Chapter 14
Weed Suppression in Legume Crops for Stress Management

Gudeta W. Sileshi and Taye Tessema

14.1 Introduction

In many cropping systems farmers spend more time and labour (up to 70% of family labour) in removing weeds from their crop than in any other farm operation (Chikoye et al., 2001). Worldwide, weeds constitute a major constraint to the production of legumes as many legume species are poor competitor to weeds because of slow growth rate and limited leaf area development at early stages of crop growth (Solh and Palk, 1990). Hence, losses could be substantial when optimum weed control is not achieved. In chickpea (*Cicer arietinum*) for instance, yield losses vary between 40 and 94% in the Indian subcontinent, between 40 and 75% in West Asia, 13–98% in North Africa, and 35% in Italy (Solh and Palk, 1990). In legumes such as chickpea, excessive weed competition may also adversely affect seed size, which is an important quality parameter in the Mediterranean region (Solh and Palk, 1990). Losses could vary from site to site or year to year depending on the legume species, the type of weed (parasitic vs. non-parasitic), the prevailing weed species, level of weed infestation, soil type, climate and management practices. Weed control becomes even more critical where moisture is limiting. When moisture is in short supply, weeds can reduce crop yields more than 50% through competition for moisture. In the past certain misconceptions about weeds have led in some cases to inappropriate use of control practices. Weeds have been assumed to exert only negative effects within cropping systems (Liebman and Dyck, 1993). However, weeds may enhance agro-ecosystem stability in terms of maintenance of ground cover, conservation of nutrients, and provision of habitat for beneficial organisms (Liebman and Dyck, 1993; Sileshi et al., 2008a). This calls for an ecosystem approach to weed management where the objective is weed management rather than control.

In the future, climate change, invasive weeds and herbicide resistance, are likely to pose challenges to weed management and water conservation. While rain-fed

G.W. Sileshi (✉)
World Agroforestry Centre (ICRAF), ICRAF Southern Africa Regional Programme, Chitedze Agricultural Research Station, Lilongwe, Malawi
e-mail: sileshi@africa-online.net

Metadata of the chapter that will be visualized online

ChapterTitle	Weed Suppression in Legume Crops to Stress Management
Chapter Sub-Title	
Chapter CopyRight - Year	Springer Science+Business Media B.V. 2010 (This will be the copyright line in the final PDF)
Book Name	Climate Change and Management of Cool Season Grain Legume Crops

Corresponding Author	Family Name	**Sileshi**
	Particle	
	Given Name	**Gudeta W.**
	Suffix	
	Division	
	Organization	World Agroforestry Centre (ICRAF), ICRAF Southern Africa Regional Programme
	Address	Chitedze Agricultural Research Station, Lilongwe, Malawi
	Email	sileshi@africa-online.net

Author	Family Name	**Tessema**
	Particle	
	Given Name	**Taye**
	Suffix	
	Division	
	Organization	EIAR
	Address	Addis Ababa, Ethiopia
	Email	tayetessema@yahoo.com

Abstract	Worldwide, weeds constitute a major constraint to the production of food legumes. Weeds can reduce crop yields more than 50% through competition for moisture, and this can be aggravated under the anticipated climate change scenarios. In the future, the spread of invasive alien species of weeds and herbicide resistance, which are partly aggravated by increased global trade and climate change, are likely to pose challenges to weed management and water conservation. In this chapter we will synthesize the state-of-art knowledge on weed management in legume production systems with a major emphasis on anticipated impacts of climate change and alien invasive species on weed management and water conservation. We provide a brief review of the types of weeds and weed effects followed by review of recent developments in the management of weeds in legume cropping systems. We also assess the strength and limitations of each practice and suggest the need for emphasis on the integration of different environmentally friendly control measures that are economically feasible to smallholder farmers.

Chapter 14
Weed Suppression in Legume Crops to Stress Management

Gudeta W. Sileshi and Taye Tessema

14.1 Introduction

In many cropping systems farmers spend more time and labour (up to 70% of family labour) in removing weeds from their crop than in any other farm operation (Chikoye et al., 2001). Worldwide, weeds constitute a major constraint to the production of legumes as many legume species are poor competitor to weeds because of slow growth rate and limited leaf area development at early stages of crop growth (Solh and Palk, 1990). Hence, losses could be substantial when optimum weed control is not achieved. In chickpea (*Cicer arietinum*) for instance, yield losses vary between 40 and 94% in the Indian subcontinent, between 40 and 75% in West Asia, 13–98% in North Africa, and 35% in Italy (Solh and Palk, 1990). In legumes such as chickpea, excessive weed competition may also adversely affect seed size, which is an important quality parameter in the Mediterranean region (Solh and Palk, 1990). Losses could vary from site to site or year to depending on the legume species, the type of weed (parasitic vs. non-parasitic), the prevailing weed species, level of weed infestation, soil type, climate and management practices. Weed control becomes even more critical where moisture is limiting. When moisture is in short supply, weeds can reduce crop yields more than 50% through competition for moisture. In the past certain misconceptions about weeds have led in some cases to inappropriate use of control practices. Weeds have been assumed to exert only negative effects within cropping systems (Liebman and Dyck, 1993). However, weeds may enhance agro-ecosystem stability in terms of maintenance of ground cover, conservation of nutrients, provision of habitat for beneficial organisms (Liebman and Dyck, 1993; Sileshi et al., 2008a). This calls for an ecosystem approach to weed management where the objective is weed management rather than control.

In the future, climate change, invasive weeds and herbicide resistance, are likely to pose challenges to weed management and water conservation. While rain-fed

G.W. Sileshi (✉)
World Agroforestry Centre (ICRAF), ICRAF Southern Africa Regional Programme, Chitedze Agricultural Research Station, Lilongwe, Malawi
e-mail: sileshi@africa-online.net

agriculture is likely to remain a feature of the subsistence and large-scale agricultural enterprises in the foreseeable future, climate change will be a major determinant of their productivity. Another emergent problem is the increase in invasive alien species of weeds, which is partly aggravated by increased global trade and climate change (Ziska and George, 2004). Many plant species have moved out of their natural geographic locations and have spread around the world with humans either as accidental or deliberate introductions. The weedy nature of these species often gives them an advantage over more desirable crop species because they often grow and reproduce quickly, have seeds that persist in the soil seed bank for many years, or have short life-spans with multiple generations in the same growing season. Some species when introduced into a new environment lack the competition and predation they evolved under in their native environments freeing them to proliferate quickly. The most serious problem that invasive weeds pose is their consumption of large quantities of water. For example, the invasive tree, slatcedar (*Tamarix ramosissima* Ledeb) uses more than twice as much water annually as all the cities in southern California (Johnson, 1986). The overall effects of climate change on weed invasions seem to bring bad news for farmers. Most of the important elements of global change are likely to increase the prevalence of invasive species (Dukes and Mooney, 1999). Thus invasive weeds could jeopardize legume production under climate change.

In this chapter we will synthesize the state-of-art knowledge on weed management in legume production systems with a major emphasis on climate change and alien invasive species. Although the focus of this book is on cool season legumes, we have also included warm season tropical legumes. Cool season legumes are more widely grown in Mediterranean climates, which are characterized by relatively scarce and erratic precipitation, with wet winter, and dry and hot summers. This is typical of the Mediterranean basin in south Europe, North Africa and West Asia as well as Western Australia and parts of South Africa. However, these legumes are also adapted to various tropical or subtropical climates. For example, most cool season legumes are widely grown at high elevations in subtropical countries such as Ethiopia. In fact, wild and primitive forms of field pea and faba bean (*Vicia faba*) are known to exist in the high elevations of Ethiopia, and hence some authorities consider Ethiopia as one of the primary centres of diversity (Keneni et al., 2007). With the increased interest in crop diversification in recent years, cool season crops are being promoted more and more in tropical and subtropical climates. For example, chickpea is being promoted in Malawi to make use of residual moisture after harvest of main crops. In such areas a substantial overlap is expected in the distribution of cool season legumes and tropical warm season legumes. We believe that limiting the discussion to cool season crops only will not be helpful to the increasing number of farmers who grow both types of legumes. Therefore, this chapter will use a broader framework in order to address the relevant issues in legume cropping systems not only in Mediterranean climates but also other climates especially in Sub-Saharan Africa and the Indian subcontinent. Because of the lack of economic development and institutional capacity, societies in these regions are likely to be among the most vulnerable to the impact of climate change (IPCC, 2001).

14.2 Types of Weeds and Weed Effects in Legume Cropping Systems

14.2.1 Parasitic Weeds

The economically important group of parasitic weeds in legumes belongs to the genera *Orobanche* (Family Orobanchaceae), *Striga* and the closely related genus *Alectra* (Family Scrophulariaceae). *Orobanche* species are holoparasites, i.e. lack chlorophyll and entirely depend on hosts for nutrition. On the other hand *Striga* and *Alectra* are hemiparasites, i.e. they have some chlorophyll and are capable of photosynthesis, but they still rely on hosts for water and minerals. All are obligate root parasites and connection with a host plant is fundamental in order to survive. Therefore, their seeds principally remain dormant until a chemical exuded by the host root indicates the vicinity of a host. Their seeds germinate and produce a germ tube that must create a contact with the host root or die. Once the parasite attaches to the host, materials are transferred from the source (crop) to the sink (parasite) through straw like penetrations, called oscula. Affected plants usually grow slowly and, dependent on the severity of infestation, biomass production is lowered. Crop damage is often very significant and depends on crop variety, soil fertility, rainfall pattern and level of infestation in the field. The loss caused by *Orobanche* spp. is often directly proportional to its biomass (Sauerborn et al., 2007). The loss inflicted by *Striga* infection may be even greater than the parasite's biomass, indicating the involvement of other than source/sink-based relations such as the reduction of photosynthesis in the host plant (Frost et al., 1997).

14.2.1.1 Orobanche Species

The genus *Orobanche* includes more than 100 species in both the eastern and western hemispheres. They attack mainly dicotyledonous crops in both rain-fed and irrigated production systems (Parker and Riches, 1993). *Orobanche* species are favoured by relatively low atmospheric humidity, which ensures a high rate of transpiration and hence enhanced transfer of water and solutes from the host (Parker and Riches, 1993). Most of the economically important species are native to the Mediterranean region (i.e. North Africa, the Middle East, and southern Europe), and western Asia (Mohamed et al., 2006). However, invasive *Orobanche* species extend to North America, South Asia, Southeast Asia, Southern Africa, and Australia (Mohamed et al., 2006; Parker and Riches, 1993; Rispail et al., 2007). With the anticipated climatic changes taking the form of higher temperatures and drought, most of the *Orobanche* species also pose potential invasive threats to much of the United States, southern and eastern South America, eastern Asia, southern Africa, and southern Australia (Mohamed et al., 2006). In the following sections we will discuss those species that affect legumes:

Orobanche crenata Forsk occurs exclusively in agricultural and disturbed habitats. It is an important pest in faba bean, pea (*Pisum sativum*), lentil (*Lens culinaris*),

136 vetches (*Vicia* spp.), grass pea (*Lathyrus sativus*), chickpea (*Cicer arietinum*) and
137 other grain and forage legumes in the Mediterranean and Middle East (Joel et al.,
138 2007; Mohamed et al., 2006; Rubiales et al., 2006). It occurs mainly in rain-fed
139 crops, and has been reported to be reduced under wet conditions (Parker and Riches,
140 1993). *O. crenata* has a limited range and has been collected primarily from south-
141 ern Europe and countries around the Mediterranean basin in North Africa and the
142 Middle East. It also shows a more restricted invasive potential compared with other
143 species (Mohamed et al., 2006). The limits of its distribution could be attributed to
144 its low and narrow range of optimum temperature requirement for conditioning and
145 germination, which was found to be around 18°C. Both lower and higher temper-
146 atures resulted in poor germination. As a result, for example, in Israel, *O. crenata*
147 was found only in winter (Mohamed et al., 2006). At high infestations, this species
148 could cause severe losses. In Israel it caused 100% loss in peas (Bernhard et al.,
149 1999). In Morocco, the total infested area was estimated to be about 50% of the
150 total faba bean area, causing 12–33% yield losses (Gressel et al., 2004). In Tunisia,
151 losses in faba bean yield were estimated at 50–80%. In Egypt, *O. crenata* occurs in

This figure will be printed in b/w

Fig. 14.1 *Orobanche crenata* infestation showing 100% yield loss on faba bean in South Wello, Ethiopia (Photo Taye Tessema)

14   Weed Suppression in Legume Crops

20% of the total area cropped with faba bean, causing 5–33% (Gressel et al., 2004). In Ethiopia the practice of harvesting green pods of faba bean is customary to prevent further yield loss by the weed. According to farmers crop loss could reach as high as 75–100% (Besufekad et al., 1999) in some areas (Fig. 14.1).

Orobanche aegyptiaca Pers attacks a wide range of cops including tomato, potato, tobacco, eggplant, bell-pepper, pea, vetch, faba bean, carrot, celery, parsley, cumin, cabbage, cauliflower, rape, mustard, turnip, hemp, sunflower, spinach. In some areas, e.g. southern Russia, melon and water melon are also hosts. Also parasitizes ornamentals like Chrysanthemum and Gazania (CABI, 2003). It is an important pest of faba bean, common vetch, grass pea, chickpea and lentil in the Middle East and Asia. In addition, it also attack peanut (*Arachis hypogea*) (Parker and Riches, 1993).

Orobance foetida Poiret is widely distributed in natural habitats in particularly in the western Mediterranean countries – Morocco, Algeria, Tunisia, Portugal and Spain (Vaz Patto et al., 2008). Until recently, it was known to attacks wild leguminous plants in the genera *Anthyllis, Astragalus, Ebenus, Lotus, Medicago, Ononis, Scorpiurus* and *Trifolium* (Pujadas-Salvá, 2002). It was considered an important agricultural parasite in faba bean and chickpea only in parts of Tunisia (Kharrat et al., 1992). In Tunisia, heavy infestation of faba bean fields by *O. foetida* is an emerging problem (Abbes et al., 2007). It has also been found in Morocco infecting common vetch (Rubiales et al., 2005). Recent studies show that *O. foetida* is evolving from parasitising wild hosts to crop plants, and this host shift is likely to pose a threat to agriculture (Vaz Patto et al., 2008).

Orobanche ramosa L. is mainly distribute in the Mediterranean but also extending to central Europe, the Middle East, northern Africa and Ethiopia. *O. ramosa* can infect several legumes including chickpea, clover, groundnut, faba bean, lentil and pea (Parker and Riches, 1993). Its host range outside the legumes is very wide, including some members of the families Alliaceae (onions), Cannabidaceae, Asteraceae (lettuce, niger seed, safflower and sunflower), Brassicaceae, Solanaceae (tomato, eggplant, tobacco), Cucurbitaceae (melon, watermelon, cucumbers), and Umbeliferae (carrot, parsley, celery, parsnip) (CABI, 2003; Parker and Riches, 1993).

Orobanche minor is found in native and disturbed habitats throughout the central and southern parts of Europe, and extends to the eastern coast of Africa and southwards (Parker and Riches, 1993). It has a wide host range among forage legumes in temperate climates. In addition, it was imported to various other parts of the world and is currently found as a garden weed. It is of economic importance on clover (*Trifolium* spp.) in the USA (Osterbauer and Rehms, 2002; Eizenberg et al., 2004). Although other *Orobanche* species can infect leguminous plants, they are generally of little economic importance.

14.2.1.2 *Striga* Species

Worldwide, more than 30 species of *Striga* are recognized, 22 of which are endemic to Africa, the centre of distribution and diversity (Mohamed et al., 2006). *Striga* species are a particular problem in sub-humid and semi-arid areas (Parker and

Riches, 1993; Rispail et al., 2007). So far, *Striga gesnerioides* (Willd.) is the only species known to parasitize legumes. This species also parasitizes members of the family Convolvulaceae, Agavaceae and Euphorbiaceae. It occurs in natural vegetation throughout the drier regions of Africa (Reiss and Bailey, 1998). *S. gesnerioides* is a highly variable but host-specific (Musselman, 1980). To-date eight host-specific strains of *S. gesnerioides* have been described (Mohamed et al., 2001). Of these, the *Vigna* strain that attacks cowpea (*Vigna unguiculata* L.). Walp is the most important biotic constraint to cowpea production in the Sahel, the Sudan savannah and the northern Guinea savannahs of Mali, Burkina Faso, Niger, Senegal, Chad, Togo, Benin, Nigeria and Cameroon (Parker and Riches, 1993). Yield losses of 30% or more are common in these regions (Riches, 2002). Host-specific strains of *S. gesnerioides* also attack tobacco in localized areas in southern Africa, and sweet potato in East Africa. Interestingly the strain, that attacks tobacco in Zimbabwe and South Africa is unable to develop on cowpea roots, even though it is stimulated to germinate by root exudates from cowpea and other legume non-hosts including pigeon pea and velvet bean (*Mucuna pruriens*) (Riches, 2002). On the other hand, the American strain of *S. gesnerioides* has not been reported to attack cultivated crops (Mohamed et al., 2006).

The *Vigna* strain of *S. gesnerioides* devastates cowpea mostly in the Guinea and Sudan savannahs and the Sahel region of West and Central Africa (Emechebe et al., 1997). However, the Sudano-Sahel zone is generally more affected than the Guinea savannah zone (Singh and Emechebe, 1997). *S. gesnerioides* in southern Bénin has been characterized as a race that is different from those found in the dry savannah of West Africa (Carsky et al., 2003; Lane et al., 1994). With more cowpea monocropping and increasing population pressure, *S. gesnerioides* damage in cowpea has become more acute, particularly in areas with sandy, infertile soils and low rainfall (Singh and Emechebe, 1997). In Ethiopia, *S. gesneroides* has been reported to attack sweet potato (Fasil and Wogayehu, 2008). In areas of low precipitation it can cause severe damage because its hosts are already stressed. Its adaptation to drought has been-well established and, with the increasing drought frequency expected under climate change scenarios it could pose a major threat to cowpea production. Recent analysis shows that *S. gesnerioides* has a great invasive potential and, may expand its range further north in Africa (Mohamed et al., 2006).

14.2.1.3 *Alectra* Species

Alectra includes about 30 species occurring primarily in tropical and subtropical Africa (Mohamed et al., 2006; Parker and Riches, 1993). However, they also occur in parts of India and China (Parker and Riches, 1993; Sauerborn et al., 2007). So far *Alectra vogelii* Benth has been the major species known to attack leguminous species. *A. vogelii* replaces *S. gesnerioides* as an important constraint to cowpea production in East, Central and southern Africa (Parker and Riches, 1993). However, its range extends from the Northern Province of South Africa and Swaziland, through central Africa to Burkina Faso and Mali in the west, and through Tanzania and Kenya to Ethiopia in the east (Riches, 2002). Its climatic requirements are similar

to those of *S. gesnerioides*, and in many cases the two are sympatic (Mohamed et al., 2006). However, deviation in temperature from the optimum significantly reduced germination and attachment showing sensitivity to extreme temperatures (Okonkwo and Raghavan, 1982). Some studies suggest sensitivity of to drought (Dawoud and Sauerborn, 1994). This probably explains its restriction to savannahs and its absence in semiarid regions (Mohamed et al., 2006). This species attacks cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) in Africa, with high crop losses reported for Botswana, Ethiopia, and Mali (Mohamed et al., 2006). Bambara (*Vigna subterranea*), mung bean (*Vicia radiata*), common bean (*Phaseolus vulgaris*), chickpea and soybean (*Glycine max*) are also damaged in parts of eastern and southern Africa. Soybean, which is relatively free of pests in the dry savannas of Africa, is increasingly being threatened by *A. vogelii*. Pot trials also indicate that *Dolichos lablab*, siratro (*Macroptilium atropurpurium*), velvet bean (*Mucuna pur-puriens*) and *Stilozobium deerinianum* can be attacked. It can also attack members of the family Compositae, Euphorbiacea, Labiatae, Malvacea and Pedaliacea (Parker and Riches, 1993). As with *S. gesnerioides*, host preference varies between regions and narrows the host range of different populations. There is evidence suggesting that *A. vogelii* has developed host-specific strains, each attacking a narrow suite of hosts, but host specificity is more complex than that for *Striga*. Those from West Africa and Cameroon attack cowpea and groundnut. Populations from Botswana and northern parts of South Africa attack mung bean, while populations from Kenya, Malawi and Zimbabwe attack bambara nut in addition to the other crops which are susceptible elsewhere (Riches, 2002). This wide range of hosts poses a problem for the introduction of alternative pulses or legume cover crops into an arable rotation.

A. vogelii cause considerable yield reduction of grain legume crops throughout semi-arid areas of sub-Saharan Africa (Parker and Riches, 1993; Singh et al., 1993). Yield losses of 80–100% have, for example, been recorded on heavily infested cowpea fields in Botswana (Riches, 2002). Complete failure of some groundnut varieties and 30–50% reduction in Bambara nut yield occur in South Africa (Parker and Riches, 1993). In the northern Guinea savannah of Nigeria, it causes yield losses of 15% in groundnut. Late-sown soybean crops may be completely destroyed in northern Nigeria (Riches, 2002). Another minor species *Alectra pica* (Hiern) Hemsl has also been reported to attack cowpea and groundnut in Ethiopia and cowpea in Cameroon (Riches et al., 1992). *A. pica* has a similar host range to West African populations of *A. vogelii* parasitizing cowpea and groundnut but not bambara or mung bean (Parker and Riches, 1993).

14.2.2 Non-parasitic Weeds

All non-parasitic weeds possess chlorophyll and can have either C_3 or C_4 photosynthesis. Most grass weeds are C_4 plants, while many broad-leafed weeds and legume crops are C_3 plants. These differences have significant implications in terms of legume weed competition. In some instances, the legumes have shown stronger

G.W. Sileshi and T. Tessema

ability to compete with the grass weeds. For example, faba bean and soybean were stronger competitors to *Cynodon dactylon* (Juraimi et al., 2005). Among the C$_4$ plants, grasses are perhaps the most dominant weeds in cool season legume cropping systems. The abundance and composition of grass and broad-leafed weeds species varies with the region, climate and soil type.

Non-parasitic weeds can be classified as native and invasive species. Terms such as noxious weed are also used somewhat loosely to refer to weeds that infest large areas or cause economic and ecological damage to an area. It must be noted however that a clear distinction exists between invasive and noxious weeds. Irrespective of their origin, noxious weeds are those species if left unchecked that often dominate the environment where crop plants are to be grown. Among the invasive weeds, the parhenium weed (*Parthenium hysterophorus* L.) is probably the best known in legume production systems (Fig. 14.2). Introduced from Central

This figure will be printed in b/w

Fig. 14.2 Close up of *Parthenium hysterophorus* (*top*) and infestation in beans at Instituto de Investigação Agrária de Moçambique (IIAM) near Maputo, Mozambique (Photo Gudeta Sileshi)

America, this invasive weed is widely distributed throughout southern Africa and East Africa (Ethiopia, Kenya, Mozambique and South Africa), South and Southeast Asia (India, China, Vietnam, the Pacific Islands, Nepal, Pakistan and Taiwan), Australia and many other countries of the world cutting across country-boundary and climate-barrier (Besufekad et al., 2005; Evans, 1997; Shabbir and Bajwa, 2006; Taye et al., 2004a, b; Taye, 2005). Thus, invasive weeds could jeopardize legume production under climate change. It is still spreading and may become more prominent in other parts of the World in the near future. Although it has not been reported from many parts of southern Africa, the first author have recently noted it in legume fields in Mozambique (Fig. 14.2). Because parthenium weed is an extremely prolific seed producer, with up to 25,000 seeds per plant, and with an enormous seed bank, estimated at 200,000 seeds/m^2, it has the potential to be an extremely aggressive colonizer of crops (Evans, 1997).

The spiny cocllebur (*Xanthium strumarium*) is another invasive species common in legume production areas of Australia, Africa and the Indian sub continent. However, it is less publicized weed. Mexican poppy (*Argemone mexicana*), native to tropical America, is now found in at least 30 countries with warm climates in the world (CABI, 2003). It is adapted to a wide range of habitats, including humid and semi-arid areas and a wide range of soil types. Legumes such as *Phaseolus vulgaris* (common bean), *Arachis hypogaea* (groundnut), and *Medicago sativa* (lucerne) are among the affected crops (CABI, 2003).

Some of the existing problems in legume crops arise from the incidence of herbicide resistant weeds. Herbicide resistance is an induced inherent ability of some plant species to survive and reproduce after receiving a lethal dose of herbicide. Since the first report in 1970 there have been many reports of herbicide resistance (Chaudhry, 2008a; Heap, 2003). A global survey shows that there are over 323 resistant biotypes in 187 species (112 dicots and 75 monocots) (HRAC, 2009). Resistance to herbicides of various modes of action has been reported in over 60 countries worldwide (Chaudhry, 2008a). The evolution of herbicide resistance is already a serious problem in parts of the Mediterranean. The first report of herbicide resistance in Tunisia concerned ryegrass (*Lolium rigidum*) in cereals in 1996 (Heap, 2003). The total infested area with herbicide-resistant *Lolium* has been estimated to be 4,000–40,000 ha and is increasing (Gressel et al., 2004).

14.2.3 Weed Effects

Parasitic weeds inflict fitness costs by withdrawing water, minerals, and photosynthates directly from the host (Sauerborn et al., 2007). On the other hand, non-parasitic weeds cause losses through competition with legumes for moisture, light and soil nutrients. In any case, weeds consume large quantities of water, and most of it is lost by transpiration to the atmosphere. Some common annual weeds growing in association with cultivated crops use up to three times more water to produce a given amount of dry matter as do the crops.

The other direct weed effect is production of toxins and allelopathy. For example, parasitic weeds may produce phytotoxins that adversely affect the growth of their host. Many non-parasitic weeds also affect crops through allelopathy, a type of interaction in which one plant releases chemicals that are detrimental to the growth of other plants growing in its vicinity. The chemicals responsible for allelopathic activity are called allelochemicals, which are synthesized within plants as secondary metabolites and released through leachation from fresh and decaying plant parts or microbial decomposition of the fallen plant parts, or as root exudates or volatilization. A good example in legume cropping systems is the allelopathy by the invasive parthenium weed. Parthenium produces water soluble allelochemicals from roots, stems, leaves, inflorescences, pollen and seeds (Evans, 1997). Allelopathic effects of foliar leachates from parthenium weed have been demonstrated on cowpea, black gram, chickpea, green gram, mung bean, soybean, French beans (Evans, 1997; Kohli and Batish, 1994; Oudhia et al., 1997; Singh et al., 2003). The germination and yields of traditional Indian pulse crops (guar, black and green gram) were also reduced when these were grown in soils previously infested by parthenium weed (Kohli and Batish, 1994). In addition, pollen allelopathy of parthenium weed has been demonstrated and, this may affect crops within the infested fields as well as in neighbouring weed-free crops (Evans, 1997). Some of the allelochemicals were also shown to have an inhibitory effect on nitrogen fixing and nitrifying bacteria (Kanchan and Jayachandra, 1981). These indirect and cryptic effects which can influence crop yields are even more difficult to quantify than direct competition.

Weeds may also act as alternative hosts of crop pests. For instance, in western Kenya *Striga hermonthica* is a good host for root-knot nematodes (Sileshi et al., 2008a). The parthenium weed has been shown to be an alternative host of bean aphid, *Aphis fabae* Scopoli in southern India (Evans, 1997). Weeds can also harbour and spread plant pathogens that infect and degrade the quality of crop. For example, the parthenium weed act as a secondary host of plant diseases. For example, the bacterial pathogen, *Xanthomonas campestris* pv. *phaseoli*, could be transmitted from parthenium weed to beans (Evans, 1997). The parthenium weed also harbours the faba bean phyllody phytoplasma (Taye et al., 2004a, b). A host range study in India (Mathur and Muniyappa, 1993) has also shown that the phytoplasma disease was transmitted to field bean (25%), soybean (20%), lupin (20%), green gram (10%), horsegram (10%) blackgram (7%) and cowpea (5%). In some agro-ecosystems, complex interactions occur between weeds, insects and pathogens (Sileshi et al., 2008a).

The negative impact to a native species caused by an invasive species might trigger additional negative interactions for other associated native species. Invasive weed such as parthenium may out-compete and displace native grasses and broadleaf plants, which may have served as the sources of food and refuge to natural enemies of crop pests (Mulisa et al., 2008; Taye et al., 2004a, b). Invasive alien species can cause significant and sometimes irreversible environmental and socio-economic impact at the genetic, species and ecosystem levels. Their management costs include not only costs of prevention, control and mitigation, but also indirect costs due to impacts on ecological services.

14.3 Drought, Climate Change and Weed Effects

Among the number of abiotic and biotic factors curtailing crop productivity, drought ranks as one of the most important ones. Drought effects could be aggravated by weed competition as weeds often use moisture before crop requirements are met. Drought is considered relative to some long-term average condition of balance between precipitation and evapo-transpiration in a particular area, a condition often perceived as "normal". It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it and can significantly aggravate its severity. For the sake of clarity and to put weed management in the context of drought, we identify three types of drought: meteorological, agricultural and hydrological drought. Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" amount) and the duration of the dry period. Agricultural drought is said to exist when soil moisture is depleted so that the yields of plants are reduced considerably. Agricultural drought links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapo-transpiration, soil water deficits, reduced ground water levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. Hydrological drought, on the other hand, is associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although the three type of drought are interlinked, agricultural drought has direct influence on the interaction between weeds and crops.

With climate change, drought is predicted to occur 10 times more frequently in the future over a large part of the Mediterranean (Weiß et al., 2007). In the Sahel, droughts with varying degrees of severity occur in two out of every five years, making harvest of the major food and cash crops highly uncertain (Hengsdijk and van Kuelen, 2002). In the Sahel, 20–40% of annual rainfall is lost as runoff. This often results in agricultural drought, which cannot always be linked to low rainfall (meteorological drought). The loss of rain water through runoff, soil evaporation and drainage below the rooting zone is often considered as the major cause of moisture stress (Zougmoré et al., 2004). Water transpired by weeds could exacerbate crop drought stress in dry periods through increasing soil moisture deficits, resulting in a decrease in crop water use efficiency (WUE). For example, in cluster bean (*Cyamopsis tetragonoloba*), water consumption was higher in unweeded plots. WUE decreased with the increase in time of weed removal beyond 20 days after crop sowing (Yadav, 1998). Thus weed control becomes even more important in drought conditions.

The effect of climate change such as rising temperature and changes in precipitation are already affecting agricultural production (Lobell et al., 2008; Long

AQ6

et al., 2006). Future impacts are projected to worsen as the temperature continues to rise and as precipitation becomes more unpredictable. Model projections suggest that increased temperature and decreased soil moisture will act to reduce global crop yield by 2050 (Long et al., 2006). There are also strong empirical reasons for expecting climate change to alter weed management (Chaudhry, 2008b; Patterson, 1995; Ziska and George, 2004; Ziska et al., 1999). Firstly, changes in precipitation, CO_2 concentration and temperature are likely to have significant direct (CO_2 stimulation of weed growth) and indirect effects (climatic variability) on weed biology and distribution (Zikas, 2002a; Ziska et al., 1999). In the following sections we will briefly describe the effects of elevated temperature, carbon dioxide and precipitation.

14.3.1 Elevated Temperature

A common feature of many projections is a rise in temperature over much of the regions where legumes are traditionally grown. Some climate models suggest that temperatures could rise up to 4°C by 2,100 in many inland areas and by over half of this over the Mediterranean Sea. There has also been a warming trend in southern Africa over the last few decades. This is consistent with the global trend of temperature rise since 1970s. According to the IPCC (2001), temperatures in the region have risen by over 0.5°C over the last 100 years. Overall, Africa has warmed by 0.7°C over the 20th century and general circulation models project warming across Africa ranging from 0.2°C to more than 0.5°C per decade (Hulme et al., 2001; IPCC, 2001). Most cool season legumes have temperature optima for growth and development processes within the range of 15–25°C, with a base temperature of 0°C (Johansen et al., 2000). The optimum temperature for warm season tropical legumes is within the range of 25–35°C, with a base temperature of 10°C (Johansen et al., 2000). Increasing temperatures may mean increased stress on legumes and susceptibility to insects and diseases. It could also lead to an expansion of weeds into higher latitudes or altitudes. Global warming could extend the northern limits of parasitic weeds by several hundred miles (Mohamed et al., 2006). Studies on the effects of increasing temperatures on the germination and emergence of some invasive weeds suggest that such weeds could increase in distribution and importance (Ahmed and Wardle, 1991).

Increase in temperature can also pose a variety of direct and indirect effects on herbicides (Chaudhry, 2008b). For example extended heat reduces moisture in both soil and plant, limiting herbicide uptake either from the soil or foliage. Elevated temperature can also lead to structural degradation of herbicides and loss of potency. Herbicide volatility and carryover may also increase with increased temperature. This may harm susceptible crops that come into rotation. Phyto-toxicity caused by Triazines (e.g. simazine and atrazine) applied pre-emergence was reported to have increased with increase in temperature (Chaudhry, 2008b).

14   Weed Suppression in Legume Crops

14.3.2 Carbon Dioxide (CO_2) Enrichment

Atmospheric CO_2 has risen from about 260 parts per million (ppm) 150 years ago to 380 ppm today (Houghton et al., 2001). The effect of increasing atmospheric CO_2 on climate change and agriculture has been a source of worry and mixed feelings for decades. The effect of rising carbon dioxide (CO_2) on crop yields is much more complicated and, more recent analyses cast doubts on earlier projections that suggested that CO_2 fertilization will increase crop yields (Long et al., 2006; Schimel, 2006). Hundreds of studies have shown that most major crops respond positively to CO_2 enrichment, because of the direct stimulatory effect of CO_2 on photosynthesis and the indirect effect of decreasing the water requirement of crops. The former effect should make crops more productive and the later more drought-tolerant (Schimel, 2006). Yet a new analysis of far more realistic studies based on the free-air concentration enrichment (FACE) technique casts doubts on projections (Long et al., 2006). The FACE results in food crops are different from earlier reports from laboratory and chamber studies in a consistent way (Schimel, 2006). Although the beneficial effects of elevated CO_2 on crop yields are well established for the experimental conditions tested, this knowledge is incomplete for numerous tropical crops and crops grown under suboptimal conditions (Schimel, 2006).

Results from various studies suggest that rising CO_2 could alter current yield losses associated with competition from weeds; and that weed control will be crucial in realizing any potential increase in economic yield of agronomic crops such as soybean as atmospheric CO_2 increases (Ziska, 2002a, b; Zikas et al., 1999). An important direct effect of high CO_2 on plants is a partial closure of stomata, which will restrict transpiration more than it restricts photosynthesis. The different effects of elevated atmospheric CO_2 have important implications for weed/crop interaction (Chaudhry, 2008b). It has been well known that the C_3 photosynthetic pathway is less efficient than the C_4 pathway. Because of this, CO_2 enrichment is more beneficial to plants with C_3 than those with C_4 photosynthetic pathway (Wolfe and Erickson, 1993). Recent studies and syntheses indicate that vegetative growth, competition, and potential yield of economically important C_4 crops could be reduced by co-occurring C_3 weeds as atmospheric carbon dioxide increases (Wolfe and Erickson, 1993; Ziska, 2002a, b). It can be argued that many weed species have the C_4 photosynthetic pathway and therefore will show a smaller response to atmospheric CO_2 relative to C_3 crops. However, this argument does not consider the range of available C_3 and C_4 weeds present in any agronomic environment. Hence, if a C_4 weed species does not respond, it is likely that a C_3 weed species will. To date, for all weed/crop competition studies where the photosynthetic pathway is the same, weed growth is favoured as CO_2 is increased. However, the interactive effect of temperature and water availability could influences the photosynthetic characteristics of the C_3 and C_4 species over the growing season (Niu et al., 2005). Many of the invasive weeds reproduce by vegetative means and may show a strong response to increases in atmospheric CO_2 (Ziska and George, 2004).

CO_2 enrichment may also stimulate vigorous weed growth, and induce physical or physiological resistance/tolerance to herbicides (Chaudhry, 2008b). These changes also could limit chemical weed control efficacy and increase weed–crop competition. In addition, elevated CO_2 could lead to further below ground carbon storage with subsequent increases in the growth of roots or rhizomes, particularly in perennial weeds. Consequently, mechanical tillage may lead to additional plant propagation in a higher CO_2 environment, with increased asexual reproduction from below ground structures and negative effects on weed control (Ziska and George, 2004).

14.3.3 Reduced Precipitation

The second effect of climate change is its effect on precipitation. Annual precipitation is projected to decline over much of the Mediterranean region south of 40–45° N (Palutikof and Wigley, 1996) where cool seasons legumes are traditionally grown. Even areas receiving more precipitation may get drier than today due to increased evaporation and changes in the seasonal distribution of rainfall and its intensity. Changes in large-scale atmospheric circulation, as represented by the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), would further affect the occurrence of extreme events (Lionello et al., 2006). The effects of climate change have also been dramatic in tropical and subtropical areas of Africa. While ENSO is a natural part of the Earth's climate, an important concern is whether its intensity or frequency may change as a result of global warming. The second half of the twentieth century has witnessed a dramatic reduction in mean annual precipitation and, severe droughts have occurred since the early 1970s (Giannini et al., 2003). East Africa, including Kenya, Tanzania and the Nile basin experiences, in the long rains from March to May, wetter than normal conditions due to ENSO. From 1996 to 2003, there has been a decline in rainfall of 50–150 mm per season across most of eastern Africa (Funk et al., 2008). Under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5–20% increased rainfall from December to February and 5–10% decreased rainfall from June to August by 2050 (Hulme et al., 2001).

Similarly, southern Africa has experienced significant rainfall variability since the late 1960s. Below-normal rainfall years are becoming more and more frequent and the departure of these years from the long-term normal more severe. In particular droughts became more intense and widespread (Faucherreau et al., 2003). Between 1988 and 1992, over 15 drought events were reported in various areas of southern Africa. Rainfall variability in southern Africa has shown increased statistical association to the ENSO phenomenon (Faucherreau et al., 2003). There has been an increase in the frequency and intensity of El Niño episodes. Prior to the 1980s, strong El Niños occurred on average every 10–20 years. However, the early 1980s marked the beginning of a series of strong El Niño events. Climatic changes of this magnitude will have far-reaching negative impacts on the availability of water resources, and hence the competition between crops and weeds.

Precipitation (both amount and temporal variation) may play important roles in regulating the growth dynamics of C_3 and C_4 plants (Niu et al., 2005). Dry winters and wet summers promote C_4 expansion, while wet winters and dry summers increase the abundance of C_3 plants. At the global scale, increasing variability of seasonal rainfall accelerated the expansion of C_4 grassland in Northern America, China, and Africa (Pagani et al., 1999).

Drought also poses serious challenges to the use of herbicides. Many herbicides lose effectiveness during dry periods or drought conditions. Soil incorporated herbicides work best when soils have reasonable moisture levels after incorporation has been completed. Pre-emergence herbicides also depend totally upon rainfall after applications to activate the product. During drought stress weeds develop a thicker cuticular layer on their leaves or increased leaf pubescence to reduce moisture loss. This subsequently reduces herbicide entry into the leaf and decrease in herbicide efficacy.

14.4 Weed Control: The *Status Quo* and Future Needs

In parts of the Mediterranean, Sub-Saharan Africa and Asia, legumes are produced mostly by smallholder farmers on marginal soils and with traditional low-input technologies. Rain-fed agriculture also remains the dominant legume production system in these regions (Oweis et al., 2001; Tuberosa et al., 2007). In dry land agriculture, intensity and type of weed pressure depend upon the rainfall pattern during the crop season. Clearly, water supply can limit crop yield and there are few management options to try and improve this. In future, water will also become increasingly scarce particularly in rain-fed semi-arid regions, thus limiting the option for irrigation (Shiklomanov, 2001). Research concerned with common annual weeds and with their water use requirements, compared with those of agricultural crops, shows that weed control must become an integral part of the farming operation. In the following sections we will briefly discuss the major approaches used for control of parasitic and non-parasitic weeds. There are a number of general and comprehensive reviews and books (Evans, 1997; Gressel et al., 2004; Parker, 1991; Parker and Riches, 1993; Rispail et al., 2007) on weed biology and management. The present work focuses on more recent developments in weed control specifically aimed at drought management in the context of anticipated climate change. In the following text, we will give a brief overview of the status quo in weed control, the limitations and main gaps in our knowledge and what further research should be undertaken to begin to address these gaps.

14.4.1 Manual Weed Control

Hand pulling, hoeing and tillage are the traditional methods practiced for a long time in West Asia, North Africa, the Indian-subcontinent and other parts of the world (Saad El-din, 2003; Sharara et al., 2005; Solh and Palk, 1990; Wortmann,

1993). For example in Egypt and Ethiopia, hoeing in faba bean fields is the most widespread method of weed control (Saad El-din, 2003; Sharara et al., 2005). The major advantage is that it usually requires no capital outlay when cash is not readily available and labour is provided from the farmer's immediate family or through non-cash exchange. It may also be the only feasible method for weeding broadcast legumes when herbicides are not available (Desta, 2000). Hand pulling and hoeing have become increasingly expensive because of scarcity of labour in rural areas. Where crops are not normally planted in rows, hand pulling is a time-consuming task. In Ethiopia it has been estimated to take up to 140 h to weed a hectare of land (Desta, 2000). This method is effective when carried out two to three times at early stages of weed development. When weeding is delayed, irreversible damage, from weed competition occurs and removal of bigger weeds requires more man-power, with little economic return and serious physical damage to the crop (Solh and Palk, 1990). In addition, parasitic weeds exert their greatest damage prior to their emergence. Therefore, the majority of field loss may occur before diagnosis of infection (Sauerborn et al., 2007).

Preparatory tillage indirectly contributes to weed control as good seedbed preparation reduces the weed population and gives advantage to the crop to grow rapidly thus improving its competitiveness with weeds (Solh and Palk, 1990). Inter-row cultivation using implements drawn by animal or tractor power contributes to weed control directly. In the Ethiopian highlands, making three to six passes with a traditional ox-drawn plough before planting is a common practice aimed at reducing weed emergence (Desta, 2000). In some of the farming systems in the West Asia and North Africa (WANA) region, however, the very wide row spacing (1.0–2.0 m) practiced to control weeds through inter-row cultivation is a major limitation to high yield in spring chickpea due to very low crop density. For example, in Algeria and Morocco, farmers increase row spacing up to 2.0 m to facilitate inter-row cultivation (Haddad, 1988). To exploit fully the potential of winter sowing, the crop should be planted at high population density (Saxena, 1987) which makes inter-row cultivation impossible, except at very early stage of crop growth. Since weeds emerge with the winter sown crop and create sever competition, inter-row cultivation is not sufficient and intra-row hand weeding is necessary under most conditions (Solh and Palk, 1990). The limited effectiveness of manual weeding methods, particularly in winter sown chickpea, and the rising labour costs impose limitations on these methods. Under climate change scenarios, elevated temperature and CO_2 may result in faster growth of both weeds and crops. This may shorten the widow of opportunity for manual weeding as this increases labour requirement at critical times.

14.4.2 Resistant Genotypes

The legumes could resistant to weed through different mechanisms: (1) chemically induced resistance, (2) transgenic resistance, (3) inherent genetic resistance; (4) weed suppressive ability; and (5) tolerance or the ability to maintain high yield despite weed competition.

14.4.2.1 Chemically-Induced Resistance

Recently, chemically induced resistance (CIR) has been identified as a tool for controlling plant pathogens, including fungi, bacteria and viruses, but only recently has this phenomenon started to be evaluated as a control strategy against parasitic weeds (Pérez-de-Luque et al., 2004). The phenomenon has been studied at the molecular level and has proven to be mediated by salicylic acid and associated with a number of defence responses and genes. CIR can be activated by exogenous application of salicylic acid or its synthetic functional analogue BTH. Recently, Pérez-de-Luque et al. (2004) demonstrated that foliar application BTH can reduced *O. crenata* infection by limiting the success in attachment and retarding the development of established tubercles. This method could be particularly useful for pea, which is highly sensitive to common herbicides and, in which little genetic resistance is available to *O. crenata* (Rubiales et al., 2003). However, using CIR strategies requires repeated applications of activators and its effect is transient (Pérez-de-Luque et al., 2004).

14.4.3 Transgenic Resistance

During the last decade, crops with resistance to broad-spectrum post-emergence herbicides such as glyphosate, have been developed through genetic engineering. This enables farmers to use a non-selective herbicide applied selectively over already emerged crops, and to easily implement zero tillage with subsequent soil protection. Herbicide-resistant crops offer the potential for simpler weed control, more effective management of problematic and resistant weeds, more timely weed control with potential to employ critical period, increased usage of minimum or zero tillage and avoidance of yield loss caused by current "selective" herbicides (FAO, 1998). However, there are several concerns with regard to deployment of transgenic crops. Objections to the use of these crops rest on several issues related to the associated risks, such as direct risks to human health, the potential transfer of genes from herbicide resistant crops to wild relatives (thus creating super weeds) and the possibility of volunteer crops becoming weeds in subsequent crops a (Ford Denison, 1999).

14.4.3.1 Inherent Genetic Resistance

Inherent genetic resistance remains as one of the most desirable components in the integrated control of parasitic weeds (Pérez-de-Luque et al., 2007). Resistance to *Orobanche* has been found in, lentil (Fernández-Aparicio et al., 2007a), species of *Pisum* (Pérez-de-Luque et al., 2005; Valderrama et al., 2004), *Cicer* (Fernández-Aparicio et al., 2007a; Rubiales et al., 2003, 2004), *Vicia* (Abbes et al., 2007; Sillero et al., 2005a) and *Lathyrus* (Sillero et al., 2005a). In the species of *Cicer* the resistance to *O. crenata* is a result of a combination of several mechanisms, including low induction of parasite seed germination, prevention of establishment, or reduced

AQ12

development of parasite tubercles (Rubiales et al., 2004). Similarly, resistance to *O. crenata* in lentils appears to have multiple components and a chain of escape and resistance mechanisms that either act alone or in combination and at different stages of the infection process (Fernández-Aparicio et al., 2007a). Abbes et al. (2007) demonstrated resistance to *O. foetida* in faba bean genotypes selected for resistance to *O. crenata*, and some Tunisian breeding lines.

Resistance of cow pea varieties to *S. gesnerioides* has also been reported widely (Carsky et al., 2003; Moore et al., 1995; Singh et al., 2006). Cowpea cultivars with different susceptibility to *S. gesnerioides* infection were first observed in 1981 in Burkina Faso, and two lines (Suvita-2 and 58–57) were found to be completely resistant (Aggarwal, 1985). Further screening of new lines revealed that IT82D-849 (breeding line from IITA) and B301 (a landrace from Botswana) were completely resistant to *S. gesnerioides* populations in Burkina Faso, Mali, Nigeria and Cameroon (Aggarwal, 1991). A systematic breeding program for resistance to *S. gesnerioides* was started in 1987. From this program several lines were obtained that had complete resistance in several countries of West and Central Africa (Singh and Emechebe, 1997). For example, two cowpea landraces, APL-1 and 87-2, were completely resistant to *S. gesnerioides* from Burkina Faso, Mali and Cameroon and partially resistant to *S. gesnerioides* from Niger (Moore et al., 1995). Varieties APL-1 and 87-2 provided additional sources of resistance to most races of *S. gesnerioides*, including a newly discovered virulent race from Benin (Moore et al., 1995). Complete resistance was expressed either as a hypersensitive response of infected root tissues or as a severely retarded development of successful infections (Moore et al., 1995). However, neither of these cowpeas was resistant to *A. vogelii* (Moore et al., 1995). On the other hand, a landrace from Botswana (B 301) has shown complete resistance to both *Striga* and *Alectra* (Singh et al., 1993).

Resistance to *S. gesnerioides* is controlled by a single dominant gene, while resistance to *A. vogelii* is controlled by duplicate dominant genes which are different from the gene conferring *S. gesnerioides* resistance (Singh et al., 2006). Therefore, transfer of resistance is more straightforward. Recently, the International Institute of Tropical Agriculture (IITA) registered 6 improved cowpea germplasm lines with combined resistance to *S. gesnerioides* and *A. vogelii* (Singh et al., 2006). In addition, the first line (IT90K-59) is also resistant to major diseases including anthracnose, web blight, brown blotch, and scab, Cowpea yellow mosaic virus and Cowpea aphid-borne mosaic virus, nematodes, cowpea storage weevil, cowpea flower thrips, and cowpea aphid (Singh et al., 2006).

From the preceding discussion it is clear that in many cases resistance of simple inheritance has been identified and exploited in breeding. This has been particularly important allowing rapid progress to develop resistant cultivars of cowpea. However, breeding programs based on only a few dominant genes are in serious risk of breakdown of resistance. Although genetic resistance remains as one of the most important components in the integrated control of parasitic weeds, breeding for resistance is a difficult task and many aspects of the host/parasite interaction remain unknown (Pérez-de-Luque et al., 2007). Resistance against most parasitic weeds

811 is of complex nature making breeding for resistance a difficult task. Precise and
812 reliable screening techniques are required for an effective transfer of resistance into
813 varieties better adapted to the target areas. Therefore, combining different escape
814 and resistance mechanisms in a single cultivar may provide increased resistance that
815 at the same time may be more difficult to lose through the evolution of the parasite,
816 compared with resistance based on a single mechanism (Fernández-Aparicio et al.,
817 2007a). In future, application of post-genomic technologies and the use of model
818 plants should improve the understanding of the plant–parasite interaction and drive
819 not only breeding programmes through either marker-assisted selection or transgen-
820 esis but also the development of alternative methods to control the parasite (Rispail
821 et al., 2007). The integration of molecular marker selection techniques into resis-
822 tance breeding is hoped to facilitated quicker transfer of desirable genes among
823 varieties and novel genes from related wild species.

14.4.3.2 Weed-Suppressive Genotypes

828 This is the ability of a crop to reduce weed growth through competition. Interest in
829 developing weed-suppressive varieties to enhance traditional herbicide and tillage-
830 based approaches has increased recently (Jannink et al., 2000, 2001). Within the
831 array of approaches available to implement integrated weed management, the com-
832 petitive suppression of weeds by crops can make several small but cumulative
833 contributions. Two arguments favour focussing breeding effort on weed-suppressive
AQ15 834 varieties over weed resistance/tolerance to aid weed management (Jordan, 1993).
835 First, suppressing weeds reduces weed seed production and benefits weed manage-
836 ment in future growing seasons while tolerating weeds only benefits the current
837 growing season. Secondly, weed pressure from unsuppressed weeds increases the
838 likelihood of crop yield loss, irrespective of the crop's tolerance. For a given initial
839 weed infestation, a weed suppressive genotype may prevent the risk of excessive
840 weed pressure and thereby also confer within-season benefits. The literature docu-
841 ments relationships between several plant traits and competitive ability, in particular
842 height, various measures of leaf area or light interception and maturity (Jannink
843 et al., 2000). Wortmann (1993) assessed morphological characteristics of over 16
844 bean genotypes and, found that the ability to suppress weeds was found to be inde-
845 pendent of bean growth habit, but was related to leaf size, leaf area index, and
846 plant growth rate. His work also shows the feasibility of inclusion of large leaf
847 size and high leaf area index as criteria for selecting high-yielding genotypes with
848 improved ability to suppress weeds (Wortmann, 1993). Tall genotypes of pea gen-
849 erally suppressed *Lolium rigidum* and wheat more effectively than short genotypes
850 (McDonald, 2003). Weed suppression is preventative in that it decreases the weed
851 seed and therefore tends to reduce weed infestations in subsequent years. While
852 competitive suppression will rarely kill weeds outright, it will act reliably across
853 environments. Moreover, competitive suppression can function independently of
854 weather conditions that might hinder the application of other management practices
855 (Jannink et al., 2000).

14.4.4 Crop Rotation and Fallowing

In the past crop rotation has often been considered in the context of facilitating rotation of herbicides in order to avoid major shifts in the weed flora and the build up of infestation of one or few noxious weeds (Liebman and Dyck, 1993). However, it forms the framework that allows one to keep weeds, insect pests and diseases off-balance in many agricultural ecosystems (Liebman and Dyck, 1993; Sileshi et al., 2008a). In a review of the literature involving 29 test crop and rotation combinations, Liebman and Dyck (1993) found that weed densities were less in 21 cases compared to the control (monoculture without rotation). Weed densities were more in the rotation in only one case, while no difference was found in the remaining five cases. In 12 cases where weed seed densities were reported, nine had lower weed seed densities than the control while the remaining three cases did not differ from the control (Liebman and Dyck, 1993). Crop yields were also higher in rotation than the control in 11 cases and equivalent in three cases. The success of rotation systems for weed suppression appears to be based on the use of crop sequences that create varying patterns of competition, allelopathic interference and soil disturbance to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species (Liebman and Dyck, 1993). These results suggest that, in general, crop rotation results in better weed control than continuous monoculture. However, it does no guarantee that all rotations work to control weeds. Therefore, the use of rotations in legume cropping systems needs to be examined on a case by case basis.

Recently, crop rotation has received more attention in the framework of conservation agriculture. Legumes such as soybean are grown in some parts of the world under this system. Conservation agriculture is based on the principle of causing the least disturbance (with minimum or zero tillage), leaving plant residue on the soil surface, and crop rotation, including the use of legumes as green manure or cover crops. While this approach is beneficial to effectively protect and increase soil fertility, the switch to zero tillage or direct seeding practices may increase weed problems. For example, in one study conducted in Nigeria there were more weed species in plots under minimum tillage than in conventionally tilled plots (Ekeleme et al., 2005). The loss of tillage as a method of weed control means that producers must adjust crop rotations, herbicide use, and other cultural practices to compensate. Perennial weeds may become a serious problem to overcome, and there is a need to implement additional cultural methods, such as the use of cover crops. Under crop-livestock mixed production systems, this practice may also be limited because legume residues are used as livestock feed rather than for use as soil cover. In the Middle East, North Africa, Ethiopia, and India, residues of cool season legumes are important as a feed for livestock (Rao et al., 2005).

Rotation with non-host crops continues to be one of the most widely recommended practices for the control parasitic weeds. However, anecdotal evidence suggests that seeds of parasitic weeds (e.g. *A. vogelii*) may remain viable in the soil as long as 12 years (Parker and Riches, 1993). Rotations that make use of a small number of crops do not allow much flexibility for varying seeding dates, altering

901 herbicide practices or using crops with different competitive abilities or life cycles.
902 Diversified rotations that use many different crops provide more opportunities for
903 varying weed control practices. For example, in the Ethiopian highlands, a weed-
904 suppressing crop is often rotated with legumes such as field peas, faba bean and
905 chick pea.
906   Fallowing has also been widely used for controlling weeds in traditional farming
907 systems in the humid tropics of Africa (Banful et al., 2007; Ekeleme et al., 2005).
908 For severely depleted soils, which are common in *Striga* infested areas, improved
909 fallows, which include nitrogen fixing woody species that increase soil fertility con-
910 currently with reducing the weed seed banks appear to be promising (Ekeleme et al.,
911 2005; Sileshi et al., 2006). Improved fallows consist of deliberately planted species –
912 usually legumes with the primary purpose of fixing nitrogen as part of a crop−fallow
913 rotation (Banful et al., 2007; Sileshi et al., 2006, 2008a). Planted fallows reduce
914 weed infestation by shading weeds surviving after crop harvest and by reducing the
915 weed seed population in the soil (Banful et al., 2007; Chikoye et al., 2001; Sileshi
916 et al., 2006).

14.4.5 Intercropping

922 The continuous production of legume crops often increases weed problems and
923 also gives weeds a chance to adapt. In some areas parasitic weeds on cowpea have
924 increased significantly as sparse stands of landraces inter-cropped with cereals have
925 been replaced by sole crops of high yielding but susceptible varieties (Riches, 2002).
926 Intercropping represents an option for spatially diversification of cropping systems
927 (Baumann et al., 2002; Vandermeer, 1989) and weed management. Intercropping is
928 widely practiced in Africa, Latin America and Asia as means of increasing crop pro-
929 duction per unit area with limited capital investment and minimal risk of crop failure
930 (Vandermeer, 1989). Legumes are traditionally intercropped with cereals. For exam-
931 ple in Ethiopia, sorghum-faba bean, sorghum-chickpea, maize-faba bean intercrops
932 are very common (Liben et al., 2001). Recent syntheses have demonstrated that
933 intercropping is an ecologically sound method for management of weeds, insect
934 pests and plant diseases in low external inputs farming systems (Baumann et al.,
935 2002; Liebman and Dyck, 1993; Sileshi et al., 2008a). A global review of literature
936 (Liebman and Dyck, 1993) showed that weed biomass in intercrops was lower in 47
937 (out of 54) cases compared to the respective sole crops. Weed biomass was higher
938 than the sole crop in four cases and variable response was observed in the remain-
939 ing three cases (Liebman and Dyck, 1993). The mechanisms by which intercrops
940 suppress weeds have been explained in detail in Liebman and Dyck (1993). In the
941 following sections, we will give specific examples relevant to legumes.
942   Intercropping is widely used in Africa as a low-cost method of controlling *Striga*
943 (Oswald et al., 2002; Sileshi et al., 2006). Intercropping with broad-leaf crops
944 which cover the inter-row also can help reduce *Striga* emergence and seed pro-
945 duction, though the practice may not always result in increased cereal yield due to

946 competitive effects. Intercropping legumes with cereals (Fernández-Aparicio et al.,
947 2007a, b) or other legumes such as fenugreek (Fernández-Aparicio et al., 2007a, b,
948 2008a) has been shown to reduce infection of legumes by *O. crenata*. Fenugreek is
949 frequently intercropped with vetches or faba bean in the Mediterranean (Evidente
950 et al., 2007). This is an important cash crop in India, China, Near East, East Africa
951 and Mediterranean countries, with market for its seeds for curry powder and for
952 flavouring agent for ruminant and pig feed. It is also a popular forage and fodder
953 crop. Some reports were inconclusive and conflicting, with some authors suggest-
954 ing a beneficial effect of fenugreek when intercropped with faba bean for *O. crenata*
955 or *O. foetida* (Kharrat et al., 1992). Fernández-Aparicio et al. (2007a, b, 2008a)
956 showed a consistent control of *O. crenata* infection in faba bean, pea, lentil and
957 chickpea when intercropped with fenugreek. The main mechanism for the reduction
958 of *O. crenata* infection in legumes by the intercrop with fenugreek was suspected to
959 be allelopathy (Fernández-Aparicio et al., 2007a, b, 2008a).

960 Weed suppression by intercrops has been reported in cool-season pulse and cereal
961 crops. Specific examples include intercrops of lentil and wheat (Carr et al., 1995),
962 barley and field pea (Mohler and Liebman, 1987), wheat and field beans (Bulson
963 et al., 1997; Haymes and Lee, 1999), pea and barley (Hauggaard-Nielsen et al.,
964 2001; Poggio, 2005). In an experiment comparing barley and pea intercrops with
965 the sole crops, winter-emerging species were less abundant in intercrops (Poggio,
966 2005).

14.4.6 Trap and Catch Cropping

Trap-crops, also known as "false hosts", produce *Alectra-* or *Striga*-germination
stimulants but are not susceptible to attack. Cowpea, pigeon pea and velvet bean
stimulate the germination of *S. gesnerioides* in southern Africa (Parker and Riches,
1993). There are some reports on potential trap crops that offer the advantage of
stimulating germination of the root parasites without themselves being parasitized
(Parker and Riches, 1993). Although the concept of using trap crops to reduce the
Striga seed bank in the soil is not new, recent research has shown that the selection
of variety within a species can increase the effectiveness of this practice.

14.4.7 Cover Cropping and Residue Management

Cover crops grown in the period between two main crops have potential as an
important component of a system-oriented ecological weed management strategy.
Residue-mediated weed suppression involves the management of residues from
cover crops, green manure legumes and crops. Cover crops and green manure
legumes fit very well in residue-mediated management of weeds (Kruidhof et al.,
AQ16 989 2009). Residues incorporated in the soil or applied as mulch on the soil surface
990 can have inhibitory effect on weeds. For example, cover crop residues have been
reported to negatively affect germination and establishment of weed seeds through

allelopathic and phytotoxic effects (Kruidhof et al., 2009; Liebman and Davis, 2000). Weed species appear to be more susceptible to phytotoxic effects of crop residues and other organic soil amendments than crop species (Liebman and Davis, 2000). Cover crops that contain a high level of allelochemicals seem well-suited for residue-mediated weed suppression (Kruidhof et al., 2009).

In addition, crop residues can exert an effect on weed germination and establishment through other mechanisms. Release of nutrients from the residues can stimulate weed germination, whereas temporary immobilization of nutrients from the soil upon decomposition can inhibit it (Kruidhof et al., 2009). Delayed availability of nutrients may favour large-seeded crops over small-seeded weeds (Liebman and Davis, 2000). Residues left on the soil surface can lead to decreased soil temperature fluctuations and reduced light penetration, which both have been shown to inhibit weed germination (Liebman and Davis, 2000). Residue-amended soil may conserve moisture better than bare soil. Cover crops and green manure legumes provide many additional services to the agro-ecosystem, including improved soil quality, increased nutrient cycling and, in some cases, a contribution to pest management (Kruidhof et al., 2009; Sileshi et al., 2008b). Addition of organic materials can change the incidence and severity of soil-borne diseases affecting weeds and crops (Conklin et al., 2002; Liebman and Davis, 2000; Manici et al., 2004). However, optimal residue management strategy for weed suppression depends both on the cover crop species used and the target weed species (Kruidhof et al., 2009). Very few systematically studies exist on the effect of different residue management methods on weed suppression in legume crops. Therefore, this is an area for future research.

14.4.8 Soil Fertility Management

Incidence of *Striga* is known to be negatively correlated with soil fertility, particularly nitrogen availability (Cechin and Press, 1993; Sileshi et al., 2006). This also applies to *Alectra* to some degree (Parker and Riches, 1993). On the other hand, soil fertility appears to be a less critical factor for *Orobanche* spp. (Parker and Riches, 1993). *Striga* seed germination can be increased by improving fertility of the soil through the use of nitrogen fertilizers, compost or green manure. Although nitrogenous fertilizers can reduce *Striga* infection rates, they are rarely economical for resource poor farmers in the first year of application. Ammonium nitrogen impairs germination and attachment of *Striga* seedlings to roots of the host plant. It also reduces production of germination stimulant by the host. In Nigeria, application of N reduced and delayed *Alectra* emergence in soybean. In some crops fertilizer use can also reduce non-parasitic weeds. For example, in Egypt faba bean yield improved under interactive effects of fertilizer and weed control treatments as growth improved (El-Metwally and Abdelhamid, 2008). Using compost favored growth and yield of faba bean more than of weeds. Application of compost alone or combined with 50 or 100% of the recommended fertilizer rate improved faba bean growth in terms of specific leaf area, and leaf weight ratio (El-Metwally and Abdelhamid, 2008).

Soil fertility and organic matter can be improved through legume cover crops and improved fallows (see crop rotation). *Striga* species thrive on degraded soils, which are the majority of soils in tropical Africa. A more remarkable effect on *Striga* is expected from organic matter as compared to mineral fertilizers (Sileshi et al., 2006). In situ production of organic matter by growing short-rotation fallows and cover crop which improves soil fertility and crop yields have been widely studied (Banful et al., 2007; Sileshi et al., 2006, 2008b). Inducing *Striga* suppression in soils is probably manageable with the long-term application of principles that improve the biological health of the soil. Nitrogen fixed by the legumes has long been known to suppress *Striga*. In contrast to the *Striga*/cereal systems, nitrogen is unlikely to play any effect in legume-legume intercrops as both the host and the intercrop improve N through biological N-fixation.

14.4.9 Biological Control

Biological control is used here in its broader sense; including natural control as well as classical biological control. Biological control is particularly attractive in suppressing parasitic weeds in annual crops because the intimate physiological relationship with their host plants makes it difficult to apply conventional weed control measures (Sauerborn et al., 2007). Both insects and fungi have been isolated that attack parasitic weeds. Most of the insects which have been reported to occur on *Orobanche* and *Striga* species are polyphagous and thus damage to these parasitic weeds is limited (Klein and Kroschel, 2002). However, the Agromyzid fly *Phytomyza orobanchia* is reported to be host-specific attacking only *Orobanche* species. Its distribution is related to the natural occurrence of *Orobanche* species (Sauerborn et al., 2007). *Phytomiza orobanchia* has been studied as a potential biocontrol agent for *Orobanche crenata* in Syria (Linke et al., 1990). *P. orobanchia* is particularly common throughout the Mediterranean area and is known in Bulgaria, Germany, England, Spain, Italy, Malta, Egypt, Israel and Ethiopia, the Balkans, the Ukraine, Central Asia, the Arabian Peninsula (Çikman and Doganlar, 2006). Larvae decrease the reproductive capacity of *Orobanche* spp., either directly through their feeding activity in seed capsules or indirectly through weakening the shoots (Klein and Kroschel, 2002). However, effectiveness of the fly could be reduced by parasitism by Eulophidae, Pteromalidae, Aphelinidae and Braconidae (Çikman and Doganlar, 2006).

Smicronyx spp., a gall-forming weevil, is described to be specialized on *Striga* species (Sauerborn et al., 2007). These insects prevent seed production through the development of larvae inside the seed capsules of their target hosts and thus contribute to reduce their reproductive capacity and spread. However, research with both insects has revealed that their effectiveness to prevent seed set is limited and will not be enough to lower the soil seed bank significantly (Smith et al., 1993; Sauerborn et al., 2007).

Approximately 30 fungal genera were reported to occur on *Orobanche* spp. and about 16 fungal genera were found on *Striga* species (Sauerborn et al., 2007).

14   Weed Suppression in Legume Crops

1081 Results of surveys for fungal pathogens of *Orobanche* and *Striga* revealed that
1082 *Fusarium* species were the most prominent ones associated with diseased broom-
1083 rapes and witch weeds. Of these, *F. oxysporum* was the predominant species. To
1084 date about 17 *Fusarium* species are reported to be associated with either *Orobanche*
1085 or *Striga*. Of these, six *Fusarium* species have shown significant disease develop-
1086 ment in selected species of *Orobanche* (Sauerborn et al., 2007). All growth stages
1087 from un-germinated seeds to inflorescences can be attacked (Sauerborn et al., 2007).
1088 Consequently, seeds of *Orobanche* and *Striga* may be infected by the application of
1089 *Fusarium* even if no host plant for the parasite is present in the field. That means
1090 that the parasite seed bank could be lowered every season. Fungal agents have also
1091 been developed as mycoherbicides (e.g. *Colletotrichum gloesporioides* trade name
1092 Lu bao) to control parasitic weeds such as *Cuscuta* spp (Auld, 1997).

1093   Opportunities for biological control of non-parasitic weeds have also been
1094 explored and, significant progress has been made in some cases (Evans, 2002;
1095 Sileshi, 1997, 1998; Taye, 2007). Classical biological control – the introduction of
1096 natural enemies of exotic plants – is probably the only long-term solution for con-
1097 trolling invasive plant species. For example, several arthropods and fungi have been
1098 identified as bicontrol agents for the control of the parthenium weed (Evans, 1997,
1099 2002). Searches for, and evaluation of coevolved natural enemies against parthe-
1100 nium weed have been conducted in the neotropics, and the leaf-feeding beetle,
1101 *Zygogramma bicolorata,* a seed-feeding weevil, *Simycronyx lutulentus*, a stem-
1102 galling moth, *Epiblema sternuana*, a leaf mining moth, *Bucculatrix parthenic*, and a
1103 sap-feeding plant hopper, *Stobaera concinna,* and a stem-boring curculionid weevil,
1104 *Listronotus setosipennis* from Mexico, Brazil and Argentina were introduced and
1105 successfully established in Australia. Two species of pathogenic rust fungi: *Puccinia*
1106 *abrupta* var. *parthenicola* and *Puccinia mealmpodii* were introduced and estab-
1107 lished. *Puccinia abrupta* and the phyllody caused by Faba Bean Phyllody (FBP)
1108 group were the two most important diseases infecting parthenium weed in Ethiopia.
1109 The rust was commonly found in mid altitude (1,500–2,500 m) with incidence from
1110 5 to 100% (Taye et al., 2004a, b) while phyllody was observed in low to mid altitude
1111 regions (900–2,300 m) of Ethiopia with incidence of 5–75% (Taye et al., 2004a, b).
1112 In India, the mycoherbicide potential of plurivorous fungal pathogens, belonging to
1113 the genera *Fusarium, Colletotrichum, Curvularia, Myrothecium* and *Sclerotium*, has
1114 and is being evaluated (Mishra et al., 1995; Evans, 1997). Potentials biological con-
1115 trol agents also exist for indigenous problematic weeds such as the blue couch grass
1116 (*Digitaria abyssinica*) and Bermuda grass (*Cynodon* spp.) (Sileshi, 1997, 1998).

1117   The strength of biological control is its environmental safety and sustainability.
1118 Because of their high host-specificity, pathogens can distinguish between a crop and
1119 associated weed where chemical herbicides may suffer from low margins of safety.
1120 However, the major constraint to the use of biological control agents may result
1121 from the regulatory authorities in the countries where the weeds are a problem. Since
1122 biocontrol agents are living organisms, regulators are fearful to introduce them from
1123 foreign countries. In such situations, biocontrol agents probably fail to be marketed
1124 internationally. This means that local strains have to be found in each country and
1125 need to be developed independently (Sauerborn et al., 2007).

A potential constraint in the future is climate change, which could alter the efficacy of biological control agents by potentially altering the development and reproduction of the target pest. Increased temperature, CO_2 enrichment and reduced precipitation will definitely affect dynamics and interaction among the biological control agent and the weed species. Drought or warming may benefit control in some cases but may be disruptive in others. Climate matching is important for selecting appropriate biological control agents (Myers and Bazely, 2003). Thus, increasing drought frequency or intensity may be detrimental to currently successful biological control agents, or it may facilitate the impact of agents by stressing the target plants.

14.4.10 Chemical Control

Despite the many limitations of chemical control (see below), it will remain an integral part of weed management in the foreseeable future especially where conservation agriculture is practiced. The use of broad-spectrum herbicides make conservation agriculture easier, but it also runs the risk of bringing about new weed problems, either by a shift in the weed populations or the presence of species able to evolve resistance to the herbicides in use.

14.4.10.1 Types of Herbicides

Seed-Applied Herbicides (SAH)

Commercial seed treatment with herbicides is increasingly being used in the control of parasitic weeds of cereals and legumes (Jurado-Expósito et al., 1997). Herbicides applied to crop seed are very important especially in the control of parasitic weeds since parasite infection occur mainly in the root zone near the site of seed planting (Jurado-Expósito and García-Torres, 2000). Recent studies and reviews indicate that the attachment of haustoria to host crops can be delayed by seed-dressing using seed-applied herbicides (Jurado-Expósito and García-Torres, 2000; Kabambe et al., 2008). Jurado-Expósito et al. (1997) studied the feasibility of controlling broomrape (*Orobanche crenata*) in faba bean and lentil by treating seeds with imazethapyr and imazapyr in Spain. In faba bean, coating with imazethapyr resulted in 60–80% control of broomrape. Similarly, lentil seed treatments with imazapyr by coating seeds controlled 85–95% of broomrape (Jurado-Expósito et al., 1997). Similarly, seed dressing with imazapyr, suppressed *Striga* emergence in addition to depleting the soil seed bank in maize (Kabambe et al., 2008). Dicamba applied pre-emergent to *Striga* can control early parasite attachment under restricted circumstances. The attachment of haustoria of *Striga* to host crops can also be delayed using imazapyr for crop seed-dressing (Kabambe et al., 2008).

14 Weed Suppression in Legume Crops

Germination Stimulants

Perhaps, the most effective germination stimulant available is ethylene gas. A number of other chemicals including cytokinins and sodium hypochlorite, which are not related to the natural stimulants, promote germination of parasitic weeds (Parker and Riches, 1993). However, the effectiveness of ethylene in some areas in Africa has been less than expected. For example, *Alectra vogelii* is unresponsive to ethylene (Parker and Riches, 1993). Recently, much attention has been focused on the isolation and identification of novel metabolites including those isolated from plant root exudates and fungal metabolites. The fungal metabolite cotylenins and fusicoccins have been reported to induce over 50% seed germination of *Striga hermonthica* and *Orobanche minor* even at very low concentrations (Yoneyama et al., 1998). Recently, Fernández-Aparicio et al. (2008b) screened several fungal metabolites to determine their capacity to stimulate the germination of several *Orobanche* species and found the highest stimulatory effect on *O. aegyptica*, and *O. minor* by ophiobolin A and derivatives of fusicoccin. The fusicoccin derivatives and ophiobolin A could represent a potential herbicide in view of their practical application in agriculture for the biocontrol of parasitic *Orobanche* species (Fernández-Aparicio et al., 2008b).

Pre-emergence Herbicides

Most of the pre-emergence herbicides used in legumes prevent the early establishment of crop seedling from germinating weed seeds. Several herbicides have been used for pre-emergence control of broomrape. For example, imazethapyr applied at 75–100 g/ha applied to faba bean and pea results in efficient control of broomrape (Jurado-Expósito and García-Torres, 2000). Those effective as pre-emergent herbicides for non-parasitic weed control in chick pea are alachlor, chlorobromuron, cyanazine, dinoseb amine, methabenzthiazuron, metribuzin, pronamide, prometryne and terbutryne (Solh and Palk, 1990). Among those used for controlling weeds in faba bean, Igran (terbutryn), Fusilade (fluazifopbutyl), Basagran (bentazon), Gezagard (prometryn), Amex (butralin) and Topstar (oxadiargyl) are the most prominent. Gezagard (prometryn) was used as pre-emergence herbicide in the control of a wide range of broad and narrow-leaved weeds in legumes (Singh and Wright, 2002). Some researchers have reported increased growth characters, yield and yield attributes of faba bean plants when prometryne was applied (Singh and Jolly, 2004). The selectivity and efficacy of these soil-acting herbicides is usually limited to specific agro-ecological conditions because of differences in soil type, moisture availability, temperature, and weed flora. Therefore, recommendations differ from one agro-climatic zone to another (Solh and Palk, 1990).

Post-emergent Herbicides

Post-emergent herbicides have limited effectiveness particularly for broad-leaf weeds. Post-emergent applications need great care with respect to stage of growth

and air temperature to avoid phytotoxicity. Post-emergent herbicides such as glyphosate (60 g/ha) effectively control broomrape in faba bean (Jurado-Expósito and García-Torres, 2000). Imidazoline herbicides are generally well tolerated by legumes after emergence. For example, post-emergence applied imazethapyr is highly selective in pea and faba bean at 20–40 g/ha. Imazapyr (2.5–10 g/ha) and imazaquin (40–60 g/ha) have been reported to be effective in control of broomrape (Jurado-Expósito and García-Torres, 2000). For non-parasitic weed control in legumes, dinosebacetate, fluazifop-butyl and e fenoxprop-ethyl have been reported to be effective (Solh and Palk, 1990).

14.4.10.2 Limitations of Herbicides

Chemical control of weeds has several limitations. Undoubtedly, the top most under the anticipated climate change scenarios will be soil moisture deficit, which limits herbicide efficacy. Generally, the efficacy of herbicide treatments to control parasitic weeds such as broomrape depends heavily on rain fall and temperature and the parasite life cycle (Jurado-Expósito and García-Torres, 2000). In the case of non-parasitic weeds, drought may induce the development of a thicker cuticular layer or increased pubescence on weed leaves. This will reduce herbicide entry into the leaf and decrease in herbicide efficacy. Herbicide adjuvants can help increase the penetration of the herbicide into the leaf. However, adjuvants may reduce herbicide selectivity and increase crop injury. Increasing numbers of studies have also demonstrated decline in chemical efficacy with rising CO_2 (Ziska et al., 2004; Ziska and Teasdale, 2000; Ziska et al., 1999). Under the increased temperature and unpredictable precipitation scenarios, current recommendations of herbicides (dozes/rates) may not be effective. Therefore, selected herbicides may need to be subjected to re-testing for specific locations. There is also a need for matching modification of current herbicide recommendations (Chaudhry, 2008b).

The second major limitation of chemical control is their residual effect and phytotoxicity. In high elevation areas severe damage occurred on cereals following legume crops on which pronamide has been applied. In Algeria, use of trifluralin in chickpea resulted in damage to cereals in the following season (Haddad, 1988). Metribuzin showed a large degree of phytotoxicity to green gram, inhibiting its vegetative growth (Zaidi et al., 2005). Herbicides suitable for broomrape control such as imazethapyr have also been shown to cause phytotoxicity depending on the level of water stress and lentil cultivar (Hanson and Hill, 2001).

Development of herbicide resistant weeds is another major problem. Where herbicides have been used, weeds have evolved resistance, or new weed species have appeared that could not be selectively controlled by herbicides.

Another limitation of herbicides in legume production systems is their negative effect on nitrogen-fixation (Anderson et al., 2004; Khan et al., 2004; Singh and Wright, 1999; Zaidi et al., 2005). For example, chlorsulfuron adversely affected the formation and activity of symbiotic nitrogen-fixing nodules, even when only

the rhizobial inoculant is exposed briefly to the herbicide (Anderson et al., 2004). Similarly soil applications of bentazone and 2, 4-D in chickpea decreased nodulation (Khan et al., 2004). Both production of late nodules and nodule growth were reduced particularly with simazine. Higher dozes of chlorobromuron and methabenzthiazuron also had adverse effect on number of nodules per plant (Malik et al., 1982). The presence of chlorsulfuron in the soil reduced the nodulation and nitrogen fixation of chickpea plants (Anderson et al., 2004). In pot experiments, the pre-emergence herbicides terbutryn/terbuthylazine, trietazine/simazine and prometryn decreased nodulation in pea (Singh and Wright, 1999). In green gram inoculated with *Bradyrhizobium* sp., pre-emergence application of metibuzin, glyphosate, fluchloralin and 2,4-D at the higher rates significantly reduced nodule number and dry mass (Zaidi et al., 2005). Many studies have concluded that herbicides affect nitrogen fixation largely via indirect effects on plant growth and consequent availability of photosynthates to the root nodules (Rennie and Dubetz, 1984; Bertholet and Clark, 1985; Sprout et al., 1992; Vidal et al., 1992; Abd-Alla et al., 2000). There is also evidence that some pesticides might impair the ability of the rhizobia to recognize appropriate host plants. Other herbicides, including glyphosate, can cause root hair deformations that apparently results in formation of fewer nodules (Mårtensson, 1992).

Other limitations of chemical control include unavailability, low persistence and lack of skills and equipment among subsistence farmers. There are no widely used chemicals for parasitic weeds especially in Africa (Parker and Riches, 1993). The intimate connection between host and parasite hinders efficient control of parasitic weeds by herbicides. Because of the close interconnection between the parasitic weed and its host, herbicidal control is difficult since herbicides cannot distinguish between the host and parasite (Sauerborn et al., 2007). Herbicides are applied at a certain growth stage of the crop when the root parasite is still underground. The herbicides concentrate in the parasites by translocation through the host-plant or through the soil solution until they die. However, often the timing and rate of herbicide application is critical because a proper concentration proportional to the parasite biomass has to be achieved without causing damage to the crop. Post-emergent herbicides that could effectively control broad leaf weeds satisfactorily are not available. The new post-emergent chemicals for grasses seem effective though the choice is limited. Most of the effective soil-acting herbicides have limited persistence in the soil and these are only effective at early stages of crop development. The narrow adaptation of these herbicides and the inconsistency of their effect from season to season are other limitations. Increasing price of some herbicides (especially with increase in fuel prices) and lack of credit facilities make herbicides inaccessible to such farmers (Gressel et al., 2004). Herbicide usage also requires skill, precision and suitable equipment which are not always present under subsistence agriculture. Development and spread of herbicide resistance (Heap, 2003) may also limit the use of those currently in use. The use of herbicides is also becoming more and more limited, due to changes in the regulatory environment.

14.4.11 Integrated Weed Management

Controlling weeds with one or a few techniques is only partially effective and sometimes inconsistent. This also gives the weeds a chance to adapt to those practices. Simply replacing herbicides by other control measures is also inadequate. Obviously, the most effective approach is the integration of different environmentally friendly control measures that are economically feasible to smallholder farmers. Integrated weed management combines different agronomic practices, so that the reliance on any one weed control technique is reduced. The objective of integrated weed management is to maintain weed densities at manageable levels while preventing shifts in weed populations to more difficult-to-control weeds. Integrated weed management using a variety of control techniques may also keep non-parasitic weeds off balance. Weeds are less able to adapt to a constantly changing system that uses many different control practices, unlike a program that relies on one or two control practices.

Three main types of practices can be used to develop integrated weed management in the framework of good agricultural practices. These practices are aimed at (1) preventing the introduction and spread of weeds, (2) giving the crop a competitive edge over weeds and, (3) making it difficult for weeds to adapt. The main principles of preventing introduction and spread of parasitic weeds are preventing seed set, reducing soil seed bank and inhibiting spread from infested to non-infested areas. Unlike normal weeds, most of the damage done by parasitic weed occurs before weed emerges above the soil (Sauerborn et al., 2007). Therefore, control methods have focused on reducing soil seed bank and interfere with the parasite's early developmental stages. Practices that reduce the soil seed bank of parasitic weeds include hand pulling stems before seed set or prompt destruction of crop residues after harvest to prevent continued parasite seed production. Other practices such as use of clean and certified seed and clean equipment can reduce chances of the introduction of new and/or noxious weeds in the fields. Composting livestock manure will reduce the viability of many weed seeds, although certain weeds can survive longer than others in composted manure. Patches of new invading weeds should be controlled to prevent them from spreading. Eradication of alien species such as the parthenium weed is mandatory.

Practices that help the plant to have a competitive edge over weeds include variety selection, high seeding rates, narrow row spacing, uniform seeding, appropriate land preparation, planting date and fertilizer application. Certain crop varieties can be more competitive than others. For example, yield losses caused by grassy weeds in tall pea varieties were less than half those suffered by shorter varieties (McDonald, 2003). High density can help give the crop an edge on weeds. Extra plants allow the crop to shade weeds and make it more difficult for weed to access nutrients and water. Narrow row spacing also allows the crop to be more competitive. There may be situations where wide row spacing is necessary, and higher seeding rates may offset the effect of wider row spacing. Shallow and uniform seeding is important for fast crop emergence and good establishment, which allows the crop to be more competitive with weeds. The closer is the seed to the soil surface,

1351 the faster the crop will emerge. Weeds that emerge after the crop cause less yield loss
1352 than those that emerge before the crop. Ensuring that the crop seed is placed in an
1353 ideal growing environment, and the weeds are not, is another way to give your crop
1354 the edge. Conservation farming practices leave crop residue in between the rows,
1355 which shades the soil and keeps it cool. Fewer weeds germinate under zero-tillage
1356 because of the reduction in soil disturbance.

1357   Crop rotation and varying herbicide practices is important for keeping weeds off
1358 balance. Recent reviews suggest that crop rotations that involve alteration between
1359 host and non-host crops can be effective against plant pathogenic organisms and
1360 insect pests that are relatively host-specific, non-mobile, and that inhabit the soil
1361 for at least part of their life cycle. Rotating herbicides with different modes of
1362 action (from different herbicide groups) will help delay the development of her-
1363 bicide resistance. Changing the planting date from year to year means that specific
1364 types of weeds cannot adapt. However, most of the cultivated area in legume pro-
1365 ducing regions relies on rainfall. In such conditions, conservation farming practices,
1366 in addition to other traditional practices such as crop rotation and fallow, plus tradi-
1367 tional or new water harvest technique become a clear option to increase WUE and
1368 sustainability of agriculture (Oweis et al., 2001).

AQ26

14.5 Scaling-Up Weed Management Practices

From the review above it is clear that a wide array of weed management options
is available, and many more are likely to be developed in the future. However, the
major challenge is to scale-up the adoption of these options. Many of the tech-
nologies developed have not been effectively disseminated and there has been little
adoption by farmers – who continue to use ineffective management practices that
exacerbate the weed problem (Abang et al., 2007). The constraints to technology
adoption are multiple and vary on a case-by-case basis (Tuberosa et al., 2007).
The adoption and effectiveness of conventional control methods may be limited
due to lack of appropriate agricultural extension services, increasing cost of agricul-
tural inputs, and the complex nature of parasitic weeds. Future work must take into
consideration the specific socio-economic characteristics of individual farming sys-
tems. Parasitic weeds are especially a community threat and effective management
requires a community-based integrated management approach.

14.6 Conclusion

This work reviewed the *status quo* of weed control in legumes and suggests future
developments aimed at weed management in the context of anticipated increases
in drought intensity and climate change. In future, water will become increasingly
scarce in rain-fed semi-arid regions where legumes are widely grown, thus severely
limiting options for irrigation. The spread of invasive alien species of weeds and

herbicide resistance, which are partly aggravated by increased global trade and climate change, are also posing more challenges to weed management. This may make conventional weed management practices ineffective. Cultural practices such as manual weeding and intercropping may also be affected by shorter growing seasons induced by climate change. Climate change may also disrupt the effectiveness of biological control as it will affect dynamics and interaction among the biological control agent and the weed species. Under the increased temperature and unpredictable precipitation scenarios, current recommendations of herbicides may not be effective. Increase in temperature and drought can reduce herbicide uptake, increase volatility, structural degradation and loss of potency. Therefore, selected herbicides may need to be subjected to re-testing for specific conditions reflecting climate change scenarios. This highlights the need for a well-planned weed management strategy to mitigate the effect of climate change and invasive alien weeds in legume cropping systems. Integrated weed management in the framework of good agricultural practices that (1) prevent the introduction and spread of invasive weeds, (2) give the crop a competitive edge over weeds and (3) make it difficult for weeds to adapt to cultural practices or herbicides need to be developed. Novel chemical control approaches, chemically induced resistance, and transgenic resistance will also play a crucial role in the integrated management of weeds in future. However, such developments must take into consideration the socio-economic and ecological conditions of individual farming systems.

References

M.M. Abang, B. Bayaa, B. Abu-Irmaileh, and A. Yahyaoui (2007). A participatory farming system approach for sustainable broomrape (*Orobanche* spp.) management in the Near East and North Africa. *Crop Prot* 26, 1723–1732.

Z. Abbes, M. Kharrat, P. Delavault, P. Simier, and W. Chaïbi (2007). Field evaluation of the resistance of some faba bean (*Vicia faba* L.) genotypes to the parasitic weed *Orobanche foetida* Poiret. *Crop Prot* 26, 1777–1784.

M. Ahmed and D.A. Wardle (1991). Increasing temperatures may enhance emergence and seedling growth of nodding thistle, summer grass and spiny emex. Proceedings 44th New Zealand Weed and Pest Control Conference: pp. 288–291.

A. Anderson, J.A. Baldock, S.L. Rogers, W. Bellotti, and G. Gill (2004). Influence of chlorsulfuron on rhizobial growth, nodule formation, and nitrogen fixation with chickpea. *Aust J Agric Res* 55 1059–1070.

B.A. Auld (1997). Bioherbicides. In: Julien, M. and White, G. (eds.), Biological control of weeds: Theory and application, pp. 129–134. Australian Center for International Agricultural Research, Canberra, Monograph no. 49, 192 pp.

B.K. Banful, S. Hauser, K. Ofori, and F.K. Kumaga (2007). Weed biomass dynamics in planted fallow systems in the humid forest zone of southern Cameroon. *Agroforestry Syst* 71, 49–55.

R.H. Bernhard, J.E. Jensen, and C. Andreasen (1999). Prediction of yield loss caused by *Orobanche* spp. in carrot and pea crops based on the soil seedbank. *Weed Res* 38, 191–197.

AQ27

14   Weed Suppression in Legume Crops

T. Besufekad, T.K. Das, M. Mahadevappa, T. Taye, and T. Tamado (2005). The weed parthenium: Its distribution, biology, hazards and control measures. *Pest Manag J Ethiop* 9, 1–17.

D.T. Baumann, L. Bastiaans, and M.J. Kropff (2002). Intercropping system optimization for yield, quality, and weed suppression combining mechanistic and descriptive models. *Agron J* 94, 734–742.

H.A.J. Bulson, R.W. Snaydon, and C.E. Stopes (1997). Effects of plant density on intercropped wheat and field beans in an organic farming system. *J Agri Sci (Camb)* 128, 59–71.

CABI (2003). Crop protection compendium, CD Documents. CAB International, London.

P.M. Carr, J.C. Gardner, B.C. Schartz, S.W. Zwinger, and S.J. Guldan (1995). Grain yield weed biomass of a wheat–lentil intercrop. *Agron J* 87, 574–579.

R.J. Carsky, C. Akakpo, B.B. Singh, and J. Detongnon (2003). Cowpea yield gain from resistance to *Striga gesnerioides* parasitism in southern Bénin. *Exp Agri* 39, 327–333.

C. Cechin and M.C. Press (1993). Nitrogen relations of the sorghum–*Striga hermonthica* host–parasite association: Germination, attachment and early growth. *New Phytol* 124, 681–687.

O. Chaudhry (2008a). Herbicide-resistance and weed-resistance management. Available at: http://www.weedscience.org/In.asp

O. Chaudhry (2008b). Futuristic vision on climate change adversity and herbicide technology. *Ann Plant Protect Sci* 16, 1–5.

D. Chikoye, M.V. Manyong, R.J. Carsky, F. Ekeleme, G. Gbehounou, and A. Ahanchede (2001). Response of speargeass (Imperata cylindrica) to cover crops integrated with handweeding and chemical control in maize and cassava. *Crop Prot* 19, 481–487.

E. Çikman and M. Doganlar (2006). Parasitoids of natural populations of Phytomyza orobanchia (Kaltenbach, 1864) (Diptera: Agromyzidae) in Southeastern Anatolia. *J Appl Sci Res* 2, 327–330.

A.E. Conklin, M.S. Erich, M. Liebman, D. Lambert, E.R. Gallandt, and W.A. Halteman (2002). Effects of red clover (Trifolium pratense) green manure and compost soil amendments on wild mustard (Brassica kaber) growth and incidence of disease. *Plant Soil* 238, 245–256.

K. Desta (2000). Weed control methods used in Ethiopia. In: Starkey, P. and Simalenga, T. (eds)., Animal power for weed control. Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands.

D. Dawoud and J. Sauerborn (1994). Impact of drought stress and temperature on *Striga hermonthica* and *Alectra vogelii* at early growth stages. *Exp Agri* 30, 249–257.

J.S. Dukes and H.A. Mooney (1999). Does global change increase the success of biological invaders? *Trends Ecol Evol* 14, 619–630.

F. Ekeleme, D. Chikoye, and I.O. Akobundu (2005). Weed seedbank response to planted fallow and tillage in southwest Nigeria. *Agroforestry Forum* 63, 299–306.

I.M. El-Metwally and M.T. Abdelhamid (2008). Weed control under integrated nutrient management systems in faba bean (*Vicia faba*) production in Egypt. *Planta Daninha* 26, 585–594.

H.C. Evans (1997). *Parthenium hysterophorus*: A review of its weed status and the possibilities for biological control. *Biocontrol News Inf* 18, 89–98.

H.C. Evans (2002). Plant pathogens for biological control of weeds. In: Waller, J.M., et al. (ed.), Plant pathologist's pocket book. CAB International, Wallingford.

A. Evidente, M. Fernández-Aparicio, A. Andolfi, D. Rubiales, and A. Motta (2007). Trigoxazonane, a monosubstituted trioxazonane from Trigonella foenum-graecum root exudate, inhibits *Orobanche crenata* seed germination. *Phytochemistry* 68, 2487–2492.

FAO (1998). Technical Meeting on benefits and risks of transgenic herbicide-resistant crops. Rome, Italy, p. 38.

R. Fasil and W. Wogayehu (2008). Parasitic weed research in Ethiopia: Current status and future prospects. A paper presented on the Ninth Ethiopian Weed Science Society (EWSS) Annual Conference, 25–26 December 2008, Addis Ababa, Ethiopia.

M. Fernández-Aparicio, J.C. Sillero, A. Perez-de-Luque, and D. Rubiales (2007a). Identification of sources of resistance to crenate broomrape (*Orobanche crenata*) in Spanish lentil (*Lens culinaris*) germplasm. *Weed Res* 48, 85–94.

M. Fernández-Aparicio, J.C. Sillero, and D. Rubiales (2007b). Intercropping with cereals reduces infection by *Orobanche crenata* in legumes. *Crop Prot* 26, 1166–1172.

M. Fernández-Aparicio, A.A. Emeranb, and D. Rubiales (2008a). Control of *Orobanche crenata* in legumes intercropped with fenugreek (Trigonella foenum-graecum). *Crop Prot* 27, 653–659.

M. Fernández-Aparicio, A. Andolfi, A. Cimmino, D. Rubiales, and A. Evidente (2008b). Stimulation of seed germination of *Orobanche* species by ophiobolin A and fusicoccin derivatives. *J Agr Food Chem* 56, 8343–8347.

R. Ford Denison (1999). Ecological risks of genetically-engineered crops. University of California, Davis.

D.L. Frost, A.L. Gurney, M.C. Press, and J.D. Scholes (1997). *Striga hermonthica* reduces photosynthesis in sorghum: The importance of stomatal limitations and a potential role for ABA? *Plant Cell Environ* 20, 483–492.

C. Funk, M.D. Dettinger, J.C. Michaelsen, J.P. Verdin, M.E. Brown, M. Barlow, and A. Hoell (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proc Natl Acad Sci* 10, 11081–11086.

J. Gressel, A. Hanafi, G. Head, W. Marasas, A.B. Obilana, J. Ochanda, T. Souissi, and G. Tzotzos (2004). Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions. *Crop Prot* 23, 661–689.

A. Giannini, R. Saravanan, and P. Chang (2003). Oceanic forcing of the Sahel rainfall on interannual to interdecadal time scale. *Science* 302, 1027–1030.

B.D. Hanson and D.C. Hill (2001). Effects of imazethapyr and pendimethalin on lentil (*Lens culinaris*), pea (*Pisum sativum*), and a subsequent winter wheat (*Triticum aestivum*) crop. *Weed Technol* 15, 190–194.

H. Hauggaard-Nielsen, P. Ambus, and E.S. Jensen (2001). Interspecific competition, N use and interference with weeds in pea–barley intercropping. *Field Crops Res* 70, 101–109.

R. Haymes and H.C. Lee (1999). Competition between autumn and spring planted grain intercrops of wheat (*Triticum aestivum*) and field bean (*Vicia faba*). *Field Crops Res* 62, 167–176.

I.M. Heap (2003). International survey of herbicide-resistant weeds. http://www.weedresearch.com

H. Hengsdijk and H. van Kuelen (2002). The effect of temporal variation on inputs and outputs of future-oriented land use systems in West Africa. *Agri Ecosyst Environ* 91, 245–259.

J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu (eds.) (2001). Climate change 2001: The scientific basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

HRAC (2009). International survey of herbicide resistant weeds. http://www.weedscience.org/In.asp (Accessed: March 10, 2009)

M. Hulme, R. Doherty, T. Ngara, M. New, and D. Lister (2001). African climate change: 1900–2100. *Climate Res* 17, 145–168.

IPCC (Intergovernmental Panel on Climate Change) (2001). Synthesis report. Cambridge University Press, Cambridge.

J.-L. Jannink, J.H. Orf, N.R. Jordan, and R.G. Shaw (2000). Index selection for weed suppressive ability in soybean. *Crop Sci* 40, 1087–1094.

J.-L. Jannink, N.R. Jordan, and J.H. Orf (2001). Feasibility of selection for high weed suppressive ability in soybean: Absence of tradeoffs between rapid initial growth and sustained later growth. *Euphytica* 120, 291–300.

D.M. Joel, Y. Hershenhorn, H. Eizenberg, R. Aly, G. Ejeta, P.J. Rich, J.K. Ransom, J. Sauerborn, and D. Rubiales (2007). Biology and management of weedy root parasites. In: Janick, J. (ed.), Horticultural reviews, vol. 33, pp. 267–350. John Wiley and Sons, Inc., New York.

Johansen, C., Duxbury, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K. (eds.) (2000). Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – Constraints and opportunities. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University. 230 pp.

S. Johnson (1986). Alien plants drain western waters. The Nature Conservancy News, Oct–Nov 1986.

14   Weed Suppression in Legume Crops

M. Jurado-Expósito and L. García-Torres (2000). Seed treatment for broomrape control. Grain Legumes No 27, 20–21.

M. Jurado-Expósito, L. García-Torres, and M. Castejón-Muñoz (1997). Broad bean and lentil seed treatments with imidazolinones for the control of broomrape (*Orobanche crenata*). *J Agri Sci* 129, 307–314.

A.S. Juraimi, S.H.D. Drennan, and N. Anuar (2005). Competitive Effect of *Cynodon dactylon* (L.) Pers. on four crop species, soybean [*Glycine max* (L.) Merr.], maize (*Zea mays*), spring wheat (*Triticum aestivum*). *Asian J Plant Sci* 4, 90–94.

V.H. Kabambe, F. Kanampiu, and A. Ngwira (2008). Imazapyr (herbicide) seed dressing increases yield, suppresses *Striga asiatica* and has seed depletion role in maize (*Zea mays* L.) in Malawi. *Afr J Biotechnol* 7, 3293–3298.

S. Kanchan and K.A. Jayachandra (1981). Effects of *Parthenium hysterophorus* on nitrogen-fixing and nitrifying bacteria. *Can J Bot* 59, 199–202.

G. Keneni, M. Jarso, and T. Wolabu (2007). Eco-geographic distribution and microcenters of genetic diversity in faba bean (*Vicia faba* L.) and field pea (*Pisum sativum* L.) germplasm collections from Ethiopia. *East Afr J Sci* 1, 10–24.

S.M. Khan, A. Zaidi, and M. Aamil (2004). Influence of herbicides on chickpea-Mesorhizobium symbiosis. *Agronomie* 24, 123–127.

M. Kharrat, M.H. Halila, K.H. Linke, and T. Haddar (1992). First report of *Orobanche foetida* Poiret on faba bean in Tunisia. *FABIS Newsl* 30, 46–47.

R.K. Kohli and D.R. Batish (1994). Exhibition of allelopathy by *Parthenium hysterophorus* L. in agroecosystems. *Trop Ecol* 35, 295–307.

O. Klein and J. Kroschel (2002). Biological control of *Orobanche* spp. with *Phytomyza orobanchia*, a review. *Biocontrol* 47, 245–277.

H.M. Kruidhof, L. Bastiaans, and M.J. Kropff (2009). Cover crop residue management for optimizing weed control. *Plant Soil*, DOI 10.1007/s11104-008-9827-6.

J.A. Lane, T.H.M. Moore, D.V. Child, K.F. Cardwell, B.B. Singh, and J.A. Bailey (1994). Virulence characteristics of new races of the parasitic angiosperm, *Striga gesnerioides*, from southern Benin on cow pea (*Vigna unguiculata*). *Euphytica* 72, 183–188.

M. Liebman and A.S. Davis (2000). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Res* 40, 27–47.

M. Liebman and E. Dyck (1993). Crop rotation and intercropping strategies for weed management. *Ecol Appl* 3, 92–122.

M. Liben, T. Tadesse, and A. Assefa (2001). Determination of nitrogen and phosphorus fertilizer levels in different maize-faba bean intercropping patterns in North western Ethiopia. Proceedings of the Seventh Eastern and Southern Africa Maize Regional Conference, pp. 513–518.

K.H. Linke, C. Vorlaender, and M.C. Saxena (1990). Occurrence and impact of Phytomyza orobanchia (Diptera : Agromyzidae) on *Orobanche crenata* (Orobanchaceae) in Syria. *Entomophaga* 35, 633–639.

P. Lionello, P. Malanotte-Rizzoli, and R. Boscolo (eds.) (2006). Mediterranean climate variability. Elsevier, Amsterdam, 438 pp.

D.B. Lobell, M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science* 319, 607–610.

S.P. Long, E.A. Ainsworth, A.B.D. Leakey, J. Nösberger, and D.R. Ort (2006). Food for thought: Lower-than-expected crop yield stimulation with rising CO_2 concentrations. *Science* 312, 1918–1921.

L.M. Manici, F. Caputo, and V. Babini (2004). Effect of green manure on Pythium spp. population and microbial communities in intensive cropping systems. *Plant Soil* 263, 133–142.

S.K. Mathur and V. Muniyappa (1993). Parthenium phyllody disease in India. In: Raychaudhuri, S.P. and Teakle, D.S. (eds.), Management of plant diseases caused by fastidious prokaryotes: Proceedings of the fourth Regional Workshop on plant Mycoplasma, pp. 21–34. University of Queensland, Australia.

1576 G.K. McDonald (2003). Competitiveness against grass weeds in field pea genotypes. *Weed Res* 43,
1577   48–58.
1578 J.H. Myers and D. Bazeley (2003). Ecology and control of introduced plants. Cambridge University
       Press, Cambridge.
1579 J. Mishra, A.K. Pandey, and S.K. Hasija (1995). Evaluation of *Sclerotium rolfsii* Sacc as
1580   mycoherbicide for Parthenium. *Ind Phytopathol* 48, 476–479.
1581 K.I. Mohamed, M. Papes, R. Williams, B.W. Benz, and A.T. Peterson (2006). Global invasive
1582   potential of 10 parasitic witchweeds and related Orobanchaceae. *Ambio* 35, 281–288.
1583 C.L. Mohler and M. Liebman (1987). Weed productivity and composition in sole crops and
       intercrops of barley and field pea. *J Appl Ecol* 24, 685–699.
1584 T.H.M. Moore, J.A. Lane, D.V. Child, G.M. Arnold, J.A. Bailey, and G. Hoffmann (1995).
1585   New sources of resistance of cowpea (*Vigna unguiculata*) to *Striga gesnerioides*, a parasitic
1586   angiosperm. *Euphytica* 84, 165–174.
1587 U. Mulisa, T. Taye, and Y. Firehun (2008). Impacts of *Parthenium hysterophorus* L. on herbaceous
1588   plant diversity in rangelands of Fentale district in the central rift valley of Ethiopia. *Ethiop J*
1589   *Weed Manag* 1, 25–41.
1590 L.J. Musselman (1980). The biology of *Striga*, *Orobanche*, and other root-parasitic weeds. *Ann*
       Rev Phytopathol 18, 463–489.
1591 S. Niu, Z. Yuan, Y. Zhang, W. Liu, L. Zhang, J. Huang, and S. Wan (2005). Photosynthetic
1592   responses of C3 and C4 species to seasonal water variability and competition. *J Exp Bot* 56,
1593   2867–2876.
1594 S.N.C. Okonkwo and V. Raghavan (1982). Studies on the germination of seeds of the root parasites,
1595   *Alectra vogelii* and *Striga gesnerioides* I. Anatomical changes in the embryos. *Am J Bot* 69,
       1636–1645.
1596 A. Oswald, J.K. Ransom, J. Kroschel, and J. Sauerborn (2002). Intercropping controls *Striga* in
1597   maize based farming systems. *Crop Prot* 21, 367–374.
1598 P. Oudhia, S.S. Kolhe, and R.S. Tripathi (1997). Allelopathic effect of white top (*Parthenium*
1599   *hysterophorus* L.) on chickpea. *Legume Res* 20, 117–120.
1600 M. Pagani, K.H. Freeman, and M.A. Arthur (1999). Late Miocene atmospheric CO_2 concentrations
       and the expansion of C4 grasses. *Science* 285, 876–879.
1601 J.P. Palutikof and T.M.L. Wigley (1996). Developing climate change scenarios for the
1602   Mediterranean Region. In: Jeftic, L., Keckes, S. and Pernetta, J.C. (eds.), Climatic change and
1603   the Mediterranean, vol. 2, pp. 27–55. Edward Arnold, London.
1604 C. Parker and C.R. Riches (1993). Parasitic weeds of the world: Biology and control. CAB
1605   International, Wallingford.
1606 D.T. Patterson (1995). Weeds in a changing climate. *Weed Sci* 43, 685–701.
1607 A. Pérez-de-Luque, J.V. Jorrín, and D. Rubiales (2004). Crenate broomrape control in pea by foliar
       application of benzothiadiazole (BTH). *Phytoparasitica* 32, 21–29.
1608 A. Pérez-de-Luque, J. Jorrín, J.I. Cubero, and D. Rubiales (2005). *Orobanche crenata* resistance
1609   and avoidance in pea (*Pisum* spp.) operate at different developmental stages of the parasite.
1610   *Weed Res* 45, 379–387.
1611 A. Pérez-de-Luque, M.T. Moreno, and D. Rubiales (2007). Host plant resistance against broom-
1612   rapes (*Orobanche* spp.): Defence reactions and mechanisms of resistance. *Ann Appl Biol*,
       doi:10.1111/j.1744–7348.2007.00212.x.
1613 S.L. Poggio (2005). Structure of weed communities occurring in monoculture and intercropping
1614   of field pea and barley. *Agri Ecosyst Environ* 109, 48–58.
1615 A.J. Pujadas-Salvà (2002). *Orobanche* L. In: López-Sáez J.A., Catalán P., and Sáez L.I. (eds.),
1616   Plantas Parásitas en la Península ibérica e Islas Baleares, pp. 348–440. Mundi Prensa, Madrid,
1617   Spain.
1618 S.C. Rao, B.K. Northup, and H.S. Mayeux (2005). Candidate cool-season legumes for filling forage
       deficit periods in the southern Great Plains. *Crop Sci* 45, 2068–2074.
1619 G.C. Reiss and J.A. Bailey (1998). *Striga gesnerioides* parasitizing cowpea: Development of
1620   infection structures and mechanisms of penetration. *Ann Bot* 81, 431–440.

14   Weed Suppression in Legume Crops

1621   C. Riches (2002). Witchweeds of pulse crops in Africa. *Grain Legumes No* 35, 25–26.
1622   C.R. Riches, K.A. Hamilton, and C. Parker (1992). Parasitism of grain legumes by *Alectra* species
1623   (Scrophulariaceae). *Ann Appl Biol* 121, 361–370.
1624   N. Rispail, M.-A. Dita, C. González-Verdejo, A. Pérez-de-Luque, M.-A. Castillejo, E. Prats,
1625   B. Román, J. Jorrín, and D. Rubiales (2007). Plant resistance to parasitic plants: Molecular
       approaches to an old foe. *New Phytol* 173, 703–712.
1626   D. Rubiales, A. Pérez-de-Luque, J.I. Cubero, and J.C. Sillero (2003). Crenate broomrape
1627   (*Orobanche crenata*) infection in field pea cultivars. *Crop Prot* 22, 865–872.
1628   D. Rubiales, C. Alcántara, and J.C. Sillero (2004). Variation in resistance to *Orobanche crenata* in
       species of Cicer. *Weed Res* 44, 27–32.
1629   D. Rubiales, M. Sadiki, and B. Román (2005). First report of *Orobanche foetida* on common Vetch
1630   (*Vicia sativa*) in Morocco. *Plant Disease* 89, 528.
1631   D. Rubiales, A. Pérez-de-Luque, J.C. Sillero, B. Román, M. Kharrat, S. Khalil, D.M. Joel, and
1632   C. Riches (2006). Screening techniques and sources of resistance against parasitic weeds in
1633   grain legumes. *Euphytica* 147, 187–199.
1634   S.A. Saad El-Din (2003). Efficiency of some weed control treatments on growth, yield and its
       components of broad bean (*Vicia faba* L.) and associated weeds. *Egypt J Appl Sci* 18, 586–604.
1635   F.A.A. Sharara, N.K. Messiha, and S.A. Ahmed (2005). Performance of some faba bean cultivars
1636   and associated weeds to some weed control treatments. *Egypt J Appl Sci* 20, 101–105.
1637   J. Sauerborn, D. Müller-Stöver, and J. Hershenhorn (2007). The role of biological control in
1638   managing parasitic weeds. *Crop Prot* 26, 246–254.
1639   D. Schimel (2006). Climate change and crop yields: Beyond Cassandra. *Science* 312, 1889–1890.
1640   A. Shabbir and R. Bajwa (2006). Distribution of parthenium weed (*Parthenium hysterophorus* L.),
       an alien invasive weed species threatening the biodiversity of Islamabad. *Weed Biol Manag* 6,
1641   89–95.
1642   I. Shiklomanov (2001). World Water Resources at the Beginning of the 21st Century. International
1643   Hydrological Series of the United Nations Educational, Scientific, and Cultural Organization
1644   (UNESCO), Cambridge University Press, Cambridge, UK. 711 pp.
1645   G. Sileshi (1997). Potential biocontrol agents for the blue couch grass Digitaria abyssinica in East
       Africa. *Int J Pest Manag* 43, 173–176.
1646   G. Sileshi (1998). Potential biocontrol agents for Bermuda grass in eastern Ethiopia. *Pest Manag*
1647   *J Ethiop* 2, 102–105.
1648   G. Sileshi, E. Kuntashula, and P.L. Mafongoya (2006). Effect of improved fallows on weed
1649   infestation in maize in eastern Zambia. *Zambia J Agri Sci* 8, 6–12.
1650   G. Sileshi, G. Schroth, M.R. Rao, and H. Girma (2008a). Weeds, diseases, insect pests and tri-
1651   trophic interactions in tropical agroforestry. In: Batish, D.R., Kohli, R.K., Jose, S., and Singh,
       H.P. (eds.), Ecological basis of agroforestry, pp. 73–94. CRC Press, Boca Raton, FL.
1652   G. Sileshi, F.K. Akinnifesi, O.C. Ajayi, and F. Place (2008b). Meta-analysis of maize yield
1653   response to planted fallow and green manure legumes in sub-Saharan Africa. *Plant Soil* 307,
1654   1–19.
1655   J.C. Sillero, M.T. Moreno, and D. Rubiales (2005a). Sources of resistance to crenate broomrape
1656   among species of *Vicia*. *Plant Dis* 89, 23–27.
1657   J.C. Sillero, J.I. Cubero, M. Fernández-Aparicio, and D. Rubiales (2005b). Search for resistance to
       crenate broomrape (*Orobanche crenata*) in Lathyrus. *Lathyrus Lathyrism Newsl* 4, 7–9.
1658   B.B. Singh and A.M. Emechebe (1997). Advances in research on cowpea *Striga* and *Alectra*. In:
1659   Singh, B.B., Mohan Raj, D.R., Dashiel, K.E., and Jackai, L.E.N. (eds.), Advances in cowpea
1660   research, pp. 215–224. IITA/JIRCAS, Ibadan, Nigeria.
1661   G. Singh and D. Wright (1999). Effects of herbicides on nodulation, symbiotic nitrogen fixation,
       growth and yield of pea (*Pisum sativum*). *J Agri Sci* 133, 21–30.
1662   G. Singh and D. Wright (2002). Effects of herbicides on nodulation and growth of two varieties of
1663   peas (Pism sativum). *Acta Agron Hungarica* 50, 337–348.
1664   B.B. Singh, A.M. Emechebe, and I.D.K. Atokple (1993). Inheritance of *Alectra* resistance in
1665   cowpea genotype B 301. *Crop Sci* 33, 70–72.

G. Singh and R.S. Jolly (2004). Effect of herbicides on the weed infestation and grain yield of soybean (Glycine max). *Acta Agronomica Hungarica* 52, 199–203.

H.P. Singh, D.R. Batish, J.K. Pandher, and R.K. Kohli (2003). Assessment of allelopathic properties of *Parthenium hysterophorus* residues. *Agri Ecosyst Environ* 95, 537–541.

B.B. Singh, O.O. Olufajo, M.F. Ishiyaku, R.A. Adeleke, H.A. Ajeigbe, and S.G. Mohammed (2006). Registration of six improved germplasm lines of cowpea with combined resistance to *Striga gesnerioides* and *Alectra vogelii*. *Crop Sci* 46, 2332–2333.

M.C. Smith, J. Holt, and M. Webb (1993). A population model of the parasitic weed *Striga hermonthica* (Scrophulariaceae) to investigate the potential of *Smicronyx umbrinus* (Coleoptera: Curculionidae) for biological control in Mali. *Crop Prot* 12, 470–476.

M.B. Solh and M. Palk (1990). Weed control in chickpea. *Options Méditerranéennes Série Séminaires* 9, 93–99.

T. Taye (2005). *Parthenium hysterophorus* L. In: Crop protection compendium 2004. CAB International, Wallingford.

T. Taye (2007). The prospects of biological control of weeds in Ethiopia. *Ethiop J Weed Manag* 1, 63–78.

T. Taye, C. Obermeier, G. Einhorn, E. Seemüller, and C. Büttner (2004a). Phyllody disease of Parthenium weed in Ethiopia. *Pest Manag J Ethiop* 8, 39–50.

T. Taye, G. Einhorn, M. Gossmann, C. Büttner, and R. Metz (2004b). The potential of Parthenium rust as biological control of Parthenium weed in Ethiopia. *Pest Manag J Ethiop* 8, 83–95.

R. Tuberosa, S. Giuliani, M.A.J. Parry, and J.L. Araus (2007). Improving water use efficiency in Mediterranean agriculture: What limits the adoption of new technologies? *Ann Appl Biol* 150, 157–162.

M.R. Valderrama, B. Román, Z. Satovic, D. Rubiales, J.I. Cubero, and A.M. Torres (2004). Locating quantitative trait loci associated with *Orobanche crenata* resistance in pea. *Weed Res* 44, 323–328.

J. Vandermeer (1989). The ecology of intercropping. Cambridge University Press, Cambridge, 237 pp.

M.C. Vaz Patto, R. Díaz-Ruiz, Z. Satovic, N.B. Romá, A.J. Pujadas-Salvà, and D. Rubiales (2008). Genetic diversity of Moroccan populations of *Orobanche foetida*: Evolving from parasitising wild hosts to crop plants. *Weed Res* 48, 179–186.

M. Weiß, M. Flörke, L. Menzel, and J. Alcamo (2007). Model-based scenarios of Mediterranean droughts. *Adv Geosci* 12, 145–151.

D.W. Wolfe and J.D. Erickson (1993). Carbon dioxide effects on plants: Uncertainties and implications for modeling crop response to climate change. In: Kaiser, H.M. and Drennen, T.E. (eds.), Agricultural dimensions of global climate change, pp. 153–178. St. Lucie Press, St. Lucie, FL.

C.S. Wortmann (1993). Contribution of bean morphological characteristics to weed suppression. *Agron J* 85, 840–843.

R.S. Yadav (1998). Effects of weed removal in clusterbean (*Cyamopsis tetragonoloba*) under different rainfall situations in an arid region. *J Agron Crop Sci* 181, 209–214.

K. Yoneyama, Y. Takeuchi, M. Ogasawara, M. Konnai, Y. Sugimoto, and T. Sassa (1998). Cotylenins and fusicoccins stimulate seed germination of *Striga hermonthica* (Del.) Benth and *Orobanche* minor Smith. *J Agr Food Chem* 46, 1583–1586.

A. Zaidi, M.S. Khan, and P.Q. Rizvi (2005). Effect of herbicides on growth, nodulation and nitrogen content of greengram. *Agron Sustain Dev* 25, 497–504.

L.H. Ziska (2002a). The impact of elevated CO_2 on yield loss from a C3 and C4 weed in field-grown soybean. *Global Change Biol* 6, 899–904.

L.H. Ziska (2002b). Changes in competitive ability between a C4 crop and a C3 weed with elevated carbon dioxide. *Weed Sci* 49, 622–627.

L.H. Ziska and K. George (2004). Rising carbon dioxide and invasive, noxious plants: Potential threats and consequences. *World Resour Rev* 16, 427–447.

L.H. Ziska, J.R. Teasdale, and J.A. Bunce (1999). Future atmospheric carbon dioxide concentrations may increase tolerance to glyphosate. *Weed Sci* 47, 608–615.

Chapter 14

Q. No.	Query
AQ1	Besufekad et al. (1999) is not listed in reference list. Please provide.
AQ2	Osterbauer and Rehms (2002) is not listed in reference list. Please provide.
AQ3	Eizenberg et al. (2004) is not listed in reference list. Please provide.
AQ4	Mohamed et al. (2001) is not listed in reference list. Please provide.
AQ5	Emechebe et al. (1997) is not listed in reference list. Please provide.
AQ6	Zougmoré et al. (2004) is not listed in reference list. Please provide.
AQ7	Faucherreau et al. (2003) is not listed in reference list. Please provide.
AQ8	Oweis et al. (2001) is not listed in reference list. Please provide.
AQ9	Parker (1991) is not listed in reference list. Please provide.
AQ10	Haddad (1988) is not listed in reference list. Please provide.
AQ11	Saxena (1987) is not listed in reference list. Please provide.
AQ12	Sillero and Moreno (2005a) has been changed to Sillero et al. (2005a) as per reference list. Please confirm.
AQ13	Aggarwal (1985) is not listed in reference list. Please provide.
AQ14	Aggarwal (1991) is not listed in reference list. Please provide.
AQ15	Jordan (1993) is not listed in reference list. Please provide.
AQ16	Kruidhof et al. (2008) has been changed to Kruidhof et al. (2009) as per reference list. Please confirm.
AQ17	Ziska et al. (2004) is not listed in reference list. Please provide.
AQ18	Ziska and Teasdale (2000) is not listed in reference list .Please provide.
AQ19	Malik et al. (1982) is not listed in reference list. Please provide.
AQ20	Rennie and Dubetz (1984) is not listed in reference list. Please provide.
AQ21	Bertholet and Clark (1985) is not listed in reference list. Please provide.
AQ22	Sprout et al. (1992) is not listed in reference list. Please provide.
AQ23	Vidal et al. (1992) is not listed in reference list. Please provide.
AQ24	Abd-Alla et al. (2000) is not listed in reference list. Please provide.
AQ25	Mårtensson (1992) is not listed in reference list. Please provide.
AQ26	Oweis et al. (2001) is not listed in reference list. Please provide.
AQ27	Sillero et al. (2005b) is not cited in text part. Please provide.