not common in safflower cultivation. If necessary, any one of the following herbicides can effectively check the weed growth in safflower crop. Alachlor 1.5-2.0 kg/ha, metoxuron 2.5-3.0 kg/ha, fluchloralin 1.0-1.5 kg/ha and pendimethalin 0.75-1.0 kg/ha are effective pre-emergence herbicides. EPTC 2.0-3.0 kg/ha, trifluralin 1.50 kg/ha, nitralin 1.5-2.0 kg/ha and chlorpropham 3.5-4.5 kg/ha are pre-plant incorporated herbicides.

Niger

One hand weeding around 20 DAS is adequate to maintain weed free environment since niger is a good competitor for weeds. Herbicide use is not economical under several situations.

Castor

The wide row spacing and initial slow growing nature of the crop is ideal for weed growth. Critical period of weed competition is first 20-60 DAS.

Cultural management

In rainfed castor crop, two or three times inter-cultivation with bullock drawn blade harrows, starting from 20 DAS along with a manual weeding within the row can effectively check the weed growth. Square planting is adopted in certain areas to run the blade in both directions for effective weed control. In irrigated castor, 2-3 hand weedings at an interval of 15 days, starting 15 DAS can check the weed growth. Alternately, herbicides may be used against the weeds.

Use of herbicides

Preplant incorporation of fluchloralin 0.75-1.5 kg/ha or trifluralin 0.75-1.0 kg/ha or neptalam 3.5-4.0 kg/ha and EPTC 2 kg/ha are effective in castor crop. Pre-emergence application of alachlor 1-1.5 kg/ha, nitrofen 1.0-1.5 kg/ha, metolachlor 1 kg/ha and pendimethalin 1.5 kg/ha are economical in irrigated castor.

Sugarcane

For germination sugarcane takes about 20 to 30 days. *Sorghum halopense*, *Cynodon dactylon, Ipomea* sp. pose special weed problems. *Ipomoea hederacea* causes around 25% loss in cane yield by twining round the clumps. *Orobanche* (*Aeginetta indica*), root parasite is capable of producing certain enzymes that cause degeneration of sucrose in cane plant to the extent of 75%. On an average mixed weed flora cause upto 80% or more yield reduction. The predominant weeds infesting sugarcane are: *Cyperus rotundus*, *Lipida nodiflora*, *Eclipta alba*, *Commelina benghalensis*, *Cleome viscosea*, *Trianthema portulacastrum*, *Coccinia indica*, *Sporobulus diander*, *Amaranthus viridis*, *Amaranthus spinosus*, *Digera arvensis*, *Asphodelus tenuifolius*, *Euphorbia hirta*, *Anagallis arvensis*, *Chenopodium album*, *Phyllanthus niruri*, *Convolvulus arvensis* and *Protulaca oleracea*. From the results of experiments at different sugarcane growing areas in India, it is estimated that weeds take away about 160 kg N, 25 kg P_2O_5 and 200 kg K_2O/ha.

Critical period of weed competition

In sugarcane fields, weeds get adequate time and space to germinate and establish well before the crop is able to compete. Hence, weeds pose tough competition to crop until the grand growth phase (150 days after planting) sets in. Generally, sugarcane is most sensitive to weed competition/infestation during tillering. Sugarcane crop should be kept weed free during its tillering phase, which under north Indian conditions falls between 60-120 days after planting for spring planted crop. Autumn planted cane crop in central, eastern and western parts of UP requires weed free environment from November to June. Sugarcane in general, requires weed free environment for the first 90-100 days before the rapid close in of the cane canopy.

Cultural Management

Deep summer ploughing and inclusion of short duration crops in intensive cropping systems are effective in minimizing the weed infestation. Inclusion of lowland rice in sugarcane based cropping systems can effectively checks *Cyperus rotundus*. Hand weeding, digging with spades and inter-cultivation using three tined cultivator are commonly used for weed control in sugarcane crop. Removal of weeds by hands at 30, 60 and 90 DAP is the best among all the cultural and mechanical methods of weed management. Sugarcane trash mulching at 7.5-10 t/ha to an average thickness of 10 cm over the soil surface is effective against many weeds besides soil moisture conservation. Optimum stage of trash mulch is 45 DAP which does not create hindrance to germination and tillering of sugarcane and also suppress excessive tillers. Intercropping green gram, black gram, cluster bean, onion, okra in autumn planted crop also reduces competition from weeds.

Use of herbicides

Pre plant incorporation of vernolate (3-4 kg/ha) for effective control of nutsedge and annual grasses for 4-6 weeks. Atrazine / Simazine (1-2 kg/ha) hold the weeds for 4-6 weeks. Vernolate (3-4 kg/ha) + simazine (0.5-1.0 kg/ha) for the control of broad leaf weeds. Atrazine (0.25 kg/ha) + 2,4-D (1 kg/ha) couple of days before crop emergence is a substitute for blind hoeing and effective for nutsedge & broad leaf weeds. Metribuzin (0.75 – 3 kg/ha) is a superior pre-emergence herbicide to control grasses and broad leaved weeds.

The other herbicides are thiazopyr 0.2-0.4 kg/ha pre-em, pendimethalin @ 1.5-2.0 kg/ha for G + BLW, prosulfuron 20-40 g/ha, alachlor 1.0-1.50 kg/ha, halosulfuron 30-40 g/ha, diuron 1.5-2.5 kg/ha, chlorimuron ethyl 8-10 g/ha, metsulfuron-methyl 5-7 g/ha.

The effectiveness of metribuzin and diuron can be enhanced by giving a light irrigation either in advance or just after herbicide spray. Commonly used other herbicides are asulam, cynazine, ametryn, trifluralin, and hexazinone. PPI of fluchloralin or trifluralin and pre-emergence alachlor provides effective weed control to the common intercropping systems of sugarcane. Pre-mergence application of ametryn 73.15% + trifloxysulfuron 1.85% at 1250-1500 g/ha can effectively manage grasses, sedges and broad-leaved weeds in sugarcane (Singh et al 2016).

Early post –emergence application of glyphosate @1-1.35 kg/ha, post-em (After manual weeding); Thiazopyr 0.2-0.3 kg/ha; limited patches of perennial grasses in sugarcane can be destroyed with 0.5-1.0% dalapon spray and application of 2,4-D 1.0 kg/ha as semi directed spray about 8 weeks age of the cane effectively controls the BLW.

Ratoon crop weed management

Perennials pose serious problem in ratoon compared with annuals. This aggravates the problem and shifts critical phase of crop-weed competition towards early stage. Hence, unhindered presence of weeds after initial 30 days cause significant reduction in number and yield of millable canes where as keeping the crop weed free after 60 days of initiation does not bring about conspicuous increase in the above parameters. This indicates that crop weed competition during the initial 30 to 60 days is more critical for weed control in sugarcane ratoon.

Initial ploughing and off-barring with trash mulching just after first irrigation provides higherst magnitude of weed control in ratoon sugarcane crop. Three manual hoeing at 30, 60 and 90 days after ratoon initiation also bring about similar effect. As far as herbicides are concerned, pre-emergence spray of atrazine 2 kg/ha just after initiation of ratoon provides weed free environment comparable to manual weeding. Broad spectrum non selective systemic herbicide glyphosate 1. 0 kg/ha can be used as blanket spray 15 days after ratoon initiation for good weed control in ratoon sugarcane.

Integrated weed management involving pre-emergence atrazine 2 kg/ha followed by 10 cm thick trash mulch 35 days after planting onwards is an ideal method for weed control in plant crop. Integration of herbicide use with manual weeding 60 DAP gives best results in plant crop and is residual effect in succeeding ratoon.

Cotton

Weds remove 5-6 times more N, 5-10 times more P and 2-5 times more K than cotton crop in the early stages of crop, leading to more than 50% reduction in seed cotton yield (with range of 45 to 85%). Dominant weeds in cotton fields are *Cyperus rotundus, Cynodon dactylon, Euphorbia sp, Phyllanthus niruri, Echinochloa colona, Acalypha indica, Dactyloctenium aegypticum, Abitilon indicum, Chloris barbata, Achyranthus aspera, Trianthema portulacastrum, Digera arvensis, Celosia argentina, Tridex procumbens* and *Chloris barbata*.

Critical period of weed competition

Cotton seed is sown in wide rows. After planting, weed germinate and begin to shade the slow growing cotton plants leading to severe competition for growth resources. Cotton crop, therefore, requires eight weeks weed free environment after emergence for economic productivity.

Cultural management

In most cotton growing areas, weeds are controlled by repeated intercultivation with blade harrows since the cotton is sown in wide rows. Within the crop rows, weeds are removed by labour intensive hand hoeing. In hill planted cotton of equal row and plant spacing, however, cross cultivation can be adopted. In general, there intercultivations at 15 days interval starting from 15 DAS, can maintain the cotton crop relatively weed free upto 60 DAS.

Once it rains, it will be difficult to control the weeds by intercultivaion in heavy black cotton soils. As a result, the crop becomes susceptible to severe weed competition. After the monsoon rains the field will be too hard to work blade harrows for removing the fully grown up weeds. Under such situation, it is desirable to plough the field with light country plough between the cotton rows to break open the hard soil surface. When once ploughing breaks the hard soil surface, one or two intercultivations with blade harrows can almost uproot the grown up weeds. The crop resumes vigorous growth due to uprooting of weeds besides improving soil physical condition, especially soil aeration.

Use of herbicides

Trifluralin (0.5-1.0), fluchloralin (0.75-1.5) and EPTC (3.0-4.0) are effective pre-plant incorporated herbicides to control grasses.

Pre-emergence

Diuron_(0.5-0.75 kg/ha) G + BLW; metolachlor (1 kg/ha) G + BLW; acetachlor (1.5-2.0kg/ha); pendimethalin (1.2-1.5); oxyfluorfen (0.2kg/ha); thiazopyr @ 0.24-0.48 kg/ha; Butachlor 1-1.25 kg/ha; metribuzin (0.5-2.0 kg/ha); alachlor; cinmethylin (0.5-1.5 kg/ha); and pronamide (1.5-2.5).

Oxadiazon has been found selective to Blackgram grown as inter crop in cotton.

Post-emergence application of Glufosinate ammonium 0.45-0.9 kg/ha for G + BLW; Glyphosate 1-2 kg/ha as directed spray for general weed control; Pyrithiobac 0.1 kg/ha to control broad leaved weeds**;** fluazifop-butyl 0.5 kg/ha to control grass weeds are effective; quazalofop 0.4-0.75 kg/ha; sethoxidin 200-400 g/ha. Lactofen 20-30 g/ha may be ideal as post directed spray against broad leaf weeds. Paraquat 1.0-2.5 and ansar 529 at 2.0-2.5 kg/ha can also be used as directed sprays at time of necessity.

Jute

Weeds poses greatest problem in jute cultivation. In terms of expenditure, weed management constitutes one-third of total cost of cultivation. Weeds may reduce the fibre yield to the extent of 40-50%. Critical period of weed competition is 30-55 DAS.

Cultural management

Broadcasting or drilling the seed in narrow rows may not permit inter-row cultivation for weed control. Manual weeding is, therefore, the only option for weed free environment in the absence of herbicides. Manual weeding and thinning are simultaneously carried out, at least twice when the crop is about 10-15 cm in height.

Use of herbicides

Recommended herbicides for weed control in jute crop are: fluchloralin 1.5-2.0 kg/ha, thiobencarb 2.0-2.5 kg/ha, butachlor 1.5-2.0 kg/ha, fluazifop-butyl 0.4-0.5 kg/ha, MSMA (3.0-4.0) and dalapon 2.0-3.0 kg/ha.

Pre-plant application of propachlor 2.0-2.5 kg/ha followed by one hand weeding 20 DAS appears to be effective and economical. PPI of tetrapian 3.5-4.0 kg/ha 10 days before seeding jute is also equally effective against many weeds in jute crop.

Mesta

Mesta competes well with weeds. Critical period of weed competition is upto 45 DAS. For a broadcast crop, two hand weedings should be given around 21 and 35 DAS. For a row crop, two intercultivations at 20 days interval starting from 20 DAS followed by a hand weeding are ideal and economical.

Among the herbicides, fluchloralin 1.5-2.0, trifluralin 0.5-1.0 kg/ha, metolachlor 0.75-1.0 kg/ha and 2,4-D DMA salt 1 kg/ha are effective against many weeds in Mesta crop.

Tobacco

Weed problem in tobacco are acute both in the seedbed and in the transplanted crop. Orobanche is also a predominant parasite in tobacco. First 9 weeks after transplanting (60 DAT) is critical period.

Nurseries

Most common method of weeding in tobacco nurseries in tropical and subtropical countries is hand pulling. In developed countries herbicides are used for effective weed control. Some of temporary soil sterilants/fumigants used in tobacco nurseries are methylbromide 5-10 kg per 100 m^{-3}; Metham 2-5 kg /100 m^{-3}; Calcium cyanamide 50-70 kg/100 m^{-3}.

Methylbromide a very volatile liquid is applied beneath a plastic gas proofing cover. Exposure below the cover should be for 1-2 days. The beds should be aerated 2-4 days before sowing seeds. Calcium cyanamide should be applied 2-3 months before sowing. Addition of urea to calcium cynamide decreased residual toxicity to the crop. Metham should be applied 3 weeks before planting and watering needs to be done after application.

Allylacohol_– surface drench and watered in to penetrate 5-10 cm of soil, to control most annual weeds as they germinate. Diphenamid 2-3 kg/ha and trifluralin 0.5-1.0 kg/ha as PPI control most annual weeds in the nursery.

Main field

In a transplanted crop, inter-row cultivation is feasible due to wider row spacing. Hence one or two cultivations followed by manual weeding give adequate control of weeds. As tobacco is sensitive to most post herbicides, PPI herbicides provide effective weed control. Herbicides commonly used in the main field are

Diphenamid (3-6 kg/ha) – PPI before raising the nursery	
Benefin 1-1.5 kg/ha	
Pebulate 3.5-4.5 kg/ha	for general weed control
Metabromuron 1-2 kg/ha	
Pendimethalin 1-1.5 kg/ha pre-em	
Pronamide 1.5-2.0 kg/ha	
Fluchloralin 1.0-1.5 kg/ha	
Isopropalin 1.5-2.0 kg/ha	
Ioxaben 1.5-2.5 kg/ha	

Orobanche

Losses due to Orabanche is upto 35%. Soil fumigation with DMTT 300-350 kg/ha 30-40 day before transplanting tobacco seedlings is effective. Post-emergence application of glyphosate 500 g/ha, MH7 1.5% spray and allyl alcohol 0.1-0.2% (2-4 weeks after transplanting) has been promising.

Vegetables and flower crops

Weed control in vegetables especially important early in the season when weed competition can substantially reduce vigour, uniformity and overall yield. Vegetable and flower crops are very sensitive to weed competition and need to keep them weed-free, from planting, emergence or until the end of their critical weed free period (Table 4.3). The period from emergence to four weeks has been found to be critical in the competition of weeds in many row crops including vegetables. The methods used for controlling weeds have been divided into two broad categories, non-chemical and chemical. Many non-chemical weed management methods are common sense farming practices. These practices are of increasing importance due to consumers' concerns about pesticide residues, potential environmental contamination from pesticides, and unavailability of many older herbicides (Masiunas 2000). Vegetables are initially slow growing crops incapable of offering competition to the aggressive weeds.

Table 4.3. Critical weed-free period for some vegetable crops

Crop	Critical weed-free Period
Beet	2-4 weeks after emergence
Cabbage,	early 3 weeks after planting
Carrot	3-6 weeks after emergence
Cucumber, pickling	4 weeks after seeding
Lettuce	3 weeks after planting
Onion	The whole season
Potato	15-45 days after planting
Squash	Early plantings compete better
Tomato transplanted	6 weeks after transplanting
Tomato seeded	9 weeks after seeding
Chilli	30-45 days after transplanting
Pea	30-60 days after planting
Turmeric	60-150 days after planting

Non-chemical methods

Weed management should start with nonchemical strategies. The aim should be to manage the weed population below a level that reduces economic return. In some instances, the cost of controlling weeds may be more than the economic return obtained from any yield increase. This situation occurs when a few weeds are present or the weeds germinate late in the season. In those instances, the best strategy may be to do nothing. In other situations, weed populations and other considerations may require combining herbicides with non-chemical approaches.

Preventive methods: These methods are closely connected with crop rotations and necessary when no direct measures of weed control can be taken for economic reasons. They are based on a reduction in the soil seed and propagule bank and the early awareness of the infestations. It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. A written record of the history of weed infestation in the field is very useful. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the use of treatments and tillage and the use of drainage tillage to prevent propagation of some species (*Phragmites* sp., *Equisetum* sp., *Juncus* sp.) that need high moisture levels. It is also necessary to scout the field edges to prevent invasions, acting only when necessary, and bearing in mind the usefulness of the edges and borders to control erosion and hosting useful fauna (Zaragoza 2001).

Cultural methods: One should aim to establish a vigorous crop that competes effectively with weeds. This approach starts with land selection. A general rule is not to plant vegetables on land with a history of heavy weed infestation, especially of perennial weeds.

Stale seedbed: Stale ('false') seedbeds are sometimes used for vegetables when other selective weed control practices are limited or unavailable. Success depends on controlling the first flush of emerged weeds before crop emergence, and on minimal disturbance, which reduces subsequent weed flushes. It consists of preparation of a seedbed 2-3 weeks before planting to achieve maximum weed-seed germination near the soil surface. These seedlings are killed by light cultivation or by applying non-residual herbicides glyphosate and paraquat just before or after planting, but before crop emergence. The crop is planted with minimum soil disturbance to avoid exposing new weed seed to favourable germination conditions. The pre-germination should occur as close as possible to the date of planting to ensure that changes in weather conditions do not have an opportunity to change the spectrum of weeds (cool vs. warm season) in the field.

Planting to moisture: The majority of small seeded weeds germinate in upper 1 to 2 inches of soil. This aspect of the germination ecology of weeds can be exploited for control of these weeds. After the weeds are killed by cultivation, the top 1 to 2 inches of soil are allowed to dry and form a 'dust mulch'. At planting, the dust mulch is pushed away and largeseeded vegetables such as corn or beans can be planted into the zone of soil moisture. These seeds can germinate, grow, and provide partial shading of the soil surface without supplemental irrigations that would otherwise provide for an early flush of weeds.

Crop rotation: Crop rotation is a key control method to reduce weed problems in vegetables. It was considered for a long time to be a basic practice for obtaining healthy crops and good yields. This concept was mistakenly eliminated with the use of more agrochemicals. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management. Weeds tend to thrive with crops of similar growth requirements. Cultural practices designed to contribute to the crop may also benefit the growth and development of weeds.

Monoculture results in a build-up of weed species that are adapted to the growing conditions of the crop. When diverse crops are used in a rotation, weed germination and growth cycles are disrupted by variations in cultural practices associated with each crop (tillage, planting dates, crop competition, and weed control methods). Traditionally, potato was introducing a fallow in the rotation is essential to reduce difficult weeds like perennials. It is best to alternate legumes with grasses, row crops with close planted crops and heavy feeders with light feeders.

The broad principles and examples of ideal crop rotations are given below:

1. Alternating crops with a different type of vegetation: leaf crops (lettuce, spinach, cole), root crops (carrot, potato, radish) - bulb crops (onion, garlic) - fruit crops (squash, pepper, melon).
2. Alternating grass and dicot crops, such as maize and vegetables.
3. Alternating different crop cycles: winter cereals and summer vegetables.
4. Avoiding succeeding crops of the same family: apiaceae (celery, carrot)-solanaceae (potato, tomato).
5. Alternating poor (carrot, onion) and high weed competitors (maize, potato).

6. Avoiding problematic weeds in specific crops (*e.g.* mulvaceae in celery or carrots, parasitic and perennials in general).

Cover crops: Rapid development and dense ground covering by the crop will suppress weeds. The inclusion of cover crops such as clovers, oilseed radish, summer greengram, summer black gram, sunhemp, *Sesbania* or forages in the cropping system can suppress weed growth. Highly competitive crops may be grown as short duration 'smother' crops within the rotation. Additionally, cover crop residues on the soil surface will suppress weeds by shading and cooling the soil. When choosing a cover crop, consideration should always be given to how the cover crop will affect the succeeding crop. In addition, decomposing cover crop residues may release allelo chemicals that inhibit the germination and development of weed seeds. The cover-crop systems tend to control small seeded annual broadleaf weeds the best.

Planting patterns: Crop population, spatial arrangement, and the choice of cultivar (variety) can affect weed growth. Narrow row spacing and proper plant density assure that the crop rapidly closes the canopy. A closed canopy shades out late emerging weeds and prevents germination of weed seeds requiring light. Similarly, fast-growing cultivars can have a competitive edge over the weeds. Weeds seldom pose a problem once the canopy closure occurs.

Planting time: The crop planted at the right time showed more competitiveness towards weeds than late planted crop. Crops may be divided into warmand cool-season plants, depending on the optimal temperature for their growth. The planting date effects the time of emergence and early seedling vigour of the crop, which are important in determining crop competitiveness. Cool-season crops germinate at cooler soil temperatures and thus compete better against early emerging weeds than do warm-season crops. The crop should be planted at a time when the temperatures are favourable for crop growth.

Mulching: Mulching or covering the soil surface can prevent weed seed germination by blocking light transmission. Mulches may be classified as either natural or organic (straw, bark, compost) or synthetic (plastic). As natural mulches are difficult to apply over large areas, they are best for small, specialized areas. Natural mulches should be spread evenly at least 1.5 inches thick over the soil to prevent light penetration; weeds can easily manage to reach the surface if the layer is not thick enough. Allelopathic chemicals in natural mulch also can physically suppress seedling emergence. Some manual weeding may be required along with the practice of mulching (Nogueroles and Zaragoza 1999). Paddy straw mulch at 6 t/ha in potato and 9-10 t/ha in turmeric recorded effective control of mixed weed flora (Kaur *et al*. 2008, Anonymous 2015). Natural mulch materials must be free of weed seeds and other pest organisms and be heavy enough that they are not easily displaced by wind or water. A major advantage of natural mulches is their biodegradability adding organic matter to the soil.

The use of plastic mulching is very popular in many vegetable-growing areas. Plastic mulches have been developed that filter out photosynthetically active radiation, but let through infrared light to warm the soil. These infrared transmitting mulches have been shown to be effective at controlling weeds. Synthetic mulches control weeds within the row, conserve moisture, increase soil temperature, and are easy to apply. Black plastic mulches are the most common and are particularly effective in improving early season growth of warm-season crops such as tomatoes, muskmelons, watermelons, and peppers. Better early season growth of these crops improves their competitive ability against weeds. Plastic mulches used in combination with trickle irrigation also improve water use efficiency. The biggest disadvantage of plastic mulch is disposal, as many landfills do not accept it. Photodegradable plastic mulches have been developed, but their season long persistence is a problem. Also, photodegradable mulches just degrade into smaller pieces of plastic that still contaminate the environment. Biodegradable plastic mulches are not yet widely available. Mulching generally prevents the germination of light sensitive weeds like *Ageratum conyzoides, Portulaca oleraceae etc*. (Adeyemi and Olaniyi 2008). Some perennial weeds are not controlled (*e.g. Cyperus* spp., *Convolvulus arvensis*) by this process and for them inter-row cultivation or herbicidal treatments are necessary.

Solarisation: In this process, moist soil is covered with a clear, thin transparent plastic sheet, to trap the soil radiation for 30-45 days. Solarization works when the heat created under the plastic film becomes intense enough to kill weed seeds. The maximal soil temperature reaches nearly 60°C under polyethylene covered plots. The factors involved in solarization are soil temperature, moisture and probably gases due to which solarization reduces the germination, establishment and biomass of heat sensitive weed species. Results are often variable, depending on weather conditions. In Northern India, high soil temperature (50-60°C) can develop in soil covered with transparent polyethylene sheets in May-June (Kumar *et al.* 1993). Cold (high latitude) or cloudy places are usually not suitable for implementing solarization. Some species can tolerate solarization (*e.g.* deep rooted perennials, *viz. Sorghum halepense, Cyperus rotundus,* and also some big weed seeds such as legumes). After solarisation, the use of deep or mouldboard tillage must be avoided and the sowing should be done with minimal soil disturbance. This system is more suitable for small areas of vegetables, but is widely used under plastic greenhouse conditions.

Mechanical method: Mechanical removal of weeds is both time consuming and labor-intensive but is one of the most effective methods. Mechanical weed management starts with seedbed preparation. Moldboard plowing is usually the first step in mechanically managing weeds. It is particularly useful in controlling emerged annual weeds. An important second step is often rotary hoeing for mechanically managing weeds in large-seeded vegetable crops (sweet corn, snap beans and peas).

Rotary hoeing needs to be done after the weeds germinate but before they emerge; it controls only small-seeded weeds. Once the crops have emerged or transplants are established, a row cultivator may be used to manage emerged weeds. Adjust the cultivator sweeps or teeth to dislodge or cover as many weed seedlings as possible. Seedling weeds can be killed by cultivating 1-2 inches deep. The best weed control is obtained with a row cultivator in relatively dry soils by throwing soil into the crop row to cover small weed seedlings. Avoid crop injury from poor cultivation, which reduces crop yields. Relying entirely on mechanical practices to manage weeds is difficult on large acreages. Also, several weeds especially perennials, are extremely difficult to manage unless herbicides are combined with nonchemical approaches.

The tillage operations for seed bed preparation should be planned keeping in view with the type of weeds present in the field. When annual weeds are predominant (crucifers, solanaceous, grass weeds) the objectives are unearthing and fragmentation. This must be achieved through shallow cultivation. If weeds have no dormant seeds (*Bromus* sp.), deep ploughing to bury the seeds will be advisable. If the seeds produced are dormant, this is not a good practice, because they will be viable again when they return to the soil surface after further cultivation. When perennial weeds are present, adequate tools will depend on the types of rooting. Pivot roots (*Rumex* sp.) or bourgeon roots (*Cirsium* sp.) require fragmentation and this can be achieved by using a cultivator. Fragile rhizomes (*Sorghum halepense*) require dragging and exposure at the soil surface for their depletion, but flexible rhizomes (*Cynodon dactylon*) require dragging and removal from the field. This can be done with a cultivator or harrow. Tubers (*Cyperus rotundus)* or bulbs (*Oxalis* spp.) require cutting when rhizomes are present and need to be dugup for exposure to adverse conditions (frost or drought). This can be done with the mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (*Phragmites, Equisetum, Juncus).* This is why reliable weed information is always necessary.

Chemical method

Herbicides offer a great scope for minimizing the cost of weed control irrespective of the situation and offer a good weed control alternative to cultural or mechanical methods in horticultural crops.

Chemical control, however, is relatively poorly developed in vegetable crops as they tend to be grown in relatively small areas, hence making use of herbicides expensive and uneconomical. With this method, less labour is required; this allows the transfer of labour to other activities. Usage of pre-emergence herbicides assumes greater importance in view of their effectiveness from the initial stages of crop growth, which is the most critical period of weed competition (Bhutani *et al.* 1978). The weeds emerging later also compete with the crop and reduce its productivity and need for post-emergence herbicides or other non-chemical approaches described above. However, the herbicides alone could not provide long term control of a wide range of weed flora present in a field. This necessitates the use of an integrated approach for long term control of weeds in vegetable crops. Several herbicides are often labeled for a crop. Scouting in your area to determine which weeds are present can allow you to select the herbicide that can give you the best control. Potential environmental hazards must be considered when selecting a herbicide. Herbicide labels contain information on these hazards. The details of herbicides commonly used for weed control in vegetable crops (Table 4.4) and in flower corps are listed (Table 4.5). If an user is not familiar with the use of herbicides, it requires preliminary tests to verify its effectiveness in local conditions and selectivity to available crop cultivars.

Nureseries

1. Metham 1 kg/20m^2. Treat the beds then drench with water for 48 hr. Cultivate 5-7 days latter and sow the seed 7-15 days after it.
2. Methyl Bromide 1 kg/20 m^2 fumigate for 24 hrs and sow the seed 3 days later.

Selective pre-emergence and early post-emergence herbicides for vegetable seedbeds

Herbicide	**Dose (kg a.i./ ha)**	**Crop**
a) Pre-emergence		
Trifluralin	1.0	Fenugreek
Clomazone	0.18 - 0.27	Pepper, cucumber
DCPA	6.0 - 7.5	Onion, cole crops, lettuce
Metribuzin	0.15 - 0.5	Tomato
Napropamide	1.0 - 2.0	Tomato, pepper, eggplant
Pendimethalin	1.0 - 1.6, 1.0 - 2.5	Onion, garlic, lettuce, fenugreek
Propachlor	5.2 - 6.5	Onion, cole crops
Imezethapyr	0.055	Fenugreek (Kumar et al. 2016)
b) Post-emergence (crops with at least 3 leaves)		
Clomazone	0.27 -0.36	Pepper
Ioxinil	0.36	Onion, garlic, leek
Linuron	0.5 - 1.0	Asparagus, carrots
Metribuzin	0.075 - 0.150	Tomato
Oxifluorfen	0.18 - 0.24	Onion, garlic
Rimsulfuron	0.0075 -0.015	Tomato
Imezethapyr	0.100	French bean (20-35 DAS)
	0.055	Fenugreek

Good practices during the use of herbicides

A summary of a 'decalogue' of good practices in the use of herbicides in extensive vegetable crops (Zaragoza 2001) is provided below:

- Periodically inspect the fields and assess the weed of importance. Identify correctly the major weeds.
- The weed and crop stage of growth must be taken into account.
- Careful selection of the product and dosage, bearing in mind points one and two.
- Read the product label and follow the recommendations.
- Avoid adverse conditions at the time off application: wind, temperatures, rainfall. Do not delay treatment.
- Quality of the spraying is obtained by the correct calculation of dosage (surface to be treated must be well measured) and by the spraying equipment, which must be calibrated and in good condition (especially nozzles).
- Band or patch application to save herbicide and reduce residues.
- Keep to the environmental norms: avoid spills, drift, respect the edges, water ways, and sensitive areas. Rinse all empty cans or containers thrice and do not re-use them.
- To avoid propagation of resistant species, the same herbicide or herbicides with the same mode of action must not be used repeatedly.

Table 4.4. List of herbicides for use in vegetable crops

Crop	**Herbicide**	**Dose (kg/ha)**	**Time of application**	**Reference**
Garlic	Pendimethalin	0.75-1.25	PRE	Madan*et al.* (1994), Suresh *et al.* (2013), Singh *et al.* (2002a), Anonymous (2009, 2015)
	Oxyfluorfen	0.125-0.240	PRI/Early POST	Madan*et al.* (1994), Suresh *et al.* (2013), Ramani and

Crop	Herbicide	Dose (kg/ha)	Time of application	Reference
				Khanpare (2010), Anonymous (2009, 2015)
	Metolachlor	1.500	PRE	Madan *et al.* (1994), Suresh *et al.* (2013), Kumar *et al.* (2013)
	Oxadiazon	1.5	PRE	Vermani *et al.* (2001), Singh *et al.* (2002a)
	Fluchloralin *fb* Oxadiazon/ Quizalofop-ethyl	0.95 *fb* 1.0/0.05	PPI *fb* POST	Sharma *et al. (*1983), Sampat *et al.* (2014)
	Oxadiargyl	0.090- 0.667	PRE/Early-POST/POST	Ramani and Khanpare (2010), Anonymous (2009)
	Fenoxaprop-P-ethyl	0.075	POST	Ramani and Khanpare (2010)
Root crops (Carrot, Radish)	Trifluralin	0.9-1.5	PRE	Jadhao *et al.* (1999), Singh *et al.* (2009), Kumar *et al.* (2001)
	Pendimethalin	0.75-1.87	PPI/PRE	Sandhu *et al.* (2002), Singh *et al.* (2009), Sharma (2000), Reddy *et al.* (2002)
	Alachlor	1.25-2.5	PRE	Channappagoudar *et al.* (2007b), Singh Bakshish *et al.* (2009), Leela (1987, 1993), Reddy *et al.* (2002)
	Oxyfluorfen	0.147-1.0	PRE	Singh *et al.* (2009), Leela (1993)
	Butachlor	1.0 – 2.0	PRE	Leela 1987, (1993), Channappagoudar *et al.* (2008)
	Metolachlor	2.0	PRE	Sharma (2000)
	Sethoxydim	0.8	POST	Reddy *et al.* (2002)
	Fluazifop-butyl	0.75	POST	Leela (1987)
Potato	Isoproturon	0.94	PRE	Anonymous (2009, 2015)
	Alachlor	2.5	PRE	
	Alachlor + Atrazine	1.25+0.125	PRE	
	Paraquat	0.25 – 0.375	at 5-10% of crop emergence	
	Metribuzin	0.250 -0.750	PRE	Channappagoudar *et al.* (2007a), Anonymous (2009, 2015)
	Atrazine	0.35-1.0	PRE	Bhullar *et al.* (2015), Anonymous (2015)
	Pendimethalin	0.75-1.5	PRE	Shekhawat and Maliwal (1991), Patel *et al.* (1995), Anonymous (2015)
	Diuron	1.0	PRE	Channappagoudar *et al.* (2007b)
Brinjal	Oxyfluorfen	0.10-0.15	PRE	Singh (2014), Reddy *et al.* (2000)
	Butachlor	1.0	PRE	Reddy *et al.* (2000), Bangi *et al.* (2014)
	Pendimethalin	1.0-1.5	PRE	Reddy *et al.* (2000), Kunti *et al.* (2012), Anonymous (2009)
	Metolachlor	1.0	PRE	Reddy *et al.* (2000)
	Alachlor	1.0	PRE	
	Oxadiazon	1.25	PRE	Nandal and Pandit (1988)
	Quizalofop	0.040	POST	Meena *et al.* (2006)
Cabbage	Pendimethalin	0.75-2	PRE	Noonia *et al.*(1992), Kaur *et al.* (2015)
	Sethoxydim	1.5	POST	Singh and Tripathi (1988)
	Alachlor	1.0	PRE	Nandal *et al.* (2005), Dhiman *et al.* (2005)
	Oxadiazon	1.0	PRE	Nandal *et al.* (2005), Dhiman *et al.* (2005)
	Oxyfluorfen	0.09-0.234	PPI/PRE	Nandanwar *et al.* (2006), Kaur *et al.* (2015), Kaur (2012)
	Trifluralin	0.90	PRE	Kaur (2012)
Cauliflower	Fluchloralin	0.84-1.5	PPI	Porwal and Singh (1993), Anonymous (2015)
	Alachlor	2.0	PRE	Govindra *et al.* (1983)
	Pendimethalin	0.50-1.0	PPI/PRE	Anonymous (2009, 2015)
Broccoli	Pendimethalin	0.50-1.0	PPI/PRI	
Onion	Pendimethalin *fb* Oxyfluorfen + Quizalofop-ethyl	0.750-1.5 *fb* 0.12-0.85+0.037-0.050	PPI *fb* POST	Kalhapure *et al.* (2013, 2014), Ved Parkash *et al.* (2000), Bhat and Bhushan (2005), Sardhar and Guggari (2015), Anonymous (2009, 2015)
	Alachlor	2.0	PRE	VedParkash *et al.* (2000)
	Fluchloralin	1.12	PPI	Bhat and Bhushan (2005)
	Metolachlor	1.0	PRE	Shekar *et al.* (2002)
	Oxadiargyl	0.667	PRE	Anonymous (2009)
Transplanted onion	Oxyflourfen	0.12	PRE	Shekar *et al.* (2002)
	Metolachlor	1.0	PRE	
	Pendimethalin	0.75-1.0	PRE	

Crop	Herbicide	Dose (kg/ha)	Time of application	Reference
	Oxadiazon	0.5	PRE	
	Alachlor	1.50	PRE	
	Butachlor	1.0	PRE	
	Oxyfluorfen	0.12-0.37	PRE	
	Pretilachlor	0.3-0.5	PRE	
	Oxadiargyl	0.06-09	PRE	
	oxyflurofen fb quilazofop –p- ethyl	0.3 fb 0.05	PRE fb 30 DAT	Singh et al. 2016
Onion nursery	Pendimethalin	0.5	PRE	Sharma *et al.* (2009)
	Oxyfluorfen	0.125	PRE	
Chilli	Pendimethalin	0.75-3.0	PPI/PRE	Mukund *et al.* (1995), Kaur (2002), Patel *et al.* (2004), Anonymous (2009, 2014), Prakash *et al.* (1999)
	Fluchloralin	0.5-1.0	PPI/PRE	Singh *et al.* (1985), Anonymous (2014)
	Oxyfluorfen	0.10-1.25	PRE	Kumar and Thakral (1993), Kumar *et al.* (1995), Shaikh *et al.* (2005)
	Alachlor	3.0	PRE	Prakash *et al.* (1999)
	Oxadiazon	1.0	PRE	Singh *et al.* (1985), Anonymous (2014)
Bell pepper	Pendimethalin + Oxyfluorfen	1.00 + 0.15	PPI	Singh *et al.* (1991, 1992)
	Ethalfluralin	0.8-1.7	Pre-plant	
Chilli (seeded)	Pendimethalin	1.0	PRE	Agasimani and Channappagoudar (2005)
	Oxadiargyl	0.09	PRE	
Tomato	Pendimethalin	0.56-1.0	PRE- transplant	Sandhu *et al.* (1993)
	Metribuzin	0.37- 0.525	PRE- transplant	Rana and Barevadia (1995)
	Isoproturon	0.62- 1.25	PRE- transplant	Anonymous (2009, 2014)
	Sulfosulfuron	0.75	PRE	Dinesha*et al.* (2012)
	Rimsulfuron	0.0075-0.015	Post	
	Ethalfluralin	0.8-1.7	Pre-plant	
Chilli + Coriander	Pendimethalin	1.0	PRE	Muthusankaranarayanan *et al.* 1997 Parkash *et al.* (1999)
Peas	Pendimethalin	1.20-1.50	PRE	Rana 2002; Anonymous (2009)
	Imazethapyr	0.15-1.5	POST	Singh *et al.* (2014), Rana *et al.* (2013)
	Quizalofop-ethyl	0.050	POST	Singh *et al.* (2014)
	Trifluralin	0.75	PPI	Banga *et al.* (1998). Anonymous (2015)
Okra	Pendimethalin	0.50-0.75	PRE	Anonymous (2015)
	Alachlor	2.5	PRE	
	Metolachlor	0.75	PRE	Anonymous (2014)
	Oxyflourfen	0.15	PRE	
	Oxadiazon	0.40 kg/ha	PRE	
	Fluchloralin	1.0-1.5	PPI/PRE	
Coriander	Pendimethalin	1.0	PRE	Anonymous (2009)
Turmeric	Pendimethalin	0.975	PRE	Kaur *et al.* (2008)
	Metribuzin	0.70	PRE	Anonymous (2015)
	Atrazine	0.75	PRE	
Beans	Ethalfluralin	0.8-1.7	Pre-plant	
Squash	Ethalfluralin	0.8-1.7	Pre-plant	
Carrot, artichoke, asparagus, faba bean	Linuron	0.50-1.25	Pre emergence	
tomato, carrots, peas	Metribuzin	0.10-0.35	Pre/Post emergence	
Artichoke, cole, lettuce, leek, pepper	Pendimethalin	1.32-1.65	PPI/PRE	
Beans, carrots, celery, cole crops, artichoke, onion, pepper, tomato	Trifluralin	0.59-1.44	pre-plant incorporated	

PP- Pre-plant incorporation; PRE- Pre-emergence; POST- Post-emergence; *fb*- followed by. The above herbicides, especially at their lower doses, should be integrated with hand weeding to remove the weeds escaped/emerged after the application of herbicides.

Table 4.5. List of herbicides for use in flower crops

Crop	Herbicide	Dose (kg/ha)	Time of application	Reference
Gladliolus	Oxyfluorfen	0.25	PRE	Manuja *et al.* (2005)
	Alachlor	1.0	PRE	Manuja *et al.* (2005)
	Atrazine	1-2	PRE	Chahal *et al.* (1994)
	Pendimethalin	0.75-1.0	PRE	Bhat and Sheikh (2015)
	Metribuzin	0.5	PRE	Rao *et al.* (2014)
	Butachlor	1.5	PRE	Rao *et al.* (2014)
	Pendimethalin + Metribuzin	0.75+0.3	PRE	Jankiram*et al.* (2014)
	Oxyfluorfen	0.5	PPI	Yadav and Bose (1987)
	Glyphosate	1.0	POST-directed	Manuja *et al.* (2005)
Gerbera	Pendimethalin	1.0	PRE	Shalini and Patil (2006)
	Alachlor	1.5	PRE	Shalini and Patil (2006)
Rose	Diuron	2-2.5	PRE	Yaduraju *et al.* (1997), Rajamani *et al.* (1992)
	Glyphosate	0.5	POST-directed	Rajamani*et al.* (1992)
	Oxyfluorfen	1.0	PRE	Rajamani (1992)
	Atrazine	1.0-2.0	PRE	Kumar and Singh (2013)
	Metribuzin	0.75-1.50	PRE	Kumar and Singh (2013)
China aster	Oxyfluorfen	0.1	PRE	Kumar and Gowda (2010)
	Metolachlor	1.0	PRE	Kumar and Gowda (2010)
Marigold	Trifluralin	1.0	PPI	Kumar *et al.* (2010)
Tuberose	Metolachlor	2.0	PRE	Murthy and Gowda (1993)
	Pendimethalin	1.25	PRE	Murthy and Gowda 1993
Winter annuals *(Helichrysum-bracteatum, Coreopsis lanceolata Chrysanthemum carinatum)*	Pendimethalin	0.50	PRE	Badhesha (2003)

PP- Pre-plant incorporation; PRE- Pre-emergence; POST- Post-emergence

Weed management in orchards

Weed management in orchards is difficult due to 1. More exposed area which adds to weed problem, 2. Very less or no smothering effect of young trees on weeds, 3. Regeneration of weeds or germination in several flushes, 4. Selection of herbicides is difficult; the direct mortality or chronic toxicity can do great damage to orchard grower and 5. With vapour drift, orchard plants may also be damaged.

Weed management is most important in orchards particularly in 1.5 to 2.5 m diameter around the fruit trees because in this area weeds instead of competing with orchard plants also interfere with fruit picking, pruning and other operations. Weeds in orchards provide shelter to casual organism of some diseases, insect-pests, snakes etc.

In order to achieve desirable control of weeds in orchards, integrated approach is the best option because no single method is so efficient in providing effective weed control throughout the year.

Preventive methods could be used more easily and effectively since weed infestation through crop seeds does not exist in an orchard. Tree saplings should be free from the reproductive parts of the perennial weeds. Reduced seed bank will make weed control much easier for next years. So seed production of annuals or perennials should be prevented by mechanical mowing or by any other method. A close watch on the near vicinity of an orchard has to be kept for appearance of new a new weed species. In case any weed develops in the close vicinity, it must be eradicated.

Physical methods include hand hoeing, mechanical cultivation, mulching mowing and slashing, burning and solarization. Weeds from young orchards can be very effectively controlled with mechanical cultivation as and when required. However, in grown up orchards it can do damage to roots and young foliage including flowers and fruit

buds. Smothering with plastic sheets or tarpaper is effective for the control of small infestations of perennial weeds (Jordan and Day 1970). However, straw, saw dust and other mulches are ineffective against perennials.
Growing of inter-crops is the best cultural technique in these crops. Selection of quick growing and less exhaustive crops such as cowpea, moong mash, sengi, metha, oats etc can help in smothering weeds particularly in inter-row areas of young orchards. Nutritional requirement of exhaustive crops if planted under compulsion should be taken care. Special and timely management of fertilization and watering in the orchard could be also a good measure to control weeds.
Biological control includes classical (inoculative), bioherbicide (inundative) and herbivore management (Wapshere 1983). Using grazing animals could be a good practice to control weeds in orchards.
Some allelochemicals isolated from plants and microbial compounds can be exploited as herbicides. Marsie and Singh (1987) reported that residues from *Lantana camara* L. shoots significantly reduced the growth of velvet leaf and Virginia pepper weed.
Use of herbicides especially for ring weeding under fruit trees is very useful. The selectivity of herbicides may be achieved in the following ways

1. The inherent tolerance of plant to the herbicides i.e. apple can tolerate application of simazine, grapes and ber to diuron
2. Directed and protected application of herbicides on weeds only i.e glyphosate
3. Selection of herbicides with minimum leaching behavior such as dichlobenil

Selection of herbicides in orchards should be made with great caution so that safety of trees can be ensured. For controlling weeds, herbicides can be used as pre-emergence or post-emergence or both. Pre-emergence application of trifluralin, simazine, terbacil, diuron, monuron, bromacil, dichlobenil etc can be made according to the type of fruit tree. Post-emergence application of any non-selective contact type of herbicide (paraquat/diquat) can be used to control the germinating weeds provided the tree plants are protected from the direct contact with the herbicide or spray fluid. Glyphosate is very popular to control annual and perennial weeds from all the type of orchards. Its drift and contact with young stem should be avoided as this herbicide is translocated in nature and do harm to the economical plants.
Like field crops, weeds also compete with orchard plants as indicated from the following data reported by Kaundal et al 1994:

Treatment	Weed biomass (q/ha)		Peach fruit yield (kg/tree)	TSS%
	Kharif	Spring		
Unweeded check	36.5	51.7	42	10.6
Hand weeding (12 every month	10.4	9.2	45.5	11
Diuron 3 kg/ha	10.1	9.6	50	12.2
Glyphosate 2 kg/ha	8.1	7.1	51	12.3
Black polythene mulch 400 gauge	2.1	1.9	58	13
LSD (P=0.05)	2.2	1.5	4.1	1.7

Tank mix application of any one pre-emergence with post-emergence herbicide can also be made in order to obtain weed free conditions for a longer period. Herbicides for banana, citrus and mango are given below:

Banana	Alachlor, ametryn, diuron (0.5-1.0 kg/ha) and simazine
Citrus	Atrazine, diuron and paraquat
Mango	Bromacil, dalapon, diuron, glyphosate and paraquat

Too much emphasis has been addressed on a single control in the past. Interaction between control measures and weed management and other farming practices have been largely ignored. The consequence is the degradation of natural resources. In future weed management integration should be strongly emphasized; it is key to achieve both effectiveness and sustainability for weed management in fruit crops. A single control method should be integrated into the whole weed management programme and the weed management integrated into the entire farming system.

Weed shifts in cropping systems

Shifts in weeds are not new. Weed shifts have happened as long as humans have cultivated crops. Weedy and invasive species can easily adapt to changes in production practices in order to take advantage of the available niches. Weeds are well equipped to flourish in disturbed agricultural systems. Weeds are genetically diverse and can readily take advantage of the variety of conditions created by any crop production system. Therefore, one key to reducing the predominance of any given weed species is to increase the diversity of crops within the cropping system, or at least the diversity of weed management practices within the cropping system.

A change from conventional tillage to a conservation tillage system can lead to shifts in weed species composition. Weed shifts can also occur both within a population of a certain species (e.g., surviving mutants), or within a plant community (e.g., certain species). A weed species shift can result in the emergence of weeds tolerant of existing weed management practices. A need to recognize and understand shifts in weed populations in various cropping systems is important. An understanding of crop production effects on weed species shifts can lead to development of improved weed management strategies. For example, due to growing rice under alternating flooding regimes and residual soil moisture conditions prevalent in the Cauvery Delta region of Tamil Nadu, red sprangletop *{Leptochloa chinensis* (L.) Nees} and European waterclover *(Marsile'a qu'adrifolia* L.) became predominant in rice fields by replacing bamyardgrass *(Echinochloa* sp.) [Yaduraju and Kathiresan 2003]. In the eastern Indo-Gangetic Plains, adoption of zero tillage has resulted in an increase in population of globally-significant perennial weeds such as purple nutsedge (*Cyperus rotundus* L.) and Bermuda grass *{Cynodon dactylon(L.)* Pers.} [Malik and Kumar 2014]. Such shifts are likely to occur in other production systems that will suggesting that changes in weed flora need to be monitored continuously in all cropping systems and agro-ecological regions in order to assess emerging weed problems and plan weed management strategies accordingly. Some more case studies in weed shifts are given below

Case studies on shift in weed flora at Palampur

Case study 1. EFFECT OF CONTINUOUS USE OF HERBICIDES ON WEED SHIFTS IN RICE-WHEAT SYSTEM (Rana et al. 2015)

Rice-wheat is the predominant cropping system in India occupying around 10.5 million ha area. The farmers realize much of their food security from this cropping system. Weeds are serious constraints in rice-wheat cropping system. Of the total losses caused by pests, weeds have a major share (30%). A long-term experiment was conducted on rice-wheat cropping system during *rabi* 2000 to 2013-14 at Palampur. The soil of the test site was silty clay loam in texture, acidic in reaction, low in available N, P and K with CEC of 11.5 mol ($P^{\pm}$). Nine treatments *viz*. farmers' practice (T_1), continue use of herbicides (butachlor + 2,4-D) with 100% N through inorganics or 25% N substitution through fresh *Lantana* leaves in rice followed by continue (isoproturon + 2,4-D; T_2 and T_4) and rotational (clodinafop/isoproturon; T_3 and T_5) use of herbicides in wheat and rotational use of herbicides (butachlor/pretilachlor (cyhalofop-butyl) in later years) + 2,4-D) with 100% N through inorganics or 25% N substitution through fresh *Lantana* leaves in rice followed by continue (isoproturon + 2,4-D; T_6 and T_8) and rotational (clodinafop/isoproturon; T_7 and T_9) use of herbicides in wheat were tested in rice – wheat cropping system from rabi 2000 to 2013-14. During *rabi* 2000, *Phalaris minor*, *Avena ludoviciana*, *Vicia sativa*, *Anagallis arvensis* and *Coronopus didymus* were dominant weeds. Population density of all these weeds decreased in later years. *Coronopus didymus* was not observed after 2009-10. After 3-4 years, *Poa*, *Lolium* and *Ranunculus* were appeared. *Poa* and *Lolium* had alarming proportion in the later years while *Ranunculus* disappeared after 2-3 years. From 2005-06, *Polygonum* and *Alopecurus* were the new invaders. In the later years, *Trifolium*, *Stellaria*, *Lathyrus*, *Plantago* and *Daucus carota* had little infestation in the experimental field. In *kharif*, *Echinochloa crusgalli*, *Panicum dichotomiflorum* and *Cyperus iria* were the main weeds initially. The population of these weeds decreased over the years. Lately *Digitaria* (2002 and 2003), *Eschaemum* (2004 and 2005), *Aeschynomene* (2004-10), *Commelina* (2005), *Paspalum* (2005), *Ammannia* (2007-14), *Eriocolon* (2009-14), and *Monochoria* (2010-14) were appeared in the experimental field. The population of *Monochoria* and *Ammannia* was in the decreasing trend while that of *Ericolon* showed increasing trend.

Based on 14 years phytosociological analysis, *Phalaris minor* was found to be the most important *rabi* season weed in T_1, T_3, T_4, T_5 and T_9 and was second most important in rest of the treatments. *Avena ludoviciana* was most important weed in T_2, T_6 and T_8 and was 2nd or 3rd important weed in other treatments. *Vicia* was most important weed in T_7 and having 2nd or 3rd ranking in importance in the other treatments. *Anagallis*, *Coronopus*, *Lolium* and *Poa* had fourth or fifth ranking in some treatments. The other weeds did not fall in the top five ranking. During *kharif*, *Echinochloa* was the most important weed in T_2, T_3, T_4, T_5 and T_8. *Ageratum* was most important weed in T_6. Irrespective of the treatment, *Cyperus* ranked 3rd or 4th. *Panicum* ranked 4th in T_8 and 5th in T_6. *Ammannia* had 3rd, 4th or 5th ranking in some of the treatments. *Eriocolon* had 5th ranking in T_1.

Case study 2. Weed shift studies in maize based cropping system under mid hill conditions of Himachal Pradesh (Suresha 2014)

The study was carried out in a continuing experiment at the Bhadiarkhar farm of the university. The soil was silty clay loam in texture, high in OC, medium in available N and high in available P and K. There were eight cropping systems [C1- Maize – Wheat, C2 - Maize (Green cob) + Frenchbean (Pole) – Pea – Summer squash; C3 - Maize + Soybean – Garlic; C4 - Maize (Green cob) – Broccoli – Potato; C5 - Maize + Asparagus bean – Radish – Onion; C6 - Maize (Green cob) + Mash –Cauliflower – Frenchbean; C7 - Maize (Green cob) + Ricebean – Cauliflower – Buckwheat and C8 -Maize (Green cob) + Asparagus bean – Broccoli – Radish] being tested in RBD with four replications. In each experimental plot three situations (S1 - normal weed control, S2 - no weed control/weedy and S3 - supplement weed control) were maintained and observations on crops and weeds were recorded. There were 28 weed species which invaded different maize based cropping systems. During *kharif, Commelina* (56% and 41% during 2012 and 2013, respectively) and *Ageratum* (21% and 33%) were the predominant weeds. In rabi, *Coronopus*, *Phalaris* and *Spergula* (54, 22 and 14%, respectively during 2012-13 and 31, 7 and 28% during 2013-14) were the main weeds. During kharif, *A.conyzoides* had highest important value index (IVI), species richness (SR), and similarity index (SI) and lowest Simpson Diversity Index (SDI) irrespective of the cropping system and situation. *C. benghalensis*, *Cyperus* sp, *Bidens pilosa* and *Ageratum houstonianum* were the other important weeds having higher value of these indices. When the weeds were controlled with additional handweeding in S3, *Ageratum conyzoides*, *Bidens pilosa*, *Ageratum houstonianum*, *Polygoenum* sp, *Echinochloa crusgalli*, *Cyperus* sp. were the robust robbers. Weed flora during *rabi* was richer than that during *kharif*. *Phalaris minor* had higher IVI, SR, and SI and lower SDI in the maize – wheat cropping system. In the other cropping systems either *Coronopus didymus*, or *Spergula arvensis* had higher values of these indices. *Bidens pilosa*, *Galinsoga perviflora*, *Stellaria media*, *Alopecurus myosuroides*, *Lolium temulentum*, *Ageratum* sp, *Polygonum* sp, *Avena ludoviciana*, and *Cynodon dactylon* which were present in S1 situation were completely eliminated in S3. In the S3 then, *Rumex* sp, *Poa annua*, *Polygonum plebegium*, *Trifolium repens*, *Polypogon monspelensis* were major invadors.

WEED SHIFT -definition

A weed shift is the change in the composition or relative frequencies of weeds in a weed population (all individuals of a single species in a defined area) or community (all plant populations in a defined area) in response to natural or human-made environmental changes in an agricultural system.

Weed shifts occur when weed management practices do not control an entire weed community or population. The management practice could be herbicide use or any other practice such as tillage, manure application, or harvest schedule that brings about a change in weed species composition.

Some species or biotypes are killed by (or susceptible to) the weed management practice, others are not affected by the management practice (tolerant or resistant), and still others do not encounter the management practice (dormant at application). Those species that are not controlled can grow, reproduce, and increase in the community; resulting in a weed shift. Any cultural, physiological, biological, or chemical practice that modifies the growing environment without controlling all species equally can result in a weed shift.

In the case of chemical weed control, no single herbicide controls all weeds, as weeds differ in their susceptibility to an herbicide. Susceptible weeds are largely eliminated over time with continued use of the same herbicide. This allows inherently tolerant weed species to remain, which often thrive and proliferate with the reduced competition. As a result, there is a gradual shift to tolerant weed species when practices are continuously used that are not effective against those species. A weed shift does not necessarily have to be a shift to a different species. For example, with a foliar herbicide without residual activity like glyphosate, there could also be a shift within a weed species to a late emerging biotype that emerges after application.

WEED RESISTANCE

In contrast to weed shift, weed resistance is a change in the population of weeds that were previously susceptible to an herbicide, turning them into a population of the same species that is no longer controlled by that herbicide. While weed shifts occur with any agronomic practice (crop rotation, tillage, frequent harvest or use of particular herbicide), the evolution of weed resistance is only the result of continued herbicide appplication. The use of a single class herbicide application continuously over time creates selection pressure so that resistant individuals of a species survive and reproduce, while susceptible ones are killed. A weed shift is far more common than weed resistance, and ordinarily take less time to develop. If an herbicide does not control all the weeds, the tendency is to quickly jump to the conclusion that resistance has occurred.

A common misconception is that weed resistance is instrinsically linked to genetically engineered crops. However, this is not correct. The occurrence of weed shifts and weed resistance is not unique to genetically engineered crops. Weed shifts and resistance are caused by the practices (for example repeated use of single herbicide) that may accompany a genetically engineered crop and not the GE crop itself. Similarly, tere is another belive that resistance is transferred from Ge crop to weed species. However, unless the crop is genetically very closely related to naturally occurring weed, weed resistance cannot be transferred from crop to weed.

Transgenic herbicide resistance crops have greater potential to foster weed shifts and resistant weeds since a grower is more likely to use single herbicide in transgenic herbicide resistance crops. The increase in acreage of these crops could increase the potential for weed shifts and weed resistance in the cropping systems utilizing transgenic herbicide resistance crops.

WEED MANAGEMENT PRINCIPLES TO REDUCE WEED SHIFTS AND RESISTANCE

WEED IDENTIFICATION

Effective weed management practices begin with proper identification to assess the competiveness of the weeds present and to select the proper herbicide if one is needed. A weed management strategy to prevent weed shifts and weed resistancce requires knowledge of the composition of weeds present. Identification of young seedlings is particularly important because seedling weeds are easier to control.

FREQUENT MONITORING FOR ESCAPES

It is difficult to detect an emerging weed shift or weed resistance problem if fields are not frequently monitored for weeds that escapes current weed management practices. Identification and frequent monitoring can detect problem weeds early and guide management practices, including herbicide selection, ratre and timing.

HERBICIDE RATE AND TIMING

In weed management programme the grower must be sure to use the proper herbicide rate for the particular weeds species as they may sometimes tolerant to lower doses. And also the time of application of the herbicide dose is important i.e it treat the weeds when they are small, because after crossing certain stgage they may be tolerant to that particular herbicide or dosage.

CROP ROTATION

One of the most effective practices for preventing weed shifts and weed resistance is crop rotation, which allows growers to modify selection pressure imposed on weeds. Crops differ in their ability to compete with weeds; some weeds are a problem in some crops, while they are less problematic in others. Rotation therefore would not favor any particular weed spectrum. Crop rotation also allows the use of different weed control practices, such as cultivation and application of herbicides with different sites of action. As a result, no single weed spices or biotype should become dominant.

AGRONOMIC PRACTICES

In addition to crop rotation, several management practices may have an impact on the selection of problem weed populations. If problem weeds germinate at a specific time of year, crop seeding date can be shifted to avoid these weed populations. Delaying irrigation after can reduce germination of certain summer annual weeds. However, this practice only works on some soil types and water stress resistant crops only. Harvest management can, assist in eliminating or suppressing problem weed populations in some cases, but harvest must occur before weed seed production to prevent weed proliferation.

ROTATION OF HERBICIDES

Weed shifts occur because herbicides are not equally effective against all weed species and herbicides differ greatly in the weed spectrum they control. A weed species that is not controlled will survive and increase in density following repeated use of one herbicide. Therefore, rotating herbicides is recommended. Rotation of herbicides reduces weed shifts, provided the rotation herbicide reduces weed shifts, provided the rotational herbicide is highly effective against the weed species that is not controlled with the primary herbicide. The grower should rotate to an herbicide with a complimentary spectrum of weed control, along with a different mechanism of action and therefore a different herbicide binding site. Weed susceptibility charts are useful to help develop an effective herbicide binding site and herbicide rotation scheme. In addition, publications on herbicide chemical families are available to assist growers in choosing herbicides with different mechanisms of action. Rotating herbicides is also an effective strategy for resistance management. Within a weed species there are different biotypes, each with its own genetic makeup, enabling some of them to survive a particular herbicide application. The susceptible weeds in a population are killed, while the resistant ones survives, set seed, and increase over time. Using an effective herbicide with a different mode of action from the one to which the weeds are resistant, however, controls both the susceptible and resistant biotypes. This prevents reproduction and slows the spread of the resistant biotype.

Frequency of rotation depends on weed species and escapes. There is no definitive rule on how often herbicides should be rotated. It is better to rotate at least once on the middle years or more often for perrenial crop. It can also be modified depending upon actual observations of evolving weed problems. The key point, which cannot be overemphasized, is the importance of thorough monitoring for weed escapes. Producers should stay alert to the appearance of weed species shifts and evolution of resistant weeds. Weed resistance should be confirmed by controlled studies conducted by a weed scientist. However in these situations, it is imperative to prevent reproduction of a potentially resistant biotype. Treat weed escapes with alternative herbicides or other effective control measure.

Control of weeds in non-cropped situations

Non-cropped land refers to all the lands that are in various uses other than crops cultivation, like road side, rail track sides, waste lands, Nallah sides and banks of streams and rivers. The weeds growing on such lands are the real threat to human and animal health and ecology. The typical example is spread of *Lantana, Ageratum*, *Parthenium* and Alligator weed which have drastically affected the grazing and pasture area resulting in shortage of fodder supply besides creating health problems and shrinkage of resource base. The fast growth and spread of these weeds prevent establishment of native trees, shrubs and grasses thus posing serious threat to the plant biodiversity. There is increased danger of wild animals to the inhabitants and their livestock. Due to fodder scarcity caused due to invasion by these weeds, farmers are compelled to leave their cattle loose for stray grazing which cause damage to the cultivated crops. The other major problematic weeds in these areas are *Oxalis latifolia, Chromolaena adenophorum, Imperata cylindrica, Sorghum halepense, Cyperus rotundus, Cuscuta* sp and *Utrica dioca*. *Parthenium hysterophorus* has covered low and mid-hills of the state. *Ageratum houstonianum* has spread from hills to the adjoining areas of Punjab. *Lantana camara* and *Ageratum* plants when taken alongwith other grasses or are grazed accidentally cause death of animals due to presence of poisonous alkaloids. The presence of these weeds in pastures and grasslands has reduced the productivity of grasses. The vast slopes and arable lands in the close vicinity of our villages have been severely infested with these weeds. These thickets of weeds are forcing people to depend on other forest trees to meet their fodder requirements causing thereby deforestation and destruction of useful vegetation. The most important non-cropped land weeds (Kumar *et al*. 2014; Angiras 2014; Rana et al. 2016) are listed in Table 4.6.

Table 4.6. Important non-cropped land weeds of Himachal Pradesh

Scientific name	Common name	Family	Category
Parthenium hysterophorus L.	Congress grass, Gajar ghas	*Asteraceae*	Perennial broad-leaf
Ageratum conyzoides	Neela phulnu	*Asteraceae*	Annual broadleaf
A houstonianum (Mill)	Bill goat weed, neela phulnu	*Asteraceae*	Perennial broadleaf
Bidens pilosa	*Cobbler's Pegs* or Spanish Needle	*Asteraceae*	Annual
Erigeron Canadensis	Horseweed	Compositae	Annual
Chromolaena adenophorum Spreng.	Crofton weed, kali basuti	Asteraceae or Compositae	Perennial broadleaf
Cirsium arvense	Canada thistle	Asteraceae	Perennial broadleaf
Ipomea	Morning glory	Convolulaceae	Annual
Cynodon dactylon	Bermudagrass	Poaceae	Perennial grass
Achyranthus	Prickly chaff flower, devil's horsewhip	Amaranthaceae	Annual broadleaf
Lantana camara L.	Wildsage, bunch berry, *lal phulanoo* and *punch phul buti*	Verbenaceae	Perennial broad-leaf
Hackelia uncinata	Jhangeer	Boraginaceae	Annual broadleaf
Imperata cylindrica (l) Beauv.	Thatch grass, chhiz, alang-alang, Congograss	Poaceae	Perennial grass
Polygonum alatum	Nepalese Knotweed	Polygonaceae	Annual broadleaf
Oxalis latifolia H.B.&K.	Khat-mithi	Oxalidaceae	Broadleaf
Echinochloa colona	Jungle rice	Gramineae	Annual grass
Polygonum barbatum	Knotgrass	Polygonaceae	Broadleaf
Urtica dioca L.	Stinging nettle, ain, bitchu booti	Urticaceae	Perennial broad-leaf
Rumex obtusifolius	Broad-leaved dock, Sorrel, wild palak	Polygonaceae	Broadleaved perennial
Solanum xanthocarpum	*Yellow Berried Nightshade,* Kantakari, Nidigadhika, Kateli	Solanaceae	Annual broadleaf
Datura stramonianum	Jimson weed, Thornapple	Solanaceae	Annual broadleaf
Xanthium strumarium L.	Cocklebur	Compositae	Annual broadleaf
Alternethera philoxeroides	Alligator weed	Amaranthaceae	Perennial plant
Galium aparine	Bedstraw, catch weed	Rubiaceae	Broadleaf

For control of *A. conuzoides* in non-cropped areas following herbicides (Angiras and Kumar 1995, Angiras 1998) can be effectively used at 6-7 leaf stage before flowering using 800 litres of water per hectare with high volume sprayers:

I. Glyphosate 0.75 -1.5 kg/ha, post emergence
II. Diuron 0.80 kg/ha, post emergence
III. Atrazine 1.00 kg/ha, post-emergence

For control of *A. houstonianum* in orchards, tea gardens, or roadsides, directed application of glyphosate 1.0 kg/ha, or repeated spray of paraquat 0.6 kg/ha or atrazine 2.0 kg/ha using 800 litres of water per hectare with high volume sprayers should be done before flowering. In pastures and grassland use only paraquat or atrazine.

Uprooting is the best known method of getting rid of *Lantana*. Its roots submit easily in rainy season when the soil is wet and soft. It can be managed by following principal of destroying its food reserves, stoppage of food supply for their survival and creating competition by growing useful vegetation. It involves cutting, pulling of the stumps during rainy season, planting of competitive plants or grasses and frequent uprooting of re-growth (Katoch 1988). However, this method is labour intensive and cannot be applied in rocky areas and steep slopes.

Angiras et al (1988) has developed three phased integrated technology as below:

- Cut the *Lantana* bushed in August – September at 5-7 cm above ground and utilize the cut biomass for making furniture, vermicompost, charcoal, brickets, agarbaties, mulch and fuel wood etc.
- Apply glyphosate 0.41% or 0.31% + surfactant 0.1% in September – October on 30-40 cm regenerated foliage.
- Utilize the land as per its capability to avoid emergence of other weeds by planting fast growing grasses (Setaria, Napier bajra hybrid, Guinea), fodder trees and other useful vegetation.
- Uproot or give spot treatment on plants (1-2%) emerged from already fallen seeds.

Glyphosate being a translocative herbicide kill the *Lantana* up to root system. In addition to *Lantana,* other perennial weeds like *Imperata cylindrica, Ageratum houstonianum* and *Eupatorium adenophorum* were also controlled at the treated site.

Under non-cropland situations (wastelands) atrazine 1.25 kg/ha, paraquat 0.50 kg/ha, 2,4-D 2.5 kg/ha and glyphosate 2.0 kg/ha (Angiras and Kumar 2010) are used to control *Parthenium*. The plant *Casia sericea*, native of Latin America, or *Cassia tora* has been found effective in displacing *Parthenium* in areas where the rainfall is more than 85 cm. Once established the *Cassia* seeds are multiplied of its own and there is no need for re-sowing of this plant. Quick results can be obtained by removing *Parthenium* manually in the area before and after sowing of *Cassia* seeds. 'Kolines' are the leachates which accumulate in soil and inhibit the growth of *Parthenium* plant. *Cassia sericea* is not grazed by cattle and being a leguminous plant enriches the soil with nitrogen. In 1983, a leaf eating beetle, *Zygogramma bicolorata* Pallister, highly specific to this weed was introduced from Mexico. This is capable of multiplying on *Parthenium* only. This insect remains active in the field during the rainy season (June to October) and attacks the terminal and auxillary buds and thereafter the leaves of this weed. The younger larvae check the plant growth and flower production, while older larvae defoliate over winter and summer by burrowing into the soil and remaining there for 6-8 months to emerge with the onset of monsoon, there is no need for introduction of beetles after initial establishment. In Kangra district, the technology was successfully demonstrated at Bairghata area in about 50 ha land (Angiras 2014).

Erigeron canadensis is a species which is particularly difficult to eradicate. Under mid hill conditions of Himachal Pradesh glyphosate (1.0 kg/ha and 0.5 kg/ha), 2, 4-D (Na) (1.50 kg/ha and 1.0 kg/ha) and 2, 4-D (EE) 1.0 kg/ha controlled this weed effectively. Gluphosinate ammonium when spray at 10-15 cm height of weeds has been found selective in peach orchards. Four litre Basta (gluphosinate), 5 litre Basagram (bentazone), 4 litre Blazer, 2 litre aciflurfen and 2 litre goal (oxyflourfen)/ha provide 100% control of *E. canadensis* within 4 weeks of treatment.

Bidens pilosa is susceptible to hand weeding. It can be easily removed with hands before flowering but after seed setting it does not allow even to pass through the invaded areas. Germination may be prevented by mulches if they are thick enough. *B. pilosa* is susceptable to several herbicides. Residual herbicides: diuron, bromacil, atrazine, oryzalin, and ametryn; translocated herbicides: 2,4-D, glyphosate, amitrole, metribuzin, and dicamba; and contact herbicides bentazone, diquat, and paraquat have all been evaluated as effective means of controlling *B. pilosa* when applied at standard rates. *B. pilosa* is thought susceptible to the majority of broad-leaf plant herbicides. Pre-emergence application of atrazine, metribuzin, etc. can keep the ground weed free for the whole season. Post-emergence application of 2, 4-D at 2 to 4 leaf stage can effectively control this weed in grasslands without any effect on grasses.

For *Rumex obtusifolius*, 2, 4-D and atrazine are quite effective herbicides and their combination has been found more promising (Rana et al 2016).

Alligator weed grows in different situations, each requiring particular herbicide controls. In non-cropped lands, it can be controlled with glyphosate 1.50 kg/ha or 2,4-D or metsulfuron-methyl.

Glyphosate 1.50 kg/ha also effectively control the population of *Chromolaena adenophorum*.

Imperata cylindrica can be managed by following hot weather cultivation in May – June by deep ploughing, spray of glyphsate 1.0 kg/ha or glyphosate 0.75 kg/ha + surfactant 0.5% in June or dalapon 4.5 kg/ha in February or paraquat 0.6 kg/ha or cheeling (scraping of existing weeds with spade) followed by spray of oxyfluorfen 0.25 kg/ha (Angiras et al 1990).

Weed management in grassland and pastures

Effective weed control begins with good pasture or rangeland management. Weeds are seldom a serious problem in a well managed, vigorously growing grass. Good management begins with proper choice of the forage species and variety, adequate fertility and soil pH, proper grazing management, and control of pests, such as insects, diseases, and nematodes. If the grass dies or is not growing well, there is usually some weed that will tolerate the condition which caused the grass not to grow, and that weed will become established. Once a weed is established, mechanical or chemical methods are usually employed to control the weeds (Table 4.7). However, unless the basic management problem is corrected, the grass will not regrow in the area, and weeds will continue to infest the area.

Mechanical control

Mowing is one of the most often used methods of weed control in pastures. Mowing improves the appearance of a pasture and if properly timed will prevent weeds from producing seed. However, the effectiveness of mowing in terms of controlling weeds depends on several factors. The major consideration is the type of weed present. Mowing is generally more effective on broadleaf weeds than on grasses and more effective on annual weeds than on perennial weeds. Knowledge of the weed and its life cycle will generally indicate how effective mowing will be. Carefully consider the amount of energy required and anticipated the likely effectiveness before mowing; other methods of weed control may be more energy efficient. Another factor to consider prior to mowing is whether the plant can regenerate vegetatively. Mowing can spread weeds that can form new plants from the cut vegetative plant parts. Prickly pear is one example of a weed that can propagate vegetatively.

Sanitation

In addition to controlling weeds in a pasture, efforts should be taken to prevent weeds from reinfesting the pasture. Knowledge of how weeds are dispersed is important.

Weeds may be dispersed by wind, carried by water, distributed in planting seed, in feed or hay, carried by animals including man, or moved by machinery. Animals grazing in a weed-infested pasture and then allowed to move directly to a clean pasture may move weed seed both internally and externally. One of the most common problems is failure to control weeds in ditch banks, fence rows, and farm roads. Weeds growing in these areas produce seed and/or vegetative growth that reinfests the pastures.

Fence rows are also a common area where poisonous plants are often left uncontrolled. Plants such as crotalaria, black nightshade, and lantana are commonly found poisonous plants in Florida.

Animals won't usually choose to graze most poisonous plants. However, if grass is limited in pastures due to poor growing conditions or overstocking, animals may try to eat poisonous plants. Some poisonous plants may become more palatable following herbicide application and then be more readily grazed. Therefore, if poisonous plants are present in fence rows, and pastures are in short supply, care should be taken and cattle watched closely.

When treating fence rows, it is often advisable to apply a foliar-applied herbicide to kill the existing vegetation along with a soil –applied residual herbicide to prevent weeds from regrowing in the fence row.

Chemical control

The herbicide and application rates are extremely important in chemical weed control. Rates too low will not give adequate weed control, and rates too high may injure the forage and result in only partial control of perennial weeds. Time of application is also important with herbicides. Pre-emergence applications are made before the weeds germinate and emerge; therefore, knowledge of the life cycle of the weed becomes important. For example, a herbicide applied in October for crabgrass (a summer annual that germinates in early spring) would be wasted.

One of the most important factors in choosing a herbicide is proper weed identification. After identifying the weed, use Tables 4.8 and 4.9 to choose the herbicide recommended for the particular weed.

Post-emergence applications

Postemergence applications are made after the weeds have emerged. Most effective applications are made when the weeds have recently germinated and are small. For perennial weeds (regrowing from storage organs) it is often advisable to allow them to grow for a short period of time before spraying. This allows a sufficient leaf surface for coverage and insures that the perennial is manufacturing food (through photosynthesis) and translocating it along with the herbicide back to the roots (which is the part of the plant you must kill).

Herbicides may be applied broadcast over the entire pasture or may be applied as spot treatments to localized infestations of weeds. The lower cost and energy saved by spot treatment makes this a desirable method in many situations.

The attached table lists the currently recommended herbicides in pastures and rangelands in Florida. In all cases it is extremely important to carefully read the label of the herbicide before purchase to determine whether that herbicide will be effective in your situation.

The herbicides listed for use in pastures and rangelands are generally safe to use and offer minimal hazard to animals when used according to label directions. Table 4.10 lists the grazing and haying restrictions for the recommended herbicides.

Precautions when Using Phenoxy or Benzoic Acid Herbicides

1. For information about growth-regulating herbicides not covered below, see IFAS Publication SS-AGR-12, *Florida's Organo-auxin Herbicide Rule* (http://edis.ifas.ufl.edu/WG051).
2. Application of other pesticides from sprayers previously used for 2,4-D, dicamba, or other phenoxy or benzoic acid herbicides to susceptible crops, may result in injury
3. Legumes in pastures or rangelands will be injured or killed by these herbicides.
4. Avoid drift to susceptible crops by applying at low pressures and when wind speeds are low and blowing away from susceptible crops. The use of a drift-control additive is advisable.
5. Clean sprayer thoroughly with household ammonia as follows:
   a. Flush system with water. Drain.
   b. Flush the system with ammonia (1 qt ammonia per 25 gallons water); let it circulate for at least 15 minutes, then flush the system again. Drain again.
   c. Remove screens, strainers, and tips and clean in fresh water.
   d. Repeat step b.
   e. Thoroughly rinse the tank, hoses, booms, and nozzles.
   f. Be sure and clean all other associated application equipment.

Table 4.7. Weed control in pastures and rangeland

Trade Name and Rate of Commercial Product/Acre	Common Name and Rate in Pounds of ai/Acre	Remarks
		DURING ESTABLISHMENT
		Preemergence to Weeds
2,4-D Several Brands[1] (1.0 - 2.0 qt of 4 lb/gal formulation)	2,4-D amine **or** LV ester (1.0 - 2.0 lb)	**Bermudagrass and Stargrass only.** Apply after sprigging and before emergence of sprigged bermudagrass. Will not give complete weed control, however, short residual control of seedling broadleaves and certain grasses may be noted for 2 to 3 weeks if proper environmental conditions exist.
Diuron 4L - (Agriliance) 1.5 to 4.5 pt/A or Diuron 80 - (Drexel) 1 to 3 lb/A	Diuron (0.8 - 2.4 lb)	**Bermudagrass only**. Will provide fair to good control of crabgrass, crowfootgrass, and goosegrass. Plant sprigs 2 inches deep. If sprigs have emerged at time of application, bermudagrass injury will occur. Do not graze or cut hay within 70 days.
2,4-D + dicamba[1] (Weedmaster, others) 2 pt	Dicamba + 2,4-D	**Bermudagrass and Stargrass only.** Similar to 2,4-D, but often provides greater weed control. Short residual control of seedling broadleaves and certain grasses may be noted for 2 to 3 weeks if proper environmental conditions exist. **Do not apply to limpograss (*Hemarthria*).**
		Postemergence to Weeds
2,4-D Several Brands[1] (0.5 - 1.0 qt of 4 lb/gal formulation)	2,4-D amine	**Do not apply to bahiagrass until plants are 5 to 6" tall. Do not apply to limpograss (*Hemarthria* sp.).** Bermudagrass can tolerate 2,4-D at any growth stage. Controls most seedling broadleaf weeds. Repeat application may be needed.
2,4-D + dicamba[1] (Weedmaster, others) 2 pt/A	Dicamba + 2,4-D	Can be used during establishment of hybrid bermudagrass, stargrass, and Pangolagrass. Annual sedges and some grasses will be suppressed if less than 1 inch at time of application. Best results are seen if applications are made 7 - 10 days after planting. **Do not apply to limpograss (*Hemarthria*).**

Trade Name and Rate of Commercial Product/Acre	Common Name and Rate in Pounds of ai/Acre	Remarks
Banvel, Clarity, Vanquish 1.5 - 2 pt/A	Dicamba	Primarily used for establishment of Floralta limpograss (*Hemarthria*). Annual sedges and some grasses will be suppressed if less than 1 inch at time of appliation. Best results are seed if applications are made 7 -10 days after planting.
		ESTABLISHED STANDS
		Dormant Pastures
Gramoxone Inteon 1 - 2 pt	Paraquat	For **dormant** bermudagrass or bahiagrass. Apply in 20 to 30 gallons of water in late winter or early spring (probably in January or February) before grass begins spring green-up. Add 1 pt. surfactant (non-ionic) per 100 gal. spray mix. Do not mow for hay until 40 days after treatment. Can be mixed with 2,4-D or other herbicides for more broadspectrum control.
Roundup Weathermax 11 oz	Glyphosate	Apply in mid- to late-winter months to bermudagrass or bahiagrass pastures and hayfields for the control of weedy grasses. Apply before new growth appears in the spring. Bermudagrass that is not dormant at the time of application may show a 2 to 4 week delay in green-up. No restrictions exist between application and grazing or haying.
		Non-Dormant Pastures
Aim 1 - 2 oz	Carfentrazone	Aim provides control of small broadleaf (<2") weeds. In most cases Aim should not be applied alone, but tank-mixed with other pasture weed control products. Combining Aim with other herbicides often increases overall weed control and speed of kill. A 2-4% v/v liquid nitrogen fertilizer, 2-4 lb/acre spray-grade ammonium sulfate or an AMS replacement/water conditioning product should be added to water prior to the addition of Aim. Use caution when applying AMS to newly established grasses as crop injury could occur. When tank-mixing Aim with other herbicides, it is important that Aim is added to the nitrogen-water solution before other herbicides. A non-ionic surfactant at 0.25% v/v must be added. Do not apply >5.9 fl oz/acre/year and do not make more than 3 applications of Aim per year.
2,4-D Several Brands [1] (2.0 - 4.0 pt of 4 lb/gal formulation)	2,4-D amine **or** LV ester (1.0 - 2.0 lb)	**Broadleaf weeds.** Annual weeds should be treated soon after emergence for best control with lower rates. Perennial weeds should be allowed to obtain a leaf surface large enough to allow sufficient spray coverage (about 12"-18" tall). Use amine formulations during warm weather and LV esters during cool weather. Avoid drift. Applications of 2,4-D to limpograss (*Hemarthria* sp.) will cause significant injury during periods of high temperatures and humidity; much less injury has been observed during cool and dry conditions.
Banvel[1], Clarity, Vanquish (0.5 - 2.0 qt)	Dicamba	**Broadleaf weeds.** Rate depends on weed species and size. Refer to the label for grazing restrictions. Avoid drift. *Hemarthria* sp. has generally exhibited more tolerance to dicamba than 2,4-D.
Cimarron Plus 0.125 to 1.25 oz/A or Cimarron Xtra 0.5 to 2.0 oz/A	Metsulfuron + Chlorsulfuron	Use on bermudagrass, pangolagrass, and stargrass. Controls several cool-season broadleaf weeds, pigweeds, and Pensacola bahiagrass. Bermudagrass should be established no less than 60 days prior to application. Add a non-ionic surfactant at 1-2 pts/100 gal of solution. Avoid application during spring green-up. Varieties and species of pasture grasses differ in their tolerance to herbicides.
Cimarron Max Part A (0.25 – 1.0 oz) Part B (1.0 – 4.0 pt)	Part A – metsulfuron Part B - 2,4-D + dicamba	Cimarron Max is a two part product that should be mixed at a ratio of 5 oz *Part A* to 2.5 gallons *Part B*. Depending on the weeds present and the rate range that is selected, this mix will treat between 5 to 20 acres. For specific information on rate selection, consult the product label.
Cleanwave 14 - 26.6 oz/A	Fluroxypyr + aminopyralid	Excellent tank mix partner for 2,4-D, Forefront, and Remedy. Tank mix 14 oz with one of these products for dogfennel < 36"; 20 oz for dogfennel between 36 and 60"; 26.6 oz for dogfennel > 60". If tank-mixing with Milestone add 20 oz Cleanwave to dogfennel < 60" and 26.6 oz to dogfennel > 60". Cleanwave is safe on limpograss.
Forefront 2 - 2.6 pt	Aminopyralid + 2,4-D	Excellent control of TSA, horsenettle, and other members of the nightshade family. Also control pigweeds and other broadleaf weeds including less than 20" dogfennel. Do not apply greater than 2.6 pt/A/yr. Do not apply to desirable forage legumes or severe injury and stand loss will occur. Do not apply to limpograss. Forefront will pass through animals and remain in the waste. Do not mulch sensitive crops with manure if animals have been grazing on Forefront-treated pastures.

Trade Name and Rate of Commercial Product/Acre	Common Name and Rate in Pounds of ai/Acre	Remarks
		Avoid applications of this product to limpograss pastures during hot and humid conditions.
Impose or Panoramic 4 to 12 fl. oz/A	Imazapic	DO NOT apply to bahiagrass. DO NOT apply during spring transition or severe bermudagrass or stargrass injury will occur. In summer months, expect 3 to 4 weeks of bermudagrass stunting after application, followed by quick recovery and rapid growth. This will reduce harvest yields of that cutting by 30 to 50%. If this yield reduction is not acceptable, do not use these herbicides. Yield reductions of subsequent cuttings have not been observed. For control of crabgrass, sandspur, nutsedges, and vaseygrass, use 4 oz/A. For suppression of bahiagrass, use 12 oz/A.
Journey (10.6 - 16 fl. oz)	Imazapic + Glyphosate	Similar to Impose and Panoramic.
Milestone (3 - 7 oz)	Aminopryalid	Excellent control of tropical soda apple, horsenettle and other members of the nightshade family. Controls pigweeds and other broadleaf weeds, but does not control blackberry or dogfennel. Can be safely applied under trees. Do not apply more than 7 oz/A/yr. Do not apply to desirable forage legumes or loss of stand will occur. The use of a non-ionic surfactant is recommended. Milestone will pass through animals and remain in the waste. Do not mulch sensitive crops with manure if animals have been feeding on Milestone treated pastures. Safe on limpograss.
Outrider (1.0 - 1.33 oz)	Sulfosulfuron	**Established bahiagrass and bermudagrass only.** Provides excellent control of annual and perennial sedges. Provides some suppression of vaseygrass.
PastureGard[1] (2 - 4 pt)	Triclopyr + fluroxypyr	Provides excellent control of dogfennel, blackberry, teaweed, and other broadleaf weeds. Less effective on tropical soda apple than Remedy alone. Forage legumes will be severely injured or lost if present at time of application. Applications of 2 pt/A may result in less than desirable weed control. Do not apply more than 8 pts/A per season. Surfactant should be added to spray mixture at 0.25% v/v.
Remedy Ultra 2 pt	Triclopyr	Provides excellent control of herbacious and certain woody plants in pasture and rangeland. For best results, apply in 30 or 40 gallons of water per acre. The addition of a nonionic surfactant at 0.25% v/v will increase control. Applications at air temperatures >85F may cause moderate to severe bermudagrass injury for 2 to 3 weeks.
Roundup Weathermax 8 - 11 fl. oz/A	Glyphosate	For control of annual grasses in bermudagrass and stargrass. Apply immediately after hay removal, but prior to regrowth. Applications made after regrowth has occurred will cause stunting. Application rates as low as 6 oz/A are often effective for crabgrass and other small annual grass weeds. Do not apply more than 2 qt/A/year. If Roundup Weathermax is applied to a dormant pasture, it can not be sprayed again that season.
Telar 0.1 - 1.0 oz	Chlorsulfuron	For use on established warm-season forage grass species. Telar will control blackberry, pigweeds, wild radish, and selected winter weeds. Not effective on ragweed, tropical soda apple and other common weeds. Ryegrasses will be severely injured or killed by Telar. Do not apply more than 1.3 oz/A/yr. There are no grazing restrictions for any animals.
2,4-D + dicamba[1] (Weedmaster, others) 0.5 - 4.0 pt	Dicamba + 2,4-D amine	See remarks for 2,4-D and dicamba above. This mixture is usually more effective than either herbicide used alone.
		Hard-To-Kill Perennial Grasses
Glyphosate (1 to 4 oz per gal)	Glyphosate (1-3% solution for hand sprayer)	**Spot treatment.** Apply when perennial weeds are actively growing. Surrounding forage will be killed if sprayed.
Glyphosate (4 to 8 qt to 2 gal water)	Glyphosate (33-50% solution)	**Wiper application.** Apply at speeds up to 5 MPH. Two passes in opposite directions. No more than 10% of any acre should be treated at one time.
		Smutgrass
Velpar L (2.75 - 4.5 pt) **or**	Hexazinone	Apply Velpar to established stands of bermudagrass or bahiagrass when soil conditions are warm and moist and weeds are actively growing. Best control of smutgrass is usually achieved in late spring to early summer

Trade Name and Rate of Commercial Product/Acre	Common Name and Rate in Pounds of ai/Acre	Remarks
Velpar DF (0.9 - 1.5 lb)		when regular rainfall occurs. Some temporary yellowing of the bermuda or bahiagrass will be noted, but plants will soon outgrow this effect. Apply Velpar by ground equipment only, and only **one** application is allowed per year. **KEEP SPRAYS WELL AWAY (AT LEAST 100 FT) FROM THE BASE OF DESIRABLE TREES, ESPECIALLY OAKS.** Check label instructions for further precautions and safe use suggestions. Control at either time of year will be enhanced with a nonionic surfactant at 0.25% v/v.
		Pensacola Bahiagrass
Cimarron Plus 0.5 oz/A or Cimarron Xtra 1.0 oz/A	Metsulfuron + Chlorsulfuron	Apply to bermudagrass hay fields early in the season, after bahiagrass green-up but prior to seed head formation. Early applications are often most effective; fall applications rarely control bahiagrass. Do not apply with liquid fertilizer solutions as poor control may occur. Prolonged periods of dry weather prior to application will greatly decrease herbicide effectiveness. Always include a nonionic surfactant at a rate of 0.25% v/v. 'Common' or 'Argentine' bahiagrass will not be effectively controlled. Pasture legumes will be severely injured or killed.
		Tropical Soda Apple
Forefront (2 - 2.6 pt)	Aminopyralid + 2,4-D	Excellent control of tropical soda apple. Provides preemergence control TSA seedlings for approximately 6 months after application. The 2 pt/a rate is highly effective on emerged TSA plants, but the 2.6 pt/a rate will provide the greatest length of residual control. Do not apply more than 2.6 pt/a/yr. Will severely injure desirable forage legumes. Do not apply to limpograss. There are no grazing restrictions, but do not harvest for silage or hay for 7 days.
Milestone (5 - 7 oz)	Aminopryalid	Excellent control of tropical soda apple. Provides preemergence control of TSA seedlings for approximately 6 months after application. The 5 oz rate is highly effective on emerged plants, but the 7 oz rate will provide the greatest length of residual control. Do not apply more than 7 oz/A/yr. Do not apply to desirable forage legumes or loss of stand will occur. Volatility is low. The use of a non-ionic surfactant at 0.25% v/v is recommended.
Remedy Ultra [1] (1.0 qt)	Triclopyr	Apply in late spring through summer as a broadcast spray for control of this species. Best results will occur when plants are adequately covered with spray solutions. Thirty to forty gal/A application will be more effective than 20 or lower. The addition of a nonionic surfactant at 0.25% v/v will increase control. Retreatment will be required as new seedlings emerge. Spot spray rate is 0.5 - 1.0% v/v.
		Prickly Pear Cactus
Remedy Ultra [1] (20%) + diesel fuel or basal oil (80%)	Triclopyr (20%) diesel fuel or basal oil (80%) (Spot treatment)	Apply as a spot treatment directly to prickly pear pads during spring and summer. Grass will be burned in treated spots but will recover. The addition of diesel fuel drastically enhances herbicide uptake which will lead to prickly pear control. Prickly pear will die slowly over a period of 6-8 months with a few plants requiring retreatment.
Cleanwave 50 oz	fluroxypyr + aminopyralid	Apply Cleanwave at 50 oz/A as a broadcast treatment in water. The use of a surfactant is required. For spot treatment, use a 2% Cleanwave solution. Control is very slow and it often takes more than 1 year to see satisfactory results.
		Blackberry
Cimarron Plus 0.75 oz/A or Cimarron Xtra 2.0 oz/A	Metsulfuron + Chlorsulfuron	Cimarron will provide good to excellent control of blackberry. Results are best when applied at blooming or late in the fall. Do not mow within 1 yr prior to application or control will be reduced. DO NOT apply to bahiagrass pastures.
PastureGard [1] 4 pt	Triclopyr + Fluroxypyr	Control similar to Remedy.
Remedy Ultra [1]	Triclopyr	For best control of blackberry, apply 2 pt when blooming and do not mow within 1 yr prior to application. Remedy does not control dewberry. The

Trade Name and Rate of Commercial Product/Acre	Common Name and Rate in Pounds of ai/Acre	Remarks
2 pt		addition of a nonionic surfactant at 0.25% v/v will increase control. Applications made during prolonged periods of dry weather can greatly decrease control. Fall applications often provide more consistent blackberry control.
Telar 0.75 oz	Chlorsulfuron	Similar to control with Cimarron. Telar can safely be applied to bahiagrass or bermudagrass.
		Dogfennel
2,4-D + dicamba[1] (Weedmaster, others) 2 to 3 pt	Dicamba + 2,4-D	Apply when plants reach a height of 12-18". Weedmaster is most effective approximately 1 month after dogfennel transition from winter dormancy. Refer to previous comments for dicamba and 2,4-D above.
PastureGard[1] (3 pt)	triclopyr + fluroxypyr	For control of larger dogfennel that has reached 40 inches or more in height.
Forefront (2 pt)	aminopyralid + 2,4-D	Apply when plants are less than 30" tall. If plants are larger than 30", tank mix Forefront with 3 pt/A 2,4-D, 1 pt/A Pasturegard, or see comments for Cleanwave herbicide.
Cleanwave (14 - 26.6 fl oz)	fluroxypyr + aminopyralid	Excellent tank mix partner for 2,4-D, Forefront, and Remedy. Tank mix 14 oz with one of these products for dogfennel < 36"; 20 oz for dogfennel between 36 and 60"; 26.6 oz for dogfennel > 60". If tank-mixing with Milestone add 20 oz Cleanwave to dogfennel < 60" and 26.6 oz to dogfennel > 60". Cleanwave is safe on limpograss.
		Mixed Stands: Grass - Clover/Lespedeza Pastures
2,4-D amine[1] (0.5 - 1.0 pt)	2,4-D (0.25 + 0.5 lb)	Apply only one treatment per year to established perennial clover. Slight to moderate injury may occur. See label of specific use information
		Thistles
2,4-D (2 qt)	2,4-D (2 lb)	Highly effective if applied to thistles in the rosette stage. 2,4-D is not effective on thistles that have bolted or flowered. During cool temperatures, the ester formulation of 2,4-D will be most effective.
Milestone (3 - 5 fl. oz)	Aminopyralid	Excellent control of thistles at any stage of growth.
2,4-D + dicamba[1] (Weedmaster, others) 1.0 - 2.0 qt	Dicamba + 2,4-D	Apply late fall to early spring when daytime temperatures are >50F. Applications are most effective if applied before flower stalks elongate. The addition of crop oil will increase herbicidal activity. Refer to previous comments for dicamba and 2,4-D above. For small rosettes 1 qt/A rate is sufficient. For larger rosettes, 1.5 to 2 qt/A will be required.

[1] EDIS Publication SS-AGR-12, *Florida Organo-Auxin Herbicide Rule* (http://edis.ifas.ufl.edu/WG051) .

Herbicide recommendations in this report are contingent upon their registration by the U.S. Environmental Protection Agency. If an herbicide's EPA registration is canceled, the herbicide is no longer recommended.

Table 4.8. Estimated effectiveness of herbicides on common broadleaf weeds in pastures and hayfields[1]

Weed Name	2,4-D	Cimarron Plus or Xtra	Banvel or others	Cleanwave	Diuron	Forefront	Impose/ Panoramic
bitter sneezeweed	E	E	E	-	G	E	-
Blackberry	P	G-E	F-G	F-G	P	P-F	P
bracken fern	P	-	G	-	P	-	-
Bulrush	G	-	G	P	P	P	-
Chickweed	F	E	E	-	P	F	-
crotalaria, showy	G	-	G	G	-	G	-
Cudweed	F	G	E	-	-	E	-
curly dock	F	E	E	-	P	E	-
Dodder	P	-	P	-	P	-	-
Dogfennel	F-G	F	F-G	G	P	G	-
evening primrose	E	G	E	-	G	E	-
Florida pusley	P	-	P-F	P	E	G-E	-
Gallberry	G	-	E	-	P	-	-
Goatweed	G	G	F-G	P-F	-	-	P

Goldenrod	F	P	G		P	G	-
honeysuckle	-	-	E	-	P	-	-
Horsenettle	P	P-F	G	F	P	E	-
Horseweed	F	F	E	-	P	E	-
Kudzu	P-F	P-F	G	P	P	G	P
Maypop	P	P	P	-	-	-	-
stinging nettle – fireweed	P	-	-	G-E	-	E	P
Palmetto	P	P	F	G	P	P	P
Persimmon	P	-	F-G	-	P	P	P
Pigweed	F	E	E	P	F	E	G
Plantains	E	E	E	-		-	-
Pokeberry	G	-	E	P	P	P	-
prickly pear	P	P	F	G	P	P	P
Ragweed	E	G	E	G	G	E	F
red sorrel	P	E	E	-	F	-	-
Shepherdspurse	E	-	E	-	G	-	-
Sicklepod	G	G	E	G	F	G	F-G
Thistles	E	F	G	G	F	E	-
tropical soda apple	P	P	F-G	F	P	E	P
Virginia pepperweed	G	-	E	G	G	-	-
wax myrtle	P	-	P-F	-	P	P	-
wild garlic	G-E	G	E	-	P	-	-
wild radish	G	G-E	E	-	P	G	-

Table 4.8, continued. Estimated effectiveness of herbicides on common broadleaf weeds in pastures and hayfields[1]

Weed Name	Journey or others	Milestone	Outrider	PastureGard	Remedy	Velpar	WeedMaster others
bitter sneezeweed	-	E	-	E	E	-	E
Blackberry	-	P	P	G-E	G-E	F	P-F
bracken fern	-	-	-	F	G	F	-
Bulrush	-	P	-	P	G	-	-
Chickweed	-	-	-	F	E	E	E
crotalaria, showy	-	-	-	E	E	-	G
cudweed	-	E	-	G	E	-	G
curly dock	-	E	-	F	E	P	E
Dodder	-	-	-	P	P	-	P-F
Dogfennel	-	P-F	P	E	G-E	G	G
evening primrose	-	E	-	G	E	E	E
Florida pusley	P	-	-	G	-	-	F
Gallberry	-	-	-	E	E	P	G
Goatweed	F	-	-	F	F	-	G
Goldenrod	-	G	-	G	G	-	G-E
Honeysuckle	-	-	-	P	P	-	E
Horsenettle	P	E	-	F	F-G	-	F
Horseweed	P	E	-	G	G	-	E
Kudzu	P	G	P	F	F	-	F
Maypop	P	-	P	G	F	-	P-F

Weed Name	Journey or others	Milestone	Outrider	PastureGard	Remedy	Velpar	WeedMaster others
stinging nettle – fireweed	-	E	P	E	E	-	F
Palmetto	P	P	P	G	F	P	P-F
Persimmon	P	P	P	F-G	F-G	F	P-F
Pigweed	E	E	-	F	E	G	E
Plantains	-	P	-	-	-	-	E
Pokeberry	-	F	-	P	P	-	E
prickly pear	P	P	P	F	G[2]	P	P-F
Ragweed	F-G	E	-	E	E	F	E
red sorrel	-	-	-	F	E	-	G
Shepherdspurse	-	-	-	G	E	E	E
Sicklepod	E	-	-	G-E	E	-	E
Thistles	-	E	-	G-E	E	E	E
tropical soda apple	P	E	P	G	G-E	F-G	F-G
Virginai pepperweed	-	-	-	G	P	E	E
wax myrtle	P	P	-	F-G	G	P	P-F
wild garlic	-	P	-	P	-	-	E
wild radish	E	P	-	G-E	E	E	E

[1]Estimated effectiveness based on rates recommended in this report. Effectiveness may vary depending on factors such as herbicide rate, size of weeds, time of application, soil type, and weather conditions; [2]When applied as spot-treatment in basal oil. Weed control symbols: E = 90-100% control; G = 80-90% control; F = 60-80% control; P = <60% control.

Table 4.9. Estimated effectiveness of herbicides on common grass and sedges in pastures and hayfields

Herbicide	bahia- grass	bermuda- grass	broom- sedge	crab- grass	dallis- grass	guinea- grass	johnson- grass	rye- grass	sandbur	smut- grass	vasey- grass	Nutsedge
2,4-D	P	P	P	P	P	P	P	P	P	P	P	P
Banvel or others	P	P	P	P	P	P	P	P	P	P	P	P
Cimarron Plus or Xtra	G	P	P	P	P		-	P	P	P	P	P
Cleanwave	P	P	P	P	P	P	P	P	P	P	P	P
Diuron	P	P	P	F-G	P	P	P	P	G	P	P	P
Forefront	P	P	P	P	P	P	P	P	P	P	P	P
Impose/ Panoramic	P-F	P	P	E	F	-	G	F	G-F	P	P-G	G-E
Journey or others	P-F	P	P	G	F	-	G	F	G-E	P	G	G-E
Milestone	P	P	P	P	P	P	P	P	P	P	P	P
Outrider	P	P	P	P	P	P	E	-	-	P	F-G	E
Pasture Gard	P	P	P	P	P	P	P	P	P	P	P	P
Remedy	P	P	P	P	P	P	P	P	P	P	P	P
Velpar	P	P	P	P	-	-	-	G	-	E	-	P
Weedmaster or others	P	P	P	P	P	P	P	P	P	P	P	P

[1]Estimated effectiveness based on rates recommended in this report. Effectiveness may vary depending on factors such as herbicide rate, size of weeds, time of application, soil type, and weather conditions. Weed control symbols: E = 90-100% control; G = 80-90% control; F = 60-80% control; P = <60% control.15594

Table 4.10. Days between herbicide application to forage or pasture for feeding or grazing

Herbicide	Non-lactating Cattle			Lactating Dairy Cattle		Horses
	Grazing	Hay Cutting	Slaughter	Grazing	Hay Cutting	
Aim	0	0	0	0	0	0

Banvel						
Up to 1 pt	0	0	30	7	37	0
Up to 1 qt	0	0	30	21	51	0
Up to 2 qt	0	0	30	40	70	0
Cimarron Plus and Cimarron Xtra	0	0	0	0	0	0
Cleanwave	0	7	0	0	7	0
2,4-D	0	30	3	7	30	0
Forefront	0	7	0	0	7	0
Impose or Panoramic	0	7	0	0	7	0
Journey	0	7	0	0	7	0
Milestone	0	0	0	0	0	0
Outrider	0	14	0	0	14	0
PastureGard	0	14	3	1 season	1 season	0
Remedy Ultra	0	14	3	1 season	14	0
Roundup WeatherMax						
Dormant application	0	0	0	0	0	0
Between cuttings	0	0	0	0	0	0
Pasture renovation	56	56	56	56	56	56
Telar	0	0	0	0	0	0
Velpar	60	60	0	60	60	60
2,-D + dicamba (Weedmaster, others)	0	37	30	7	37	0

Weed management in tea

India has unique distinction of being the largest producer and consumer of tea in the world. Indian tea industry produces about 840 million kg tea from an area of 5,10,492 ha. North East India produces about 75% of total Indian production. In Assam, tea occupies about 2,28,260 ha area with an annual production of 4,25,430 and thus contributes 55% of the country's tea production. There are about 1000 tea estates in Assam besides having thousands of small tea gardens. Tea industry in India has an annual turnover of INR 6000 crores and provides employment to 1.2 million people of which 50% is women besides providing indirect employment to millions. It also earns foreign exchange of INR 2000 crores from export of quality tea (Mukhopadhyay, 2001). Indian tea industry contributes INR 1100 crores annually to Indian economy as taxes and duties. During 2013, about 211.86 million kg of tea worth INR 4211.49 was exported to different countries (Tea board of India, 2014). India has witnessed a many fold increase in production of tea, which is mainly attributed to efficient and integrated agricultural practices including efficient weed management.

Weeds are the number one pest and can reduce the productivity of tea by 10 – 50% (Rao et al., 1977) depending on the intensity of weed growth, extent of competition, weed species and the competitive ability of cloning. Weeds complete with the crops for nutrient, sunshine and moisture. Besides reducing the yield, weeds also produce the following adverse effects on tea:

- Restrict branching and frame development in young tea.
- Harbour and serve as alternate host for many organisms, including some important pest of tea
- Reduce plucking efficiency
- Creepers like Mikania contaminates plucked shoots
- Reduce water flow in the drains.

Being a perennial crop, tea needs to be fully protected from weed competition particularly in young stage to allow the bushes in developing its strong frame as well as for obtaining good harvest, long term productivity and weed infestation in the subsequent years. The tea industry of North East India spends about INR 200 million annually on weed control. In general, weed infestation is severe in young tea and in the years following light pruning, medium pruning and deep skiffing. Grassy weeds reduce the productivity of tea by 21%, while broad-leaved weeds accounts for 9-12%. Weeds remove substantial amount of nutrients and moisture from the soil besides increasing the incidence of pests and diseases in crop by serving as alternate host.

Weed flora

Gogoi and Sarma (2009) revealed the occurrence of 165 weed species in the Dibrugarh and Tinsukia districts of Assam of which 39 were monocotyledonous, 112 dicotyledonous and 14 pteridophytic. Of these, 40 species were found during the winter season, 48 during summer season while 43 species during both winter and summer season. 18 weed species were very common and grown in all sites during the summer and winter seasons. 130 species were annuals and 35 were perennials. 133 species found to be reproduced by seeds, 31 species by seeds and vegetative organs, 8 species reproduced only by vegetative organ. Two pteridophytic species reproduced through spores and 12 species reproduced by spores and vegetative organs. Monocotyledonous (13.56 to 17.47%) and pteridophytic (2.4 to 12.42%) species occurred more in the summer than the winter season. 31 exotic weed species successfully established in the tea gardens of Assam. *Ageratum conyzoides and A. houstonianum (17 and 25.9% during first and second year, respectively), Bidens pilosa (19 and* 13%), *Erigeron canadensis (2 and 16.2%) and Chromolaena adenophorum (9.1 and 9.7%) were the* major weeds infested tea at Palampur (Kumar et al 2014). *Ipomoea (6.5%), Fragaria vesca (2.6%), Cynodon dactylon (5.2%), Achyranthus (2.6%), Lantana camara (5.2%), Polygonum alatum (1.3%) and Imperata cylindrica (10.5%) infested the field during* the first year only while *Hackelia uncinata, 6.0% was* present during the second year. *Oxalis latifolia, Echinochloa colona, Polygonum barbatum, and Trifolium repens (white clover) also infested the experiment* field.

Critical Period of Crop-Weed Competition

The critical period of weed competition in tea is from April to September and hence utmost care is need to be taken to control the weed during this period so that the productivity is not affected.

Manual and mechanical control of weeds:

Weed control is the second most expensive input in tea production costing INR 1500 to 4,500/ha depending on the age of the tea and the severity of weed problems. Manual removal/uprooting of weed is mostly followed in tea nurseries and young plantations and sometimes to control weeds like Mikania, Imperata and Setaria, Melastoma, etc. Mechanical control in the form of cheeling, sickling hoeing or forking etc. is commonly followed in young plantations. Mechanical and manual control of weed are costly, time consuming, laborious and sometimes injurious to feeder roots of young tea plants in comparison to herbicidal control of weeds. These methods require about 75 man days/ha annually for young tea and 35 man days for mature tea while, 15 man days/ha for young tea and 8 man days for mature tea in the first year are required for herbicidal control of weeds excluding the cost of herbicides (Mustafee, 1995). Such methods are also limited by non – availability of labours in peak season. Cheeling, mostly followed in young tea not only expensive but often lead to greater weed infestation primarily due to exposure of the top soil layer and the weed seed present therein. It also damages the surface root of young tea. Light pruning, medium pruning and deep skiffing expose the surface soil layers, which encourage heavy weed growth.

Chemical weed control

With the introduction of herbicides in mid 1960's, chemical control of weed has become more popular because of its many fold advantages besides cost effectiveness. At present, herbicides worth over INR 7 crores are being used by tea industry of North East. India alone is expected to increase further in view of acute shortage of labours in time and escalating wages of labour. Tea plantations alone consume about 70% or more of the herbicides used in the cropped area in India.

Herbicides, as a tool for controlling weeds in tea plantations is very much popular and have been widely used ever since their introduction – primarily due to their cost effectiveness, efficiency in controlling diverse weed flora and less labour intensiveness, etc. Tea plantations alone use about 20% of the total quantity of herbicides used in India (Chakravartee and Borbora, 1993).

A number of pre- and post-emergence herbicides have been recommended for controlling weeds in tea. However, the choice of herbicides is mainly dependent on the weed flora present, type of herbicides, its availability, age of tea plantations and economic considerations. The intensity of weed infestation and weed species predominant are different from area to area or even from section to section in the same estate. The number of herbicide applications in a season also depends on the efficiency of a particular herbicide in controlling the weeds and the type of weeds appearing after the initial application. Herbicide programmes vary with weed situations. A particular programme may be used as long as the relevant weed situation exists. But the weed spectrum changes over the years and suitable programmes for the new weed situations should be used.

Simazine, diuron, oxyfluorfen are the pre-emergence herbicide and 2,4-D, dalapon, glyphosate, glufosinate ammonium are the post-emergence herbicides commonly used in tea plantations. The doses of different herbicides for tea are given in Table 4.11 & 4.12.

Table 4.11. The herbicides recommended for young and mature tea

Herbicide		Dilution (amount of herbicide per 200 l of water)	Concentration (%)
2,4-D (Sodium salt)		0.50 kg	0.25
2,4-D (Dimethylamine salt)		0.25 – 0.40 l	0.12 – 0.20
Paraquat	First round	0.671	0.33
	Subsequent round	0.501	0.25
Dalapon (Tea over 3 years only)		1.75	0.87
Glufosinate ammonium		0.51	0.25
Glyphosate		1.51	0.75
		0.51	0.50
Simazine		1.50 – 2.0 kg	0.75 – 1.00
Diuron		0.40 kg	0.20
Oxyfluorfen		0.5 l	0.25

Table 4.12. Herbicide mixtures used in tea

	Young tea		Mature tea	
	Herbicide (s)	Dose (Product/ha)	Herbicide (s)	Dose (Product/ha)
Grassy weeds	Oxyfluorfen + glyphosate	0.45 l+ 1.88 l	Paraquat + diuron	1.25 l + 1.0 kg
			Paraquat + simazine	1.25 l + 1.0 kg
Mixed weeds	Glyphosate + 2,4-D	1.51 l + 0.75 kg	Paraquat + 2,4-D	1.25 l + 1.25 kg
Thatch grass and broad-leaved weeds	Glyphosate + 2,4-D	1.51 l + 0.75 kg		

Herbicidal programme for young and mature tea is also different due to variation in weed species as well as their intensity of infestation. It is advisable to use pre-emergence herbicides on soil after the early rains to prevent weed emergence and their subsequent establishment. For greater activity of the soil- applied herbicides, soil should have adequate moisture. The weed flora present, type of herbicide and its availability and economic considerations, governs the choice herbicides for an effective weed control.

As there is no single herbicide, which can control weeds for the entire season, rotational programme of herbicides and frequency of herbicide application are therefore, dependent on the following –

- The extent and rate of new weed growth following initial application.
- The regenerative capacity of the weed species following initial application.
- The type of weeds persisting following application of a herbicide; and
- The efficiency of initial spraying.

In a rotational programme the following sequences occur

A pre – emergence herbicide followed by a post-emergence herbicide.

One post-emergence herbicide followed by another post–emergence herbicide.

Repetitive application of the same or another pre- or post- emergence herbicide.

Herbicide mixtures

In mixed weed situations in tea, different herbicide combinations and the use of herbicide in rotation should be practiced in order to control broad- spectrum weeds and to prevent resistant weeds from predominating in an area. Herbicide mixtures perform better weed control due to their synergistic effect. It also reduces the overall cost of weed control and minimizes the possible phyto- toxicity of the chemicals. The major benefit from herbicide combinations in tea are

Broad-spectrum weed control.

Better control of weeds due to additive/synergistic effect of two or more herbicides.

Dose of component herbicide could be reduced by mixing appropriate chemicals, thereby reducing the phyto-toxicity from the components.

Low rates in combination will result in minimum residue in soil which will biodegrade in a shorter time.

Combinations help to avoid shift of resistant weed species due to the repeated use of the same herbicide.

Herbicide spraying

The quantity of spray volume required per hectare depends on (a) type of herbicide use (contact or translocated), (b) intensity of weed infestation, (c) stage of weed growth and (d) weed control efficiency. Hand operated Knapsack type sprayer fitted with a flood-jet or fan type nozzle should be used for herbicide spraying. Under intensive and uniform weed infestation, WFN 40 size nozzle should be used. However, scattered weed infestation would require WFN 24 size nozzle for spot application. The spray delivery pressure is to be maintained at 10 to 15 psi (700 to 1050 g/cm^2). The nozzle should be used only for about 200 spraying hours. The spray delivery height from the ground should be 9 to 12 inches (22.5 to 30.0 cm).

Integrated management approach

Integrated approach of weed management practices comprises of an appropriate combination of different methods to reduce the weed growth. Closer spacing of tea plants, inter-planting, use of quick growing planting materials will help uniform ground coverage and thereby reduce weed growth. Hand weeding around collar region of young tea bushes is always safe and it should be done as an integral component in the integrated weed control programme. Herbicide rotation, their appropriate dose and suitable mixture, timely change in herbicide programmes and introduction of new herbicides will assist in overcoming the problem of tolerant and resistant weeds. Care should be taken so that the weeds do not flower and seeds infest the new areas, drains and estate boundaries.

Managing Aquatic Weeds

Types of Aquatic Weeds

Aquatic weeds are typically categorised into four main groups depending on their growth habit. These are: emergent, free floating, marginal and submerged weeds.

Emergent weeds have both the stems and leaves above the waterline and are often growing on the fringes of ponds and waterways. Free floating weeds are not attached to the soil in any way but can still have root systems. Floating leaf weeds are rooted into the soil with long stems that stretch to the water surface where the leaves float. Submerged weeds are rooted into the soil and all parts of the plant are completely submerged under the water.

Water Use Situations

The demand for water resources for recreation, agriculture, and industry is increasing. Many kinds of plant and animal aquatic pests can interfere with water uses. Control of aquatic pests must be done without harm to people and the environment.

Habitats for aquatic weeds involve various proportions of water and soil, including intermittently wet ditches, ditches which always hold standing water, streams, stock ponds, farm ponds, lakes, ornamental ponds, and inter- mediate habitats. This manual considers three types of water situations - static, limited flow impoundments, and moving water.

1) Static water is confined for considerable periods of the year, or totally confined within a known area, with no downstream movement. However, even totally enclosed bodies of water often have appreciable water move- ment because of wind and changes in water temperature. Weeds commonly grow in static water up to 12 feet deep. Weeds may grow in very clear water that is more than 20 feet deep. If a herbicide is applied for weed con- trol, there is no reason to expect that any appreciable downstream effect may occur, unless there is overflow re- sulting from unusual storm conditions.

2) Limited -flow Water Impoundments Ditches may be intermittently wet or dry, depending upon climatic conditions. However, herbicides applied to these habitats may move downstream following an influx of water from surrounding areas. The purpose of the ditch is to drain the surrounding land area so considerable amounts of water must pass through it.

Many farm ponds may be characterized as having limited flow because there nearly always is an overflow pipe and an emergency overflow channel (spillway). The overflow pipe is designed to permit passage of a continuous and relatively well-defined amount of water at all times. The emergency spillway is provided to release from the pond when storms dump in excess amounts of water in a short time. In these situations, small amounts of pesti-
cides may be carried downstream from the application site. Larger amounts may be found downstream after sud- den rain storms, which interrupt or come immediately after pesticide application.

3) Moving water is found in small streams, creeks, streams, and rivers where there is always some detectable downstream current. Applied pesticides may be found in downstream locations in varying amounts away from the area of original application. Such situations present the greatest potential for concern as an environmental hazard.

Methods of weed management

Preventive measures such as proper design and construction of ponds is an important factor in preventive control of weeds. Shallow water at the margins provides an ideal habitat for immersed weeds, such as cat- tails. These weeds can spread then to deeper water. Banks should be sloped steeply so that very little water is less than 2' to 3' deep.

Proper design and construction of ditches and channels makes weed control easier in the future. If the banks are leveled and smoothed, hard-to-reach places will be eliminated. Lining canals will help to alleviate water weed problems, too.

Mechanical control may be needed if severe waterweed infestations develop in spite of preventive meas- ures, many ponds still have severe waterweed infestations. In some cases, use of a herbicide may not be pos- sible if the water is used for livestock, drinking, or fish. Hand-pulling the weeds or dredging the pond are possible methods of control. But often the infestation is so severe that these methods are impractical or un- economical.

Motor-driven underwater weed cutters are available and can be used for the control of such plants as water- lilies and watermilfoil. Some mowers simply cut the weeds loose beneath the water surface. Aquatic weed harvesters collect weeds for removal. Disposal of harvested weeds can be a problem. Most mechanical con- trol methods fragment weeds. Many weed species can spread and reproduce from these pieces. Mechanical control is usually slower and more expensive than use of herbicides. Underwater weed cutting must be done continuously during the summer and usually represents a long term financial investment.

Characteristics of physical management techniques

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant Species Response
Dredging/ Sediment Removal	Use mechanical sediment dredge to remove sediments, deepen water	Creates deeper water, very long- term results	Very expensive, must deal with dredge sediment	Shallow ponds and lakes, particularly those filled in by sedimentation	Often creates large usable areas of lake, not selective
Drawdown	"De-water" a lake or river for an extended period of time	Inexpensive, very effective, moderate-term	Can have severe environmental impacts, severe recreational/ riparian user effects	Only useful for manmade lakes or regulated rivers with a dam or water control structure	Selective based on perennation strategy; effective on evergreen perennials, less effective on herbaceous perennials
Benthic Barrier	Use natural or synthetic materials to cover plants	Direct and effective, may last several seasons	Expensive and small- scale, nonselective	Around docks, boat launches, swimming areas, and other small, intensive use areas	Nonselective, plant mortality within one month underneath barrier
Shading / Light Attenuation	Reduce light levels by one of several means: dyes, shade cloth, plant trees (rivers)	Generally inexpensive, effective	Nonselective, controls all plants, may not be aesthetically pleasing	Smaller ponds, man- made waterbodies, small streams	Nonselective, but may be long-term
Nutrient Inactivation	Inactivate phosphorus (in particular) using alum	Theoretically possible	Impractical for rooted plants limited by nitrogen	Most useful for controlling phytoplankton by inactivating water column P	Variable

Characteristics of mechanical management techniques

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response

Hand- Cutting/ Pulling	Direct hand pulling or use of hand tools	Low-technology, affordable, can be selective	Labor-intensive, cost is labor-based	Most of the undeveloped world, volunteer labor pools	Very effective in very localized areas
Cutting	Cut weeds with mechanical device (typically boat-mounted sickle bar) without collection	More rapid than harvesting	Large mats of cut weeds may become a health and environmental problem, may spread infestation	Heavily-infested systems	Nonselective, short- term
Harvesting (Cut and Remove)	Mechanical cutting with plant removal	Removes plant biomass	Slower and more expensive than cutting; resuspension of sediments	Widespread use with chronic plant problems	Like cutting, it is cosmetic, non-selective short-term
Grinder or "Juicer" (Cut and Grind)	Mechanical cutting with grinding of plant material and in-lake disposal	Immediate relief of plant nuisance, no disposal	Resuspension of sediments, decomposition of plants in lake, floating plant material	Useful for chronic plant problems where disposal of plants is problematic	Like cutting and harvesting, it is cosmetic, non-selective short-term
Diver-Operated Suction Harvester	Vacuum lift used to remove plant stems, roots, leaves, sediment left in place	Moderately selective (based on visibility and operator), longer-term	Slow and cost-intensive	Useful for smaller nuisance plant populations in which plant density is moderate	Typically have minimal regrowth for Eurasian watermilfoil; not effective for tuber- setting hydrilla
Rotovating	Cultivator on long arm for tilling aquatic sediments	Disrupts Eurasian watermilfoil stem bases, intermediate-term results	May spread large numbers of fragments; resuspension of sediments	Used extensively in the Pacific Northwest and British Columbia, with mixed results	Effective in disrupting Eurasian watermilfoil dense stands; not selective and only intermediate-term

Cultural control and habitat alteration through certain methods of manipulating or altering the aquatic environment can be effective in controlling aquatic weeds. One of the more successful methods is the draw- down technique in which water levels are lowered over the winter. Exposure of the sediments in the shallow areas of a lake or pond to alternate freezing and thawing action will kill the underground rhizomes of many aquatic weeds (the majority of aquatic weeds are perennial and come from rhizomes).

This method has been quite successful for the control of Eurasian watermilfoil and waterlilies, although the degree of control depends somewhat upon the severity of the winter. There are several advantages to a win- ter drawdown in addition to weed control. As the sediment dries, it is compacted, thereby increasing the depth of shallow areas. Drawdown also concentrates the fish which increases the predation of the smaller fish by the larger ones. Fishing quality can often be improved following a drawdown.

Many aquatic weeds or their seeds are carried into a pond by wind birds, fish introduction, fishermen, etc. These weeds infest a pond only if the water conditions are just right. This usually means that nutrients are entering the pond from runoff or stream inflow. To help prevent serious weed infestations you can do the following things:

- Most waters are sufficiently rich in plankton and other food organisms to support large fish without the need for supplemental fertilization.
- Maintain a good sod and grass cover around your pond. This will help prevent runoff and erosion. Do
- not fertilize the turf directly around the pond.
- Do not allow livestock access to a pond except under conditions of extreme heat. If the water is used for livestock, fence the pond and water the animals from a stock tank below and outside the fence. Animals will increase turbidity and fertility and tear down the banks.
- Check septic tanks for possible leakage or seepage into the pond. Locate new septic drainage fields so that the nutrient-rich effluent will not reach your pond.
- Do not permit runoff from chicken coops, feedlots. etc., to enter your pond. If this kind of runoff is occurring upstream from your pond, you should check with your county Board of Health to see if any- thing can be done about it.

All of these measures will help prevent weed growth, particularly in a new pond. In older ponds these meas- ures will probably aid in reducing infestations of floating plants such as algae and duckweed.

Other types of habitat manipulation include riprapping shorelines and anchoring screens (e.g., Aquascreen) or black plastic sheets on the bottom sediments to prevent rooted plant establishment. Dyes such as Aq- uashade are used to inhibit light penetration through the water. This blue dye can be applied right out of the bottle along the shoreline. It mixes throughout the body of water within 24 hours. The dye intercepts light normally used for photosynthesis by underwater plants. The dye can only be effective if its concentration is maintained.

Some general rules for using Aquashade:

a. Do not apply where water outflow will reduce Aquashade concentration.
b. Apply in March or April before weeds reach the water surface. Midsummer reapplication is usually necessary. It is effective only on rooted underwater plants growing at depths greater than 2 to 3 feet. Supplemental treatments of copper sulfate might be needed for algae control.
c. Do not use in muddy water.

Aeration has been publicized as another method of weed control. Although aeration is definitely beneficial for fish life and can help prevent fish kills, there is no evidence that aeration inhibits weed growth.

Biological controls for aquatic vegetation have received considerable publicity. Several species of fish are herbivorous in that their principal diet is aquatic vegetation. One such species, the grass carp (also known as the white amur or Chinese carp), is being tested in various parts of the United States and is legal in several states. However, it is illegal to introduce these fish to the ponds, lakes, and streams of many states. Check with your local or state fisheries department for regulations regarding the grass carp.

Summary of biological management methods for aquatic plants.

Management Method	Description	Advantages	Disadvantages	Systems where used effectively	Plant species response

Grass Carp / White Amur	Herbivorous Fish	Long-term (decades), relatively inexpensive	Cannot control feeding sites, difficult to contain in water body, tendency for "all or none" community response, persistent	Isolated water bodies, effective against hydrilla and other preferred species. Operational.	Fish have strong preference for hydrilla and some native plants, avoid Eurasian watermilfoil, generally do not prefer floating plants
Neochetina sp.	Waterhyacinth weevils	Species selective	Not effective in reducing areal coverage in many situations	Released in Florida, Gulf Coast states. (Developmental)	Leaf scars, some reduction in growth
Hydrellia sp. Bagous sp.	Hydrilla fly, hydrilla stem weevil	Species Selective	Has not yet been established	Released in Florida, Alabama, Texas. (Research)	Limited
Euhrychiopsis lecontei and other native insects	Weevil - native or naturalized	Already established in U.S.	Less selective, currently under R&D	Currently under study in Vermont, Minnesota (Research)	Plants loose buoyancy, weevil interferes with transfer of carbohydrates
Mycoleptodiscus terrestris (Mt)	Fungal pathogen; acts as a contact bioherbicide	Low dispersion, fairly broad spectrum	Expense, cross-contamination, inconsistent viability and virulence of formulation	Under R&D for both Eurasian watermilfoil and hydrilla	"Contact Bioherbicide", plants rapidly fall apart, but regrow from roots
Native Plant Community Restoration	Planting of desirable native plant species or community	Provides habitat, may slow reinvasion or initial invasion	Expensive, techniques still under development	Under R&D around the country	Native plants provide ecosystem benefits, slow invasion

Chemicals used in aquatic weed control are classified as herbicides. Herbicides used primarily to control algae may be called algicides, even though they also kill other aquatic plants. For most aquatic weed prob- lems, properly-used herbicides control vegetation without harming the fish. Aquatic herbicides are effective and commonly used means of controlling aquatic vegetation.

Four zones of a body of water may be treated

Aquatic herbicides generally are available in sprayable or granular formulations.

Sprayable formulations- Most herbicide formulations must be mixed with water and applied so that they dis- perse evenly. These include-

- **WSP**- water soluble powders that dissolve and form true solutions in water.
- **WP**- wettable powders form suspensions in water. The particles do not dissolve.

- **EC**- emulsifiable concentrates form milky white "oil-in-water" emulsions
- **G—**granular formulations are small clay-based pellets that carry the active ingredient on or in the product. They are usually distributed by some sort of slinger-spreader and sink to the bottom. Slow-release granules or pellets release the pesticide active ingredient over an extended period of time.

Four zones of a body of water may be treated with herbicides

Surface	Generally, only 1/4 to 1/3 of the surface area of the water should be treated at a time. This helps to protect fish from a possible shortage of oxygen. Surface area (in acres) of a rectangular body of water equals length in feet times width divided by 43,560 (the number of square feet in an acre).
Total water volume	The whole body of water from the surface to the bottom is treated by treating 1/4 to 1/3 of the water volume (based on surface area) at a time. 1) Calculate the acre-feet of the body of water to be treated. Multiply the surface acres by the average depth in feet. An acre-foot of water weighs 2.7 million pounds (2,700,000). 2) 2.7 * ppm concentration wanted * acre-feet = pounds of active ingredient needed. The following calculation shows how to calculate the number of pounds of active ingredient needed to treat a body of water containing 10 acre feet at the rate of 0.5 ppm. 2.7 * 0.5 * 10 = 13.5 pounds of active ingredient
Bottom 1 to 3 foot layer of water	Treating the bottom 1 to 3 feet of water is especially useful in deep lakes where it is impractical to treat the entire volume of water. Treatments are generally made by attaching several flexible hoses at 3 to 5 foot intervals along a rigid, weighted boom. Each hose has a nozzle at the end. The herbicide is applied as a blanket in the lower 1 to 3 feet of water.
Bottom soil surface	Herbicide applications may be made to the bottom soil of a drained pond, lake, or channel.

Floating and immersed weeds can be killed with direct sprays on the foliage applied from a boat or the shore. **Submersed weeds and algae** can be treated using sprays or granular formulations. Sprays are applied as water surface treatments, particularly in shallow water. The herbicide is then dispersed by diffusion, thermal currents, and wave action. Good control depends upon good dispersion of the chemical. Granules are used primarily to control algae or submersed weeds. They sink to the bottom and work about the same manner as bottom soil treatments. Application rates for granules are given as amount per unit of surface area or as a concentration in ppm. They must be broadcast evenly over the water surface for best results.

Advantages to granular formulations include

- treatment is confined to the bottom are where submersed weeds are
- slow-release formulations can provide extended control
- low concentrations of herbicides can be used
- toxicity to fish may be reduced

Weed Control in Large Impoundments

Herbicides that work well in small bodies of water may perform poorly in large impoundments because of much greater water movement by thermal currents and wave action. In these cases, weed control may be improved by

- using maximum recommended rates
- treating relatively large areas at one time
- apply when winds are at a minimum
- use bottom treatments in deep water
- select herbicides that are absorbed quickly by the plants

Weed Control in Limited-Flow Waterways

Flood drainage canals, sloughs, and drains are good examples of limited-flow waterways. Weed control methods in these systems are very similar to those for static water. Evaluate the possibility of contamination when plan- ning herbicide use. In some areas, drainage water may flow onto crop land or into drinking water supplies.

Use suggestions for US Environmental Protection Agency-approved aquatic herbicides

Compound	Exposure Time (Water)	Advantages	Disadvantages	Systems where used effectively	Plant species response
Complexed Copper	Intermediate (18-72 hours)	Inexpensive, rapid action, approved for drinking water	Does not biodegrade, but biologically inactive in sediments	Lakes as algicide, herbicide in higher exchange areas	Broad-spectrum, acts in 7-10 days or up to 4-6 weeks
2,4-D	Intermediate (18-72 hours)	Inexpensive, systemic	Public perception	Waterhyacinth and Eurasian watermilfoil control, Lakes and slow-flow areas, purple loosestrife	Selective to broad-leaves, acts in 5-7 days up to 2 weeks
Diquat	Short (12-36 hours)	Rapid action, limited drift	Does not affect underground portions	Shoreline, localized treatments, higher exchange rate areas	Broad-spectrum, acts in 7 days
Endothall	Short (12-36 hours)	Rapid action, limited drift	Does not affect underground portions	Shoreline, localized treatments, higher exchange rate areas	Broad spectrum, acts in 7-14 days
Fluridone	Very long (30-60 days)	Very low dosage required, few label restrictions, systemic	Very long contact period	Small lakes, slow flowing systems	Broad spectrum, acts in 30-90 days
Glyphosate	Not Applicable	Widely used, few label restrictions, systemic	Very slow action, no submersed control	Nature preserves and refuges; Emergent and floating-leaved plants only	Broad spectrum, acts in 7-10 days, up to 4 weeks
Triclopyr	Intermediate (12-60 hours)	Selective, systemic	Not currently labeled for general aquatic use	Lakes and slow-flow areas, purple loosestrife	Selective to broad-leaves, acts in 5-7 days, up to 2 weeks

Application restrictions of US Environmental Protection Agency-approved aquatic herbicides

Compound	Persistence (half-life, in days)	Maximum Application Rate	Maximum water concentration	Safety Factor	Application Notes	WES Recommended for
Complexed Copper	3	1.5 gal/ft/acre	1.0 mg/L	>50	Algicide / Herbicide	Hydrilla, other submersed sp.
2,4-D	7.5	0.5 gal/acre	2.0 mg/L	>25	Some formulations for special permits only	Eurasian watermilfoil, water-hyacinth, and others
Diquat	1-7	2 gal/acre	2 mg/L	5	Binds with particles (suspended solids) in water	All

Endothall	4-7	13 gal/acre	5.0 mg/L	>10 (Aquathol) <1.0 (Hydrothal)	Fish are sensitive to Hydrothal 191 - over 1 mg/L may cause fish kill	All submersed spp.
Fluridone	21	1.1 qt/acre	0.15 mg/L (150 ppb)	>20	Applications have been successful below 10 ppb	Most submersed spp.
Glyphosate	14	2 gal/acre	0.2 mg/L	>20	Aerial portions only - not for submersed plants	Most emergent and floating spp.
Triclopyr	Na	Na	2.5 mg/L	>50	EUP/Special Needs only	Eurasian watermilfoil, water-hyacinth, Others

Exercise

Q.1. Discuss the integrated weed management techniques in rice

Q.2. Discuss the integrated weed management strategies in sugarcane

Q.3. Give chemical weed control including herbicide dose and time of application in case of following crops/situations:

Wheat, gram, sarson, potato, cauliflower, peas, Lantana invasion and tea plantation

Q.4. Give chemical weed control including herbicide dose and time of application in case of following crops/situations:

Maize, lentil, sesamum, cotton, radish, turmeric, *Parthenium* invasion and aquatic situations

Q.5 Tick the correct choice

i. To control broad-leaved weeds in barley, which of the herbicide is most suitable

a). 2,4-D
b). Metsulfuron
c). Alachlor
d). **Both a and b**

ii. To manage mixed weed flora in barley which of the herbicides is to be applied

a).2,4-D
b). Isoproturon
c). **a and b as tank mix**
d). None of these

iii. Which of the herbicides can be used in gram crop?

a). Pendimethalin
b). Metolachlor
c). Fluchloralin
d). **All**

iv. To manage grassy weed flora in barley which of the herbicides is to be applied

a). Pendimethalin

b). Isoproturon
c). **a and b**
d). Metsulfuron

vi. Commonly used algicide
a). Copper sulphate pentahydrate
b). Simazine
c). Diuron
d). **All**

vii. a very successful pre-emergence herbicide in banana in India
a). Atrazine
b). **Alachlor**
c). Glyphosate
d). Dalapon

viii. The most commonly used herbicide in rubber plantation
a). Amitrole T
b). Paraquat
c). **Both**
d). None

ix. Present day versatile herbicide to control difficult, perennial, broadleaved weeds and brushes in grasslands
a). Alachlor
b). Atrazine
c). **Picloram**
d). All

x. At sub lethal dose which of the herbicides improves colour of the apple
a). 2,4-D
b). **2,4,5-T**
c). MCPA
d). All of these

xi. Herbicide residue in soil are undesirable because of
a). Injury to sensitive crops
b). Accumulate in the produce
c). Inhibit soil micro-organisma
d). **All**

xii. Persistence herbicides pose hazard in soil when
a). High persistence herbicides are used
b). Crop failure necessitate re-planting
c). Susceptible crop follows a short crop
d). **All**

xiii. Which type of herbicides act as growth promoter under sub-lethal dose
a). Phenoxys
b). Triazines
c). Ureas and uracils
d). **All**

xiv. Application of organophosphorus group of pesticides along with which herbicides cause injury to crops

a). Triazines
b). Ureas
c). **Both**
d). None

xv. Effective rate (kg/ha) of 2,4-D for weed control

a). 0.2-0.5
b). **0.5-1.0**
c). 2
d). 5

xvi. Which formulation of 2,4-D has fastest absorption by crop plants?

a). **Ethyl ester**
b). Dimethylamine
c). Na salt
d). All

xvii. Which of the weeds are rapidly controlled by MCPA than 2,4-D

a). Nutsedge
b). Canada thistle
c). **Both**
d). None

xviii. The major consumer of dalapon in India

a). Coffee planters
b). Jute growers
c). **Both**
d). None

xix. How many times atrazine is more soluble than simazine?

a). 1
b). 2
c). 4
d). **6**

xx. A very potent herbicide for the control of perennial, broad-leaved weed and brushes in grasslands and forests?

a). Atrazine
b). 2,4-D
c). **Picloram**
d). Amitrole

xxi. Which is the contact, non-selective and zero persistent herbicide in soils?

a). **Paraquat**
b). Atrazine
c). 2,4-D
d). Bromacil

xxii. Largest pre-emergence herbicide for weed control in citrus and pineapple orchards

a). Atrazine

b). **Metham**
c). Allyl
d). All

xxiii. Alachlor is an effective pre-emergence herbicide in ______
a). Maize
b). Soybean
c). **Both**
d). None

xxiv. Butachlor has to be applied to control weeds in upland rice at
a). Immediately after sowing
b). 2 DAS
c). 6-8 DAS
d). **15 DAS**

xxv. Propanil has to be applied to rice crop at
a). One leaf stage
b). **2-3 leaf stage**
c). 4 leaf stage
d). None of these

xxvi. 2,4-D to wheat is effective when it is applied at
a). 15 DAS
b). 20-25 DAS
c). **25-30 DAS**
d). 45 DAS

xxvii. 2,4-D is injurious to
a). Cotton
b). Mustard
c). Chickpea
d). **All**

xxviii. Isoproturon to wheat is effective at
a). 15 DAS
b). **25-30 DAS**
c). 45- DAS
d). 5 DAS

xxix. a broad-spectrum commonly used herbicide in groundnut
a). **Fluchloralin**
b). Atrazine
c). Alachlor
d). 2,4-D

xxx. Selective herbicide under cotton + blackgram intercropping system
a). Diuron
b). **Oxadiazon**
c). Fluchloralin
d). All

xxxi. A herbicide tolerant to lucerne and can be applied mixed with seed is

a). **EPTC**
b). Benefix
c). Pendimethalin
d). None of these

xxxii. Herbicide which increase tuber size besides weed control in potato
a). **EPTC**
b). Fluchloralin
c). Pendimethalin
d). Atrazine

xxxiii. Application of which herbicide at 5-10% of emergence in potato is more common in India?
a). Paraquat
b). Diquat
c). EPTC
d). **Both a and b**

UNIT V
Cost: benefit analysis of weed management, weed indices

Cost: benefit analysis of weed management

Weeds should be controlled by least expensive available technology that does not interfere with other phases of crop production or other human activities. Any weed control measures should be used only when its results are expected to be more economically beneficial than without using any control measure (Moody 1993). Farmers compare time and cost of weed control and usually select management tactics having the lowest cost. Therefore, choice of weed control inputs depends not only on its efficacy but also on its cost (De-dutta and Foster 1977). In order to work out the most profitable treatment, the economics of each treatment is worked out on the basis of prevalent market prices of the inputs and output.

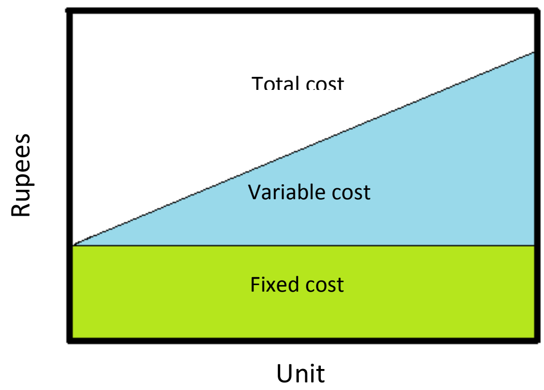
a. Cost of cultivation

Cost of cultivation is obtained by adding all the costs involved in each operation or input (seed bed preparation, seed and sowing, fertilizer, irrigation, weed control, plant protection, harvesting and post harvest operations, land rent etc).

Types of cost

Total Cost

In economics, the total cost (TC) is the total economic cost of production. It consists of variable costs and fixed costs. Total cost is the total opportunity cost of each factor of production as part of its fixed or variable costs.



This graphs shows the relationship between fixed cost and variable cost. The sum of the two equal the total cost.

Variable Costs

Variable cost (VC) changes according to the quantity of a good or service being produced. It includes inputs like labour and raw materials. Variable costs are also the sum of marginal costs over all of the units produced (referred to as normal costs). For example, in the case of a clothing manufacturer, the variable costs would be the cost of the direct material (cloth) and the direct labour. The amount of materials and labour that is needed for each shirt increases in direct proportion to the number of shirts produced. The cost "varies" according to production.

Fixed Costs

Fixed costs (FC) are incurred independent of the quantity of goods or services produced. They include inputs (capital) that cannot be adjusted in the short term, such as buildings and machinery. Fixed costs (also referred to as overhead costs) tend to be time related costs, including salaries or monthly rental fees. An example of a fixed cost would be the cost of renting a warehouse for a specific lease period. However, fixed costs are not permanent. They are only fixed in relation to the quantity of production for a certain time period. In the long run, the cost of all inputs is variable.

Economic cost

The economic cost of a decision that a firm makes depends on the cost of the alternative chosen and the benefit that the best alternative would have provided if chosen. Economic cost is the sum of all the variable and fixed costs (also called accounting cost) plus opportunity costs.

Opportunity cost

The cost of an opportunity forgone (and the loss of the benefits that could be received from that opportunity); the most valuable forgone alternative. The cost of any activity measured in terms of the value of the next best alternative forgone (that is not chosen). The value of investing in the next best alternative; the value forfeited by taking a particular route.

Marginal cost

The additional cost from taking a course of action. The increase in cost that accompanies a unit increase in output; the partial derivative of the cost function with respect to output. The additional cost associated with producing one more unit of output. Marginal cost is the change in total cost that arises when the quantity produced changes by one unit. That is, it is the cost of producing one more unit of a good.

b. Gross returns

The total monetary returns of the economic produce such as grain, tuber, bulb, fruit, etc. and byproducts viz. straw, fodder, fuel etc. obtained from the crops are calculated based on the local market prices. The total return is expressed in terms of unit area, usually one hectare. Generally gross return calculated is somewhat inflated compared to the actual receipt obtained by the farmer.

c. Net returns

This is worked out by subtracting the total cost of cultivation from the returns. This value gives the actual profit obtained by the farmer. In this type of calculation only the variable costs are considered. Fixed costs such as rent for the land, land revenue, interest on capital etc. are not included. For a realistic estimate, however, fixed costs should also be included.

d. Net returns per rupee invested

This is also called benefit cost ratio or input: output ratio. Net returns per rupee invested were obtained by dividing net returns with the treatment-wise cost of cultivation as follow:

$$\text{Net returns per rupee invested} = \frac{\text{Gross/Net returns from a treatment}}{\text{Cost of cultivation of the treatment}}$$

This index provides an estimate of the benefit derived and expenditure incurred by the farmer in adopting a particular practice. Anything above the value of 2/1.0 (meaning that the farmer can get Rs.2/1 as additional return for every rupee invested) can be considered worthwhile.

Conveniently, the economic viability of a treatment can be assessed by the methodology given as below

Cost of weed control - Here only the control cost is estimated.

$$Gross\ return\ due\ to\ weed\ control, GRwc = Gross\ return\ of\ a\ treatment - Gross\ return\ of\ control$$

$$Net\ return\ due\ to\ weed\ control, NRwc = Net\ return\ of\ a\ treatment - Net\ return\ of\ control$$

or

$$NRwc = GRwc - Cost\ of\ weed\ control$$

$$Marginal\ benefit\ cost\ ratio, MBCR = \frac{NRwc}{Cost\ of\ weed\ control, Cwc}$$

Example

Table 5.1 embodied data after Kumar *et al*. 2013 (Kumar Suresh, SS Rana, Ramesh and Navell Chander 2013. Herbicide combinations for broad-spectrum weed control in wheat. Indian Journal of Weed Science 45(1):29-33.). The economic indices are calculated as per the method described as above.

Herbicidal treatments had only 0.06-0.17 times of application cost than that under weed free (handweeding thrice). Due to higher grain and straw yield owing to effective weed control, clodinafop 60 g/ha + metribuzin 122.5 g/ha resulted in highest net return due to weed control. This was followed by pinoxaden 50 g/ha, clodinafop 60 g/ha + metribuzin 105 g/ha. Due to lower cost herbicidal treatments resulted in 7.2-20.4 times higher marginal benefit cost ratio than weed free. Metribuzin 175 g/ha resulted in highest marginal benefit cost ratio followed by clodinafop + metribuzin 122.5 g/ha and sulfosulfuron 25 g/ha.

Table 5.1. Yield and economics

Treatment	Dose (g/ha)	Grain yield	Straw yield	GR	GRwc	CWC	NRwc	MBCR
Clodinafop	60	3175	4128	54134	27979	1605	26374	16.43
Sulfosulfuron	25	2643	3435	45055	18900	1036	17864	17.25
Metribuzin	175	3020	3926	51491	25336	830	24506	29.53
Pinoxaden	50	3480	4524	59334	33179	2280	30899	13.55
Clodinafop + metribuzin	60+105	3435	4466	58567	32412	1815	30597	16.86
Clodinafop + metribuzin	60+122.5	3764	4893	64176	38022	1849	36172	19.56
Sulfosulfuron + metribuzin	25+105	2673	3474	45566	19411	1246	18166	14.58
Sulfosulfuron + Pinoxaden	25 + 40	3194	4152	54458	28303	2476	25827	10.43
Weed free	-	3650	4745	62233	36078	14760	21318	1.44
Weedy check	-	1534	1994	26155	0	0	0	
LSD (P=0.05)	-	671	872					

Yield, kg/ha; Grain INR 12.5/kg and straw INR 3.5/kg; GR, gross return (INR/ha); GRwc, gross return due to weed control (INR/ha); CWC, cost of weed control (INR/ha); NR_{WC}, net return due to weed control (INR/ha); MBCR, Marginal benefit cost ratio;

Weed indices

The under listed terms provide a logistic support in impact assessment, interpretations and drawing appropriate conclusions in weed management research.

Weed control efficiency (WCE)

$$= \frac{Weed\ weight/count\ in\ control\ (unweeded) -\ Weed\ weight\ in\ a\ treatment}{Weed\ weight/count\ in\ control\ (unweeded)}$$

$$Weed\ index = \frac{Yield\ from\ weed\ free - Yield\ of\ particular\ treatment}{Yield\ of\ weed\ free}\ x\ 100$$

Weed index is the measure of the efficiency of a particular treatment when compared with a weed free treatment. It is expressed as percentage of yield potential under weed free. More conveniently weed index is the percent yield loss caused due to weeds as compared to weed free check. Higher weed index mean greater loss.

Weed persistence index (WPI)

$$WPI = \frac{Weed\ weight\ in\ treated\ plot}{Weed\ weight\ in\ control\ plot}\ x\ \frac{Weed\ count\ in\ control\ plot}{Weed\ count\ in\ treated\ plot}$$

Crop resistance index (CRI)

$$CRI = \frac{Crop\ weight\ in\ treated\ plot}{Crop\ weight\ in\ control\ plot}\ x\ \frac{Weed\ weight\ in\ control\ plot}{Weed\ weight\ in\ treated\ plot}$$

Pest (weed) management index (PMI or WMI)

$$PMI = \frac{Percent\ yield\ over\ control}{Percent\ control\ of\ the\ pest}$$

Agronomic management index (AMI)

$$AMI = \frac{Percent\ yield\ over\ control - Percent\ control\ of\ the\ pest}{Percent\ control\ of\ the\ pest\ (weed)}$$

Integrated Management index (IPMI)

$$IPMI = \frac{PMI + AMI}{2}$$

Treatment (Herbicide) efficiency index (TEI)

$$TEI = \frac{\frac{Yield\ of\ treatment - Yield\ of\ control}{Yield\ of\ control}\ x\ 100}{\frac{Weed\ weight\ in\ treatment}{Weed\ weight\ in\ control}\ x\ 100}$$

HEI indicates the weed killing potential of a herbicide treatment and its phytotoxicity on the crop.

$$Weed\ intensity = \frac{Weed\ population}{Weed + crop\ population}\ x\ 100$$

$$Weed\ infestation = \frac{Weed\ species\ population}{Total\ weed\ population}\ x\ 100$$

Performance index

'Overall performance index' is determined, by calculating firstly the 'comparable unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean value of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

Where Uij is the unit value for ith treatment corresponding to jth parameter, Vij is the actual measured value for ith treatment and jth parameter and AMj is the arithmetic mean value for jth parameter.

Secondly, the overall performance index was calculated as an average of unit values (Uij) of all the parameters under consideration:

$$OP_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where OPi is the overall performance index for ith treatment and N is the number of parameters considered in deriving performance index.

Weed thresholds

The economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, may be calculated after modifying the formula presented by Uygur & Mennan (1995) as well as those given by Stone and Pedigo (1972) as below

Uygur & Mennan:

$Y= [\{(100/He*Hc)+A_C\}/(Gp*Yg)]*100$

Where, Y is percent yield losses at a different weed density; He, herbicide efficiency; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price and Yw;f, yield of weed free.

Stone and Pedigo:

Economic threshold = Gain threshold/Regression coefficient

Where, gain threshold = Cost of weed control (Hc+Ac)/Price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/biomass (x), Y = a + bx.

Phytosociological attributes of weeds

Random quadrat method is adopted for studying phytosociological attributes of weeds. In each field site, quadrats of 100 cm^2 are laid down. All the weeds encountered in the field sites of the crop fields are carefully collected and identified. All the weeds from each quadrat are collected separately in polythene bags. All the plant species encountered in studied quadrats of each crop are listed. The phytosociological attributes: abundance, density and frequency and their relative values and importance value index (IVI) were calculated according to the principles of Curtis and Mclntosh (1950), Misra (1968) and Dombois and Ellenberg (1974). The following were the different formulae for calculation of the relevant attributes.

$$Frequency\ (\%) = \frac{Total\ number\ of\ quadrats\ in\ which\ the\ species\ occur}{Total\ number\ of\ quadras\ studied} x\ 100$$

$$Density = \frac{Total\ number\ of\ individuals\ of\ a\ species\ in\ all\ quadrats}{Total\ number\ of\ quadras\ studied}$$

$$Abundance = \frac{Total\ number\ of\ individuals\ of\ a\ species\ in\ all\ quadrats}{Total\ number\ of\ quadrats\ in\ which\ the\ species\ occured}$$

$$Relative\ frequency = \frac{Frequency\ of\ individuals\ of\ species}{Total\ frequency\ of\ all\ species} x\ 100$$

$$Relative\ density = \frac{Density\ of\ individuals\ of\ species}{Total\ density\ of\ all\ species} x\ 100$$

$$Relative\ abundance = \frac{Abundance\ of\ individuals\ of\ species}{Total\ abundance\ of\ all\ species} x\ 100$$

Importance Value Index = Relative density + Relative frequency + Relative abundance

Based on Raunkiaer (1934), the frequency classes of weed species are determined. Accordingly there are five frequency classes, i.e. 'A' class with the species of frequency ranging from 1-20%; 'B' class 21-40%; 'C' class 41-60%; 'D' class 61-80% and 'E' class 81-100%. Furthermore, the weed community frequency patterns are compared with the normal frequency pattern of Raunkiaer (A>B>C>=D<E). Based on the frequency pattern of the community, the homogeneity and heterogeneity of the vegetation are determined. If the values are high with respect to B, C and D, then the community is said to be heterogeneous where as higher values of E indicates the

homogeneous nature.

EXERCISE

Example 1. _Calculate weed index (WI), and weed control efficiency (WCE) of all treatments, from the following data:-

Treatment (g.a.i/ha)	Weed dry matter (g/m^2)	Grain yield (t/ha)
Azimsulfuron 50 DF 27.5 + 0.2% surf	50.93	2.8
Azimsulfuron 50 DF 30.0 + 0.2% surf	46.86	2.93
Azimsulfuron 50 DF 35.0 + 0.2% surf	33.44	3.37
Hand weeding	27.48	3.56
Fenoxoprop- F- ethyl 56.25 + ethoxy sulfuron 15	37.84	2.86
Chlorimuron +Metsulfuron 4.0	56.92	2.55
Weedy check	65.58	0.98

Solution (a) Calculation of Weed Index (%)

(i) WI of T1 = $\frac{3.56 \quad 2.8}{3.56} \times 100 = 21.34$

(ii) WI of T2= $\frac{3.56 \quad 2.93}{3.56} \times 100 = 17.69$

(iii) WI of T3 = $\frac{3.56 \quad 3.37}{3.56} \times 100 = 5.33$

(iv) WI of T5= $\frac{3.56 \quad 2.86}{3.56} \times 100 = 19.65$

(v) WI of T6= $\frac{3.56 \quad 2.55}{3.56} \times 100 = 28.56$

(vi) WI of T7= $\frac{3.56 \quad 0.98}{3.56} \times 100 = 72.44$

(b) Calculation of Weed Control Efficiency (%)

(i) WCE of T1= $\frac{65.58 \quad 50.93}{65.58} \times 100 = 22.26$

(ii) WCE of T2= $\frac{65.58 \quad 46.86}{65.58} \times 100 = 22.26$

(iii) WCE of T3= $\frac{65.58 \quad 33.44}{65.58} \times 100 = 22.26$

(iv) WCE of T4= $\frac{65.58 \quad 27.48}{65.58} \times 100 = 22.26$

(v) WCE of T5= $\frac{65.58 \quad 37.84}{65.58} \times 100 = 22.26$

(vi)WCE of T6= $\frac{65.58 \quad 56.92}{65.58} \times 100 = 22.26$

Example 2. Calculate following weed indices of *Echinochloa colona* in the paddy field from the given observation:- Weed Occurrence; Density /Sq. m.; Dominance; Frequency; Relative Density(RD); Relative Frequency (RF); Relative Dominance(RDo.); Important value index (IVI)

Observation table

Weed Name	Quadrate 1	Quadrate 2	Quadrate 3	Quadrate 4	Quadrate 5	Dry weight
Ageratum conyzoides	7	0	9	11	0	2.11
Celosia argentia	0	9	11	0	12	1.71
Commelina benghalensis	0	11	0	0	15	1.64
Cynodon dactylon	15	0	0	32	26	0.65
Cyperus rotunds	23	10	0	39	33	1.09
Ischaremum ruosum	11	0	13	19	21	0.89
Echinochloa colona	31	24	29	36	33	0.77
E. crusgalli	0	19	31	0	35	1.11

Note: Quadrate used is of 0.5 m length

Solution

Weed	Occurrence	Total	Density/m^2	Dry weight	Dominance	Frequency %	Relative density %	Relative frequency %	Relative Dominance %	IVI
Ageratum conyzoides	3	37	21.60	2.11	45.58	60.00	4.78	11.11	1.01	16.90
Celosia argentia	3	32	25.60	1.71	43.78	60.00	5.68	11.11	0.97	17.75
Commelina benghalensis	2	26	20.80	1.64	34.11		4.60	7.41	0.76	12.77
Cynodon dactylon	3	73	58.40	0.65	37.96	60.00	12.92	11.11	0.84	24.87
Cyperus rotunds	4	105	84.00	1.09	91.56	80.00	18.58	14.81	2.03	35.43
Ischaremum ruosum	4	64	51.20	0.89	45.57	80.00	11.33	14.81	1.01	27.15
Echinochloa colona	5	153	122.40	0.77	34.25	100.00	27.08	18.52	2.09	47.69
Echinochloa crusgalli	3	85	68.00	1.11	75.48	60.00	15.04	11.11	1.67	27.83
TOTAL	27	565	452.00	9.97						

(i) Occurrence of *E. colona* : Out of 5 quadrants, *E. colona* occurred in 4 quadrants, so its occurrence is 4.

(ii) Total of *E. colona* in all the 5 quadrants= 31+24+29+36+33=153

(iii) Density per sq. m. of *E. colona*
Weed density per 0.25 sq.m. = 153/5=30.6
As we know that the quadrate used is of 0.5 m length
So, area of the quadrate = 0.5 x 0.5 = 0.25 sq.m.
(Area of the square=length x length)
Hence, density per sq.m. is 30.6 x 4=122.4 (0.25 x 4= 1 sq.m.)

(iv) Dominance of *E. colona* = 122.4 x 0.77= 94.25

(v) Frequency % of *E. colona* = 5/5 x 100= 100%

(vi) Relative Density (RD) of *E. colona* = (153/565) x 100= 27.08

(vii) Relative Frequency (RF) of *E. colona* = (5/27) x 100 = 18.52

(viii) Relative Dominance (RDo.) of *E. colona* = (94.25/ 452.0 x 9.97) x 100= 2.09

(ix) Importance Value Index (IVI) of *E. colona* = 27.08+ 18.52+ 2.09 = 47.69

Exercise

Q.1. Define explain the following: (5.0)

Cost of cultivation, opportunity cost, weed control efficiency, crop resistance index, threshold, abundance,

Q2. Define explain the following: (5.0)

Total cost, net return, weed index, integrated weed management index, economic threshold, frequency,

Q.3. Tick the correct choice

i. Economic cost is the sum of________
a). Variable and fixed costs
b). **Variable, fixed and opportunity costs**
c). Fixed and opportunity costs
d). Variable, fixed and marginal costs

ii. Marginal cost is defined as____
a). Cost that arises when the quantity produced changes by one unit
b). Cost of producing one more unit of a good
c). Increase in cost that accompanies a unit increase in output
d). **All the above**

iii. The additional cost from taking a cost of action is called
a). Total cost
b). Opportunity cost
c). Variable cost
d). **Marginal cost**

iv. A cost independent of the quantity of goods and services produced
a). Variable cost
b). **Fixed cost**
c). Opportunity cost
d). Marginal cost

v. The cost of any activity measured in terms of the value of the next best alternative forgone
a). Economic cost
b). Variable cost
c). **Opportunity cost**
d). Marginal cost

vi. If the gross returns from an enterprise are INR 30000 and the net returns INR 20000, the benefit cost ratio based on net gain would be
a). 3.0
b). **2.0**
c). 1.0
d). 1.5

vii. If the yield from weed free is 3500 kg and that from weedy 1500 kg/ha, weed index would be
a). **57.1%**
b). 133.3%
c). 45.0%
d). 25.6%

viii. If the count of *Echinochloa* in weedy check is 70 and that in a treatment 25/m^2, weed control efficiency will be

a). 54.3%
b). **64.3%**
c). 73.4%
d). 79.6%

ix. If weed population is 70/m^2 and the crop 140/m^2, weed intensity would be

a). **33.3%**
b). 66.6%
c). 50%
d). 73.4%

x. Out of 50 quadrats studied, if *Echinochloa* is found in 26 quadrats, its frequency of occurrence would be

a). 13%
b). 26%
c). **52%**
d). 68%

xi. If *Echinochloa* falls in frequency class 'E', the weed community is said to be

a). Contiguous
b). Heterogenous
c). **Homogenous**
d). Random

xii. In a 100 quadrat study of 1 sqm each *Cyperus rotundus* was found in 80 quadrats with overall of 5640 individuals. The frequency (%), abundance and density (m^2) would be

a). 70.5, 80.0 and 56.4
b). 56.4, 70.5 and 80.0
c). **80.0, 70.5 and 56.4**
d). 80.0, 56.4 and 70.5

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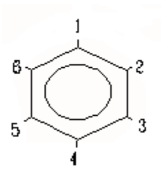
Appendix-I

Structures of Herbicides

Growth Regulators

Phenoxyacitic Acids/ (Aryloxy) Alkanoic Acids

Aromatic carboxylic herbicides are composed chemically of (1) an aromatic (benzene) ring structure, (2) one or more carboxyl (-COOH) group, and (3) various substitutions (e.g. –Cl, -CH_3, NH_2, NO_2) etc.) replacing hydrogen atom on the ring or aliphatic side chain or both.



Benzene ring

2 position – Ortho
3 position – meta
4 position – para

Various substitutions are

-OH	Hydroxy	-O-CH_3	Methoxy
-CH_3	Methyl	-S-CH_3	Methyl thio
-NH_2	Amino	-COOH	Carboxyl group
NO_2	Nitro		

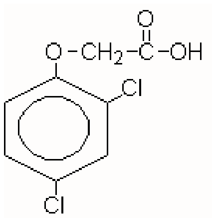
This group was developed in 1940s simultaneously in Britain and the USA following the discovery of MCPA and 2,4-D. It includes both 2-(aryloxy) alkanoic acid (phenoxy and pyridyloxy-) and also precursors of phenoxyacetic acid that are converted to the corresponding acids in vivo. The propionic acid derivatives contain a chiral centre and only the (R)(+) isomer are herbicidally active.

Important herbicides belonging to the group are:

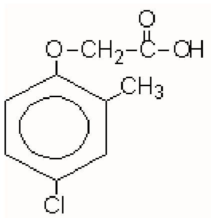
2,4-D: (2,4-dichlorophenoxy) acetic acid; **MCPA**: (4-chloro-2-methylphenoxy)acetic acid; **2,4,5-T**: (2,4,5-trichlorophenoxy)acetic acid

Dichlorprop: 2-(2,4-dichlorophenoxy)propanoic acid; **Mecoprop**: 2-(4-chloro-2-methylphenoxy)propanoic acid

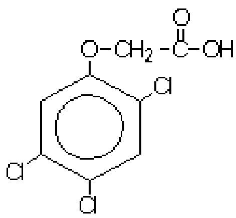
MCPB: 4-(4-chloro-2-methylphenoxy)butanoic acid; **2,4-DB**: 4-(2,4-dichlorophenoxy)butanoic acid; **2,4,5-TB**: 4-(2,4,5-trichlorophenoxy)butanoic acid



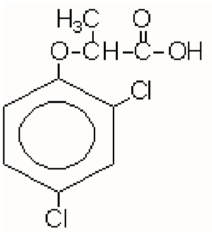
2,4-D

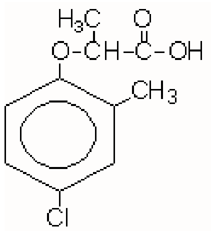


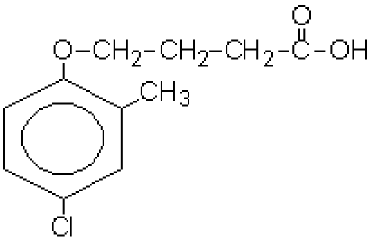
MCPA

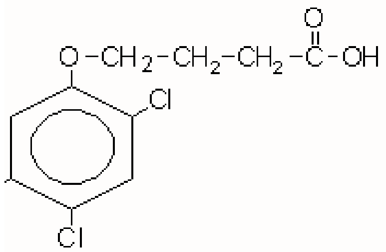


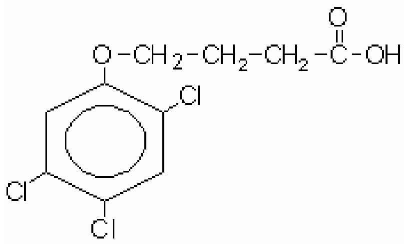
2,4,5-T


Dichlorprop


Mecoprop

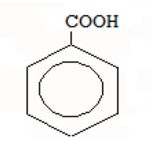

MCPB

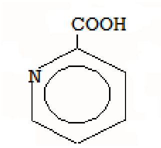

2,4-DB

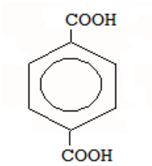

2,4,5-TB

Arylcarboxylic acids (Benzoic acids, picolinic acid, terephthalic acid)

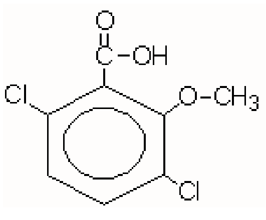
There are three groups of arylcarboxylic acids based on benzoic acids, picolinic acid and terephthalic acid

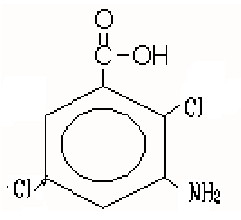

benzoic acid

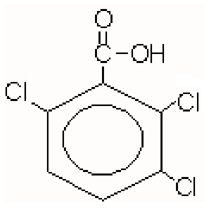

picolinic acid

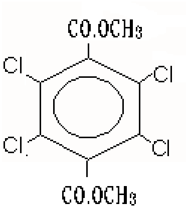

terephthalic acid

Dicamba: 3,6-dichloro-2-methoxybenzoic acid; **Chloramben**: 3-amino-2,5-dichlorobenzoic acid; **2,3,6-TBA**: 2,3,6-trichlorobenzoic acid; **Chlorthal-dimethyl**: 2,3,5,6-tertchloro-dimethyl terphthalanoate


Dicamba

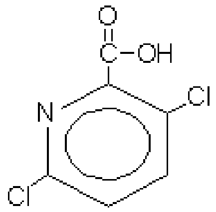

Chloramben


2,3,6-TBA

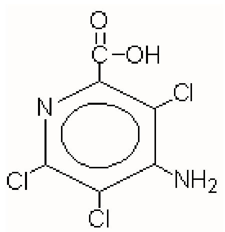

Chlorthal-dimethyl

Pyridines

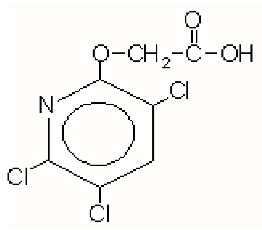
Clopyralid: 3,6-dichloro-2-pyridinecarboxylic acid; **Picloram**: 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid; **Triclopyr**: [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid



Clopyralid



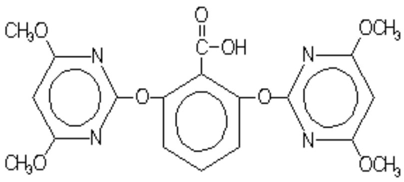
Picloram



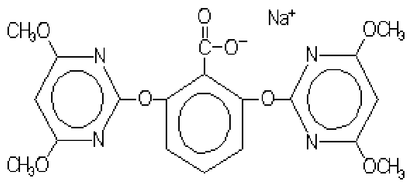
Triclopyr

Pyrimidinyloxybenzoic acid**s**

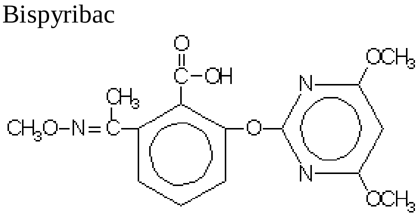
Bispyribac: 2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoic acid; **Pyriminobac**: 2-[(4,6-dmethoxy-2-pyrimidinyl)oxy}-6-methoxyimino)ethyl] benzoic acid



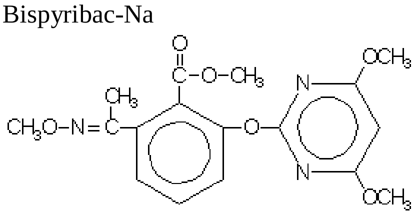
Bispyribac



Bispyribac-Na



Pyriminobac

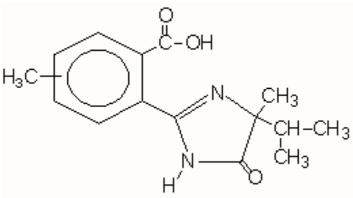


Pyriminobac –methyl ester

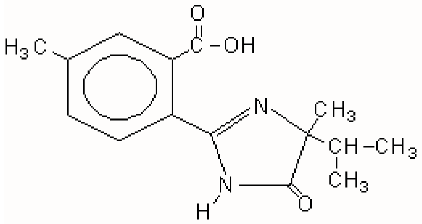
Amino Acid Synthesis Inhibitors

Imidazolinones

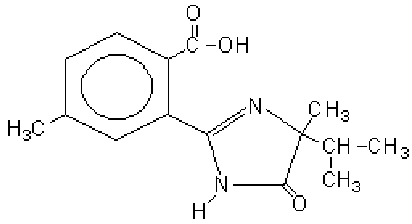
Imazamethabenz: (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-4(and 5)-methylbenzoic acid (3:2); **Imazaquin:** 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid; **Imazethapyr:** 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid



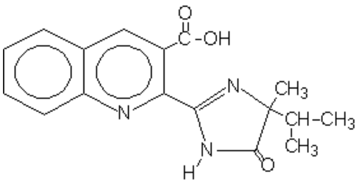
Imazamethabenz (generic)



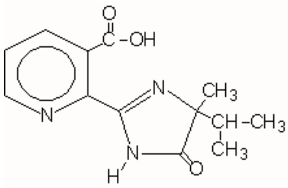
Imazamethabenz (meta)



Imazamethabenz (para)

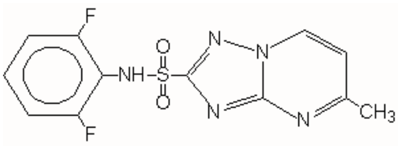


Imazaquin



Imazethapyr

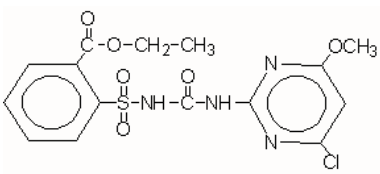
Triazolopyrimidine sulfonanilide or sulfonamide



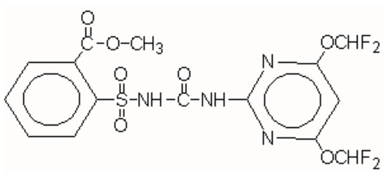
Flumetsulam (N-(2,6-difluorophenyl)-5-methyl[1,2,4]triazolo[1,5-a]pyrimidine-2-sulfonamide)

Sulfonylureas

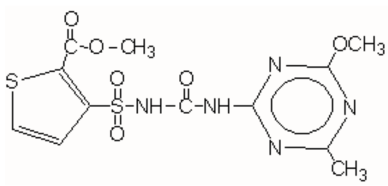
Chlorimuron: 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; **Primisulfuron**; 2-[[[[[4,6-bis(difluoromethoxy)-2-pyrimidinyl]amino]carbonyl]amino]sulfonyl]benzoic acid; **Thifensulfuron**: 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid; **Triasulfuron**: 2-(2-chloroethoxy)-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; **Nicosulfuron**: 2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-N,N-dimethyl-3-pyridinecarboxamide; **Metsulfuron**: 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid; **Tribenuron**: 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid; **Rimsulfuron:** N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-3-(ethylsulfonyl)-2-pyridinesulfonamide; **Triflusulfuron:** 2-[[[[[4-(dimethylamino)-6-(2,2,2-trifluoroethoxy)-1,3,5-triazin-2-yl]amino]carbonyl]amino]sulfonyl]-3-methylbenzoic acid; **Pyrazosulfuron**: 5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-1-methyl-1H-pyrazole-4-carboxylic acid;



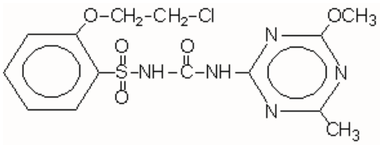
Chlorimuron

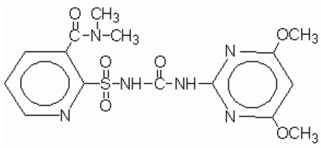


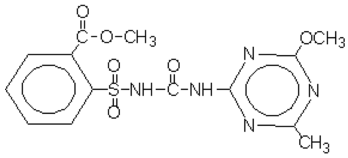
Primisulfuron

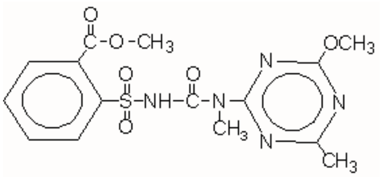


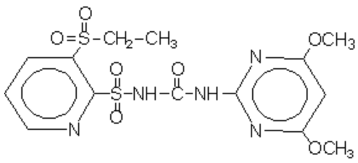
Thifensulfuron

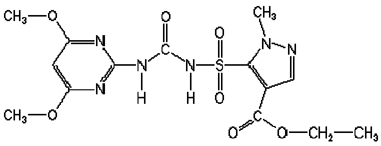

Triasulfuron


Nicosulfuron

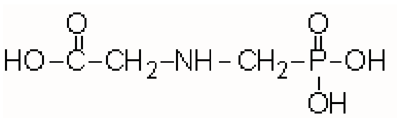

Metsulfuron


Tribenuron


Rimsulfuron


Pyrazosulfuron

Amino Acid Derivatives

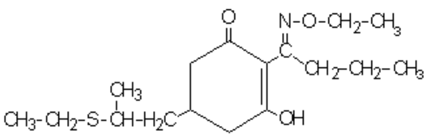


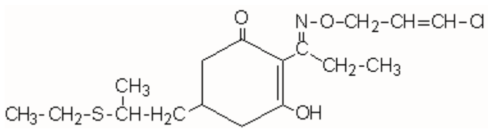
Glyphosate (N-(phosphonomethyl)glycine)

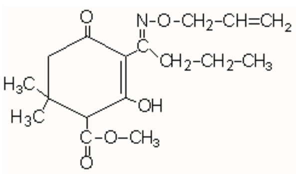
Lipid Inhibitors

Cyclohexanediones

Sethoxydim: 2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; **Clethodim:** (E,E)-(6)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; **Alloxydim**: methyl 2,2-dimethyl-4,6-dioxo-5-[1-[(2-propenyloxy)amino]butylidene]cyclohexanecarboxylate;

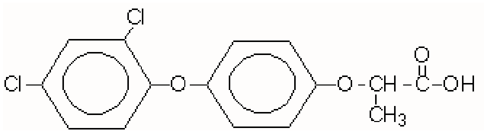

Sethoxydim


Clethodim

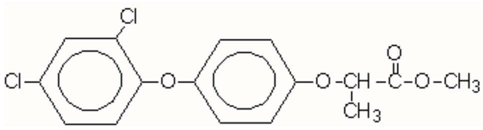

Alloxydim

Aryloxyphenoxypropionates

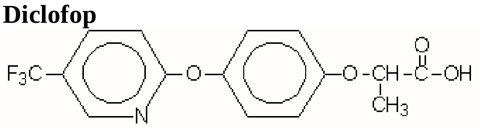
Diclofop: (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid; **Fluazifop:** (±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid; **Fenoxaprop:** (±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid; **Quizalofop:** (6)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid; **Haloxyfop**: (6)-2-[4-[[3-chloro-5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid;



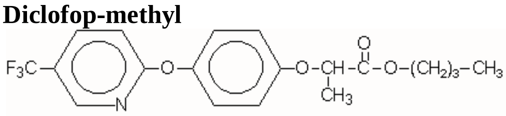
Diclofop



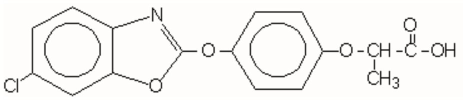
Diclofop-methyl



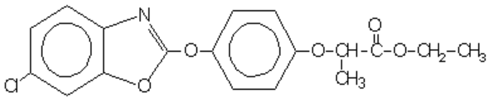
Fluazifop



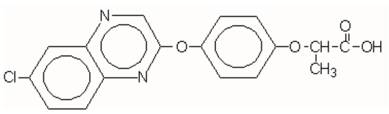
Fluazifop-butyl



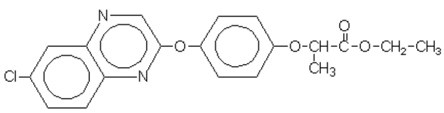
Fenoxaprop



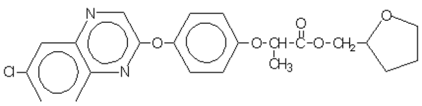
Fenoxaprop-ethyl



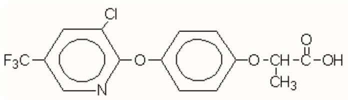
Quizalofop-p



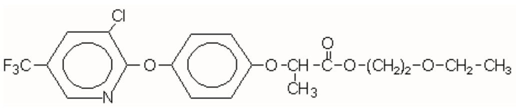
Quizalofop-ethyl



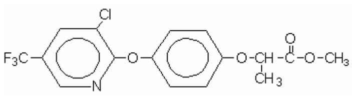
Quizalofop-tefuryl



Haloxyfop



Haloxyfop-2-ethoxyethyl



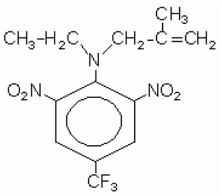
Haloxyfop-methyl

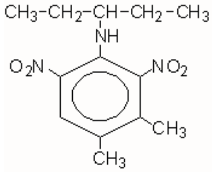
Seedling Growth lnhibitors

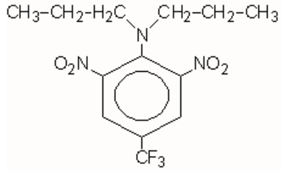
A. Root Inhibitors

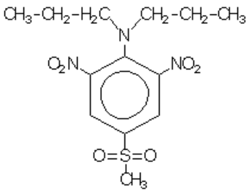
1. Dinitroanilines

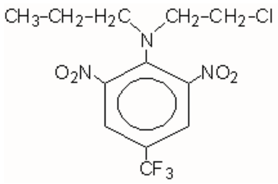
Ethalfluralin: N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine; **Pendimethalin:** N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine **Trifluralin:** 2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine; **Nitralin**: 4-(methylsulfonyl)-2,6-dinitro-N,N-dipropylbenzenamine; **Fluchloralin**: N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl)benzenamine;


Ethalfluralin


Pendimethalin


Trifluralin

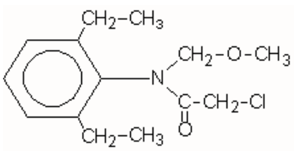

Nitralin

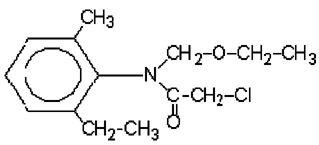

Fluchloralin

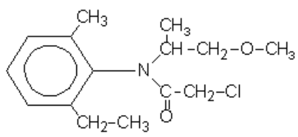
B. Shoot Inhibitors

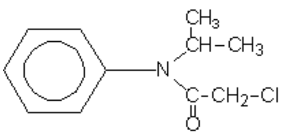
1. Acetanilides

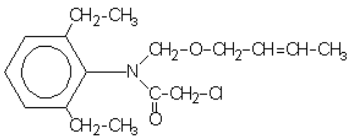
Alachlor: 2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)acetamide; Acetochlor: 2-chloro-N-(ethoxymethyl)-N-(2-ethyl-6-methylphenyl)acetamide; Metolachlor: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide; Propachlor: 2-chloro-N-(1-methylethyl)-N-phenylacetamide; Butachlor: N-(butoxymethyl)-2-chloro-N-(2,6-diethylphenyl)acetamide; Dimethenamid: (RS) 2-chloro-N-(2,4-dimethyl-3-thienyl)-N-(2-methoxy-1-methylethyl)acetamide; Pretilachlor 2-chloro-N-(2,6-diethylphenyl)-N-(2-propoxyethyl)acetamide;

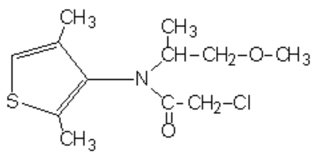

Alachlor

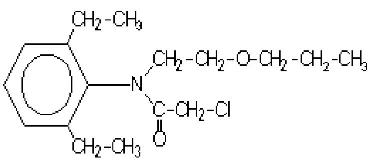

Acetochlor


Metolachlor


Propachlor


Butachlor

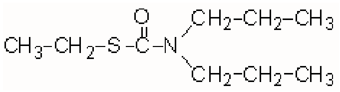

Dimethenamid


Pretilachlor

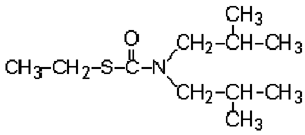
2. Thiocarbamates

EPTC: S-ethyl dipropyl carbamothioate; **Butylate:** S-ethyl bis(2-methylpropyl)carbamothioate; Diallate: S-(2,3-dichloro-2-propenyl)bis(1-methylethyl)carbamothioate**;Triallate:** S-(2,3,3-trichloro-2-propenyl) bis(1-

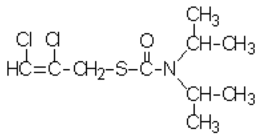
methylethyl)carbamothioate; **Cycloate:** S-ethyl cyclohexylethylcarbamothioate; Thiobencarb: S-[(4-chlorophenyl)methyl]diethylcarbamothioate;



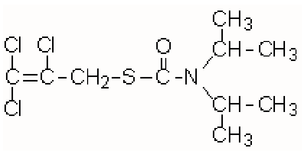
EPTC



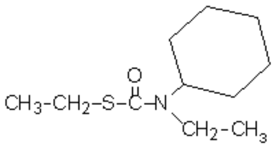
Butylate



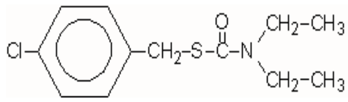
Diallate



Triallate



Cycloate

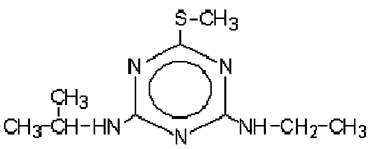


Thiobencarb

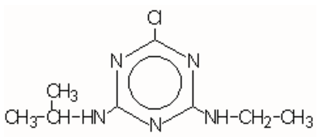
Photosynthesis Inhibitors

1. **Triazines**

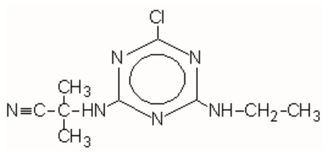
Ametryn: N-ethyl-N'-(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine; **Atrazine**: 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine; **Cyanazine**: 2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile **Simazine**: 6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine; **Metribuzin**: 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one; **Hexazinone**: 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione**; Aziprotryn**: 2-azido-4-isopropyl amino-6-methylthio-1,3,5-triazine; **Desmetryn**: N-methyl-N9-(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine; **Prometryn**: N,N'-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine; **Terbutryn**: N-(1,1-dimethylethyl)-N'-ethyl-6-(methylthio)-1,3,5-triazine-2,4-diamine;



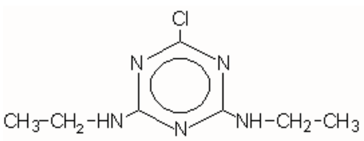
Ametryn



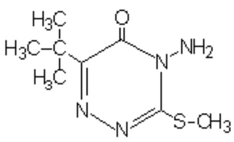
Atrazine



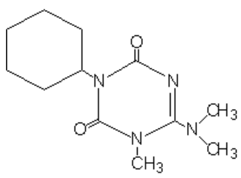
Cyanazine



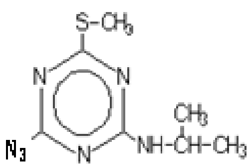
Simazine



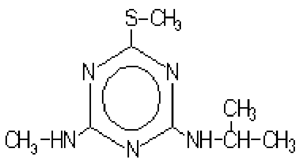
Metribuzin



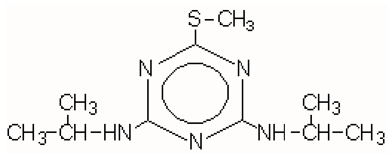
Hexazinone



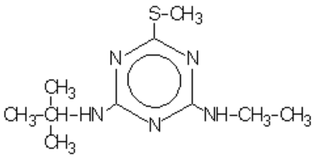
Aziprotryn



Desmetryn

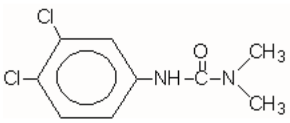


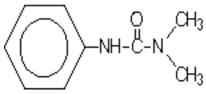
Prometryn

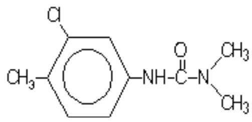

Terbutryn

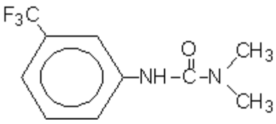
2. **Phenylureas**

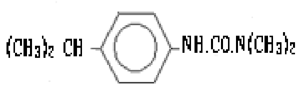
Diuron: N’-(3,4-dichlorophenyl)-N,N-dimethylurea; **Fenuron**: N,N-dimethyl-N9-phenylurea; **Chlorotoluron**: N’-(3-chloro-4-methylphenyl)-N,N-dimethylurea; **Fluometuron**: N,N-dimethyl-N9-[3-(trifluoromethyl)phenyl]urea; **Isoproturon**: N,N-dimethyl-N’-[4-(1-methylethyl)phenyl]urea; **Linuron**: N’-(3,4-dichlorophenyl)-N-methoxy-N-methylurea **Methabenzthiazuron**: N-(2-benzothiazolyl-N,N’-dimethylurea; **Metoxuron**: N’-(3-chloro-4-methoxyphenyl)-N,N-dimethyl urea; **Monolinuron**: N’-(4-chlorophenyl)-N-methoxy-N-methylurea; **Monuron**: N’-(4-chlorophenyl)-N,N-dimethylurea; **Tebuthiuron**: N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N’-dimethylurea

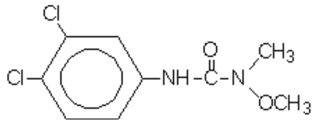

Diuron

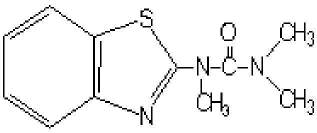

Fenuron

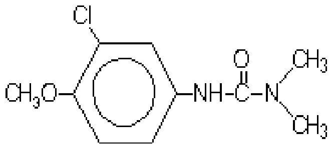

Chlorotoluron

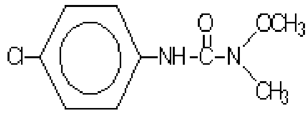

Fluometuron

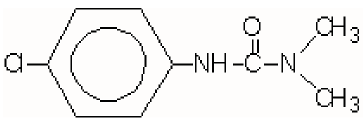

Isoproturon

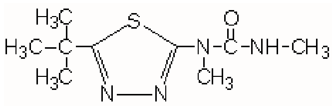

Linuron


Methabenzthiazuron


Metoxuron

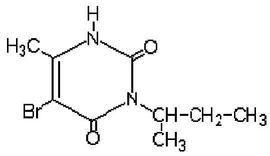

Monolinuron

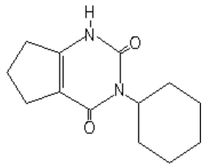

Monuron

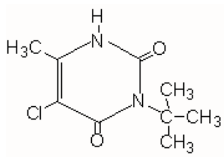

Tebuthiuron

3. **Uracils**

Bromacil: 5-bromo-6-methyl-3-(1-methylpropyl)-2,4(1H, 3H)pyrimidinedione; Lenacil: 3-cyclohexyl-6,7-dihydro-1H-cyclopentapyrimidine-2,4(3H,5H)-dione; Terbacil: 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4(1H,3H)-pyrimidinedione;

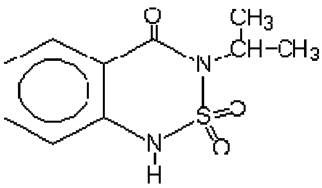

Bromacil


Lenacil


Terbacil

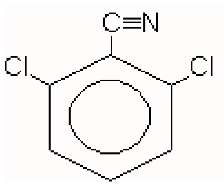
4. Benzothiadiazoles

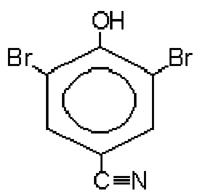
Bentazon: 3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide;

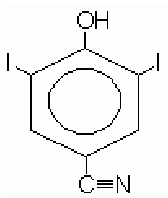

Bentazon

5. Nitriles

Dichlobenil: 2,6-dichlorobenzonitrile; Bromoxynil: 3,5-dibromo-4-hydroxybenzonitrile; Ioxynil: 4-hydroxy-3,5-diiodobenzonitrile;

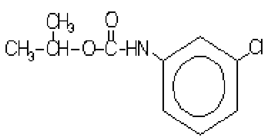

Dichlobenil

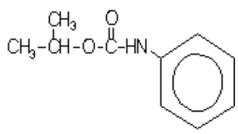

Bromoxynil

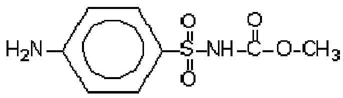

Ioxynil

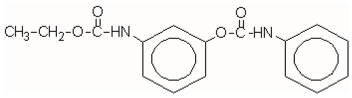
6. Carbamate

Chlorpropham: 1-methylethyl 3-chlorophenylcarbamate; Propham: 1-methylethyl phenylcarbamate; Asulam: methyl[(4-aminophenyl)sulfonyl]carbamate; **Desmedipham:** ethyl[3-[[(phenylamino)carbonyl]oxy]phenyl]carbamate; Phenmedipham: 3-[(methoxycarbonyl)amino]phenyl (3-methylphenyl)carbamate

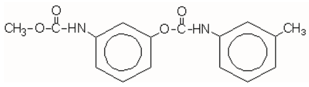

Chlorpropham


Propham


Asulam



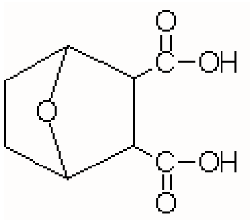
Desmedipham



Phenmedipham

7. Dicarboxylic Acid

Endothall: 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid;

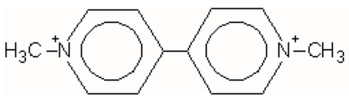


Endothall

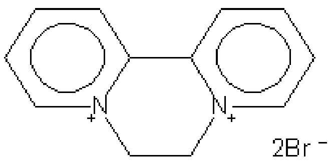
Cell Membrane Disrupters

1. Bipyridyliums

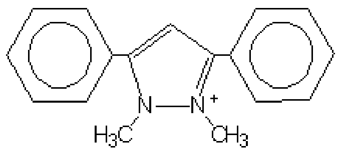
Paraquat: 1,1'-dimethyl-4,49-bipyridinium ion; Diquat: 6,7-dihydrodipyrido[1,2-a:2',1'-c]pyrazinediium ion
Difenzoquat: 1,2-dimethyl-3,5-diphenyl-1H-pyrazolium



Paraquat



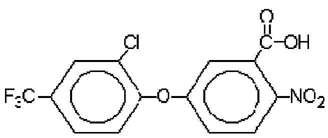
Diquat



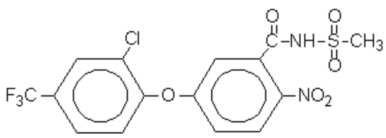
Difenzoquat

2. Diphenylethers

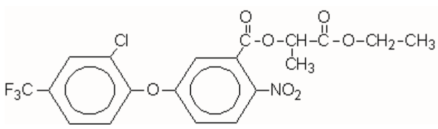
Acifluorfen: Fomesafen: 5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide;
Lactofen: (±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate



Acifluorfen



Fomesafen

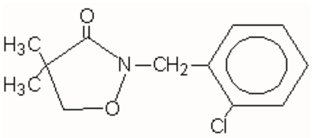


Lactofen

Pigment Inhibitors

1. Isoxazolidinones

Clomazone: 2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone;



Clomazone

Appendix -II

APPROVED USES OF REGISTERED HERBICIDES

(As on 01.10.2014)

HERBICIDES

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
Alachlor 50% EC				
Cotton	2-2.5 kg	4-5 l	250-500	210-240
Maize	2.5 kg	5 l	250-500	90
Groundnut	2.5 kg	5 l	250-500	120-150
	1.5-2.5 kg	3-5 l	250-500	120-150
Soybean	2.5 kg	5 l	250-500	
Alachlor 10% GR				
Cotton	2.0-2.5 kg	20-25 kg	-	-
Maize /Groundnut /Soybean	1.5-2.5 kg	15-25 kg	-	-
Anilofos 30% EC				
Transplanted paddy	0.3-0.45 kg	1-1.5 l	375-500	30
Anilofos 18% EC				
Transplanted Paddy	0.30-0.45 kg	1.66-2.5 kg	500-600	-
Anilophos 2 % G				
Transplanted rice	0.4-0.5 kg	20-25 kg	-	30
Atrazine 50% WP				
Maize	0.5-1.0 kg	1-2 kg	500-700	-
Azimsulfuron 50% DF				
Rice (Transplanted)	35	70	300	59
Rice (Direct Seeded)	35	70	300	59
Bensulfuron Methyl 60% DF				
Transplanted Rice. Pre-em (3 DAT)	60 g	100 g	300	88 days
Transplated Rice (post-em 20 DAT)	60g	100 g	300	71
Bispyribac Sodium 10% SC				
Rice (Nursary)	20 g	200 ml	300	-
Rice (Transplanted)	20 g	200 ml	300	78
Rice (Direct seeded)	20 g	200 ml	300	78
Butachlor 50% EC				
Paddy (transplanted)	1.25-2.0 kg	2.5-4 l	250-500	90-120
Butachlor 5% GR				
Rice	1.25-2.0 kg	25-40 kg	-	90-120
Butachlor 50 % EW				
Transplanted Rice	1.25-1.5 kg	2.5-3.0	2.50-500	-
Carfentrazone ethyl 40% DF				
Wheat	20g	50 g	400	80
Chlorimuron Ethyl 25% WP				
Soybean	9 g	36 g	300 l +Surfactant 0.2 % (Iso-octyl phenoxyl-poloxethanol 12.5 %)	45

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
Rice (transplanted)	6g	24 g	500-600	60
Cinmethylin 10% EC				
Transplanted Rice	75-100 g	0.75-1.0 l	500-700	110
Clodinafop- propargyl 15%WP				
Wheat	60 g	400 g	375-400	110
Clomazone 50%EC				
Soybean	0.75-1.00 kg	1.5-2.0 l	500-600	90
Transplanted Rice	0.4 - 0.5 kg	0.8-1.0 l	500-750	90
Cyhalofop Butyl 10% EC				
Rice (Directed seeded)	75-80 g	0.75-0.80 l	500-600	90
2,4-D Dimethyl Amine salt 58% SL				
Maize	0.5 kg	0.86	400-500	50-60
Wheat	0.5-0.75 kg	0.86-1.29	500-600	-
Sorghum	1.8 kg	3.1	500-600	-
Potato	2.0 kg	3.44	400	-
Sugarcane	3.5	6.3	500	-
Aquatic Weeds Non crop area	0.5-1.0 kg 2.65 kg 2.5 kg	0.86-1.72 4.56 4.30	600-700 300-400 300-400	15-20 15-20 -
2,4-D Sodium salt Technical (having 2,4-D acid 80 % w/w) (Earlier Registered as 80%WP)				
Citrus	1.00-2.5 kg	1.25-3.2 kg	600	>6 months
Grapes	2.0	2.5	500	> 90 days
Maize	1.00 kg.	1.25	500	120(Pre-em) 90(post-em)
Sugarcane	2.0-2.6	2.5-3.25	600-900	300
Wheat	0.5-0.84 kg.	0.625-1.0	500	90
Aquatic Weeds	1.5 kg	1.85.	600-1000	-
Non crop land	2.5-6.0 kg. 4-8 kg 1.8 kg	3.2-7.5 5-10 2.25	600-1000 500-600 500-600	- - -
2,4-D Ethyl Ester 38 % EC (having 2,4-D acid 34 % w/w)				
Maize	0.9 kg	2.65 l	400-450	50-60
Sorghum	1.0 kg	2.94	425	-
Transplanted Paddy	0.85 kg	2.5	400	-
Wheat	0.45-0.75 kg	1.32-2.2	450-500	-
Sugarcane	1.2 to 1.8	3.53- 5.29	500	300-330
Aquatic Weeds	2.5 kg	7.5	700-1000	-
2,4-D Ethyl Ester 4.5 % GR (having 2,4-D acid 4 % w/w)				
Transplanted Rice	1.0 kg	25 kg	-	-
Diclofop Methyl 28% EC				
Wheat	0.7-1.0 kg	2.5-3.5 l	500	90
Diuron 80% WP				
Cotton	0.75-1.5 kg	1-2.2 kg.	625	-
Banana	1.60 kg	2 kg.	625	-
Rubber	1.6-3.2 kg	2-4 kg.	625	-

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
Maize	0.8 kg	1.0 kg.	600	-
Citrus (sweet orange)	2-4.0 kg	2.5-5.0 kg	600	-
Sugarcane	1.6-3.2 kg	2.0-4.0 kg.	600	-
Grapes	1.6 kg	2.0 kg.	625	-
Diclosulam 84% WDG				
Soybean	22-26 g	Time of application 0-3 DAS		60
Ethoxysulfuron 15% WDG				
Transplanted Rice.	12.5-15 g	83.3-100 g	500	110
Fenoxaprop-p-ethyl 9.3% w/w EC (9% w/v)				
Soybean	100g	1111 ml. (15-20 DAS)	250-300	100
Rice (transplaned)	56.25 g	625 ml. (10-15 DAT)	300-375	70
Blackgram	56.25-67.5 g	625-750 ml. (15-20 DAS)	375-500	43
Cotton	67.5 g	750 ml. (20 -25 DAS)	375-500	87
Fenoxaprop-p-ethyl 10% EC				
Wheat	100-120g	1.0-1.20 kg.	250-300	110
Fenoxaprop-p-ethyl 6.7% w/w EC				
Rice (Transplanted & Direct Seeded)	56.6-60.38g	812.5-875	375-500	61
Fluazifop-p-butyl 13.4% EC				
Soybean	125-250 g	1000-2000	500	90
Fluchloralin 45% EC				
Cotton	0.9-1.2 kg	2.0-2.68 l	500-800	180
Soybean	1.0-1.5 kg.	2.22-3.33	500-800	120-150
Flufenacet 60% DF				
Paddy (Transplanted)	120 g	200 g	500	90-110
Glufosinate Ammonium 13.5% SL (15% w/v)				
Tea	0.375-0.500	2.5-3.3	375-500	15
Cotton	375-450	2.5-3.0	500	96
Glyphosate 20.2% SL IPA salt				
Non Crop area	0.82-1.23 kg	4.1-6.15	400-500	N/A
Glyphosate 41% SL IPA Salt				
Tea	0.820-1.230 kg.	2.0-3.0	450	21
Non-cropped area	0.820-1.230 kg.	2.0-3.0	500	-
Glyphosate 54% SL (IPA Salt)				
Non Crop Area	1.8 kg	3.33 l	400-500	-
Glyphosate Ammonium Salt 5% SL				
Tea	1.5 kg	30 l	500	7 days
Non Crop area	2 kg	40 l	500	-

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
Glyphosate 71% SG (Ammonium Salt)				
Tea & Non Crop area	2.13 kg	3.0 kg	500	7
Sugarcane	60-67.5	80-90	375	
Imazethapyr Technical (H)				
Soybean	100	1000	500-600	75
Ground nut	100-150	1000-1500	500-700	90
Imazethapyr 10% SL				
Soybean	100 g	1.0 l	500-600	75
Groundnut	100-150 g	1.0-1.5 l	500-700	90
Isoproturon 50% WP				
Wheat	1.0 kg	2.0	750	-
Isoproturon 75% WP				
Wheat	1.0 kg	1.33 kg	750	60 days
Linuron 50% WP				
Pea	0.625-1.0 kg	1.25-2.0	500	80-90
MCPA, Amine salt 40% WSC				
Transplanted Rice	0.8-2.0 kg	2-5	400-600	
Wheat	1.0 kg	2.5	300-600	
Methabenzthiazuron 70% WP				
Wheat (PE –2DAS)	1.05-1.4 kg	1.5-2.0 kg	700-1000	100
Wheat (Post –EM 30 DAS)	1.05-1.75kg	2.0-2.5 kg	700-1000	100
Wheat (Early POE.16-18 DAS)	0.7-0.87 kg	1.0-1.25 kg	700-1000	100
Metolachlor 50% EC				
Soybean	1.0 kg	2.0 l	600-750	-
Metribuzin 70% WP				
Soybean	0.35-0.525 kg	0.5-0.75kg	750-1000	30
Wheat	Medium soil-0.175 kg Heavy soil -0.21 kg	0.25 kg 0.30 kg.	500-750	120
Metsulfuron Methyl 20% WP				
Wheat	4 g	20 g	500-600 + Surfactant (Iso-Octyl Phenoxyl-Poloxethanol 12.5%)@ 500 ml/ha	80
Rice (transplanted)	4 g	20 g	500-600	60
Sugarcane	6	30	500-600 (Add non -ionic surfactant Iso-octyl-phenoxyl -poloxethanol 12.5% @ 2ml per liter of spray volume (0.2%)	346
Metsulfuron Methyl 20% WG				
Wheat	4 g	20 g	500-600 + Surfactant (Iso-Octyl	76

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
			Phenoxyl-Poloxethanol 12.5%) @0.2%	
Transplanted Rice	4 g	20 g	500-600 + Surfactant (Iso-Octyl Phenoxyl-Poloxethanol 12.5%) @0.2%	71
Orthosulfamuron 50% WG				
Transplanted Rice (Paddy)	60-75	150 3 DAT	500	65
Oxadiargyl 80% WP				
Transplanted Rice	100 g	0.125 kg.	500	97
Oxadiargyl 6%EC				
Transplanted Rice	100 g	1.66 l	500	97
Cumin	60-75g	1.0-1.25 l	500	87
Mustard	90	1500	500	35
Oxadiazon 25% EC				
Transplanted Rice	0.5 kg	2.0 l	500	-
Oxyflourfen 0.35% GR				
Rice (Direct sown puddled or Transplanted)	100-150 g	30-40 kg	-	-
Oxyflourfen 23.5% EC				
Rice (Direct sown as pre-emergence)	150-240 g	650-1000	500	-
Tea	150-250 g	650-1000	500-750	15 days
Onion	100-200 g	425-850	500-750	-
Potato	100-200 g	425-850	500-750	-
Groundnut	100-200 g	425-850	500-750	-
Pendimethalin 30% EC				
Wheat	Light soil-1.0 kg, Medium soil-1.25 kg, Heavy soil-1.5 kg	3.3 l 4.2 5.0	500-700 500-700 500-700	-
Rice (Transplanted &direct sown Upland)	Light to Heavy soil 1-1.5 kg	3.3 –5 l	500-700	
Cotton	0.75-1.25kg	2.5-4.165 l	500-700	150
Soybean	0.75-1.0 kg	2.5-3.3 l	500-700	110
Pendimethalin 5% G				
Rice (Transplanted & Direct sown puddled)	1.0-1.5 kg	20-30 kg	-	-
Soybean	580.5-677.25 g	1500-1750	500	40
Cotton	677.27	1500-1750	500	101
Chilli	677.27	1500-1750	500	98
Onion	580.50-677.25g	1500-1750	500	104
Wheat	40-45 g	800-900 ml 30-35 DAS	225-300	90
Pretilachlor 37%EW				
Transplanted Rice	0.60-0.75 kg	1.5-1.875 l	500	90
Pretilachlor 30.7% EC				
(Direct seeded rice under	0.45-	1.5-2.0 l	500	110

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
puddled condition)	0.60kg.			
Pretilachlor 50% EC				
Transplanted Rice	0.50-0.75 kg	1.0-1.5 l	500-700	75-90
Propaquizafop 10% EC				
Soybean	50-75 g	500-750	500-750	21
Blackgram	75-100 g	750-1000	500-750	21
Onion	62.5	625	500L/ha	7
Paraquat dichloride 24% SL				
Tea (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.2-1.0 kg	0.8-4.25 l (For season long weed control, use 2.5-5.0 ltr for initial application. For subsequent repeat spot application use 1 litre)	200-400	Not Necessary (For season-long weed control, muse 2.5 to 5 lit for initial application. For subsequent repeat spot application use 1 lite)
Potato (Post-emergence overall / inter-row application at 5-10 % emergence)	0.5 kg	2.0 ltr.	500	100
Cotton (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.3-0.5 kg	1.25-2.0	500	150-180
Rubber (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.3-0.6 kg	1.5-2.5	600	N.A.
Coffee	250	1.0	400	N.A.
Sugarcane	500	2.0	500	270
Sunflower	400	1.6	500	120
Rice [pre-plant (minimum tillage) before sowing/transplanting for controlling standing weeds]	0.3-0.8 kg	1.25-3.5	500	N.A.
Wheat [pre-plant (minimum tillage) before sowing]	1.0 kg	4.25 l	500	120-150
Maize [pre-plant (minimum tillage) before sowing]	0.2-0.5 kg	0.8-2.0 l	500	90-120
Maize (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.2-0.5 kg	0.8-2.0 l	500	90-120
Grapes (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.5 kg	2.0 l	500	90
Apple (Post-emergence directed inter row application at 2-3 leaf stage of weeds)	0.75 kg	3.25 l	700-1000	N.A.
Aquatic weed control Water ways	1000	4.25	600-1000	N.A

Herbicide name & approved Crops	Dosage/ha		Dilution in water (l)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/kg)	Formulation in (g/ml /kg/l)		
Canals, Ponds Etc	1000 1000-2000	4.25 4.25-8.5	600 600-1000	
Pyrazosulfuron Ethyl 10% WP				
Transplanted rice	10-15 g	100-150	500-600	95
Pyrithiobac Sodium 10% EC				
Cotton (Gossypium)	62.5-75 g	625-750	500	160
Pyrozosalfuron Ethyl 70% WDG				
Transplanted Rice	21 g	-	-	43
Quizalofop-ethyl 5% EC				
Soybean	37.5-50 g	0.75-1.0	500-600	95
Cotton	50.5	1000	500	94
Groundnut	37.5-50.0	750-1000	500	89
Black gram	37.5-50.0	750-1000	500	52
Onion	37.5-50.0	750-1000	375-450	7
Quizalofop-ethyl 10% EC				
Soybean	375-45.0	375-450	300-500	69-103
Quizalofop –p-tefuryl 4.41% EC				
Soybean	30-40 g	750-1000 ml	400	30
Sulfosulfuron 75% WG				
Wheat	25 g	33.3 g	200-250 + Cationic surfactant 1250ml/ha	110
Tembotrione 34.4% SC				
Maize	120 g	286 ml	500L	55
Triallate 50% EC				
Wheat	1.25 kg	2.5 kg.	250-500	150
Triasulfuron 20% WS (H)				
WHEAT	20	100	500	81

HERBICIDE COMBINATIONS

Herbicide name & approved Crops	Dosage /ha		Dilution In Water (Litres)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/ kg)	Formulation in (g/ml/kg/l)		
Anilofos 24% +2,4-D ethyl Ester 32% EC				
Transplanted rice	(0.24+ 0.32) to (0.36 + 0.48) kg	1-1.5 l	300	90
Bensulfuron methyl 0.6%+Pretilachlor 6% GR				
Transplanted Rice	60 + 600 g	10 kg	N.A.	88
Carfentrazone ethyl 20% + Sulfosulfuron 25% WG				
Wheat	20+25 +750 ml Surfactant	100	300	110
Clodinafop Propargyl 15% + Metsulfuron Methyl 1% WP				
Wheat	60+4	400	375 (Add 1250 ml surfactant at the time of sparying)	100
Clodinafop propargyl 9% + Metribuzin 20% W/W				
Wheat	54+120	600	300	120
Clomazone 20%+2,4-D EE 30% EC				
Transplanted Rice	0.250-0.375 kg	1.25 l	500	100-110
Fenoxaprop-p-ethyl 7.77% w/w + Metribuzin 13.6% w/w EC				
Wheat	100+175	1250	375	110
Hexazinone 13.2% + Diuron 46.8 % WP				
Sugarcane	1200 g (264+936)	2 kg	500	282-306
Imazamox 35% + Imazethapyr 35% WG				
Soybean	70	100	375-500 Add surfactant (Cyspread) @ 1.5ml/litre of water + Ammonium sulphate @ 2.0 gm/litre of water	56
Mesosulfuron Methyl 3% + Iodosulfuron Methyl Sodium 0.6% WG				
Wheat	12+2.4 g	400 ml	400-500 + Surfactant (Genopol LRO fluid) @ 500 ml/ha	96

Herbicide name & approved Crops	Dosage /ha		Dilution In Water (Litres)	Waiting period / PHI between last application & harvest (days)
	a.i. (g/ kg)	Formulation in (g/ml/kg/l)		
Metsulfuron Methyl 10% + Chlorimuron ethyl 10% WP				
Transplanted Rice (Pre-emergence application-3 DAT	4g	20 g	300	90
Oxyflurofen 2.5% + Glyphosate (Isopropyl amime salt)41% SC(w/w)				
Tea	50+820	2000	500L/ha.	14
Pendimethalin 30%+ Imazethapyr 2% EC				
Soybean	750+50 to 900+60 g	2.5-3.0 l	500-600	90
Pretilachlor 6% + pyrazosulfuron Ethyl 0.15%(H)				
Paddy	600+15	10	-	83
Sulfosulfuran 75%+ Metsulfuron Methyl 5%WG				
Wheat	(30+2)	40 g	250-500 + surfactant 1250 ml/ha	110
Penoxsulam 21.7 % SC				
Rice (Transplanted)	22.5 to 25 (pre-emergence 0-5 DAT) 20 to 22.5 (post-emergence 10-12 DAT)	93.7 to 104.2 83.3 to 93.7		60
Sodium Aceflourofen 16.5% + Clodinafop Propargyl 8% EC				
Soybean	80 + 165	1000	500	61