CONSERVATION AGRICULTURE:

MOVING TOWARDS THE PRESERVATION AND IMPROVEMENT OF BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS

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PUBLISHER

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ABOUT ECAF

The European Conservation Agriculture Federation (ECAF) was founded in Brussels on 14th January 1999, as a non-profit making international association. It was conceived to promote all issues related to the conservation of agricultural soils and their biodiversity in the context of sustainable agriculture. ECAF brings together nineteen national associations promoting the best practice aspects of Conservation Agriculture (CA) to European farmers and represents the interests of the majority of the European Union's agricultural land.

The aims of ECAF are:

- To contribute to the positioning, knowledge and understanding of CA at a European level.
- To promote the collaboration between national/regional CA organisations and the CA-CoP in the sharing of best practices, learnings, research, methodologies, and the transition pathway of farmers from conventional towards CA.
- To promote information to farmers, agrarian technicians, and society in general, about the techniques that make it possible to conserve agrarian soil and its biodiversity, in the context of sustainable agriculture.
- To encourage the development, teaching and investigation on any aspect related to CA and the biodiversity of agrarian soil.
- To develop all kinds of activities and programs, as mentioned hereafter.
- To provide decision makers of all levels with adequate information on CA

DISCLAIMER

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INTRODUCTION

European and world agriculture is at a critical juncture. According to the FAO, about 33% of the world's soils are degraded, with intensive agriculture (maximising agricultural production on a given area of land with excessive use of inputs, intensive tillage and monocultures) being one of the main drivers. Biodiversity loss in agricultural ecosystems is directly linked to the degradation and loss of functions of agricultural soils. The future of agriculture depends on how effectively this challenge can be addressed. Not only is it necessary to produce food for the world's population, but also to ensure the economic profitability of farmers while protecting agricultural ecosystems.

Since the mid-20th century, a substantial increase in pressure on agricultural ecosystems has been observed. According to the European Environment Agency (EEA), the biodiversity of agricultural ecosystems is being put under serious threat, with an estimated 81% of the EU's agricultural habitats being in poor condition. Agricultural intensification, landscape fragmentation and soil depletion are compromising biodiversity conservation in these ecosystems.

To conserve and enhance biodiversity in agricultural ecosystems, the European Union (EU) has created a regulatory framework for biodiversity conservation that brings together several policies that promote the environmental sustainability of agricultural landscapes. These are as follows:

- The European Green Deal aims to conserve and restore agricultural landscapes and ecosystems as well as to promote incentives to prevent biodiversity loss.

- The Common Agricultural Policy (CAP) aims to encourage farmers to develop more sustainable models for natural resource management including the preservation of soil and biodiversity.

- The EU Biodiversity Strategy 2030 has set targets for the conservation and legal protection of at least 30% of the EU's land and sea area.

- The Farm to Fork strategy promotes a transition towards sustainability of agricultural ecosystems and to make them more resilient to crises.

To meet these policy challenges and objectives, it is necessary to provide solutions and tools that are capable of meeting the needs of European agriculture. In this context, Conservation Agriculture (CA) is presented as one of the key systems to restore and conserve agricultural landscapes and provide habitats to preserve and enhance biodiversity on European farms.

WHAT IS CONSERVATION AGRICULTURE? PRINCIPLES AND PRACTICES

Conservation Agriculture is an integrated system of agricultural production and land management applicable to all agricultural and agroforestry systems. According to FAO, Conservation Agriculture is described as an ecosystem approach to sustainable regenerative agriculture based on the application of the three interrelated principles through context-specific and locally adapted practices which are:

(1) **Continuous no or minimum mechanical soil disturbance** (no-till sowing): this principle is implemented through the practice of no-tillage seeding, directly placing the seeds into the soil without tilling, and also managing weeds without tillage. The aim is to minimise any soil disturbance and to improve soil quality by: minimizing soil erosion, and organic matter loss, promoting biodiversity and microbiological processes, protecting, and improving soil structure by not hindering the movement of gases and water, and promoting overall soil health and function, including improved water infiltration and retention of soil moisture, plant nutrients and soil carbon.

(2) **Permanent maintenance of a vegetative mulch cover on the soil surface:** this principle is implemented through the retention of crop biomass, stubble and cover crop biomass and biomass from ex-situ sources. A minimum of 30% permanent cover is required as a threshold for soil protection. The use of crop biomass (including stubble) and cover crops reduces soil erosion, protects the soil surface, increases water infiltration, reduces runoff; conserves water and nutrients, supplies organic matter and carbon to the soil system, and promotes soil biodiversity and microbiological activity that maintains and improves soil health and function.

(3) **Species diversification:** this principle is implemented through the adoption of economically, environmentally and socially adapted crops in rotations and/or sequences and/or associations that may involve annual and perennial crops, including a mix of leguminous and non-leguminous crops, including cover crops where possible. The use of diversified cropping systems contributes to diversity in root morphology and composition, improves soil biodiversity and microbiological

activity, accumulates organic matter in the soil, and improves nutrition and crop protection through suppression of pathogens, diseases, insect pests and weeds. Crops may include annual plants, short-term perennial plants, trees, shrubs, nitrogen-fixing legumes, and grasses, as appropriate.

All the three interlinked principles contribute to the integrated management of weeds, insect pests, pathogens, nutrients and water.

The practices required to introduce Conservation Agriculture principles into the system vary according to the soil-climatic and cultural characteristics of the area but should aim to optimise soil conditions and provide resilience to extreme events and climate change. Therefore, to fulfil these premises under Conservation Agriculture principles, the following practices exist.

ANNUAL CROPS

No tillage. Avoiding tillage is the best form of applying the minimum soil disturbance principle. It will be considered a CA practice, if the soil cover is maintained by retaining crop biomass that is not removed from the soil but retained as mulch. The aim of this practice is to establish a crop directly in a seedbed without prior mechanical preparation, for which a direct seeder will be necessary to carry out the sowing properly on a layer of residues.

Minimum soil disturbance strip seeding. Strip seeding is an integrated practice within CA systems provided the soil strip opened for seeding is less than 15 cm and total soil surface disturbance is less than 25%, thus keeping the soil and biomass soil cover between the plant rows undisturbed. Seeding equipment must be used with precision to avoid reducing the percentage of soil covered after sowing to less than 30%. If strip seeding is practiced with a tyne strip seeder, the objective should be to move towards no-till status with a disc seeder as soon as possible.

Crop diversification. Crop diversification through crop rotation refers to growing more than one type of crop in rotation on the same field over time. It is recommended that species used are economically, environmentally, and socially well adapted to the soil and climatic conditions of the area, and attention is paid to maintaining optimum sequences and cycles of crops. The establishment of several crops on different portions of land (fields) on the farm in sequence is a form of diversification of the cropping system. In addition, associations such intercropping, relay cropping and under sowing can be used as a form of diversification where different crops are grown on the same piece of land in the same season.

Cover crops. These are auxiliary crops or service crops that are temporarily established between main cropping seasons as an alternative to fallow land. They are planted for soil cover to protect against erosion or to provide an ancillary service rather than for production. However, there are many multi-purpose cover crops which can also be food crops. These can be legumes and non-legumes.

WOODY CROPS

Groundcovers. This practice consists of maintaining a living green cover or dead dry cover within the area between crop rows. This is considered a type of intercropping or alley cropping and can include multi-purpose cover crops. This promotes the principle of permanent soil cover and crop diversification.

CA PRINCIPLES:

- >> Continuous no or minimum mechanical soil disturbance
- >> Permanent maintenance of a vegetative mulch cover on the soil surface
- >> Species diversification

Conservation Agriculture (CA):

ecosystem approach to sustainable regenerative agriculture based on the application of the three interrelated principles through context-specific and locally adapted practices.

CA PRACTICES:

ANNUAL CROPS

- No tillage
- Minimum soil disturbance strip seeding
- Crop diversification
- Cover crops

WOODY CROPS

- Groundcovers

CONSERVATION AGRICULTURE'S CONTRIBUTION TO IMPROVING SOIL FAUNA BIODIVERSITY

Soil fauna refers to living organisms that live and carry out their biological activity in the soil profile. They play a key role in maintaining soil health and are therefore essential for ensuring that agricultural ecosystems are productive and regenerative. Within the soil fauna, there are key organisms that allow identification of soil quality in relation to the variety and quantity of soils, such as soil mites, nematodes, springtails, and earthworms.

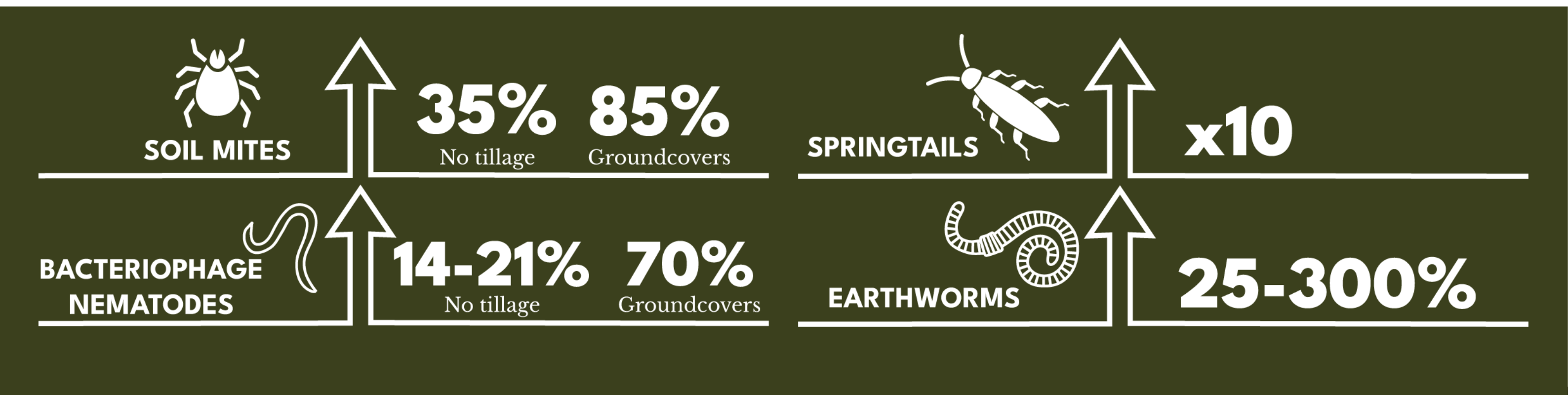
The adoption of CA system and practices in the field, involving both herbaceous and woody crops, bring multiple benefits in terms of the quantity and variety of soil mites, mainly in cereal crops, where they have been most studied. Several trials have shown that in CA fields, around 35% more of these beneficial organisms present, and many of them are efficient predators of harmful organisms. These values are even higher in CA systems with woody crops, with an increase of up to 85% in vineyards managed with groundcover, compared to those under conventional tillage and bare soil management.

Bacteriophage nematodes presence helps to control plant diseases. CA brings clear benefits through an increase in these organisms. Several studies show that the adoption of CA in arable crop systems lead to an increase in the number of these creatures of between 14% and 21%. These values are much more conclusive for groundcovers in woody crops, where the improvement in the number of nematodes can be as high as 70%.

As for springtails, small arthropods that decompose plant residues and improve soil structure, their biodiversity benefits significantly from the presence of plant biomass on the soil surface, as this is the main food source for their development. Practices based on CA principles in both annual and woody perennial crops favour the presence of springtails, with a 10-fold increase in springtail populations compared to soils managed under traditional tillage agriculture.

Regarding earthworms, they are considered as an indicator of soil biodiversity, partly because they are easy to recognise. The elimination of tillage, together with the maintenance of soil cover and the diversification of species, provides ideal conditions for the development of earthworms, providing them with residues for food, and maintaining a more stable temperature and humidity throughout the year. Therefore, the adoption of CA systems and practices bring large increases in earthworm population and species diversity, reflected in increases ranging from 25% to 300%, depending on the soil and climatic conditions of the area under study.

Therefore, soil fauna biodiversity benefits from CA, especially the springtails group, both in herbaceous annual and woody perennial crops. In the case of mites and earthworms, the practice that most increases their abundance and/or biodiversity is direct no-till sowing in herbaceous annual crops, while groundcovers in woody perennial crops are the most favourable for nematofauna.



ENHANCEMENT OF EPIGEAN FAUNA BIODIVERSITY

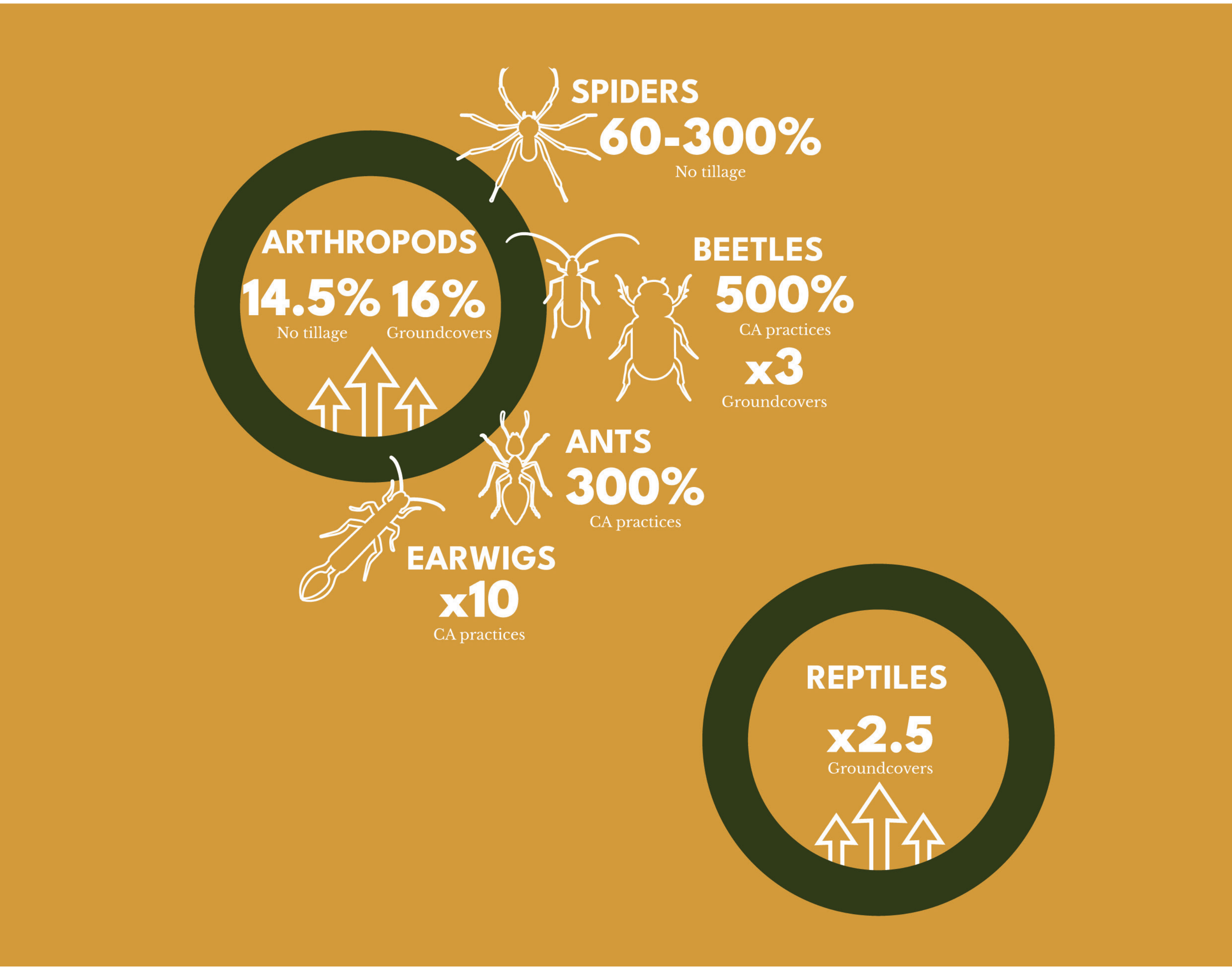
Soil biodiversity is not only limited to the living beings that inhabit the soil profile. There is also a large biocenosis whose habitat is mainly the soil surface. These animals are called epigean fauna. Agricultural soils have a rich representation of this fauna, providing important benefits to crops. Epigean fauna is mainly composed, both in abundance and diversity, of arthropods. This group predominantly includes insects, such as beetles and ants, as well as arachnids (mainly spiders) and crustaceans and myriapods to a lesser extent.

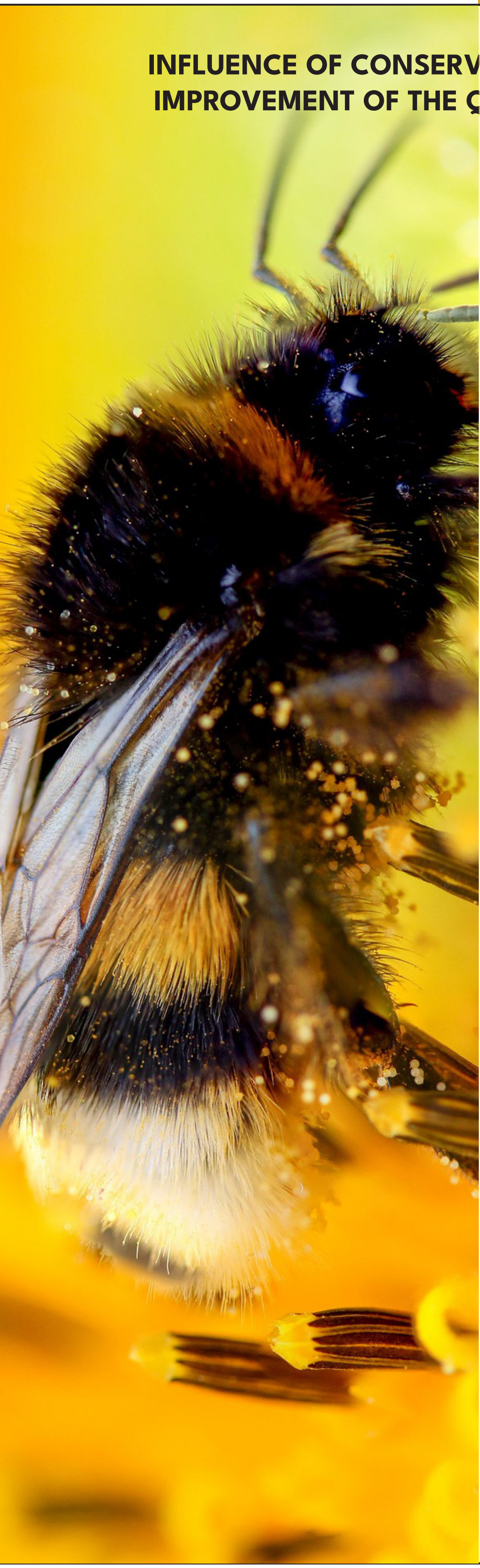
Regarding the effect of the adoption of CA on arthropod populations, improvement in individual numbers is not high. However, increases in species richness of 14.5% in CA systems herbaceous annual crops and 16% in CA woody perennial crops have been observed compared with conventional tillage systems.

Spiders play a key role in agricultural ecosystems as the largest predators on the soil surface. Their impact on the application of CA systems and practices therefore becomes much more visible. Maintenance of soil cover favours the habitat of these organisms, with increases ranging from 60% to 300% in their number in crops managed under CA. This is due not only to the greater shelter they can find in the mulch cover, but also due to the fact that the undisturbed soil surface favours the maintenance of their ground nests. In addition, there is an increase in potential prey at lower trophic levels that also benefit from CA practices.

In relation to beetles, the most abundant beetle family on the soil surface are the carabids, which are usually predators, thus helping to control populations of other soil animals that could become pests for crops. Accordingly, increases in beetle abundance observed in CA systems are around 500% compared to conventional tillage systems in different regions of the world. However, it is not only the increases in their numbers that are found, but also one of the most important indicators is the variety and richness of species that can be observed, which is also very favourable in agricultural ecosystems managed under CA principles. These beneficial effects are similar to those with groundcovers in woody perennial crops, where an increase of these arthropods by up to 3 times is observed compared to bare and tilled soil system.

For species belonging to other orders of epigean fauna (crickets, ants, earwigs, and reptiles) there are not many studies, but the trend in terms of populations in CA systems with herbaceous annual crops and with groundcover in woody perennial crops, shows an increase in populations. With ants, population increases of up to 300% have been found, while for earwigs a 10-fold improvement over conventional tillage production has been observed. Finally, as regards the number of reptiles, there are few studies, but they show 2.5-fold increase in observations made in CA with groundcovers in woody perennial crops, mainly olive groves.





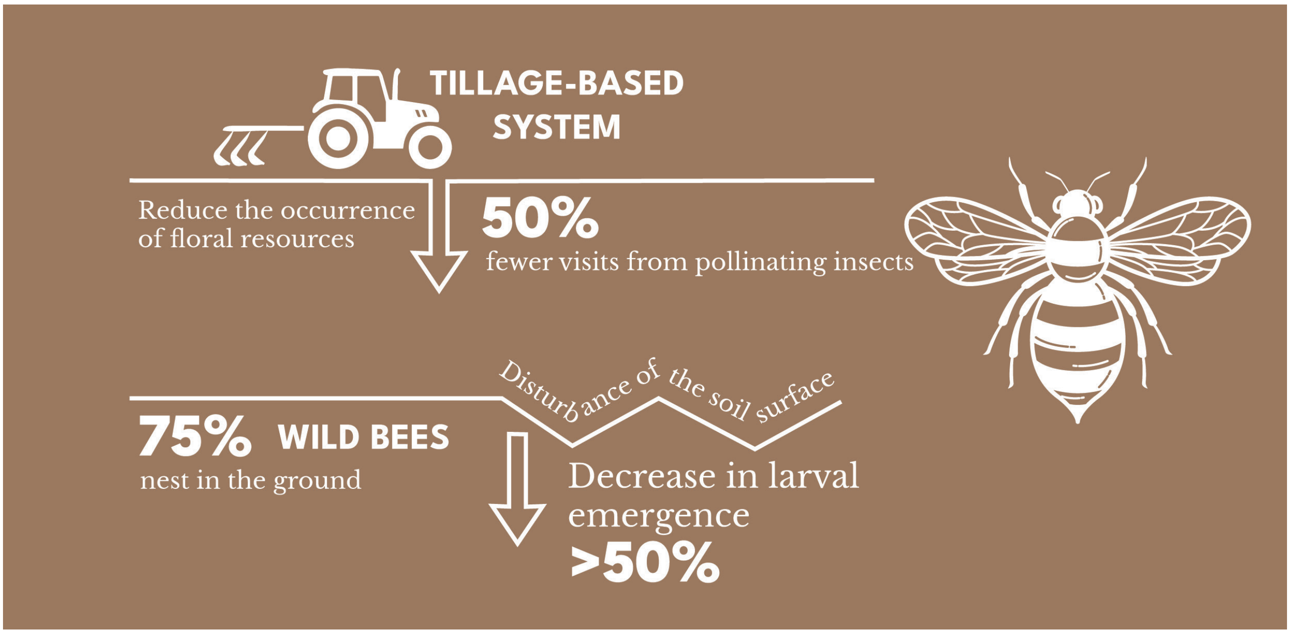
INFLUENCE OF CONSERVATION AGRICULTURE ON THE MAINTENANCE AND IMPROVEMENT OF THE QUANTITY AND VARIETY OF POLLINATING INSECTS

Approximately 87% of the world's major food crops and 35% of global crop production volumes depend on animal pollination in which insect pollinators play an essential role. The most important group of pollinating insects are members of the family Apoidea, with more than 20,000 species, including the honeybee. Butterflies, moths, flies, and beetles are also efficient pollinators. Conservation of these insects, which is threatened by multiple factors, is a global concern, as an increase in the number and variety of pollinators provides unique and essential ecosystem services relevant to food security and environmental security.

Management and preservation of agricultural ecosystems to provide habitats and shelter for pollinating insects, essentially wild bees, and hymenopterans, is key to improving their population. An agricultural land management system based on CA principles provides these necessary resources. On the one hand, non-disturbance of the soil surface, together with the diversification of species, favours the maintenance of floral resources, which are key to the life cycle of these insects. Fields managed under a tillage-based system reduce the occurrence of floral resources, reducing the visits of pollinating individuals by up to 50%, depending on the plant species involved. However, an increase in floral resources does not necessarily lead to an increase in pollinator visits, as there are other factors that can influence the observations. However, it can be stated that not disturbing the soil surface by avoiding tillage favours the germination and emergence of vegetation, thus making these plant resources available to pollinators. This availability of vegetation and floral resources occurs particularly in CA systems with groundcovers in woody perennial crops.

Another aspect to bear in mind when considering the conservation of pollinating insects, is that 75% of wild bees, whose role is essential for pollination, nest in the ground and spend a large part of their life cycle in the ground. Disturbance of the soil surface can eliminate or break the continuity of nests, leading to a decrease in larval emergence of up to 50% in some wild bee species, resulting in a severe reduction of the wild bee population. In addition, this disruption of the continuity of the nest channels may cause a delay in the emergence of the bees from the nest in tilled plots, as the brood must emerge from deeper cells because the shallower ones have been destroyed. These delays in bee emergence from tilled soils can have an undesirable effect on crop productivity, affecting the synchronisation between blooms and the main pollinators. A study in cotton in the United States quantifies the benefit of no soil disturbance, estimating that for each 1% of no-till area in the studied site leads to a benefit of USD 16,000.

However, due to the high mobility of pollinating insects, not only adequate management at plot level is necessary, but also an integrated landscape management is necessary. Providing floral and forage resources for refuge for these species on a permanent basis, avoiding the disruption of landscape continuity to avoid large distances that cannot be covered by these pollinators, is key to maintaining populations. Integrating a system under CA principles into the agricultural landscape ensures the continuous maintenance of a living cover, as well as the minimum alteration of the soil surface. This combined with other complementary practices, such as the introduction of vegetative margins or biodiversity islands, favours the conservation and improvement of pollinating insect populations.



IMPROVEMENT OF SMALL MAMMAL BIODIVERSITY

Farmland supports a wide range of wildlife, including vertebrates. Although there are not many studies on the effect of the practice of CA systems on mammal populations, it can be stated that CA systems provide a more suitable habitat for mammals, as the undisturbed soil maintains burrows and small mammals find more opportunities to feed, as there is more stubble biomass and greater amount of scattered fallen seeds than in tillage systems. Accordingly, the presence of small vertebrates, mainly rodents, can help in the control and elimination of weeds and some worm infestations. Up to 64% of the annual weed seed production could be consumed by rodent species. Thus, cover crops and mulches may increase weed seed predation by invertebrates and small mammals compared to bare soil.

One of the points to bear in mind is that CA systems favour the abundance of small mammals, which could otherwise become pests. However, there is a pest-predator balance in CA ecosystems that increases the abundance of predatory birds that help control pest populations. In addition, the integration of cover crops with plant species that are unattractive to these small mammals helps to control pest populations.

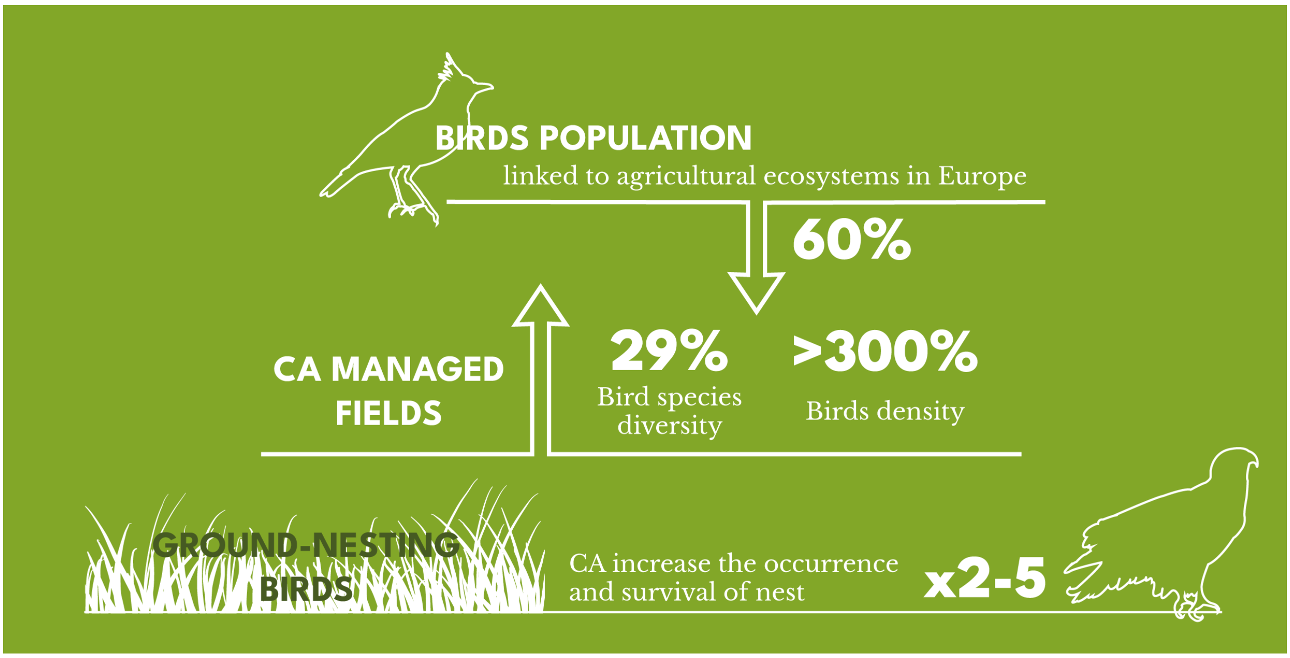
EFFECT OF THE INTRODUCTION OF CONSERVATION AGRICULTURE ON THE IMPROVEMENT OF AVIFAUNA BIODIVERSITY

Birds are part of the natural heritage of the agricultural ecosystem. Since 1980, the population of birds linked to agricultural ecosystems in Europe has declined by 60%. Intensification of agriculture, with the development of machinery capable of carrying out deeper ploughing, coupled, on occasions, with the inappropriate use of plant protection products, and monocultures or inadequate crop diversity, has endangered bird populations in agricultural areas.

Application of CA principles favours an increase in the quantity and quality of food available to birds, as the quantity of spontaneous vegetation seeds and invertebrates in their food chains is increased by the maintenance of soil cover and the elimination of tillage. It also creates an agricultural landscape that favours bird habitats, particularly ground-nesting birds. Consequently, during the breeding season, CA fields under direct seeding host higher densities of birds as they provide more food and better shelter from weather and predators.

Therefore, agricultural management has a direct impact on bird density and diversity, and it has been shown that, for various bird species, soil tillage reduces their presence, both in conventional and organic tillage agriculture, while their presence is maintained in CA systems with direct sowing. Bird species diversity under CA managed fields has been found to be up to 29% higher than in tilled fields. In terms of the density of birds present, the reasons why CA favours an increase, are similar to those favouring species diversity. All the studies discussed in this report show that density of individual birds increases on CA farms with direct seeding or groundcovers. Quantification of this increase in terms of density is variable depending on the bird species and the characteristics of the study area. However, average increases of more than 300% in bird density can be observed in CA fields.

For ground-nesting birds, tillage operations have a negative effect on their numbers because they destroy their nests or cause disturbances in their habitats that cause birds to abandon their nests. CA avoids tillage operations, which is highly beneficial for nest establishment and survival, and reduces the nest predation rate. Thus, it has been shown that the occurrence and survival of nests in CA fields is, for some bird species, 2 to 5 times greater than in tilled fields. In woody crops, the positive effect is not so obvious as there is a higher rate of nest predation by small mammals and reptiles which proliferate to a relatively greater extent in woody crops managed with groundcovers.



FINAL REMARKS

Biodiversity conservation and enhancement is one of European policies premises as expressed in the: European Green Deal, Common Agricultural Policy, Biodiversity Strategy and Farm to Fork Strategy. With around 40% of the EU's land area used for agriculture, agricultural ecosystems management has a major impact on achieving the proposed goals in terms of preserving and enhancing biodiversity. In this respect, farmers who manage their farms based on the CA principles have an essential role to play in achieving these objectives. CA systems and their practitioners can provide ecosystem services associated with biodiversity enhancement. The proven improvement in the density and richness of populations of soil organisms, insects, birds, and small mammals in agricultural ecosystems managed under CA systems makes CA essential and therefore deserving special attention. Farmers are the primary stakeholders in conserving the productivity and integrity of agricultural landscape, and those who practice CA are aware of the wide-ranging benefits that accrue. Therefore, providing farmers with the necessary tools for the transition to agricultural land management based on the application of the CA principles must be a priority of the Common Agricultural Policy to achieve real sustainability of European agriculture.

CHAPTER 1

SOCIO-POLITICAL CONTEXT IN EUROPE FOR THE CONSERVATION AND ENHANCEMENT OF BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS

1.1 BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS AT THE GLOBAL LEVEL

Biodiversity loss in agricultural ecosystems is directly linked to the degradation and loss of functions of agricultural soils and landscapes. This is a critical problem on a global scale that threatens the food and environmental security and livelihoods of millions of people around the world, and it is also linked to the climate crisis. Soil degradation refers to the reduction or loss of biological, and therefore economic, productivity of soil due to factors such as: i) soil erosion; ii) deterioration of the physical, chemical, biological or hydrological properties of soil through salinization, acidification, compaction, etc; iii) contamination by an inappropriate use of chemical inputs such as fertilisers, pesticides and herbicides; and iv) long-term loss of natural vegetation and organic matter (UN, 1994). It is a gradual process that has been going on for decades as a result of various factors and unsustainable agricultural systems and practices, and has been driven by increased demand for food, population growth and agricultural intensification. Expanding markets, population growth, economic development, and rising incomes, have boosted demand for agricultural land, and imposed intensive management practices and techniques, driving unprecedented land-use change (FAO & ITPS, 2015).

FAO estimates that around 33% of the world's soils are degraded (FAO & ITPS, 2015), with intensive agriculture being one of the main drivers. Cropland accounts for approximately 18% of the global total of degraded land (Bai et al., 2013). Soil degradation is estimated to cost the global economy between $18-20 trillion annually (UNCCD, 2017). However, there are international efforts to help halt and reverse these alarming rates of degradation globally, as well as to combat desertification (UNCCD, 2017). Various global policies, including the United Nations Sustainable Development Goals (SDGs), directly and indirectly include land and soil. Many of these SDGs cannot be achieved without healthy soils and sustainable land use. Specifically, SDG 15.3 aims to achieve land degradation neutrality by 2030. (EEA, 2019).

However, the global policies and initiatives currently under way fall short of setting targets and commitments, especially binding ones (EEA, 2019).

Additionally, further loss of productive soils would severely damage food production and food security, increase food price volatility, and potentially plunge millions of people into hunger and poverty (FAO & ITPS, 2015).

However, this loss of soil resource and its functions can be avoided. Sustainable soil management (emphasising the importance of conserving and improving soil health through practices such as CA along with complimentary practices of integrated crop, nutrient, pest, water and energy management, and the adoption of agroforestry practices, based on scientific knowledge, local knowledge, and proven, evidence-based approaches and technologies, can increase land productivity and food supply, and provide a valuable tool for climate regulation and safeguard ecosystem services (FAO & ITPS, 2015). Indeed, the Assessment Report on Land Degradation and Restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018) states that it is cheaper to preserve land and soil resources than to restore or repair them.

Soil and United Nations Sustainable Development Goals

Many global policy frameworks, including the United Nations Sustainable Development Goals (SDGs), directly and indirectly address land and soil. Many of these SGDs cannot be achieved without healthy soils and a sustainable land use. Below is an overview of the SDGs with strong links to soil.

Take urgent action to combat climate change and its impacts. Soil can play a positive role in reducing the impacts of climate change, by sequestering CO2, sustainably managing the resource and restoring degraded soils.

“Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.”

Improving the quality of land and soil to “end hunger, achieve food security and improved nutrition and promote sustainable agriculture.”

“Ensure healthy lives and promote well-being for all at all ages” by preventing dangerous chemicals, air and water pollution from contaminating land and soil. Additionlly, reducing soil degradation can help to increase food production.

Figure 1.1. Soil and United Nations Sustainable Development Goals. Source: United Nations Sustainable Development Goals.

“Ensure sustainable consumption and production patterns,” through making sure chemicals and waste does not make its way into the air, water and soil, which can have adverse impacts on our health and environment. That is why it is important to sustainably manage and efficiently use soil resources.

“Make cities and human settlements inclusive, safe, resilient and sustainable,” by ensuring land and soils are protected as they safeguard our cultural and natural heritage.

“Ensure availability and sustainable management of water an sanitation for all,” by preserving soil quality because of the role it plays in helping to provide clean water for drinking and agriculture.

1.2 BIODIVERSITY IN EUROPE'S AGRICULTURAL ECOSYSTEMS

The situation in Europe is no different. According to Eurostat (2022), almost 40% of Europe's land area is devoted to agriculture. However, since the mid-20th century, the accelerated conversion of natural areas into farmland, the fragmentation of the landscape, the introduction of agricultural machinery, the widespread and excessive use of pesticides and fertilisers, the expansion of monocultures and soil erosion are the main pressures on agricultural fauna and flora. This has been responsible for the high degree of biodiversity loss and degradation of agricultural ecosystems (EEA & UNEP, 2002).

In the European Union (EU):

- 81% of habitats are in poor status.
- 18% of the total area is part of the Natura 2000 network of protected areas, the EU-wide ecological network of biodiversity conservation areas that includes Special Areas of Conservation (SACs) and Special Protection Areas for Birds (SPAs), designated under the Habitats and Birds Directives, respectively.
- The goal is to reach 30% of protected areas by 2030 (EC, 2023a).

Although the situation of agricultural ecosystems in Europe varies according to regions, countries and soil and climatic conditions, trends and challenges are common in the face of critical levels of habitat and biodiversity loss (Bourlion & Ferrer, 2018).

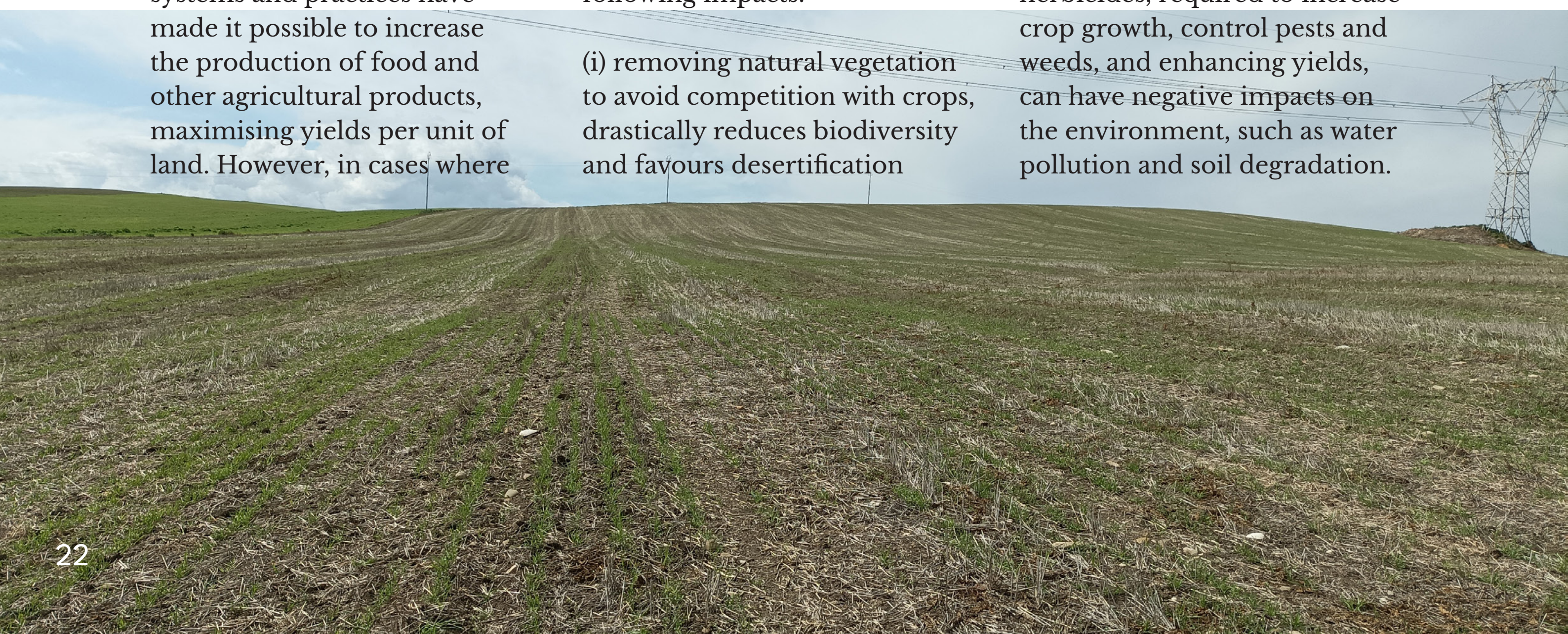
Agricultural intensification

In Europe there is strong pressure to increase agricultural productivity due to population growth, food and energy demand and competitiveness in international markets. The use of technologies such as advanced machinery, efficient irrigation systems, monitoring and control systems, precision farming, genetically improved seeds and intensive farming systems and practices have made it possible to increase the production of food and other agricultural products, maximising yields per unit of land. However, in cases where intensification was accompanied by using inadequate agricultural and soil management practices such as intensive tillage, narrow rotations or inappropriate use of agricultural inputs it led to detrimental effects on soil health and functionality leading to soil erosion, compaction and contamination (Van Oost et al, 2006; De Graaff et al., 2019; EEA, 2023), in addition to the following impacts:

(i) removing natural vegetation to avoid competition with crops, drastically reduces biodiversity and favours desertification processes, especially in arid and semiarid climates;

(ii) monocultures on large tracts of land leads to loss of landscape heterogeneity and specialisation can increase vulnerability to diseases and pests;

(iii) an inappropriate use of chemical inputs, such as fertilisers, pesticides and herbicides, required to increase crop growth, control pests and weeds, and enhancing yields, can have negative impacts on the environment, such as water pollution and soil degradation.



Landscape fragmentation

Landscape fragmentation occurs when a large area of land is divided into smaller fragments due to the expansion of agricultural or other human activities. Already in 2013, the report Landscape Fragmentation in Europe, published by the European Environment Agency (EEA) and the Swiss Federal Office for the Environment (FOEN) indicated that roads, motorways, railways, intensive agriculture and urban development were breaking Europe's landscapes into smaller and smaller pieces, with potentially devastating consequences for flora and fauna across the continent. Despite a slowdown between 2012 and 2015, landscape fragmentation continues to increase in the 39 EEA member countries (EEA, 2022).

This trend, still increasing, due to the expansion of cities and concrete infrastructure (EEA, 2019), has caused, among others, the following adverse effects:

(i) loss of natural habitats and biodiversity by transforming areas of forests, grasslands and wetlands, into agricultural land;

(ii) fragmentation of ecosystems, by dividing continuous ecosystems into smaller, isolated fragments, hindering the movement of species and interaction between different populations;

(iii) loss of biodiversity, either through total destruction of habitat for many species or through their degradation in terms of food, reproduction and shelter; and

(iv) impairment of the provision of ecosystem services that a healthy, non-fragmented ecosystem provides, such as crop pollination, climate regulation, water purification, prevention of soil erosion.

In parallel to the above, and caused by urban sprawl, there is a perverse effect of loss of fertile agricultural land, as most European cities were built on and surrounded by fertile land. It is these areas that are occupied and covered by artificial surfaces (EEA, 2019).

Soil depletion

In the case of agricultural ecosystems in Europe, intensive land use, excessive use of fertilisers, unsustainable farming practices and lack of crop rotation are leading to a loss of soil quality, reducing soil productivity and increasing dependence on external inputs through:

(i) nutrient loss, as monocropping practices deplete levels of essential nutrients, such as nitrogen, phosphorus and potassium, needed for plant growth. Likewise, the loss of organic matter decreases the soil capacity for nutrient retention and natural fertility;

(ii) soil erosion, due to inadequate soil management, such as excessive use of heavy ploughing machinery and lack of vegetative cover. Soil erosion is thus a complex phenomenon involving two processes: the breakdown of aggregates and the transport of the resulting fine particles to other locations, resulting in the loss of the fertile soil layer. In addition to the loss of the soil layer, which contributes to desertification, washed away particles can act as a vehicle for pollution transmission (pesticides, metals, nutrients, minerals, etc.). Erosion can be caused by any human activity that exposes the soil to the impact of water or wind, or that increases the flow and velocity of runoff water (Orgiazzi et al., 2016). The loss of fertile soil can negatively affect crop productivity and reduce the soil's capacity to retain water;

(iii) soil compaction, due to the intensive use of heavy agricultural machinery, which reduces porosity and hinders water flow and adequate aeration of plant roots. As a result, roots may have difficulty accessing the nutrients and water needed for optimal growth;

(iv) soil structure degradation due to improper management and excessive use of machinery, which alters soil structure, breaking down aggregates and reducing the capacity to retain water and nutrients;

(v) biological degradation due to loss of organic matter, due to the use of practices such as intensive agriculture, burning of crop residues in situ and burning of weeds in grazing areas, among others (Orgiazzi et al., 2016).

Use of plant protection products (PPP) and fertilisers

The use of plant protection inputs is common and plays an important role in the control of pests, diseases and weeds, as well as in increasing agricultural productivity in the European farming system. However, inappropriate use of these products can lead environmental and health impacts such as: water pollution, loss of biodiversity, pest and weed resistance, loss of fertility, soil contamination and toxicity to human health. Society is increasingly concerned about the use of agricultural inputs. The application of good agricultural practices in combination with modern technologies including digital and precision agriculture bear a great potential to reduce and optimize the use of these inputs.

- Plant protection products such as herbicides and pesticides are used to control weeds, that compete with crops for nutrients, water and space; and to control pests and diseases on crops, they include insecticides, fungicides, nematicides and other chemicals The use of PPP without following label advice can create an imbalance in the system, which can lead to soil and water pollution through runoff and which might impact soil biodiversity e.g. by changing species composition. Improper use of PPP can encourage the development of pest and weeds resistance, which can lead to higher doses being used, so label recommendation should be strictly followed.

- Fertilisers are used to provide essential nutrients to crops and improve their growth and yield. The most common are chemical fertilisers containing nitrogen, phosphorus, and potassium. Their excessive or incorrect use can contribute to water pollution, eutrophication of water bodies or soil acidification or salinization In Europe, although there has been a decrease in nitrogen emissions from agriculture, nutrient levels still exceed the maximum critical load in most countries (EEA, 2010).

As is evident, conservation of biodiversity in agricultural ecosystems requires a balanced combination of food production and preservation of habitats and species. The promotion of sustainable agricultural practices, such as CA-based integrated pest and weed management, can contribute to the improvement of biodiversity, soil health and water quality, while maintaining productivity.

Biodiversity in Europe's and the world's agricultural ecosystems is not only essential for the health of the environment, but also for the resilience of food systems, the quality of life of rural communities and food security. For example, pollination is crucial for life on Earth. Pollinators affect 35% of the world's agricultural land and support the production of 87 of the world's major food crops (EEAS, 2022). The challenge is to identify ways to manage land and resources sustainably, integrating biodiversity conservation into agricultural planning and building on traditional knowledge and technological innovations. Cooperation between farmers, scientists, policy makers and society at large will be crucial to achieve the necessary balance between food production and the protection and restoration of Europe's biodiversity.

1.3 EUROPEAN REGULATORY FRAMEWORK FOR THE CONSERVATION OF BIODIVERSITY IN AGRICULTURAL ECOSYSTEMS

The degradation of agricultural ecosystems is recognised as a threat to the sustainability of agriculture and environmental conservation in Europe. The European framework for biodiversity conservation aims to ensure the protection and restoration of ecosystems and species in Europe, promoting a more sustainable and environmentally friendly approach in different sectors of the economy and society.

The first biodiversity protection measures in Europe date back to the 1970s. Since then, concern has grown as the challenges have been recognised and the negative impacts of human activity (WEF, 2020), on ecosystems and biodiversity have been better understood, which is evidenced by an increasingly strong regulatory framework "*Agrifood policies need to sustainably, responsibly and inclusively manage natural resources while tackling climate change and minimizing food loss and waste"* (FAO, 2022, § 28).

The European framework for biodiversity conservation is made up of multiple policies, strategies and agreements established by the EU and its Member States to address and halt biodiversity loss and protect the continent's natural wealth. Among them, the key elements in relation to biodiversity conservation in agricultural ecosystems are:

EUROPEAN GREEN DEAL

The European Green Deal is a European Commission initiative launched in 2019, that sets out a roadmap for making Europe the first climate-neutral continent by 2050, by boosting the economy, improving health and quality of life, and protecting nature.

The objectives of the EU Green Deal are (EC, 2022a):

- Ensuring food security in the face of climate change and biodiversity loss,
- Reducing the environmental and climate footprint of the EU food system,
- Strengthening the resilience of the EU food system, and
- Lead a global transition to competitive farm-to-fork sustainability.

This ambitious plan addresses a range of environmental and social challenges, promoting sustainable and inclusive economic development. This initiative is closely linked to the conservation of agricultural ecosystems, by promoting more environmentally friendly agricultural practices. Some of the key points, according to the EEA (2019), are:

>> **Sustainable Agriculture.** The European Green Deal promotes the adoption of more sustainable agricultural practices that mitigate environmental impacts, such as input optimisation, organic farming and systems that promote crop diversity and soil health, such as CA and other Regenerative Agriculture systems.

>> **Reduction in the use of plant protection products.** It aims to reduce the environmental footprint of the EU food system, protecting the health and well-being of citizens and agricultural workers, helping to mitigate the economic losses that are occurring due to deteriorating soil quality and pesticide-induced loss of pollinators (EC, 2023b). Although progress has been made with the Directive on the sustainable use of pesticides (DIRECTIVE 2009/128/EC), legislation has proved to be too weak and has been unevenly implemented. Nor has sufficient progress been made in the use of integrated pest management, as proposed by Conservation Agriculture, or alternative approaches (EC, 2022a).

>> **Conservation and restoration of agricultural landscapes and ecosystems.** Traditional agricultural ecosystems such as meadows, hedgerows, wetlands, and arable fields, are home to a large number of species of flora and fauna. The European Green Deal recognises the importance of preserving these agricultural landscapes as critical habitats for biodiversity, and the urgent need to restore degraded ecosystems through reforestation of degraded areas, restoration of wetlands or promotion of practices that improve soil health (Benayas & Bullock, 2012).

>> **Incentives for Biodiversity.** The European Green Deal, in support of the transition to more sustainable food production systems, proposes the creation of financial incentives for farmers who implement practices that promote biodiversity and sustainability on their farms, such as subsidies for conversion to organic farming, direct payment programmes for environmental services, funding for investments in sustainable technologies, and agricultural education and advisory programmes, among others (EC, 2022a).

>> **Research and Innovation.** The European Green Deal (2020) encourages investment in research and innovation in the agricultural sector in the search for technological and practical solutions that improve biodiversity conservation and sustainability (EC, 2023c).

Soil is an essential and non-renewable resource for agriculture, providing the basis for the production of food, fibre, and other resources. Soil also plays a key role in the conservation of biodiversity in agricultural ecosystems, in carbon capture and storage, and provides other ecosystem services such as water regulation and nutrient cycling (EC, 2023c). To protect these and other vital functions and ecosystem services, the CAP supports sustainable soil and land management through support measures and subsidies to farmers to promote soil and water conservation, biodiversity protection and the implementation of sustainable farming practices, such as organic farming, environmental management, landscape conservation, crop diversification, resource efficiency and environmental protection. The new CAP 2023-2027, which entered into force on January 1, 2023, articulates environmental considerations through Eco-schemes. Its objectives (EC, 2022b) include:

- To support farmers in improving agricultural productivity, to ensure a stable food supply and in increasing the profitability of their farms, thus ensuring an improvement in their living conditions.

- Supporting farmers in the transition to a more sustainable and environmentally friendly model, preserving soil and biodiversity and conserving landscapes and rural areas, thus contributing to the fight against climate change and the sustainable management of natural resources.

- Strengthen the development of rural communities and invigorate their economy, boosting employment in agriculture, agri-food industries, and associated sectors.

GREEN COMMON AGRICULTURAL POLICY (CAP)

The CAP is the EU's agricultural policy, created in 1962, representing a partnership between Europe's agriculture, society, and its farmers.

EU BIODIVERSITY STRATEGY 2030

This strategy, presented in 2020, is a central component of the European Green Deal, and sets out the EU's objectives for biodiversity conservation and restoration.

It aims to halt biodiversity loss, and restore Europe's damaged ecosystems by 2030, as well as ecosystem services essential for human well-being. In particular, it sets among its objectives the legal protection of at least 30% of the EU's land area and 30% of the EU's marine area, and the incorporation of ecological corridors within a genuine Trans-European Network of Natural Areas.

Unsustainable land and sea use, overexploitation of natural resources, pollution, and invasive alien species, are the main drivers of biodiversity loss addressed by this Strategy.

FARM-TO-FORK STRATEGY

The ecological transition of economies is one of the most important challenges to be faced. The aim of the Farm to Fork strategy, is to move towards more sustainable, fair, healthy, and environmentally friendly food systems, which will build resilience to potential crises or disasters.

Food systems are responsible for almost one third of global greenhouse gas emissions (Crippa et al., 2021). They are also polluting, consume large amounts of natural resources and are responsible for biodiversity loss, as well as for enhancing economic and social asymmetries.

This important strategy is based on the following principles:

i. have a neutral or positive environmental impact;
ii. contribute to climate change mitigation and adapt to its impacts;
iii. reverse biodiversity loss;
iv. guarantee food security, nutrition and public health, ensuring that all people have access to sufficient, safe, nutritious and sustainable food; and
v. ensure the availability of affordable food, while generating higher economic returns, fostering the competitiveness of the EU supply sector and promoting fair trade (EC, 2022c).

In summary, the European framework for the conservation of biodiversity in agricultural ecosystems, aims to ensure the protection and restoration of agricultural ecosystems and their biodiversity in Europe, promoting a more sustainable and environmentally friendly approach.

Today, knowing the challenges facing the continent, 50 years after Europe's first biodiversity protection measures, there is a much more robust regulatory framework in place to control biodiversity loss in agricultural ecosystems and to restore ecosystems. However, it should be stressed that biodiversity protection is an ongoing challenge that requires constant and coordinated effort at all levels, from international policies to local actions.

> ***"Positive production for nature in agri-food systems depends on all actors understanding and playing their roles in protecting natural resources for future generations."***
>
> ***(FAO 2022).***

1.4 SUSTAINABLE SOLUTIONS

Against this background, there is a clear need to seek and implement positive solutions with nature that address the root causes of degradation of agricultural ecosystems. These solutions focus on conserving biodiversity, improving soil health, reducing pollution, and promoting more environmentally friendly agricultural practices, as well as enhancing food security.

Sustainable agriculture is an approach that seeks to balance agricultural production with environmental protection, conservation of natural resources and long-term social and economic well-being. According to this approach, agriculture should meet the needs of present and future generations, ensure profitability and environmental health, and promote social and economic equity, through practices that maximise environmental, social, and economic benefits while minimising potential negative impacts.

Accordingly, CA is positioned as an ally in tackling the degradation of agricultural ecosystems in Europe and worldwide. It consists of the application of various agronomic practices of agricultural soil management that alter its composition, structure, and biodiversity as little as possible, reducing the risk of erosion and degradation, considerably increasing the energy efficiency of agriculture (Gil Ribes, 2007).

CA is based on the application of three interlinked principles, namely: continuous no or minimum mechanical soil disturbance, permanent soil mulch cover and crop diversification. Its main benefits, in terms of soil conservation, biodiversity, climate change mitigation and economic sustainability, have been widely studied, and there is a large body of scientific evidence of how CA can be a positive and effective solution (Kassam, 2020):

- Prevention of soil pests and diseases: Different crops have different nutrient demands and different root systems, so crop rotation helps to maintain a nutritional balance in the soil and reduces the need for chemicals (Ryan et al., 2008).
- Improvement of organic matter content: Avoidance of soil disturbance (No-till) and crop biomass retention favours the increase of soil organic matter, since approximately 50% of the weight of crop biomass corresponds to carbon, hence its importance as a source of organic carbon in agricultural soils (Crovetto, 2002). Crop biomass and cover crops, in addition to improving organic matter content, protect the soil from erosion, improve soil structure, maintain soil moisture, and provide habitat for beneficial soil organisms (Blanco-Canqui et al., 2015).
- Biodiversity enhancement: minimising soil disturbance and encouraging the presence of cover crops or crop biomass, creates an environment conducive to soil biodiversity, beneficial insects, reptiles, birds and small mammals. This can help control pests naturally and improve soil health (Day et al., 2020).
- Reduction of erosion: erosion of fertile soil is directly related to desertification processes. In general, CA reduces soil erosion by up to 90% (Gil Ribes, 2007) respectively. Compared to conventional tillage, CA limits soil compaction and degradation, and helps maintain soil structure and its capacity to retain water and nutrients (Holland, 2004).
- Carbon sequestration: CA can increase the amount of organic carbon in the soil, which contributes to climate change mitigation by sequestering atmospheric carbon (González-Sánchez et al., 2012).
- Reduced Emissions: by avoiding tillage, the emission of greenhouse gases associated with soil disaggregation is minimized (Cabonell-Bojollo et al., 2011).

- >> Improving surface water quality: by reducing erosion, runoff and nutrient flushing, CA can help improve water quality in nearby rivers and water bodies. In addition, plant residues from the previous harvest contribute to the retention of fertilisers and pesticides (Ordóñez-Fernández et al., 2007).

- >> Savings in production costs: by not tilling, CA consumes less fossil fuel, resulting in cost savings (ECAF, 2023).

- >> Saving time for agricultural work: by not tilling, farmers have more free time or need to hire fewer labourers (ECAF, 2023).

- >> Water saving: the water holding capacity of a soil depends on the management conditions, being higher in CA fields (Vanderlinden, et al., 2021).

- >> Economic sustainability: although transition to CA require changes in practices, in the long term it can improve the resilience of farming systems and reduce costs associated with external inputs such as diesel, pesticides and fertilisers (ECAF, 2023).

- >> Integrated Pest Management: this strategy is built into CA and involves combining different methods to control pests, such as the use of natural enemies of pests, traps, and cultural techniques, minimising the need for pesticides.

- >> Rational use of phytosanitary inputs: the promotion of integrated pest management and fertilisation in CA based on ecological principles reduces dependence on chemical inputs such as pesticides and synthetic fertilisers. The aim is to minimise negative impacts on the environment and human health, while maintaining adequate levels of productivity.

Other positive solutions for nature would be:

- **Organic farming based on CA principles:** Organic farming minimises the use of synthetic chemicals, encourages crop diversity and promotes soil health. The absence of chemical pesticides and fertilisers helps to maintain biodiversity and soil quality, provided that tillage for crop establishment and weed management is avoided and the soil is covered with biomass mulch.

Source: Day et al., 2020.

- **CA-based Agroforestry:** Agroforestry combines tree planting with agricultural production similar to CA system with perennial crops. Trees help prevent soil erosion, provide shade and habitats for wildlife, and can improve soil fertility (Mosquera-Losada & Prabhu, 2019).

- **Biological control:** using living organisms to control pests and diseases instead of chemical pesticides reduces pollution and preserves biodiversity.

- **Hedgerow and Riparian Forest Conservation:** maintaining hedgerows and riparian forests in agricultural areas, provides shelter and food for wildlife, prevents erosion, and improves water quality (Reichenberger et al., 2007).

- **Efficient Water Use:** the implementation of efficient irrigation systems and water management practices, helps to conserve this scarce resource and reduce environmental degradation.

- **Restoration of Degraded Land:** rehabilitation of degraded areas through reforestation, planting of native species and habitat restoration, contributes to the recovery of ecosystems.

- **Changing dietary habits:** Changing consumer behaviour and agri-food innovations in relation to sustainable healthy diets (FAO & WHO, 2019) can address the triple challenge posed by nutrition, overpopulation, and climate. A healthy diet can help the environment by reducing the water and carbon footprint caused not only by food production, but also by reducing the health costs associated with poor eating habits (National Geographic, 2021).

- **Community participation and social equity:** Sustainable agriculture encourages the participation and collaboration of local communities, farmers and other relevant stakeholders in decision-making and the implementation of sustainable agricultural practices. It also seeks to ensure social and economic equity by promoting fair trade practices, access to resources and opportunities for all farmers, including small farmers and rural communities.

- **Education and Awareness Raising:** Promoting education and awareness-raising among farmers and society at large about the benefits of sustainable practices, can encourage their adoption.

These and other sustainable solutions, not only contribute to the conservation of agricultural ecosystems, but can also improve long-term productivity, reduce environmental risks and promote greater resilience in agriculture.

Through the adoption of sustainable practices promoted by CA systems, the agricultural sector can play a key role in conserving natural resources and building more resilient and equitable food systems.

CHAPTER 2

CONSERVATION AGRICULTURE: FUNDAMENTALS OF A SUSTAINABLE AND BIODIVERSITY-ENHANCING MANAGEMENT SYSTEM

2.1 CONSERVATION AGRICULTURE SYSTEM

Conservation Agriculture (CA) is defined as an integrated system of agricultural production and land use that is applicable to all rainfed farming and irrigated farming systems, including annual, perennial, and mixed systems, orchards, agroforestry and plantation systems, crop and livestock systems, as well as pasture and rangeland systems. According to FAO (FAO, 2023), CA is described as an ecosystem approach to sustainable regenerative agriculture and land management, based on the practical application of three interrelated context-specific and locally adapted principles, namely:

>> **Continuous no or minimum mechanical soil disturbance** (direct sowing/ no tillage): this principle is implemented through the practice of no-tillage seeding, directly placing the seeds without ploughing, and controlling weeds without ploughs. The aim is to minimise any soil disturbance, and to improve soil quality by: controlling erosion, controlling organic matter loss, promoting biodiversity and microbiological processes, protecting, and improving structure by not hindering the movement of gases and water, and promoting overall soil health and functions, including improved retention of moisture, plant nutrients and soil carbon. In parallel, no-till reduces labour and energy requirements, greenhouse gas emissions, and contributes to the integrated management of adventitious weeds, insect pests, pathogens, and nutrients, as well as to overall resilience and sustainability.

>> **Permanent maintenance of a biomass mulch cover on the soil surface:** this principle is implemented through the permanence of crop biomass, stubble and cover crop biomass and other forms of biomass from ex situ sources. In this sense, it has been verified that a minimum of 30% permanent cover is required as a threshold for soil protection. The use of crop residues (including stubble) and cover crops reduces soil erosion, protects soil surface, increases water infiltration rates, reducing runoff, conserves water and nutrients, supplies organic matter and carbon to the soil system, promotes soil biodiversity and microbiological activity that maintains and improves soil health and functions, including aggregate structure and stability (as a result of glomalin production by mycorrhizae), better capture and retention of water, plant nutrients and soil carbon; and, like the previous principle, contributes to integrated management of weeds, insect pests, pathogens and nutrients, as well as overall resilience and sustainability.

>> **Species diversification:** this principle is implemented through the adoption of economically, environmentally, and socially adapted crops in rotations and/or sequences and/or associations that may involve annual and perennial crops, including a balanced mix of leguminous and non-leguminous crops, and cover crops where possible. The use of diversified cropping systems contributes to diversity in root morphology and composition, improves soil biodiversity and microbiological activity, accumulates organic matter in the soil, and improves nutrition and crop protection through suppression of pathogens, diseases, insect pests. Crops may include annual plants, short-term perennial plants, trees, shrubs, nitrogen-fixing legumes, and grasses, as appropriate. Of the three principles, it is the latter that contributes most to the integrated management of adventitious weeds, insect pests, pathogens, and nutrients.

These principles are applied along with other locally adapted complementary practices including integrated crop, soil, nutrients, pest, water, machinery and energy management.

Figure 2.1. CA three interrelated context-specific and locally adapted principles.

2.2 CONSERVATION AGRICULTURE PRACTICES

Practices required to implement the CA system, differ according to local conditions, and needs. However, they should consider the following characteristics based on optimising root zone and soil surface conditions (Kassam & Kassam, 2020), which are essential for:

a) Biotic activity.
b) Water supply and crops.
c) Securing soil structure and porosity.
d) Protection against weeds, pests, and pathogens.

Likewise, CA practice should also provide resilience to extreme climatic events, especially waterlogging and flooding, drought, and heat stress. Techniques should therefore enhance:

> Rainwater infiltration, which will result in reduced runoff and optimised soil water retention.
> Minimise compaction.
> Reducing diurnal temperature ranges in upper soil layers.
> Supplying carbon-rich organic matter to the soil.
> Minimise loss of organic matter through oxidation.
> Maintaining nitrogen levels in the soil.
> Optimising phosphorus availability.
> Promote integrated management of weeds, pests and pathogens.
> Resilience to the effects of biotic and abiotic stresses.

Practices related to CA principles favour the sustainability of production and the conservation and enhancement of soil biodiversity and ecosystem services (Lal, 2013; Jayaraman et al., 2021).

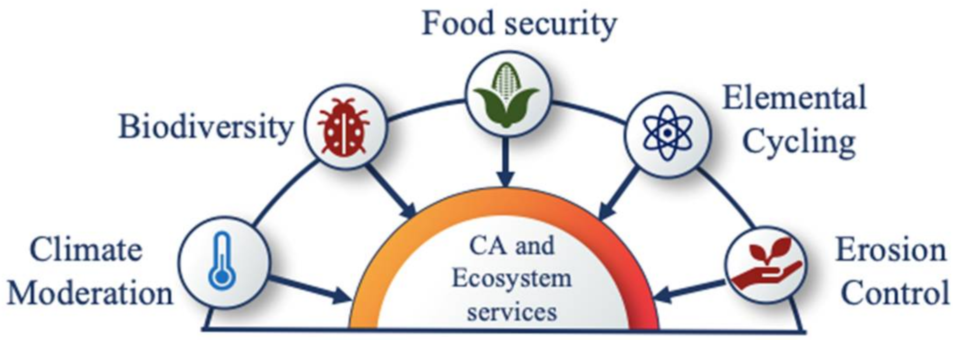


Figure 2.2. CA and ecosystem services. Source: Jayaraman et al., 2021.

CA principles improve hydrological, biological, physical, and chemical soil conditions related to productive capacity. In general, to achieve sustainable intensification, CA practices need to be complemented by good production and management practices (Lal, 2018), such as:

- Use of adapted varieties and quality seeds.
- Good crop nutrition based on soil health enhancement.
- Integrated insect pest, disease and weed management.
- Efficient water management.
- Proper handling of machinery and equipment and their transit in the field to avoid compaction.

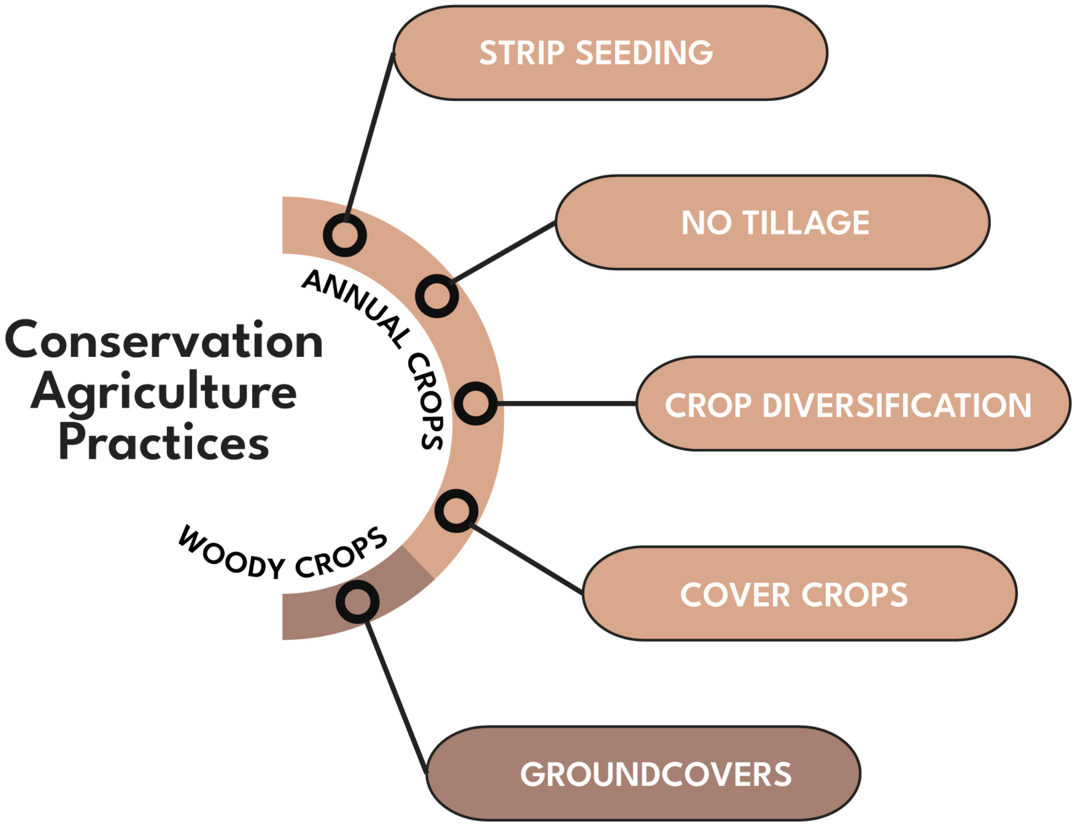
Therefore, sustainable soil and land management depends on the type of crop(s) and the particular conditions of the area being managed. Furthermore, CA principles must be integrated with complementary practices that allow for the optimisation of production inputs. Sustainable production systems are dynamic systems that offer different combinations or practices that should be prioritised according to particular conditions and possible local production constraints (Kassam et al., 2009).

Development of sustainable systems such as CA requires consideration of, among others, the following criteria:

- Maintenance of the root zone environment to optimise soil biota conditions (Kell, 2011). In this way, roots can perform their function without restriction, capture and retain water and nutrients, as well as interact with micro-organisms beneficial to the health of the soil and the crop.

- Maintenance and improvement of soil structure. To this end, mechanical disturbance of the soil must be limited in the handling and preparation of the crop. This preserves soil aggregates and facilitates water infiltration. In addition, a well-structured soil is less susceptible to erosion than a disaggregated soil.

- Maintenance and improvement of soil organic matter (SOM). This is achieved by maintaining the carbon input provided by a biomass soil cover, both living and non-living biomass. In addition, reducing mechanical disturbance minimises oxidation of SOM, thus improving natural soil fertility and productivity (Lal, 2010).



2.2.1 Practices in annual crops

To comply with the no or minimum mechanical soil disturbance principle, the evolution of agricultural practices has historically been directed towards a reduction of tillage. Originally, the term 'conservation tillage' was used, as defined by the Soil Science Glossary Terms Committee (2008), as "any sequence of tillage where the aim is to minimise or reduce soil and water loss; operationally, a tillage or combination of tillage operations that leaves at least 30% residue cover on the surface". Conservation tillage describes a series of practices that vary in their tillage intensity, which has evolved towards no soil disturbance, no-tillage (or zero-tillage). Thus, the term minimum or reduced tillage limits primary or secondary tillage for crop production, reducing operations compared to conventional tillage. Soil should be disturbed only vertically, without soil inversion tools, and at least 30% soil cover should be left after crop establishment. Minimal tillage is considered a conservation practice of a lesser degree than no tillage or a transition to minimum soil disturbance.

Different practices are included in so-called conservation tillage, however, not all of them should be included as true Conservation Agriculture practices (Reicosky, 2015). For this study, including literature review, no tillage and minimum disturbance strip seeding practices have been considered for annual crops, as well as diversified crop rotation including cover crops are considered as CA practices.

i. Strip seeding

Minimum soil disturbance strip seeding is an integrated practice in CA systems. This practice limits soil disturbance to a 15 cm band in which the seed is placed, thus keeping the soil and biomass mulch cover between crop rows undisturbed. Equipment must be used with precision, as if excessive soil disturbance or residue removal occurs, the percentage of soil that will be covered after sowing will be less than 30% (González-Sánchez et al., 2015).

In strip seeding, seedbed preparation, seeding, fertilisation and application of crop protection products processes can generally be carried out in a single pass, thus reducing working time, manpower and fuel consumption.

Equipment of a strip seeding machine includes row markers, opening discs, coulters and furrow covering discs on each sowing unit. After closing the furrow with the covering disc, other accessories are often added to condition and smooth the soil surface of the seed bed.

In some conditions, especially in arid areas or on heavy soils, strip seeding can lead to better crop establishment, especially in mono-grain crops (corn, sunflower, etc.). In addition, this type of seeding allows nutrients to be localised in the sowing line, providing cover between rows. Coverage is usually above 50% after sowing and remains above 30%.

Figure 2.3. Strip seeding machine. Source: Empresa Agraria.

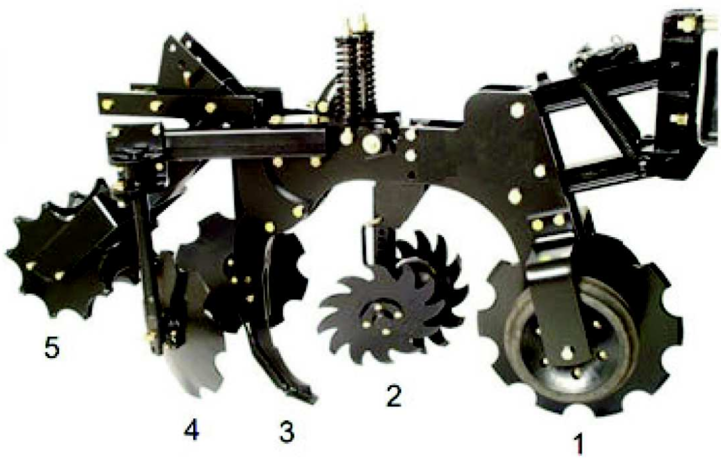


Figure 2.4. Typical components of a strip seeding unit: (1) Opening disc; (2) biomass mulch managers; (3) coulter and fertilizer injector; (4) cover disc; (5) seedbed conditioner. Source: Husti et al., 2016.

ii. No tillage

No-tillage (No-till or NT) is the best form of applying the no or minimum soil disturbance principle. It is considered a CA practice if the cover is maintained, retaining the straw or plant biomass that is not removed from the land but retained as a mulch cover. In No-Till, a direct seeder (No-till drill) is needed for seeding through a biomass mulch layer. Thus, 'direct seeding' or 'direct sowing' are used as synonyms of the term No-tillage as well as of 'Zero-tillage'. This practice aims to establish a crop directly in a seedbed without prior mechanical preparation (Kassam et al., 2009). When introducing this practice, the altered soil area should be in lines less than 15 cm wide (disturbance by the seed drill to place the seed) and less than 25% of the total soil surface should be affected by this minimum disturbance.

Figure 2.5. Winter wheat on rapeseed stubble in no-tillage. Source: Anne Kjærsgaard (FRDK).

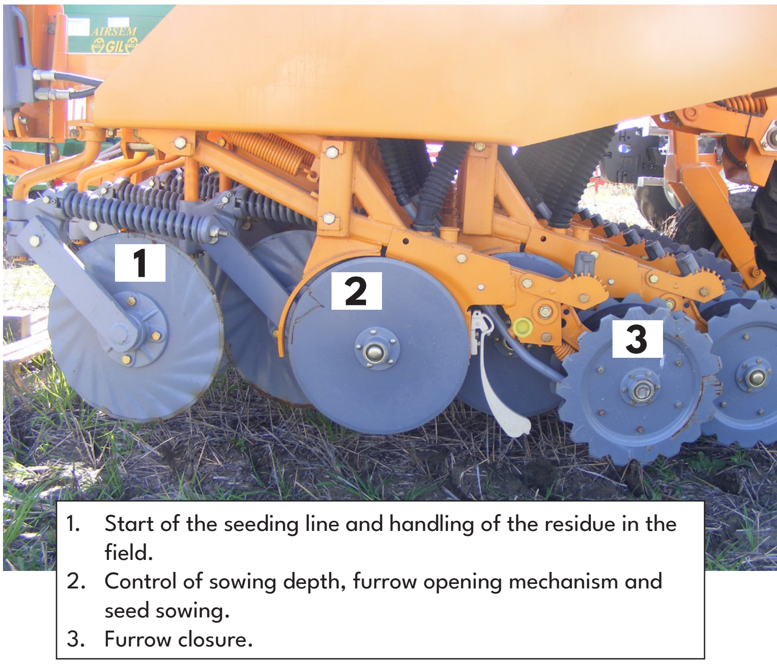


Figure 2.6. Sowing unit of a direct sowing seeder. Source: ECAF.

To establish this practice correctly, start with the harvest of the previous crop, evenly spreading the straw at harvest, so that there is not a large variation in the amount of residue over which the machine will sow. This requires the combine harvester to be equipped with certain accessories, such as straw spreaders and deflectors.

For sowing on residues, it is necessary to place the seed in the soil in such a way as to encourage germination and development with minimum disturbance of the soil surface. Direct sowing seeders are equipped with a cutting disc for plant debris at the beginning of the sowing train to ensure the placement of the seed in the soil.

Direct sowing seeders have a more solid and robust seeding train, which exerts more weight or force on the soil to ensure proper residue cutting and seed placement. Its elements must have adequate strength to withstand working conditions of increased ground pressure. Likewise, direct sowing seeders must be able to regulate the seed rate and spacing, as well as being adequately covered. They should be easily adjustable to suit different crops and apply fertilisers and crop protection products simultaneously, where necessary.

Direct sowing seeders required for no tillage are basically of two types:

- Direct *disc coulter* seeders

In this type of seeder, components that allow the furrow to be opened for sowing are single or double discs. In both cases, discs are inclined with respect to the ground surface, and are mounted in the direction of travel of the machine. Single disc seeders do not usually have a front cutter, as the discs perform the functions of cutting and opening the seed furrow. The outer edge of the disc can be smooth or grooved, the latter giving better results in relation to straw cutting. In the case of discs, it is advisable to chop the longest straw so that it can be cut more effectively.

- Direct *tine coulter* seeders

  This type of seeders uses coulters to open and close a narrower seed furrow than that produced by conventional seeders. In this case, the coulter seeder opens the furrow by cutting vertically, considerably reducing the pressure required to achieve the desired sowing depth. This type of seeders requires a minimum distance between the arms to avoid the accumulation of debris from the previous crop, which would reduce the efficiency of the sowing. A chopping system that leaves the straw shorter, facilitates the movement of the residue between different sowing units.

In addition to the *discs* or *coulters* as furrow-opening elements, these seeders are equipped with a (single or double) furrow-closing wheel, which presses down after the seed has been placed. Sometimes they are equipped with harrows afterwards to smooth the soil surface.

Previously, in the sowing train, in cases where there is excess residue, furrow pre-opening elements can be placed (before the discs or coulters) to clean the residue on the sowing line before opening the furrow.

These seeders perform important functions, such as creating the right soil microenvironment for the seed. These must be designed to work properly in terrain with surface variations and to travel over a certain amount of debris without obstruction. With the right equipment, no-tillage not only does not compromise crop success, but the risk of crop problems and possible yield losses is often reduced compared to conventional management, even in the short term (Baker et al., 2007).

iii. Crop diversification

Crop diversification through crop rotation is necessary in herbaceous crops to reduce weeds, pests, and diseases, as well as to diversify the root zone and improve soil aggregates. It is recommended to use species that are economically, environmentally, and socially well adapted to the soil and climatic conditions of the area, and to pay attention to the sequence and cycles of crops. A well-designed crop rotation can help achieve better yields, maintain soil fertility, and control unwanted flora (Jabran et al., 2017). Monoculture or a crop rotation with very similar or few crops in sequence favours the emergence of weeds with a niche like that of the crop (Dorado et al., 1999).

Diversity in root morphology and composition improves soil biodiversity and microbiological activity, builds soil organic matter, improves crop nutrition, and helps prevent the build-up of pest populations by breaking the pest cycle (Ryan et al., 2008). In addition, it has a positive impact on soil structure as aggregates are improved (Kassam et al., 2009).

From a soil protection point of view, starting the crop sequence with a grass can help to maintain soil cover as grass residues have a higher C/N ratio than legumes and are slower to decompose. In addition, grasses, such as cereals, tend to generate more biomass, as they have a smaller row spacing than industrial crops such as sunflower. Stuble management has a cumulative effect, which is why it is recommended to produce more biomass in the first year.

The establishment of different crops on portions of land (plots) on the farm is a form of diversification of the system. It requires different management and operations but, as a result, it favours the presence of different types of root systems, which improves the efficiency of nutrient absorption. When combined with crop rotation, it has a noticeably positive effect on soil structure (Kassam et al., 2009).

Crop associations also diversify the system. It is more like a natural system, where different plant species grow together, which is not usually the case on the farm. Associations may involve only herbaceous crops (intercropping) or herbaceous and woody crops (groundcovers).

Intercropping is the practice of growing more than one crop simultaneously on the same piece of land (spatially intercropped) during the same season. In the case of intercropping with annual crops, tolerance in crop association must be considered, as there are species that may have a certain intolerance when combined. In addition, sowing of the secondary crop must be established between rows of the main crop at an appropriate time to avoid damage to the established crop.

Intercropping is established to improve the ecosystem services of the farming system, such as: optimising space and resources, ensuring better yields, repelling pests, reducing weeds, providing nutrients for neighbouring plants and protecting bare soil in case of long distances between crop rows (Cong et al., 2015). Intercropping reduces weeds by limiting the "niche space" weeds need to grow (Liebman & Dyck, 1993). In addition, pest and disease pressure is reduced due to the dilution of suitable hosts (Boudreau, 2013).

Figure 2.7. Intercropping of legumes and grasses.

iv. Cover crops

Cover cropping is another technique that helps to keep the soil covered in arable crops. These are auxiliary crops or service crops that are temporarily established between main cropping seasons as an alternative to fallow land. They are planted for ground cover to protect against erosion or to provide an ancillary service rather than for production. Depending on the main purpose, cover crops are also called catch crops, when they are established mainly to absorb CO_2 and nutrients, green manure acting mainly as a source of nutrients (for which especially legumes are used), or even used for fodder (Ramírez-García et al., 2015).

Cover crops are recommended when there is a relatively long non-cropping period between harvesting and sowing the next crop. This could reduce protection, as the residues would have been decomposing over a long period of time, reducing soil cover. The introduction of legumes is recommended because of their nitrogen fixing capacity, which could reduce fertiliser use for the main crop. Other species, such as grasses or crucifers, act as nutrient stores when the risk of leaching and erosion is higher, providing these nutrients after mowing (Blanco-Canqui et al., 2015).

Precipitation in the area could be limiting for establishing the cover crop. In areas or periods of low rainfall it may not be feasible to develop this technique. However, recent scientific literature suggests that the introduction of a cover crop in areas of limited rainfall (<500 mm) does not necessarily reduce the yield of the subsequent main crop; moreover, the improvement of ecosystem services such as erosion reduction, water quality improvement, weed control, soil biodiversity improvement, etc., could outweigh yield decline through soil and environmental quality improvement (Blanco-Canqui et al., 2022).

Cover crops fulfil the principle of permanent soil cover, but at the same time contribute to the principle of diversification and crop rotation. If established by direct seeding, they would also comply with the principle of minimum soil disturbance, if mowing is carried out by chemical control, mechanical weeding or grazing.

2.2.2 Practices in woody crops

i. Groundcovers

Groundcovers (the term 'cover crops' in woody crop is also found in the literature) are the agronomic practice of CA par excellence in woody crops. This practice consists of maintaining a growing cover crop or biomass mulch soil cover in the area between crop rows. It is a type of intercropping or alley cropping (Morugán-Coronado et al., 2020). This promotes the principle of permanent soil cover and crop diversification.

Groundcovers may be sown as cover crops or consist of spontaneous natural vegetation. Likewise, biomass material, such as chopped pruned material or tree leaves, can be used to establish mulch covers of 30% or more (González-Sánchez et al., 2015).

Seeded groundcovers are recommended when there is a low seed bank in the soil, which is common when the soil has been continuously tilled or kept free of vegetation by pre-emergence herbicide application (bare soil). Locally adapted species are always recommended. Ideally, they should be economical and with low water and nutrient demand to avoid competition with trees. Most widely used species belong to the following families:

- Legumes (*Fabaceae* or *Leguminosae*): through symbiosis with bacteria of the genus *Rhizobium*, legumes have the ability to fix atmospheric nitrogen, being effective as green manure (Stagnari et al., 2017). Legumes also a large root system. Some species used as cover crops are different types of clover and vetches.

- Grasses (*Poaceae*): which provide good ground cover and are not very competitive with trees and are usually easy to control. Some of the most used species are barley, rye or oat.

- Cruciferous (*Brassicaceae*): can be more competitive with trees if not properly controlled. The advantages they provide are:

    a. They are fast-growing and protect the soil quickly.
    b. The cycle normally starts in winter when trees are less water demanding.
    c. Cruciferous plants have a powerful root system that helps to decompact the soil and improve infiltration (Ren et al., 2019).
    d. Some species have the potential to protect the crop against fungal diseases (Couëdel et al., 2019).

Some species typically used as cover crops are mustard, rocket and radish (Alcántara et al., 2009a).

- Mixed species: a mixture of two or more species is also used as cover. They provide the benefits of the different types of species, as well as some synergies that can be produced by achieving more ecosystem services (Tribouillois et al., 2016). Composition of mixed groundcovers should be determined specifically for local conditions.

The seeding of the groundcover requires the use of standard seeders and, in general, some preparatory work on the soil. Normally, the groundcover does not need to be sown every year, but a band of groundcover should be left to continue to grow until the growth cycle is complete to self-seed the following season. In this respect, there are species with a higher self-seeding capacity. The emergence of existing species should be assessed, and a new sowing should be considered at the beginning of the following season in case of insufficiency or the appearance of many unwanted species. Under normal conditions, a new groundcover will not be necessary for several years, when the ground flora will have evolved into spontaneous species, which are likely to be more competitive and difficult to control. At that time, at the beginning of the following season, it would be advisable to sow a different species, both from the one used in the previous season and from the most abundant species that appear spontaneously. In this way, a rotation would be carried out in the area between the rows of the main woody crop, with the agronomic advantages that this brings.

In case of spontaneous groundcover, more attention must be paid because it is usually more competitive with trees for water and nutrients. In addition, the farmer must ensure that there is sufficient seed bank in the soil to establish the groundcover, covering at least 30% of the area between the rows. Spontaneous vegetation has the advantage of saving the cost and labour of planting, as well as contributing to the establishment of a more species-diverse cover.

Groundcovers of pruned biomass as mulch cover are an interesting option in permanent crops, since woody crops are managed with periodic pruning. The pruned biomass generated are a by-product that can be used for mulching between crop rows protecting the soil surface. This type of groundcover has the advantage of not competing with the main crop for water and nutrients (Repullo et al., 2012). In addition, mulching of pruned biomass can have an allelopathic effect that reduces the amount of spontaneous flora (Alcántara et al., 2009b).

Figure 2.8. Spontaneous vegetation cover on almond trees. Source: ECAF.

Pruned and chopped biomass is applied in a band corresponding to the width of the chopping machinery. Chopping is necessary to reduce the risk of insect pests and to facilitate the transit of machinery. As the width is determined by the machinery, it must be checked that the degree of soil protection is more than 30%. Otherwise, pruned biomass material should be supplemented with living vegetation.

The use of pruned biomass groundcovers is increasing due to the need for pruning in tree crops and the easy and economical management as a groundcover as opposed to managing a living groundcover. This practice is a sustainable alternative, as pruned biomass is usually burned in the field, which emits CO_2 into the atmosphere, can cause damage to trees, and increases the risk of fires (Calatrava & Franco, 2011).

Figure 2.9. Pruned biomass cover. Source: ECAF.

a. Groundcover management

The groundcover must be controlled when it competes for water and nutrients with the main crop. This control must be carried out at the right time, considering phenologically-sensitive stages in the crop, such as flowering, because a reduction of water and nutrients available to the crop at this stage generally has a negative impact on yield.

Different types of control are possible in plant covers:

- Mechanical control: by means of a brush cutter, which can be horizontal (hammers) or vertical (chains).
- Chemical control: applying herbicide under integrated management.
- Grazing control: by livestock, when crop and animal agriculture is integrated. In this case, management is more specific because control is done by zones while the cattle graze in them. This requires more time than other types of control. In addition, there may not be sufficient residue left to ensure soil protection after monitoring.

Control through mechanical tillage is avoided to comply with the principles of no or minimum soil disturbance and permanent groundcover, by keeping the soil covered throughout the year. For this reason, tillage control, which is a possible form of groundcover management in tree crops, is not considered in CA systems.

Timing of control will change, depending on weather conditions and the amount of biomass involved, but at least one control intervention will always be necessary, usually in the spring, when reduced water availability at the flowering stage of most trees can lead to a decrease in production.

Biomass cover retained after the groundcover control protects the soil, even if the groundcover has been controlled. This generates a biomass mulch that helps to control erosion (Repullo-Ruibérriz de Torres et al., 2018), to maintain soil moisture by reducing soil evaporation (Palese et al., 2014), and to control weeds (Alcántara et al., 2011).

2.3 INTEGRATED WEED MANAGEMENT IN CONSERVATION AGRICULTURE

2.3.1 Annual crops

Weeds are characterised by their high dispersal capacity, high persistence, and by being competitive with the crop for water, light, and soil nutrients. Where techniques that minimise soil disturbance are employed, weeds are controlled through integrated weed management involving minimum use of herbicides.

A one-time application per crop season usually takes place before or a few days after sowing, prior to emergence. Timing of weed germination is a key factor. In many cases, delaying the sowing of the main crop is a good strategy, choosing short-cycle varieties. By delaying sowing, most of the weeds will have germinated and could be controlled by applying a light doze of herbicide.

The dormancy period of weed seeds allows them to remain in the soil for some time without germination. Effective crop rotation as part of an integrated weed management strategy should be considered with this factor in mind. The use of a certified seed variety should also be considered as it prevents the introduction of new weed seeds while ensuring good seed quality and rapid growth and soil cover formation.

2.3.2 Woody crops

In addition to the use of herbicides as a groundcover control possibility, the main crop line (canopy area in trees) is often also chemically controlled. However, manual, or trailed mowing machines are also used, but designed and operated in such a way that they can reach very close to the base of the tree trunks. In vineyards and tree crops in a super-intensive framework, inter-vine and inter-tree control machinery can be used to keep the crop rows clear of weeds. This type of machinery can control groundcovers by mowing. Mechanical groundcover can also be used but only on the fringe of the crop line.

2.3.3 Synergies of the interlinked Conservation Agriculture practices in weed control

Application of the interlinked practices of CA themselves aid integrated weed management. Thus, synergies can be established between CA practices and any herbicide use. The rationale for the weed control effect of CA principles is described below:

- No or minimal mechanical soil disturbance: tillage can reduce weeds in the first instance by burying seeds in deeper layers, preventing weed germination. However, tillage passes in the following seasons will bring weed seeds back to the surface. No-tillage prevents the movement of weeds from deeper layers to the surface and accelerates the rotting and decomposition. In addition, minimal soil disturbance avoids burying weed seeds, leaving a larger fraction of seeds closer to or on the surface which allows them to be eaten by birds, insects and mesofauna. Consequently, this allows better herbicide control (Nichols et al., 2015).

- Maintenance of permanent biomass cover: keeping the soil covered with the residues of the previous crop reduces germination capacity by limiting light penetration and providing a physical barrier (Teasdale & Mohler, 2000). Mulch can also prevent weed seed contact with the soil, reducing its germination potential. Further, biomass cover can provide more shelter for insect predators of weed seeds than uncovered soil.

- Crop diversification: this principle has the reduction of weeds, insect pests, and diseases as one of its clear objectives. Each crop applies a unique set of biotic and abiotic constraints on the weed community which promotes the growth of some weeds while inhibiting the growth of others. In this way, any given crop can be considered as a filter that only allows certain weeds to pass through its management regime (Booth & Swanton, 2002). In addition to the use and mode of action of herbicides, secretion of allelopathic substances from some crop associations favours weed control.

CHAPTER 3

EDAPHIC FAUNA IN CONSERVATION AGRICULTURE

3.1 EDAPHIC FAUNA

Edaphic fauna consists of the living organisms that inhabit the soil profile under natural vegetation. It plays a vital role in terrestrial ecosystems by performing essential functions in carbon, water and nutrient cycling and in maintaining soil ecological health and functions. It also contributes to the stability and resilience of the soil system and to soil fertility and productivity. These essential attributes are also present in agricultural soils where they are of particular importance because of the productive role required of them.

Edaphic fauna includes a wide range of organisms, from micro-organisms such as bacteria, fungi, algae and protozoa, to small animals, mainly mites, nematodes, springtails, and earthworms. Micro-organisms are essential in the decomposition of organic matter and the release of nutrients, as well as in the fixation of atmospheric nitrogen and other biogeochemical processes, while small animals feed on decomposing organic matter and other organisms, and even contribute to the formation and stabilisation of soil structure by constructing galleries and mobilising materials.

A detailed study of the soil fauna will promote its conservation. This will ensure its role in maintaining soil health., the sustainability of agriculture and the conservation of biodiversity, which is affected by various factors such as soil quality, availability of food resources, humidity, temperature and the presence of plants and other organisms. Therefore, the application of soil conservation measures in CA systems will have a positive impact on the communities of these living creatures, including earthworms, mites, nematodes and springtails.

Source: Anne Kjærsgaard Krogh_ FRDK

3.2 SOIL MITES

Soil mites are a group of tiny arthropods that play important roles in the decomposition of organic matter and the recycling of nutrients. Although some species may be considered agricultural pests, most soil mites are beneficial, as their biological activity releases nutrients that become available to other soil organisms and plants. In addition, their digging and feeding activity contributes to the formation of soil aggregates, improving soil structure and water holding capacity. Soil mites are very numerous and are found in virtually all types of soil. Due to their small size, they are generally not visible to the naked eye and require sampling and microscopy techniques for their study.

There are multiple scientific studies that demonstrate the benefits for soil mite biodiversity in CA systems relate to no-till direct sowing in annual crops and to the practice of groundcover in woody crops.

Biodiversity can be measured in different ways, either using indices such as Shannon's index or other comparative data such as species richness or abundance of individuals, to name a few. Compilation studies based on meta-analyses are also carried out to quantify, in a general way, the effects of a given management or practice on biodiversity. In this case, for mite biodiversity, a meta-analysis (Betancur-Corredor et al., 2022) of 218 studies, using log-response ratio methodology, showed that the application of no-till direct sowing in annual crops caused a positive effect, with a result of 0.16, compared to conventional tillage.

The biodiversity benefit of soil mite when applying soil conservation measures in agriculture has been studied to a greater extent in cereal crops. In a cereal rotation carried out in Spain (Bosch-Serra et al., 2014), it has been observed that oribatid mites increased its biodiversity in no-tillage treatment compared to minimum tillage. Oribatids are one of the most important mite orders, so much so that they are even considered to be the most abundant of the arthropods inhabiting organic soil horizons. Within these horizons, they play a major role as ecological regulators and builders of soil structure. In the work of Bosch-Serra et al. (2014), the calculated Shannon biodiversity index was 0.51 in no-till direct sowing treatment, while it was 0.45 in minimum tillage.

Other work on soil mites in no-till direct sowing measures in cereal rotations has been based on the study of the abundance of individuals (Figure 3.1). In this regard, Crotty et al. (2016), in a wheat and barley rotation trial in Wales, UK, found that mite abundance was 33.5% higher in no-till direct sowing than in conventional tillage. While another study conducted in Russia (Kutovaya et al., 2021) on a wheat-sunflower-corn rotation recorded double the number of mites in soils under no-till direct sowing compared to tilled ones.

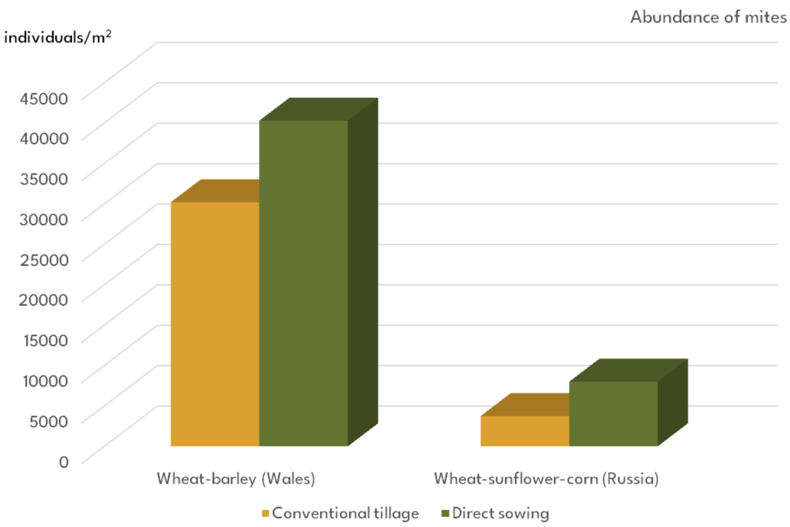


Figure 3.1. Comparison of mite abundance in two studies on annual crop rotations, located in Wales (Crotty et al., 2016) and Russia (Kutovaya et al., 2021).

Another rotation in which a greater abundance of mites has been observed in CA is the corn-legume rotation. In particular, a study in Kenya (Ayuke et al., 2019) found that after 15 years of no-tillage, the number of mites in the upper part of the soil profile increased by just over 75%, compared to management without rotation or soil conservation measures (Figure 3.2).

In relation to the results obtained at a depth of 15 to 30 cm, tillage rotation showed an increase in the number of individuals per m^2, probably because the tillage implement reached a depth of 15 cm, thus not affecting the existing fauna below 15 cm, or even favouring their migration towards a deeper level to avoid the most disturbed surface area.

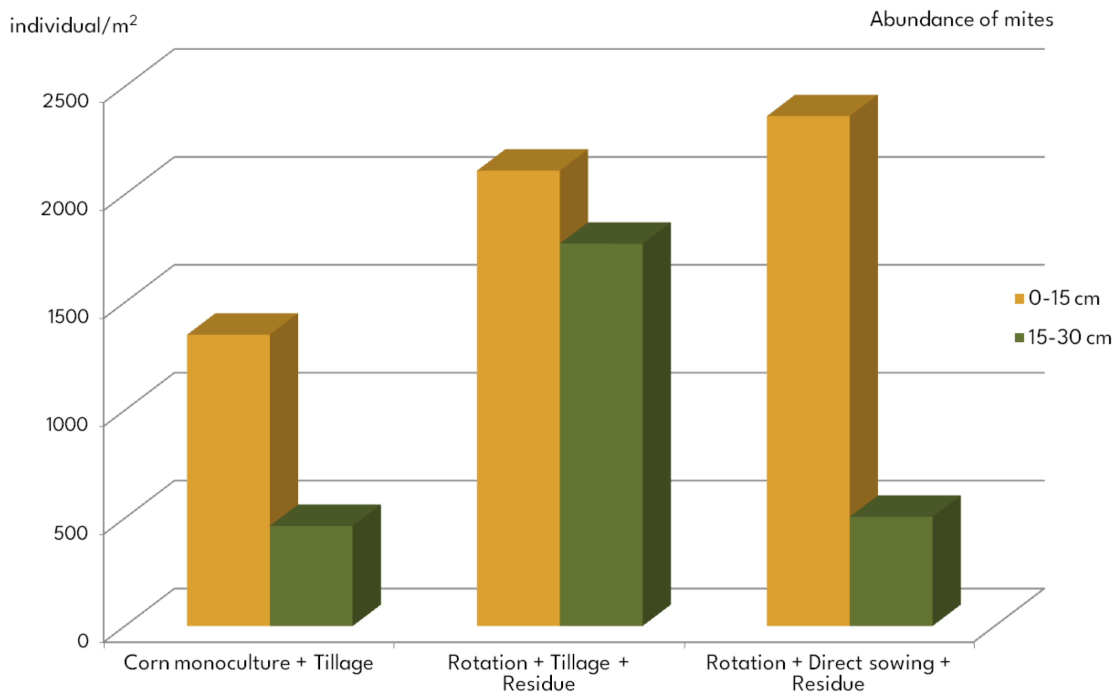


Figure 3.2. Mite abundance in a corn-legume rotation in Kenya. Source: Ayuke et al., 2019.

In woody crops, groundcover allows mite populations to grow. In Spain, several studies have been carried out, among which two have been prioritised for this report, one in vineyards and the other in olive groves. After 30 years of groundcover in the alleys of a vineyard (Andrés et al., 2022), it was found that the number of predatory mites was almost 85% greater than in a neighbouring vineyard where the soil had been left bare for the same period. In the case of fungivorous mites (feeding exclusively on fungi), this increase was almost 95%. Both types of mites are beneficial to the vineyard, regulating the functioning of the agroecosystem, and minimising the impact of insect pests and diseases.

In the case of olive groves, Vignozzi et al. (2019) had less pronounced results in trials in Italy. After 10 years of groundcover implementation, they observed that the number of mites in the centre of the alleys was more than twice as high in alleys with groundcover compared to those without. However, this was not the case under the canopy of the olive trees, where they obtained a higher abundance of mites in management without groundcover (500 individuals per m^3) than in management with groundcover (300 individuals per m^3). This is mainly due to the positive effects that tree canopies contribute to soil improvement, either through shade or by increasing nutrients through the accumulation of leaf litter, which can also lead to an increase in soil moisture.

In summary, application of CA principles on both annual and woody crops seems to have a favourable effect on the soil mite community, with high percentage increases that can even exceed a 100% population increase.

3.3 NEMATODES

Nematodes are microscopic animals, similar in appearance to tiny worms or small maggots. They are found abundantly in agricultural soils, and their role can be beneficial or detrimental to the crop depending on the functional group to which they belong. Bacteriophage nematodes help to control diseases that pathogenic bacteria in the soil can cause to plants. There are also predatory nematodes, which feed on other organisms in the soil and even on other nematodes. Therefore, they also have a beneficial effect on agriculture, by helping to maintain a balance in the organism populations and controlling the populations that are considered as pests and potentially harmful to the crop. This is also the case for fungivorous nematodes which, by feeding on fungi, protect the crop from fungal diseases. Finally, there are also plant-parasitic nematodes, which feed on the roots of plants, potentially weakening them, and even causing a decrease in growth and subsequently, crop yields. Therefore, studies on how populations of different functional groups of nematodes evolve when agronomic measures are applied are of particular interest.

For nematodes, biodiversity benefits of CA are not as clear cut as they are for mites. In fact, a meta-analysis (Betancur-Corredor et al., 2022) using log-response ratio methodology on 244 scientific articles, showed that the effect of no-till direct sowing practice is slightly detrimental to nematode biodiversity compared to reduced tillage. In the case of woody crops, the use of groundcovers does seem to bring clear benefits to the nematofauna.

The response in terms of nematode abundance in CA systems involving different cereal rotations is variable according to reported literature. For example, in a long-term study on a wheat-soybean rotation (Escalante et al., 2021) carried out in Arkansas, USA, the number of nematodes was 13.47% greater in CA system than in tillage system. However, in another study involving a wheat-barley rotation (Crotty et al., 2016) conducted in Wales, UK, nematode abundance was 21.61% higher in conventional tillage system. Further, in this study, it was observed that in the specific case of predatory nematodes CA led to an improvement in abundance of around 14% was similar to that reported for the CA system studied in Arkansas. Following the measurement of the response of different trophic groups of nematodes to the application of CA principles in herbaceous rotations, Figure 3.3, shows the results obtained by Henneron et al. (2015), on a farm in France with cereal and legume crops in the cropping system. Both the overall abundance of nematodes and the abundance of different functional groups (bacterivores, fungivores and phytophagous) show a clear increase in CA system using no-till direct sowing.

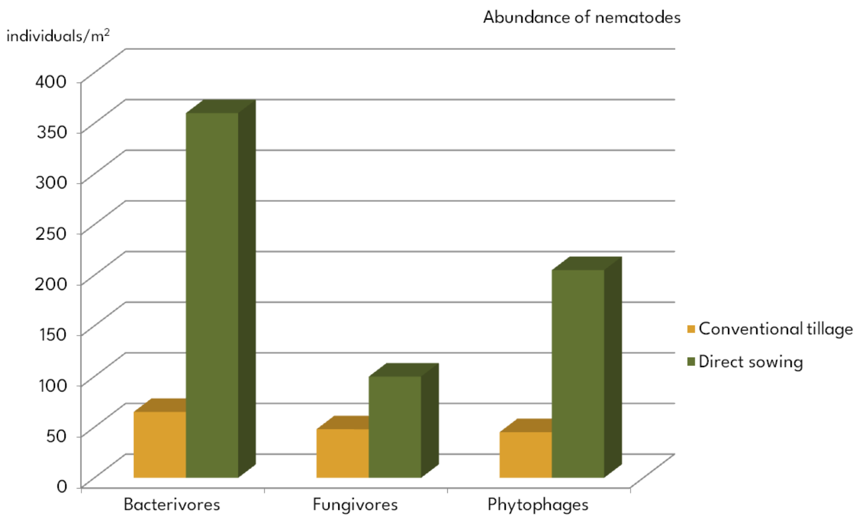


Figure 3.3. Comparison of nematode abundance between conventional tillage and no-till direct sowing conditions. Source: Henneron et al., 2015.

On the other hand, another study conducted in the USA under a wheat-soybean rotation (Treonis et al., 2018) showed opposite results when making this comparison using Shannon's biodiversity index within three different nematode families (Figure 3.4). Specifically, it was observed that both in the surface soil and up to 20 cm depth of the profile, CA soil had lower values than conventional tillage for *Tylenchidae* and *Cephalobidae* families. In contrast, the *Rhabditidae* family improved its biodiversity in the CA soil. This may be due to the fact that the CA soil condition encourages the presence of nematodes of the family *Rhabditidae* which are characterised by their predatory nature. They may therefore reduce the populations of the other two nematode families. This is of particular interest with regard to the family *Tylenchidae* in which phytoparasitic nematodes are abundant.

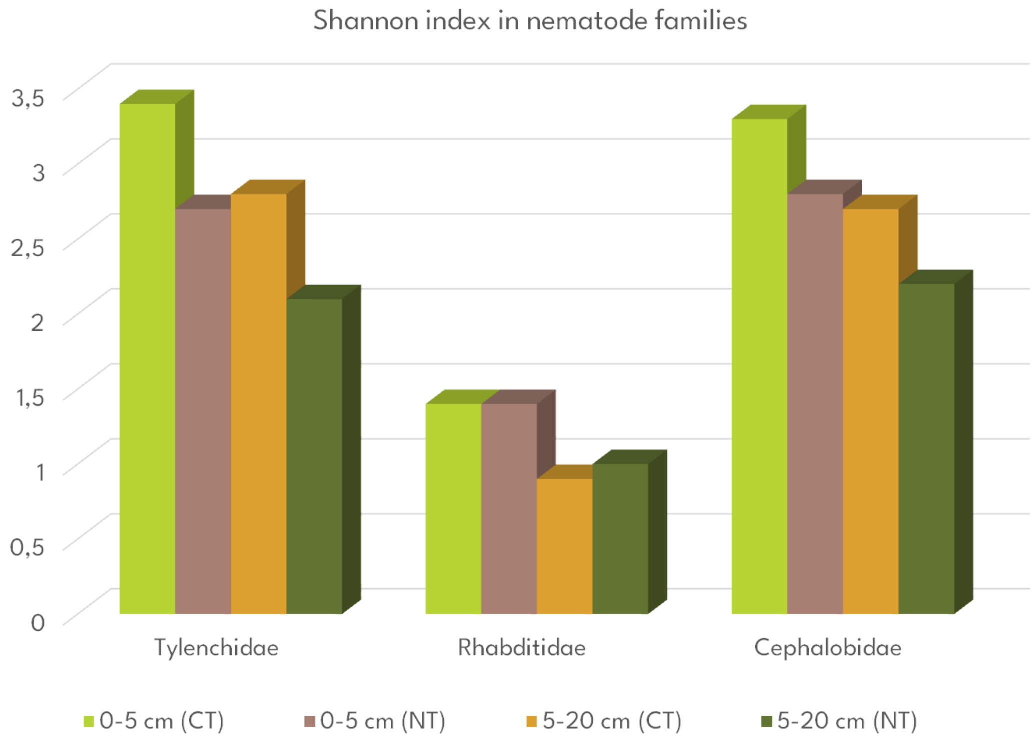


Figure 3.4. Effects on biodiversity (Shannon index) in different nematode families, when applying conventional tillage (CT) and no-tillage (NT). Source: Treonis et al. 2018.

The beneficial effect of no-tillage has been showed in other less common CA rotations, such as the one practiced on an island in China under a tropical climate (Zhong et al., 2017). In the trial farm, banana production was followed by passion fruit production. Under CA system, the nematode species richness improved compared to conventional tillage system.

When crop rotation has consisted of a winter cover crop, results in CA system have been favourable. In a garlic crop production system in Hawaii, where a legume (*Crotalaria juncea*) was used as a winter cover crop, Quintanilla-Tornel et al. (2016) observed an average increase of a beneficial nematode species for pest control in CA fields. This increase was also observed in CA plots in an experiment conducted in California, USA, by Zhang et al. (2017). The results they obtained (Figure 3.5) showed, except for herbivorous nematodes, a higher species richness under CA in chickpea. However, in sorghum, the opposite seems to be true, with herbivores appearing with a greater diversity of species in CA plots.

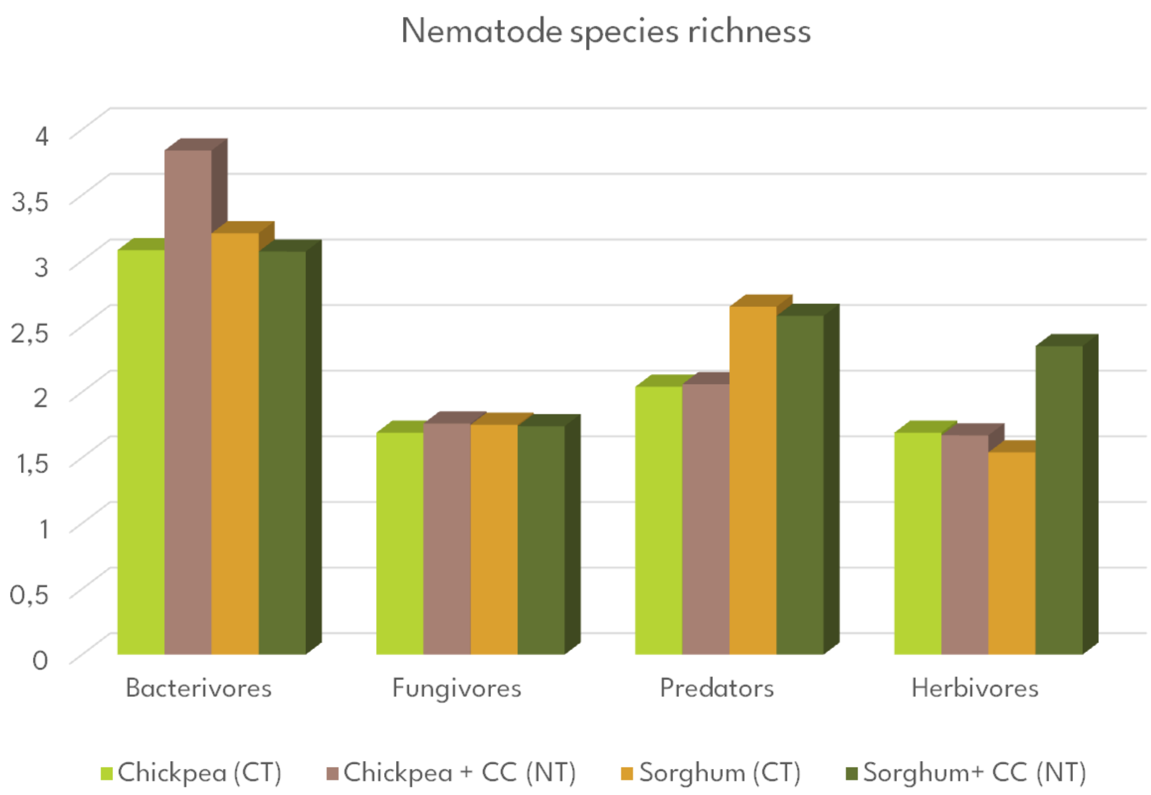


Figure 3.5. Study of species richness in different functional groups of nematodes. In chickpea and sorghum, conventional tillage (CT) without winter cover crop was compared to no-tillage (NT) with winter cover crop (CC). Source: Zhang et al., 2017.

The application of groundcovers in woody crops has a clear beneficial effect on nematodes living in the soil profile. In a study on vineyards in Spain (Andrés et al., 2022), an enrichment of carbon from nematofauna of almost 70% was obtained in vineyards with groundcover, compared to those without cover and with bare soil. These data are also corroborated by other studies on woody crops (Table 3.1) which show that increases in nematode populations are doubled when groundcovers are introduced.

Table 3.1. Number of nematodes counted in woody crops with and without groundcover.

Article	Crop	Location	**With groundcover** (no. nematodes / 100 g)	**Without groundcover** (no. nematodes / 100 g)
Salomé et al., 2016	Vineyard	France	1371	351
Blanco-Pérez et al., 2020	Vineyard	Spain	8.2*	4.5*
Sánchez-Moreno et al., 2015	Olive grove	Spain	597	252

(*) refers to juveniles of entomopathogenic nematodes.

3.4 SPRINGTAILS

Springtails are small arthropods found in the soil. They are the evolutionary predecessors of insects and, unlike soil mites and nematodes, can be observed with the naked eye. Nonetheless, they are generally no more than 5 mm in length. In agriculture, springtails are considered beneficial as they decompose organic matter and plant biomass, thus participating in the cycling and release of nutrients in the soil. In addition, springtails also improve soil structure through the fragmentation of organic matter and the formation of soil aggregates.

Betancur-Corredor et al. (2022) used a Log-response ratio meta-analysis to study the results of 244 scientific studies related to springtails and soil agricultural practices. They concluded that CA has a positive impact on the biodiversity of these small arthropods. Specifically, the value obtained by this methodology was 0.26 in favour of CA compared to other production management methods.

There are numerous studies on how the introduction of CA has affected the abundance of soil springtails, with values ranging from a 10-fold increase in population (Dominguez et al., 2014) to 50% reduction (Olejniczak & Lenart, 2017). Table 3.2 shows the results obtained in 5 comparative studies of springtail populations in CA and conventional tillage system. Most of them (4 out of 5) show large improvements in the populations of springtails.

Table 3.2. Number of springtails counted in comparative studies of direct sowing and conventional tillage.

Article	Rotation	Location	Direct sowing (n° springtails/ m^2)	Conventional tillage (n° springtails/ m^2)
Crotty et al., 2016	Wheat-barley	Wales	33200	21600
Dulaurent et al., 2023	Cereal-rapeseed-pea	France	11000	4300
Olejniczak et al., 2017	Wheat-barley-rapeseed	Poland	10000	15000
Dominguez et al., 2014	Cereal-sunflower-soybean	Argentina	3000	300
Ayuke et al., 2019	Corn-bean	Kenya	3100	1900

In addition to counting the individuals that appear in the soil, the determination of the different species that appear in the samples allows other types of results to be obtained. One of them is Shannon's biodiversity index, which is based on the quantification of the number of individuals of each species. In the recent work of Dulaurent et al. (2023), an increase in this index of 0.16 in tillage compared to 0.22 in no-tillage was obtained. Values of the Shannon index in this study are very low, since springtail communities have many individuals, and precisely the value of the number of individuals per species is placed in the denominator of the equation by which the Shannon index is obtained. In contrast, the number of species, which is much lower, is in the numerator.

<table>
<tr><th>Formula</th><th colspan="2">Components</th></tr>
<tr><td rowspan="4">$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$</td><td colspan="2">*S* is the number of species</td></tr>
<tr><td colspan="2">p_i is the proportion of individuals of the *i* species in relation to the total number of individuals (i.e., the relative abundance of i) species: $$\frac{ni}{N}$$</td></tr>
<tr><td rowspan="2">$$\frac{ni}{N}$$</td><td>*ni* is the number of individuals of the *i* species</td></tr>
<tr><td>*N* is the number of all individuals of all species</td></tr>
</table>

As in the case of previous faunal groups (mites and nematodes), biodiversity of springtails benefits significantly from allowing ground cover to develop in the alleys of woody crops. Andrés et al. (2022) quantified the amount of carbon from springtails living in vineyards with groundcover as being more than 85% greater compared to that from springtails in vineyards with bare soil. Similarly, a study carried out in vineyards in Romania (Fiera et al., 2020) recorded more than twice as many springtail species in vineyards with a groundcover than in those without.

Groundcover in the olive grove alleys also favours the presence of springtails, as shown by their higher values in the study by Vignozzi et al. (2019). This study (Figure 3.6), carried out in Italy, showed the highest number of springtails in alleys with groundcover, both under the canopy of olive trees and in the centre of the alley. In both cases, groundcovers increased the soil springtail population by three-fold compared to bare soil.

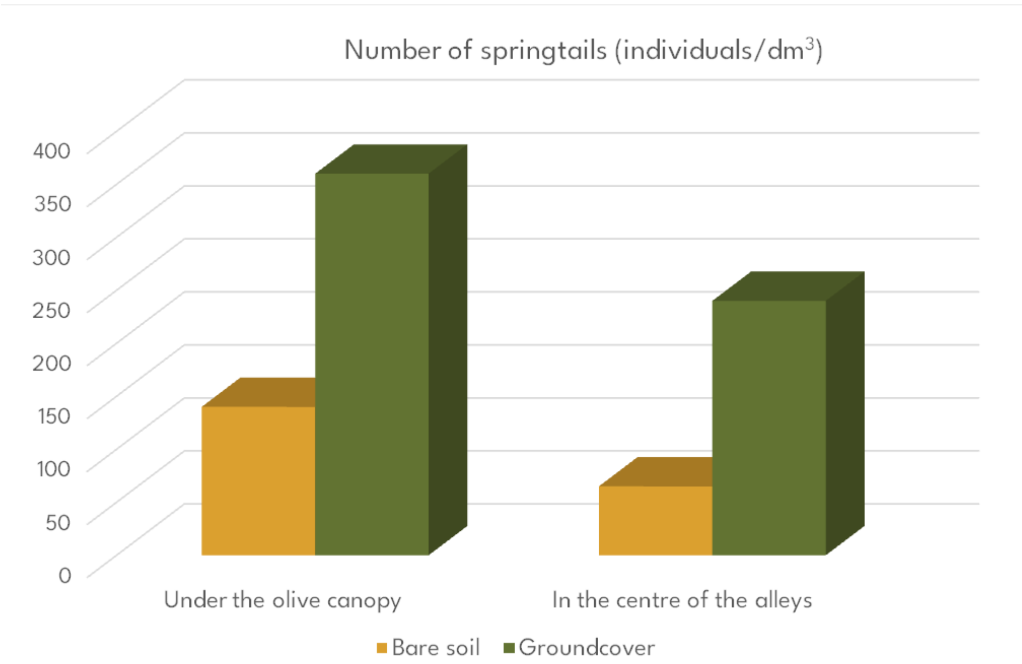
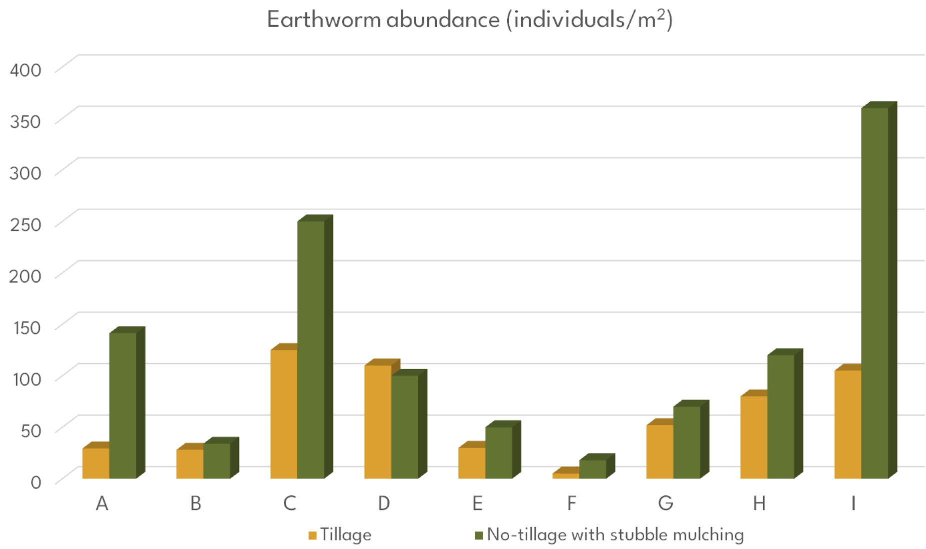


Figure 3.6. Effects on the abundance of springtails in olive groves with bare soil and with groundcover, differentiating data obtained under olive canopy or in the centre of the alleys. Source: Vignozzi et al., 2019.

3.5 EARTHWORMS

Earthworms, being larger and easily visible, are the best-known living organisms of the soil fauna by farmers and society in general. Earthworms feed on decomposing organic matter, such as plant biomass, and transform it into a material that is rich in nutrients, enhancing the fertility of the soil in a natural way. In addition, they excavate galleries while feeding, leading to improved soil structure and porosity that facilitates the circulation of air, water, and nutrients in the soil profile, and promotes a conducive environment for plant and root growth. Improved water infiltration also helps to prevent erosion and increase moisture retention. This is especially beneficial in heavier or clay soils. CA is a great ally of the biodiversity of earthworms. Scientific studies have shown that CA has a positive impact on the abundance of earthworms and in the richness of species.

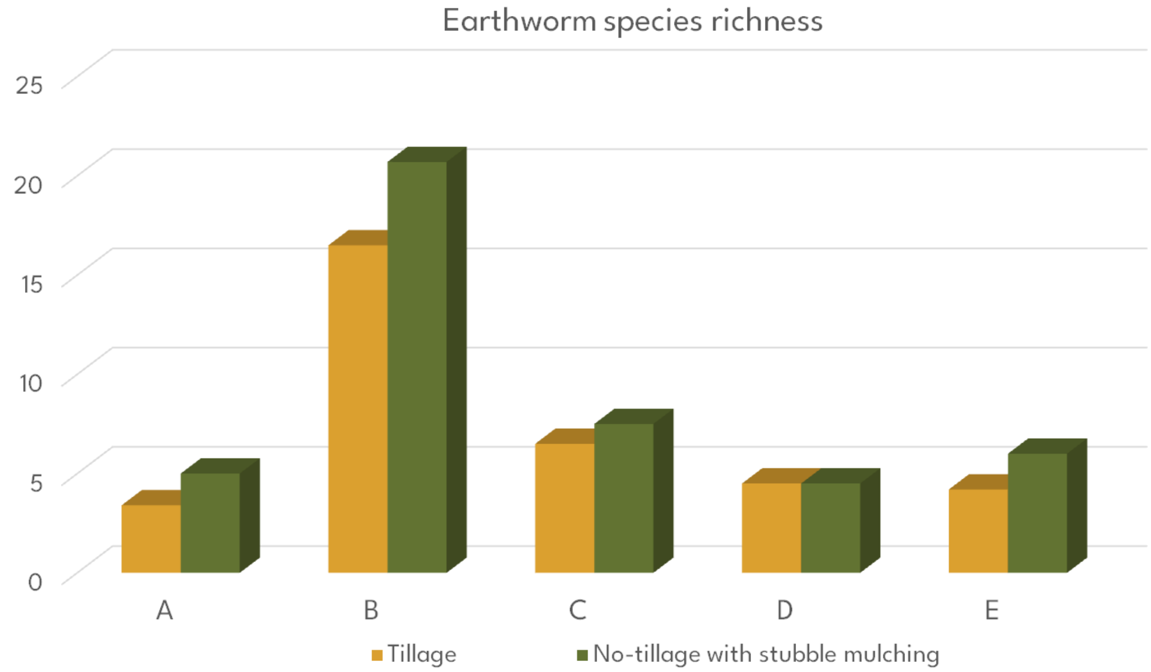
Figure 3.7 shows the results on earthworm abundance in CA systems with different herbaceous crop rotations. Except for one of the rotations, the rest showed a significant positive effect of CA systems, with the studies of A (Dulaurent et al., 2023) and B (Henneron et al., 2015) a three-fold increase in the earthworm numbers.



Study	Reference article	Rotation	Country
A	Dulaurent et al., 2023	Wheat, barley, rapeseed, and peas	France
B	Mcinga et al., 2020	Corn, wheat, and soybeans	South Africa
C	Pelosi et al., 2014	Corn, wheat, and rapeseed	France
D	Pelosi et al., 2014	Wheat, barley, rapeseed, and peas	France
E	Pelosi et al., 2014	Alfalfa, corn, wheat, and soybeans	France
F	Muoni et al., 2019	Cotton-Corn	Zambia
G	Torppa & Taylor, 2022	Wheat and barley	Sweden
H	Torppa & Taylor, 2022	Wheat, barley, rapeseed, and peas	Sweden
I	Henneron et al., 2015	Wheat and pea	France

Figure 3.7. Studies on the impact of no-tillage on earthworm abundance in different annual crop rotations.

Earthworm species richness in CA systems follow a similar pattern to that observed for abundance. In Figure 3.8 it can be seen that four out of the five rotations showed an increase in the number of earthworm species. Only in rotation D (wheat, barley, rapeseed and pea), the number of earthworm species remained unchanged. Rotation D is the also the rotation in which a decrease in the abundance of earthworms was observed under conventional tillage system.



Study	Reference article	Rotation	Country
A	Dulaurent et al., 2023	Wheat, barley, rapeseed, and peas	France
B	Denier et al., 2022	Rapeseed, wheat, and corn	France
C	Pelosi et al., 2014	Corn, wheat, and rapeseed	France
D	Pelosi et al., 2014	Wheat, barley, rapeseed, and peas	France
E	Pelosi et al., 2014	Alfalfa, corn, wheat, and soybeans	France

Figure 3.8. Results obtained when studying the impact of no-tillage on earthworm species richness in different annual crop rotations.

Abundance of earthworms was also studied in rotations with the addition of a winter cover crop. In this study, carried out in California (USA) by Kelly et al. (2021), the effects on earthworms in a chickpea-sorghum rotation of a winter cover crop consisting of five (5) forage species were studied. Under this system, it was observed that there was a greater number of earthworms present in CA plots than in conventionally tilled plots (Figure 3.9).

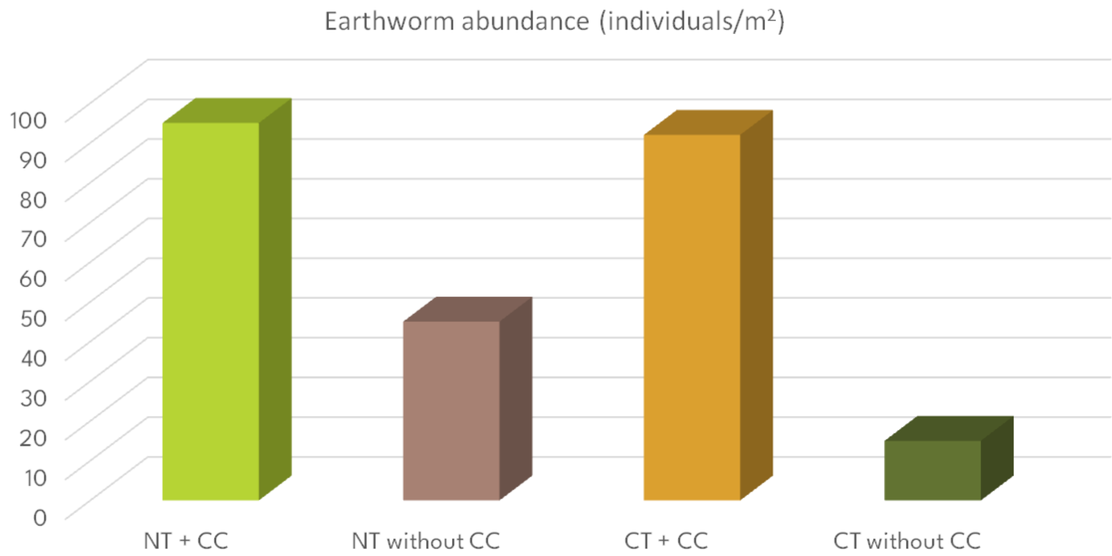


Figure 3.9. Effects on earthworm abundance in a chickpea-sorghum rotation in no-tillage (NT) and conventional tillage (CT). With or without winter cover crop (CC). Source: Kelly et al., 2021.

Studies on the effect of biodiversity and/or earthworm abundance in woody crops with groundcovers are fewer than those on annual crop systems. This is mainly because most of the woody crops (olive groves, vineyards and almond trees) that are suitable for having groundcover in their alleys are typical Mediterranean crops and are generally located in agroecologies that are usually semi-arid. This makes it difficult for earthworms to be in abundance and to be found easily. In one of the few studies carried out on this subject (Popescu et al., 2019), it was found that groundcovers benefit earthworms. Specifically, in a vineyard in Romania, researchers found an average increase in earthworm species richness from 1.3 species in vineyards with bare soil to 1.6 species in vineyards with groundcover, representing a 23% increase.

3.6 SUMMARY AND CONCLUSIONS

A qualitative assessment can be made (Table 3.3) of the effects of CA on soil edaphic fauna biodiversity.

Table 3.3. Qualitative summary of the application of Conservation Agriculture on different faunal groups in the soil profile. Very positive (+++), positive (++) or indifferent (+) effect.

Measurement of AC	Mites	Nematodes	Springtails	Worms
No-Tillage	+++	+	+++	+++
Groundcover	++	+++	+++	++

In general, it can be seen that the biodiversity of soil fauna benefits from CA, particularly the springtails, both in herbaceous and woody crops. In the case of mites and earthworms, the practice that most increases their abundance and/or biodiversity is no-till direct sowing in annual crops, while groundcovers in woody crops are the most favourable for nematodes.

CHAPTER 4

EPIGEAN FAUNA IN CONSERVATION AGRICULTURE

4.1 INTRODUCTION

Soil biodiversity is not limited to the organisms that inhabit the soil profile. There is also a large biocenosis or an association of different organisms forming a closely integrated community whose habitat is mainly the soil surface. These animals are called epigean fauna. Agricultural soils, when managed sustainably, have a rich representation of this fauna, providing important benefits to crops, environment, farmers and society. Epigean fauna in agricultural ecosystem is mainly composed of arthropods in both abundance and diversity. This group predominantly includes insects, such as beetles and ants, as well as arachnids (mainly spiders) and crustaceans and myriapods to a lesser extent.

In general, the presence of different groups of living things on the soil surface is richer, in both abundance and diversity, in Conservation Agriculture (CA) compared to conventional agriculture. Therefore, there are benefits from biodiversity in agricultural environments which have an impact on the crops themselves through the ecosystem services that this fauna provides. This is because the constituent components of the fauna are key parts of the food chains and perform important roles in the control and regulation of natural processes. Firstly, they degrade crop biomass, facilitating the cycling of chemical elements and organic compounds from dead biomass, transforming it into nutrients that can be used by the rest of the soil biota and the crops. Secondly, they are important predators that slow down or stop the emergence of pests, carrying out important and free biocontrol work. Thirdly, they serve as food for other living organisms, especially birds. This is particularly important in agricultural environments where they support the conservation of species such as the great bustards (*Otis tarda*) or the little bustards (*Tetrax tetrax*).

There are studies on the impact of CA on epigean fauna that focus on a specific order or faunal group, such as arachnids, coleoptera or hymenoptera. Other studies provide analyses or results from several groups at the same time, based on information obtained from observations made simultaneously. Finally, there are also studies at the global level of the phylum Arthropoda in which all the species or morphospecies belonging to this faunal group are assessed together.

In addition to the above, within the epigean fauna of crops, the presence of reptiles is also interesting, including preferably geckos, lizards, and snakes. Although their study in relation to the effects on their biodiversity derived from the application of CA is still at an incipient level.

4.2 ARTHROPODS

Biodiversity studies to find quantitative indicators for comparison between different habitats, communities, land management, etc., are often based on biodiversity indices. The most common are Shannon and Simpson. Their use within arthropod communities is also frequent, especially in the case of the Shannon index. The disadvantage of this type of index is that the biodiversity value tends to be low when populations of certain species are very high, as the number of individuals is part of the quotient of the formulas. This circumstance may explain the results obtained by Krolow et al. (2017), Massaccesi et al. (2020) and Adams et al. (2017) (Figure 4.1) in studies monitoring the effect on the arthropod community of no- tillage system compared to tillage system, using the Shannon index. As can be seen in the figure, there is heterogeneity in terms of the predominance of one type of management or another, and there is a fair degree of equality between the different management methods if the results obtained in each particular study are considered.

In contrast, if the study is based on the influence of no-till direct sowing on fauna populations (Rakotomanga et al., 2016; Santos et al., 2016), the results are much more evident (Figure 4.2) and are in favour of this soil conservation practice.

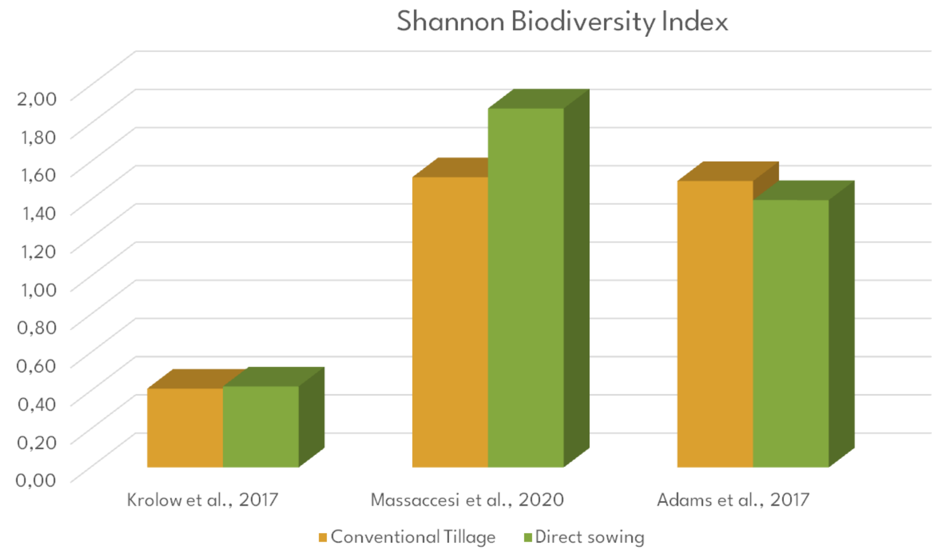


Figure 4.1. Effects on the Shannon biodiversity index of direct sowing application in three rotations in Brazil (Krolow et al., 2017), Italy (Massaccesi et al., 2020) and North Carolina (Adams et al., 2017).

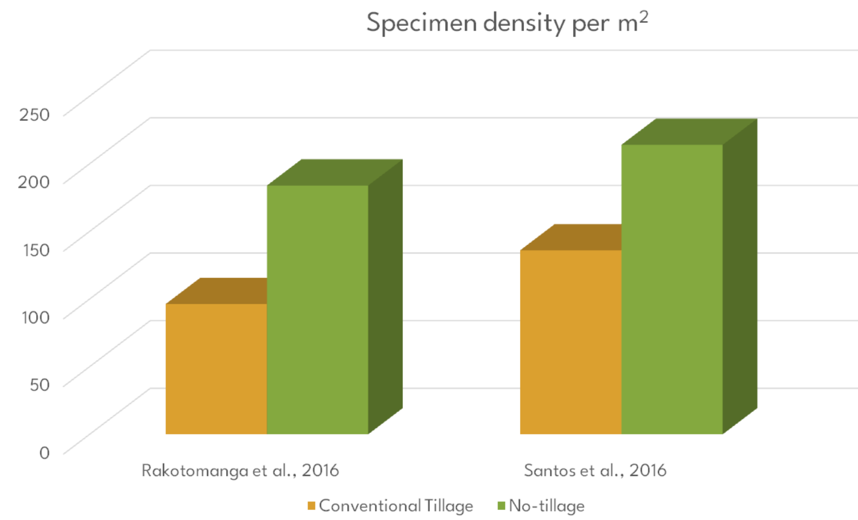


Figure 4.2. Differences in arthropod abundance in two rotations in Madagascar (Rakotomanga et al., 2016) and Brazil (Santos et al., 2016), comparing conventional tillage and no-tillage.

Quintanilla-Tornel et al. (2016) instead considered using Simpson's biodiversity index to study the effect of no-till direct sowing in a garlic rotation with a legume in Hawaii, USA. Their results showed a value of 5.93 for biodiversity in no-tillage system which was higher than the value 5.88 for conventional tillage system. Despite this difference in Simpson's index, it was measured in parallel that species richness was 14.5% higher in the no-till direct sowing system than in the soil tillage system.

In the case of groundcover, results are similar, with a small but obvious difference in terms of the Shannon index (Figure 4.3) and much more accentuated difference in terms of the increased abundance of individual numbers (Figure 4.4).

In Figure 4.3, the Shannon index values above four obtained by Sáenz-Romo et al. (2019a) are noteworthy. It should be noted that in tilled agricultural areas, the Shannon index does not normally exceed three, as illustrated by the case of Inagaki et al. (2022).

Figure 4.4 shows that the groundcover in an olive grove in Spain almost doubled the population of arthropods compared to bare soil.

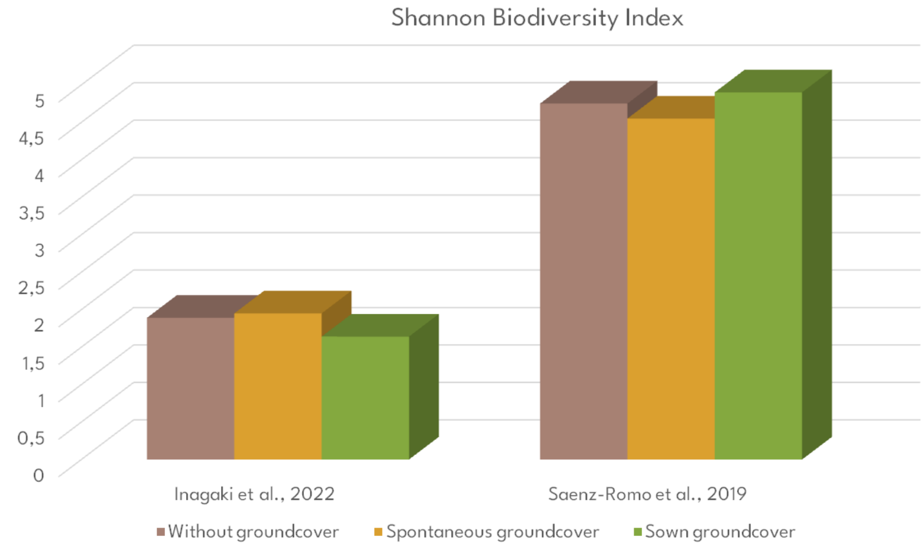


Figure 4.3. Shannon biodiversity index in epigean arthropods, obtained for a lemon grove in Japan (Inagaki et al., 2022) and a Spanish vineyard (Sáenz-Romo et al., 2019a), where spontaneous and sown groundcovers were introduced.

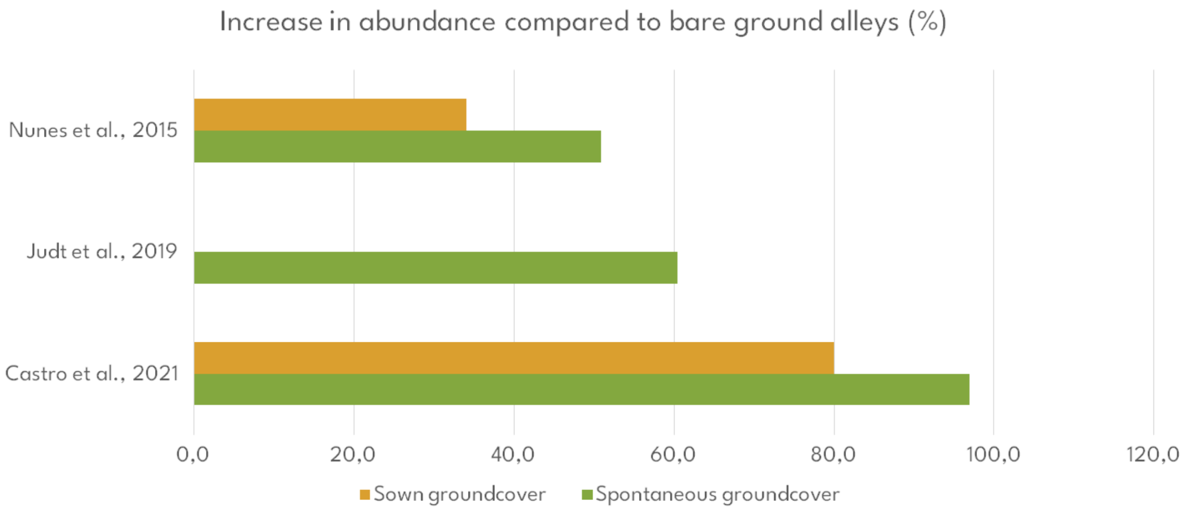


Figure 4.4. Percentage increase in arthropod abundance over conventional bare soil management, by introducing groundcovers in vineyards (Nunes et al., 2015; Judt et al., 2019) and olive groves (Castro et al., 2021).

4.3 SPIDERS

Spiders, because of their role as top predators on the soil surface, have very important implications for the maintenance of soil health. Their greatest benefit for crops is in the regulation of the populations of a multitude of species that inhabit the soil surface because they act as biocontrollers of pests.

The application of no-till direct sowing system in annual crop rotations has a clear impact on spider populations (Figure 4.5). Large increases have been observed in this respect, ranging from i around 60% (Puliga et al., 2021; Redlich et al., 2021; Quintanilla-Tornel et al., 2016) to more than six-fold increase (Rakotomanga et al., 2016; Massaccesi et al., 2020) compared to conventional tillage system. In the study conducted in France, the results showed intermediate increase of 150% in the number of spiders in no-tilled crop compared to the tilled crop (Henneron et al., 2015).

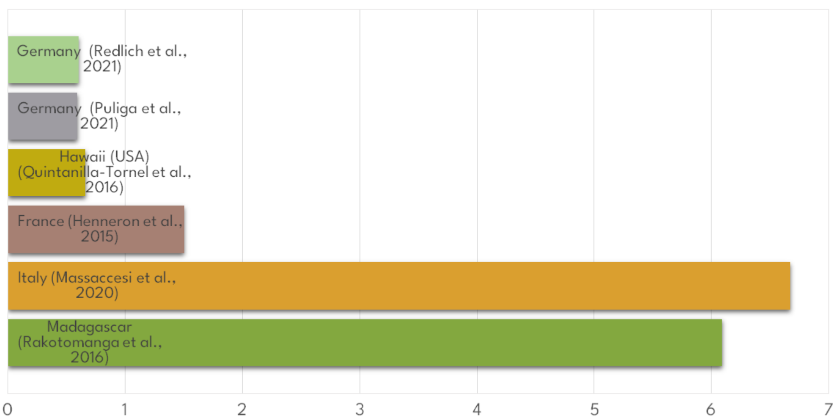


Figure 4.5. Increases observed in spider abundance when implementing no-till farming compared to conventional management.

Evidence shows clear benefits for spider populations under no-tillage system. This may be due not only to the greater shelter they can find in the stubble mulch, but also to the undisturbed soil in which they build their burrows. Also, the accompanying increase in populations of potential prey (springtails, small insects, mites, etc.) in no-till system should be noted.

The situation in groundcover remains positive for spiders (Figure 4.6), but the magnitude of the increases is not as large as in the case of no-till direct sowing in annual crops.

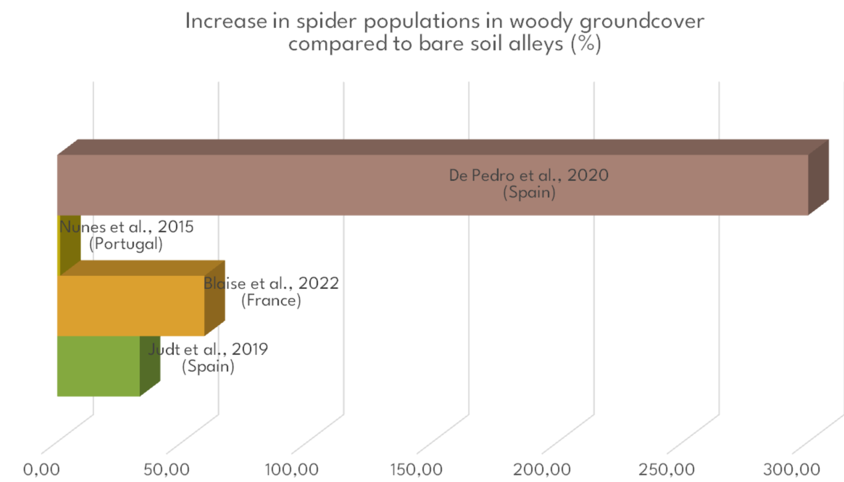


Figure 4.6. Percentage increases in spider abundance in several crops (vines and pear trees) when groundcover are planted, compared to conventional management with bare ground in the alleys.

The most significant increases in spider populations with groundcovers are found in a study of pear trees in Spain (De Pedro et al., 2020) where a value of over 300% is reached compared to bare soil. In contrast, the values observed in vineyard groundcovers (Judt et al., 2019; Blaise et al., 2022; Nunes et al., 2015) in Spain, France, and Portugal, are not as high. However, the average increase of populations with groundcovers in these three vineyards exceeded 30% compared to the vineyards with bare soil between the alleys.

In the case of groundcover establishment in a lemon grove in Japan (Inagaki et al., 2022), the mean abundance of spider per square metre was seven in the bare soil, and five for the natural cover dominated by *Equisetum arvense* and *Digitaria ciliaris*. In the same trial, when two different groundcovers were planted, the results were positive. In the *Vulpia myuros* grass cover, the average spider number reached 11 while in the *Trifolium repens* clover cover, 30 spiders were counted on average.

4.4 BEETLES

Beetles are the group with the largest individuals among the arthropods on the soil surface of agricultural land. In general, Coleoptera, the order in which beetles are grouped, with almost 30 different families, have a great diversity of shapes, colours and feeding habits. Of these families, the most frequently associated with the soil surface are the carabids. Most beetles that have their main biological activity on the ground are usually black or quite dark. They are usually predators, thus helping to control populations of other soil animals that could be a pest to the crop.

No-till direct sowing seems to affect soil beetle abundance positively. In nine of the ten articles reviewed on the subject, beetle populations were larger in no-till crop than in the conventionally tilled crop. Only in two rotations studied in the USA (Kelly et al., 2021; Quintanilla-Tornel et al., 2016) was a reduction in the beetle population density in no-tillage system was observed. In the rest of the studies (Figure 4.7), the introduction of no-till practice had a positive impact on the beetle populations.

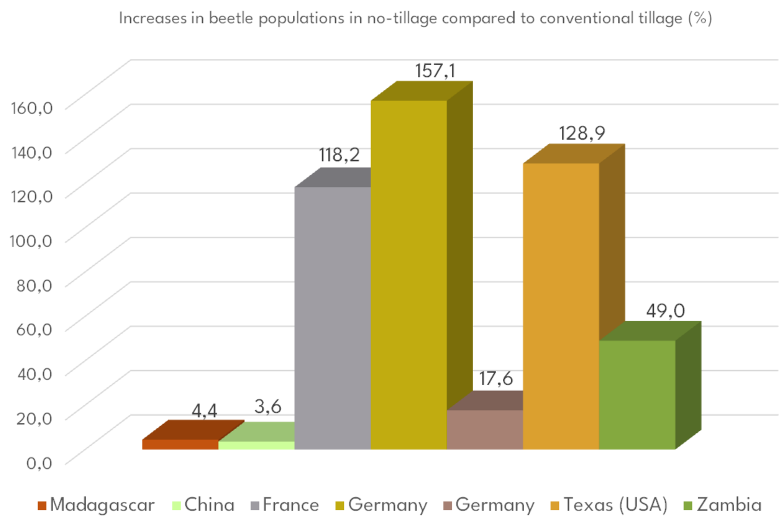


Figure 4.7. Percentage increases, in different comparative studies, of beetle abundance in no-tillage compared to conventional tillage.

The figure shows that increases of 500% in beetle abundance in no-tillage system compared to conventional tillage system were obtained in the study carried out in Italy (Massaccesi et al., 2020) The results obtained in conventional tillage system were duplicated in other studies such as those of Henneron et al. (2015), Puliga et al. (2021) and Hakeem et al. (2021) held in France, Germany, and Texas, respectively. However, in the research work conducted in Madagascar (Rakotomanga et al., 2016), China (Xin et al., 2018), Germany (Redlich et al., 2021) and Zambia (Muoni et al., 2019), beetle population increases were smaller. The overall average increase across the eight studies was more than 100%. In other words, the abundance of beetles doubled in no-till system compared to conventional tillage system.

There are also studies that have considered not only the beetle population, but also the species richness. For both variables, studies have been able to show, using the Shannon index, the overall effect on beetle biodiversity in this order of arthropods (Figure 4.8).

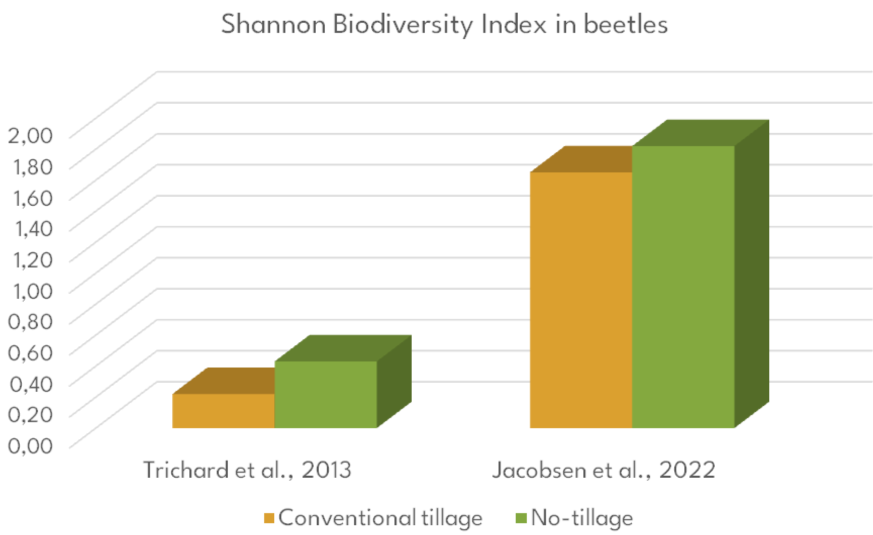


Figure 4.8. Comparison of the Shannon biodiversity index obtained in studies carried out in France (Trichard et al., 2013) and Denmark (Jacobsen et al., 2022).

Numerically, in both rotations studied in France (Trichard et al., 2013) and Denmark (Jacobsen et al., 2022), the increase in the Shannon biodiversity index for beetles was around two tenths. In percentage terms the study by Trichard et al. (2013) showed that the index value doubled in the no-till system. Although in this study low values of the Shannon index were obtained for what is considered normal for cultivated soils, those obtained in the study by Jacobsen et al. (2022) were normal.

In terms of groundcovers, an even greater effect of CA practices has been observed (Figure 4.9). For both spontaneous (natural) and planted groundcovers, increases in beetle population ranged from 50% in the study by Blaise et al. (2022) to more than 200% in De Pedro et al. (2020) and Nunes et al. (2015) and 300% in Sáenz-Romo et al. (2019a) compared to populations from bare ground alleys.

In the case of beetles (Figure 4.9), vineyards are the crops on which studies have predominantly been carried out by Nunes et al. (2015) in Portugal, Sáenz-Romo et al. (2019a) in Spain and Blaise et al. (2022) in France. De Pedro et al. (2020) studied the beetle population in a Spanish pear tree orchard, and Inagaki et al. (2022) in a Japanese lemon grove.

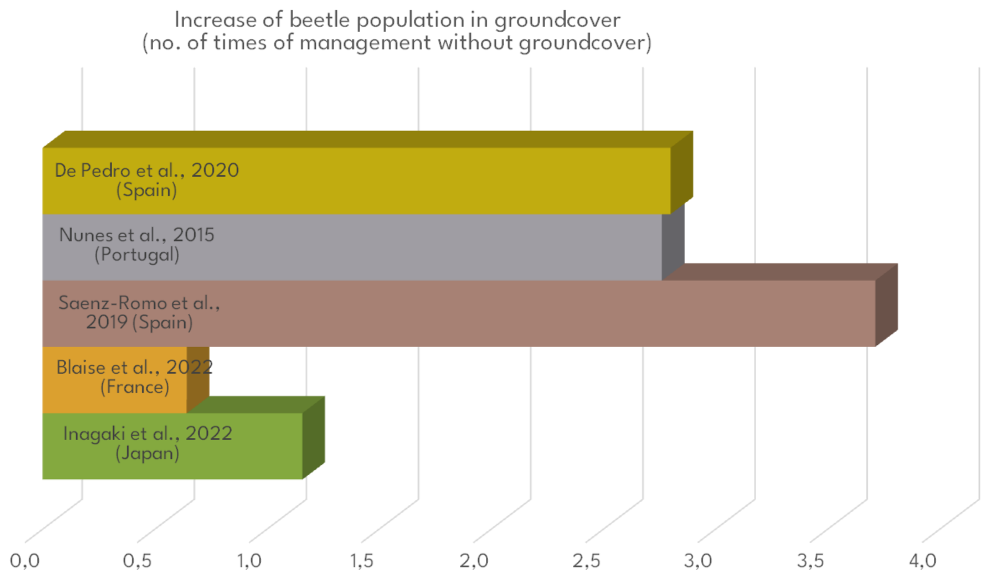


Figure 4.9. Number of times beetle population in various crops (lemon, grapevine, and pear) is increased by groundcover compared to conventional management with bare soil in the crop alleys.

4.5 ANTS

Ants are one of the most conspicuous living creatures on the ground surface, due to their large numbers and high degree of activity, being very easy to observe both directly and by means of dropping traps. In terms of the ecology of this order of arthropods, the functions they perform and their feeding habits, they can produce benefits or problems in the crop, as there are species that act as biocontrollers of pests, by directly preying on them, and others that become a pest, because their main food is related to the crop.

Despite their biological importance and ease of sampling, there has not been as much scientific information on the effects on their populations in CA as there is on the two previous orders of spiders and beetles. However, in two no-till rotations in a tropical environment, increases in ant population have been observed with respect to conventional tillage. Rakotomanga et al. (2016) observed in Madagascar that ant populations were more than 300% higher in no-tillage system, while in Brazil Fernandes et al. (2018) measured a difference of11.8%. The latter authors also observed a higher richness of ant species, 24 in conventional tillage and 26 in no-tillage. Biodiversity data through the Shannon index for this order were 0.79 and 0.85, respectively.

Regarding comparative studies in woody crops between with and without groundcover, overall results are inconclusive (Figure 4.10). The data show a 50% smaller population in no-till system in two of the studies (De Pedro et al., 2020; Nunes et al., 2015) whereas in the study by Sáenz-Romo et al. (2019a) the number of ants is more than two times greater in the no-till system (Sáenz-Romo et al., 2019a).

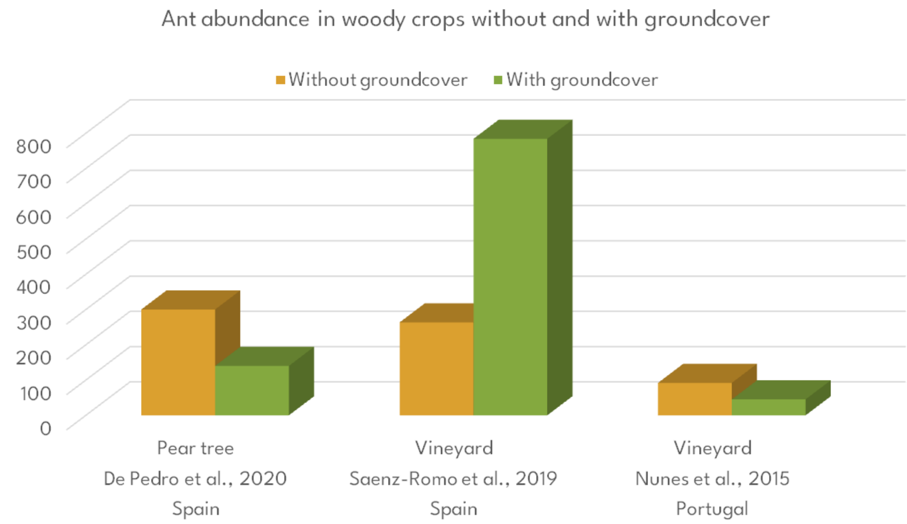


Figure 4.10. Comparison of ant abundance in different woody crop plots, with and without groundcover.

4.6 CRICKETS

Crickets belong, together with grasshoppers, to the order Orthoptera, although there are great differences between them, both morphologically and with respect to feeding habits. Crickets are omnivores, feeding on a multitude of resources found in the soil, from plant remains to small insects, while grasshoppers are mostly herbivores. Crickets can be considered primarily epigean while grasshoppers are animals that tend to fly and live on groundcover.

In a study conducted on groundcovers in lemon groves in Japan (Inagaki et al., 2022), it was observed that the number of crickets caught was higher in alleys planted with *Vulpia myuros* than in cover-free lemon groves, from an average of two to four individuals. However, leaving the spontaneously growing groundcover in the alleys or planting *Trifolium repens* had no effect, with two crickets on average per sampling.

4.7 EARWIGS

Earwigs have a behaviour similar to that of crickets, foraging mainly at the ground surface. During the day, they usually take refuge in cracks in the ground or under stones, coming out at night to move along the ground in search of food which is very varied due to their omnivorous nature.

No-till direct sowing system seems to favour the presence of earwigs. Quintanilla-Tornel et al. (2016) measured increases in the mean number of earwigs for this management, with 0.12 in conventional tillage to 0.29 in no-tillage in a rotation of garlic with a legume in the Hawaii, USA. A larger difference in terms of increase was measured in Madagascar (Rakotomanga et al., 2016), where the average density of earwigs in conventional tillage was 1.07 individuals, and in no-tillage it was 11.35 individuals.

In woody crops, earwig populations have also been favoured by soil conservation practices (Figure 4.11). In lemon trees in Japan (Inagaki et al., 2022) and in Spanish vineyards (Saenz-Romo et al., 2019a) a significant increase with respect to bare soil can be observed compared to both sown and spontaneous groundcovers.

In lemon trees, the best results were obtained in sown groundcover where there was a large increase in earwig number compared to conventional tillage. In the case of vineyards, most notable increases were in spontaneous groundcover.

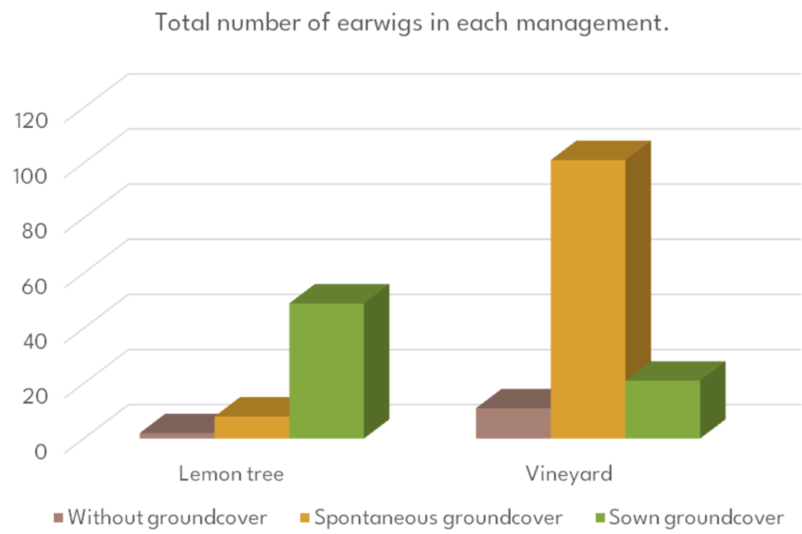


Figure 4.11. Total number of earwigs in crops without groundcover, spontaneous groundcover and sown groundcover, in lemon trees (Inagaki et al., 2022) and vines (Saenz-Romo et al., 2019a).

4.8 REPTILES

Reptiles are also part of the ground surface fauna. There are three main groups: lizards, geckos and snakes. The presence of groundcover in the alleys of an olive grove in Spain (Carpio et al., 2017) shows a benefit for reptiles compared to the absence of groundcover. The average number of species observed per sample was eight in olive groves without groundcover, and ten in those with groundcover. Also, the number of observations in olive groves was 2.5 times higher in groundcovers than in groves without groundcovers.

4.9 SUMMARY AND CONCLUSIONS

Based on the evidence presented in preceding sections, a qualitative assessment can be made (Table 4.1) of the effects of CA on soil surface epigean fauna biodiversity.

Table 4.1. Qualitative summary of the application of conservation agriculture on different above-ground faunal groups. Very positive (+++), positive (++) or indifferent (+) effect.

Measurement of CA	Spiders	Beetles	Ants	Crickets	Earwigs	Reptiles
No-Tillage	+++	+++	++		++	
Groundcover	+++	+++	+	++	+++	++

Spiders and beetles appear to be the groups that benefit most from CA. These are epigean animals which show a large increase in population and in species richness in no-till system compared to conventional tillage system in annual crops and woody crops. The benefits derived by epigean fauna from the practice of CA is doubly positive because of their contribution to the conservation of biodiversity and to the provision of ecosystem services for the crop.

For the rest of the epigean faunal groups, there is a deficiency of studies, with hardly any studies available on ants in CA.

CHAPTER 5

QUALITY AND VARIETY OF POLLINATING INSECTS IN CONSERVATION AGRICULTURE

5.1 INTRODUCTION

When pollinators are considered, they usually refer to honeybees (*Apis mellifera*). While the importance of this species is undisputed, agriculture also depends on other wild pollinating insects in each region which contribute greatly to crop development. The most important group consists of the members of the *Apoidea* family, with more than 20,000 species, including the honeybee. Butterflies, moths, flies, and beetles, which feed on nectar or pollen, can also be efficient pollinators. These pollinating insects play an important role in the production of crops (Garibaldi et al, 2013) and are essential for the sustainability of agriculture. Approximately 87% of the world's major food crops and 35% of global crop production volumes depend on animal pollination (Klein et al. 2007).

In addition to their role in crop production, pollinators also have a significant impact on biodiversity. Pollinators are crucial for the conservation of biodiversity and the maintenance of ecosystem structure and function, as they facilitate the reproduction of flowering plants (Ollerton et al., 2011). This allows the proliferation of habitats that support a wide range of species, making it a key ecosystem service. The plant-pollinator relationship provides indispensable ecosystem functions that underpin global biodiversity (Ollerton, 2017). However, the conservation of pollinators is not just about increasing the diversity of plant species. Studies show that an increase in the number and variety of pollinators provides unique and essential ecosystem services relevant to food security, and that different groups of pollinators are vital for fostering environmental security. They also positively contribute to human health and well-being and provide socio-cultural benefits. Therefore, better conservation of pollinator diversity requires adopting ecosystem management approaches in land use management that integrate ecosystem services with socio-cultural services and biological control of crop insect pests and disease vectors (Katumo et al., 2022). Undoubtedly, pollination services are essential for successful plant reproduction, playing an important role in the maintenance of plant communities (Rodger et al., 2021).

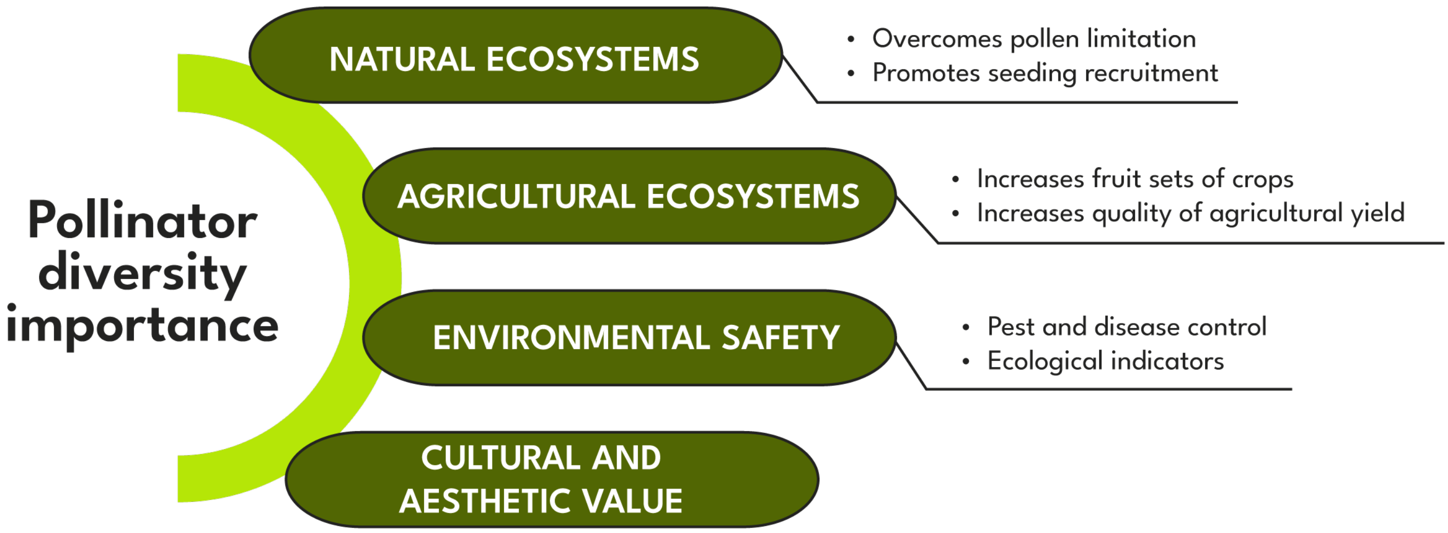


Figure 5.1. Importance of pollinator diversity in natural and agricultural ecosystems (Own elaboration based on Katumo et al 2022).

Unfortunately, pollinating insects face numerous threats that have implications for the sustainability of agricultural ecosystems. The diversity and abundance of wild pollinating insects has declined in many agricultural landscapes (Garibaldi et al., 2013) and may become an urgent ecological challenge (Christmann, 2019). The European Commission, in the review of the Pollinator Initiative (2023), addresses several priorities to intervene in pollinator decline. In particular, Priority II: "Improving pollinator conservation and addressing the causes of pollinator decline", identifies the main threats facing pollinating insects. These include land-use changes, such as intensification of agriculture and forestry, urbanisation, and infrastructure development, which limit habitat availability and fragment habitat continuity. Similarly, the Intergovernmental Science Policy Platform for Biodiversity and Ecosystem Services (IPBES) clearly identifies agriculture as a threat to pollinators, but also postulates it as a possible solution to prevent their decline (IPBES, 2016). Adventitious vegetation provides the necessary resources for the installation of wild pollinators (Carvalheiro et al. 2011; Bretagnolle & Gaba 2015; Requier et al., 2015). Therefore, their continued removal by physical (tillage) or chemical means may indirectly cause pollinator populations to decline (Steffan-Dewenter et al., 2005; Diekötter et al. 2010). This leads to disruption of soil continuity and deterioration of soil health, and together with the removal of natural vegetation and the proliferation of monoculture, degrades agricultural landscapes. This results in an erosion of floral resources and nesting spaces for wild pollinating insects, impacting pollinator abundance and diversity and ultimately pollination services (Kovács-Hostyanszki et al., 2017)

Given this scenario, which compromises the continuity of pollinator populations, it can be assumed that the introduction of agricultural practices based on Conservation Agriculture (CA) principles, contributes to the conservation and improvement of pollinating insect populations.

5.2 ROLE OF CONSERVATION AGRICULTURE IN MAINTAINING AND IMPROVING POLLINATING INSECT POPULATIONS

5.2.1 Conservation Agriculture for the conservation of floral resources

Strategies to improve insect pollinator habitats in agricultural ecosystems should be based on the conservation of floral and nesting resources to support wild pollinator communities.

To conserve and increase the number of pollinating insects, the management of agricultural ecosystems must consider an appropriate floral selection that is attractive to pollinators.

The introduction of groundcovers in perennial crops is the most suitable practice for the conservation of flowering resources in woody crops. In this regard, Saenz- Romo et al. (2019a) compared the average number of pollinating insects, counted by trapping them, according to soil management and groundcover type (Figure 5.2).

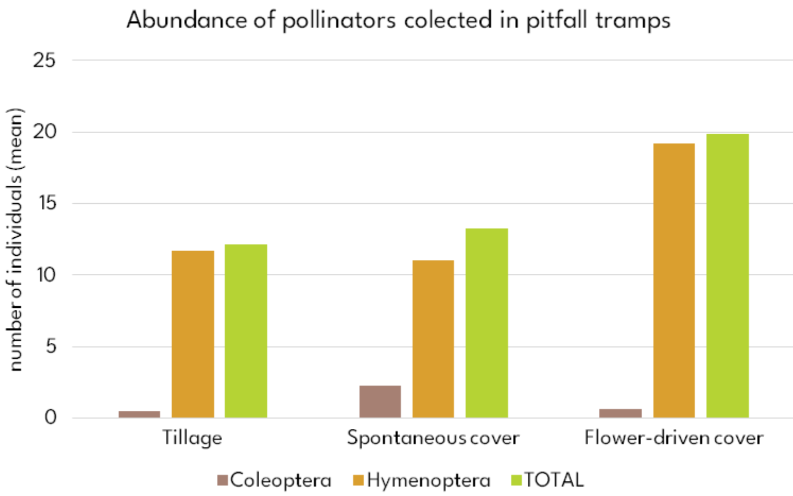


Figure 5.2. Abundance of pollinating insects according to management and type of groundcover. Source Saenz-Romo et al., 2019a.

This study shows how the variation of pollinating insect communities is influenced by the soil management technique in grapevine production. Although there was no real difference in the number of individuals captured in the study on ploughed soils and those with spontaneous groundcover, a greater number of pollinating insects were observed under management with sown groundcover. However, it is evident that the selection of the cover contributes significant positive effects in terms of the overall abundance of pollinators, mainly reflected in the number of hymenopterans.

Thus, the application of agronomic practices based on the principles of CA that favour the proliferation of floral resources, such as the diversification of species and the avoidance of mechanical alteration of the soil surface, allows for a greater density and variety of floral resources for these insects. To test the influence of both floral species selection and soil management, Barbir et al. (2019) studied the effect of introducing various floral species into the rotation to test the attraction of pollinating insects, and the effect of tillage on the self-seeding of plants for subsequent emergence (Table 5.1). For this purpose, they compared the self-emergence of different species in a no-tillage and a shallow-tillage scenario, as the maintenance of tilled soil is intended to eliminate and prevent the emergence of spontaneous vegetation.

Table 5.1. Difference in emergence by soil management. Source: Barbir et al, 2019.

Plant Species	Treatment	Number of plants/m² (±SD)	
		Year 1	Year 2
Borago officinalis	Shallow Tillage	26.67± 30.98	1.78± 5.33
	No-Tillage	26.67± 17.88	19.56± 31.78
Calendula arvensis	Shallow Tillage	2816.89± 1103.66	231.11± 119.23
	No-Tillage	4522.67± 1664.15	1223.11± 78.02
Centaurea cyanus	Shallow Tillage	0	58.67± 32.98
	No-Tillage	0	190.22± 97.47
Coriandrum sativum	Shallow Tillage	313.56± 246.96	1.78± 5.33
	No-Tillage	16.19± 16.54	0
Diplotaxis tenuifolia	Shallow Tillage	0	5.33± 8.00
	No-Tillage	0	152.89± 78.43
Echium plantagineum	Shallow Tillage	234.61± 60.1	1.78± 5.33
	No-Tillage	230.26± 135.35	236.44± 127.94
Phacelia tanacetifolia	Shallow Tillage	226.12± 96.79	1.78± 5.33
	No-Tillage	318.13± 80.83	115.56± 160.75

The results obtained, showed that the lack of soil disturbance favours, in most cases, the self-sowing of plants that serve as a food reservoir for pollinators. This increased emergence on untilled soils may be directly related to an increase in the number of pollinators nesting in and visiting such areas. Even though there are no insect pollinator count data by type of management in their study, a higher number of visits by observed insect pollinators can be observed for all floral species (Figure 5.3).

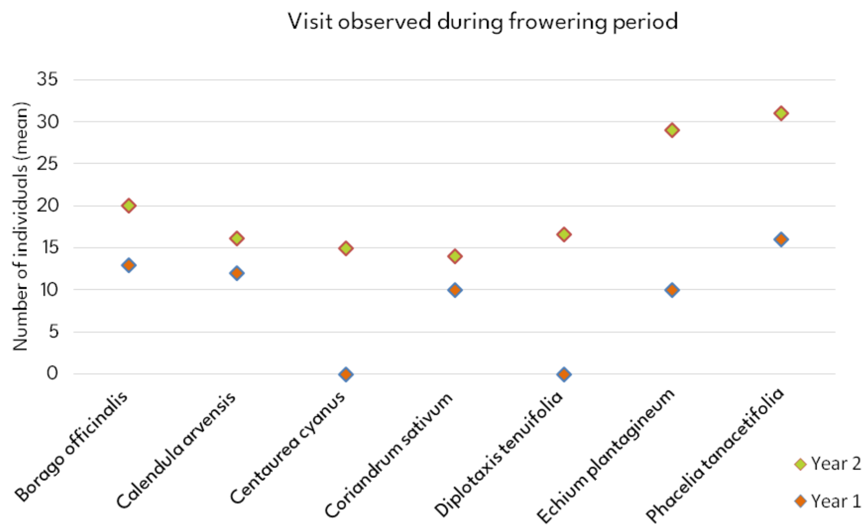


Figure 5.3. Attractiveness efficiency of the studied plant species for pollinators. Source: Barbir et al., 2019.

It should be noted that an increase in floral resources, does not necessarily lead to an increase in pollinator visits, as there are many more factors that can influence observations. However, not altering the soil surface by tillage favours the germination and emergence of vegetation, making these resources available to pollinators. It is worth mentioning that, as these plant species may be considered as weeds and therefore potentially detrimental to the crop, their invasiveness should be considered and managed appropriately.

One of the major contentious issues in the maintenance of groundcover under CA systems and practices is the use of chemical herbicides and the effects they can have on pollinating insects. Angelella et al. (2019) analysed the overall abundance of pollinators, dominated by native bees, in relation to wildflower establishment under different management, corroborating that establishment of wildflower habitats may be more successful in the absence of tillage. Like other authors (Frances, 2008; Love et al., 2016; Washburn & Barnes, 2000), they also noted that herbicides applied in no-tillage system, prior to the emergence of this vegetation, have no effect on the development and density of wild plants that appear (Figure 5.4), suggesting that the presence of pollinators does not decrease.

However, the use of herbicides for the control of flowering groundcover must be done with great care because, if the aim is to eliminate the cover crop to avoid water competition with the main crop, its application when part of the floral resources for pollinators are still present can have a detrimental effect on pollinator populations. In these terms, McDougall et al. (2021) studied the effects of herbicide application on pollinators for groundcover control in woody crops. It is observed that pollinator abundance, richness, diversity, and evenness were significantly lower in the plots where herbicide treatment had removed most of the flowering weeds compared to untreated plots (Figure 5.5).

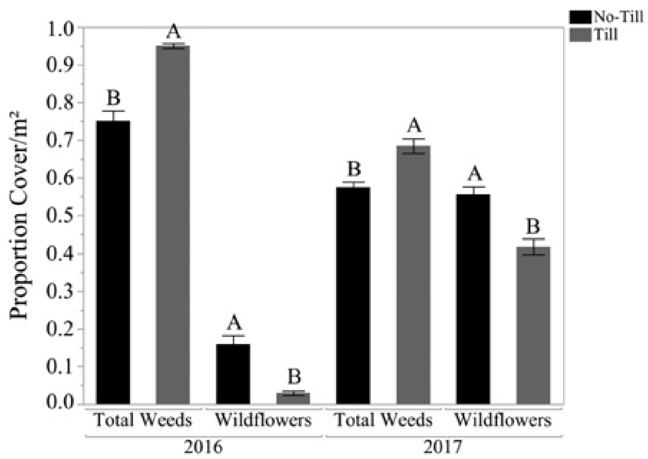


Figure 5.4. Proportions of wildflower and weed cover by no-till and till. Source: Angelella et al., 2019.

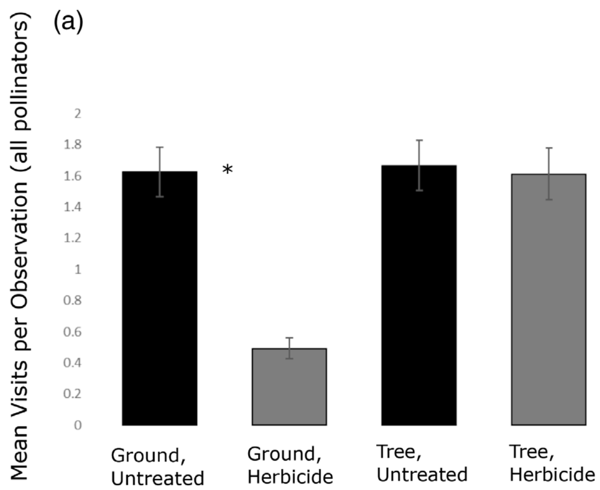


Figure 5.5. Mean number of pollinators recorded per visual observation by treatment and habitat type. Source: McDougall et al., 2021.

Thus, it is advisable to conserve part of the floral resources by maintaining a row of vegetation, rather than completely removing the groundcover with herbicides. This practice, together with integrated weed management, helps to maintain adequate pollinator populations.

Therefore, the maintenance of floral resources as a refuge for pollinator species is enhanced by CA practices, essentially in woody crops.

A separate mention must be made of the planting of cover crops which, although in line with one of the principles of CA (diversification of species), has not been considered in the preparation of this report. Planting of cover crops is an agro-ecological practice that can be implemented both in conventional and CA management, and therefore the benefits it provides cannot be attributed to CA per se. Even so, it should be noted that the introduction of cover crops provides floral resources capable of supporting large insect pollinator communities (Carreck & Williams, 2002; Ellis & Barbercheck, 2015). Including this practice with main crops is proven to be beneficial for biodiversity and to provide additional ecosystem services. The provision of dense floral resources in cover crops has also been shown to attract more pollinators and may increase the foraging efficiency of pollinators (Dauber et al., 2010; Haaland et al., 2011). Likewise, floral diversity in crop rotations may also influence pollinator conservation, as the presence of diverse plant species may be more important than the total number of plants in attracting pollinators (Warzecha et al., 2018). Thus, increasing resource availability by using cover crops as part of a crop rotation or association can help provide flowers for both managed and wild bees, while providing other agricultural ecosystem services (Mallinger et al., 2019).

Therefore, the inclusion of cover crops in CA management provides an additional benefit in terms of enhancing floral resources to conserve and improve the quantity and variety of pollinating insects in agricultural ecosystems.

5.2.2 Conservation Agriculture for the conservation of nesting areas for pollinating insects.

One of the aspects to consider when talking about the conservation of pollinating insects, is that 75% of wild bees, whose role is essential for pollination, nest in the ground and spend a large part of their life cycle in the ground (Antoine et al., 2021). Female ground-nesting bees and wasps excavate tunnels leading to brood cells, in which they lay eggs on a food reserve. Therefore, agronomic practices that alter the continuity of topsoil layers and disrupt soil structure, create unfavourable conditions for the nesting of these pollinating species (Holzschuh et al., 2007). In particular, intensive tillage, the total removal of groundcover and the disappearance of spontaneous vegetation, pose a serious problem for the nesting of these pollinators (Scheper, 2015), as they require natural or semi-natural nesting environments (Las Casas et al., 2022). In this situation, the adoption of practices based on CA principles (no-tillage and cover crops in annual crop systems and no-tillage and groundcover in woody crop systems) is postulated as the most appropriate crop management system to provide favourable conditions for pollinating insects to nest in the soil.

To test whether mechanical soil disturbance affected pollinator nesting, Shuler et al. (2005) studied the impact of tillage on the populations of the squash bee (*Peponapis pruinose*). The nest dug by females of this species near host plants, can be up to 46 cm deep. According to the study, they found that the density of squash bees was related to tillage practices, with their presence being three times greater in untilled plots compared to tilled plots (Figure 5.6).

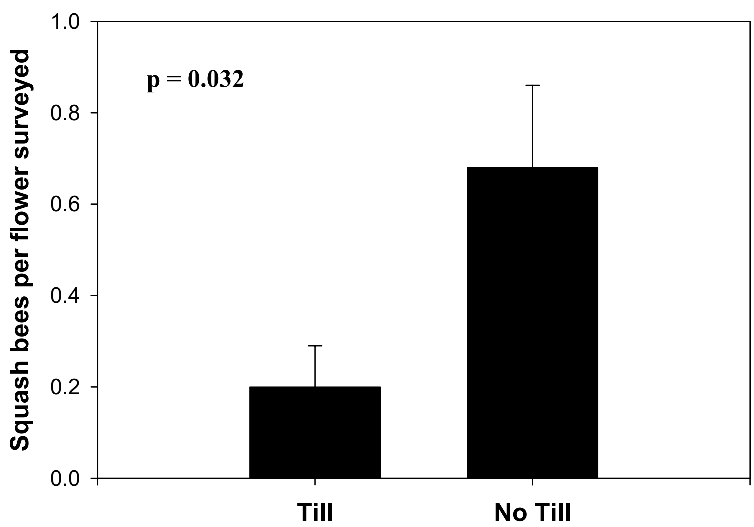


Figure 5.6. Effect of soil management practices on squash bee density. Source: Shuler et al., 2005.

One of the aspects to be considered in the preservation of bee nests, is the application of plant protection products on the soil surface. In this study, Shuler et al., (2005) statistically analysed the influence of pesticide use on squash bee density, showing that the application of pesticides had no effect on the density of insects visiting the flowers, but the soil disturbance by tillage did (Table 5.2).

Table 5.2. Effect of pesticide use and tillage on P. pruinose density on squash and pumpkin flowers. Source: Shuler et al., 2005.

Source	df	Seq SS	Adj SS	Adj MS	*F*	*P*
Tillage or no-tillage	1	1.0382	1.0382	1.0382	6.09	0.022
Pesticide use	1	0.0002	0.1063	0.106	0.62	0.438
Error	22	3.7485	3.7485	0.1704		
Total	24	4.8468				

General Linear Model ANOVA with tillage and pesticide use (yes/no) as factors

Nonetheless, this last statement would be in contrast to the results obtained by Kremen et al. (2002) who state that the use of herbicides and pesticides has an influence. In this regard, Shuler et al. (2005) explain this discrepancy on the grounds that the studies by Kremen et al. (2002) were conducted in fields isolated from natural areas or with bare soil, which as detailed above has a negative impact on nesting by these insects. On the other hand, effects differ according to the timing of pesticide and herbicide application. Thus, adopting practices based on CA principles, which improve the biological, physical, chemical and hydrological characteristics of the soil and increase the organic matter content of the soil, favouring the degradation of the active ingredients of plant protection products more easily (Kah et al., 2007), reducing the risk of affecting wild bees if application is made when they are still in the larval stage.

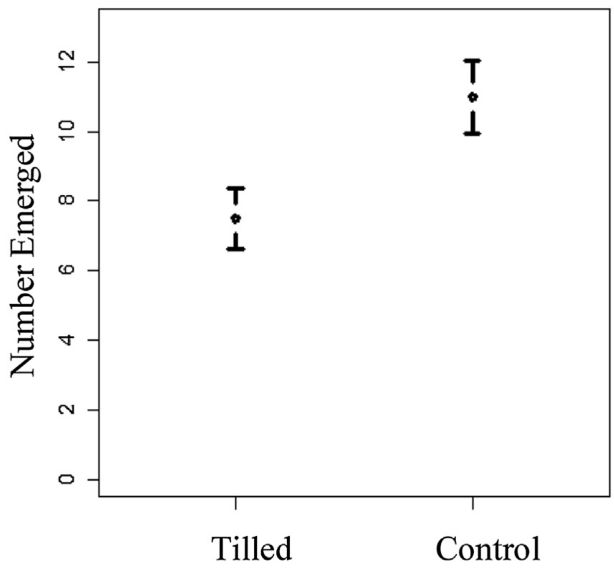


Figure 5.7. Mean number of bees emerging per plot. Source: Ullmann et al., 2016.

These findings are corroborated by Ullmann et al. (2016) who compared how intensive tillage affected the emergence of squash bee brood. Based on their results, there is evidence that tillage reduces the emergence of squash bee brood (Figure 5.7).

Tillage therefore affects the young of this pollinator species in various ways, with negative consequences for population growth and crop development. It is evident that, as in the previous study, ploughing reduces brood emergence by an average of 50% compared to unploughed plots.

Another aspect to be considered in the emergence of broods from pollinator nests is seasonality. Physical characteristics of the soil, such as temperature or structure, are an important factor in triggering the emergence of squash bee brood (Forrest & Thomson, 2011). Ullmann et al. (2016), found that there was a delay in bees leaving the nest in tilled plots because soil disturbance breaks the soil structure, making it difficult for the bees to excavate (Hamza & Anderson, 2005). In addition, brood emerge from deeper cells, as shallower cells have been destroyed, which may result in the bees taking longer to reach the soil surface. These delays in bee emergence on tilled soils can have an undesirable effect on crop productivity, affecting the synchronisation between blooms and the main pollinators.

In order to corroborate the effect of CA soil management system on the improvement and conservation of nesting conditions for wild and solitary bees, Cusser et al. (2023) modelled the incidence of different ranges of tillage suppression in cotton to quantify the economic benefits of pollinators. They confirmed that the adoption of this system offered benefits with respect to the services that pollinators provide, which in turn contribute to maintaining, and even improving crop production. Conventional tillage is known to decrease the nesting resources for wild bees (Ullmann et al., 2016) and that of most cotton pollinators nest on the ground (Cusser et al., 2018; Esquivel et al., 2019). Cusser et al. (2023) assume in the model that the adoption of no-tillage offers improved nesting resources, comparable to what might occur in a fallow field, where the habitat is considered naturalised for pollinator nesting. The model showed that the introduction of no-tillage can benefit pollination service and crop yields. It was estimated that for every 1% reduction in tillage in the study area (Refugio County, South Texas), an increase in cotton production of 1.5% was achieved for the study region, resulting in an additional USD 16,000 benefit from improved pollination service, so that eliminating tillage altogether could increase the benefit by up to USD 1,600,000. (Figure 5.8).

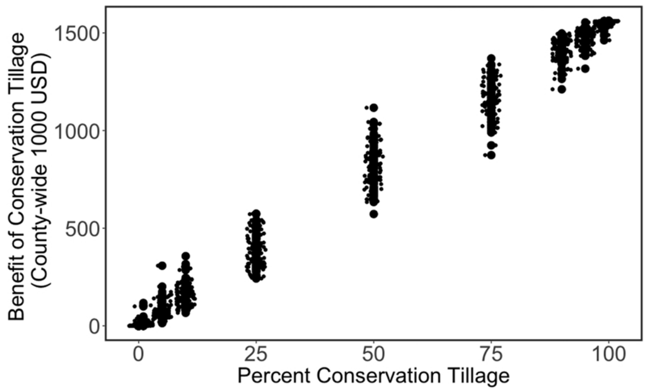


Figure 5.8. Scatterplot depicting the change in county-wide revenue (USD per year) from the adoption of conservation tillage. Source: Cusser et al., 2023.

However, it is not always the adoption of no-tillage system that makes a noticeable difference to the nesting of pollinator species. Some bee species change nesting sites every year (Rozen & Buchmann, 1990), others maintain nesting sites for years or decades (Cane, 2008). Thus, there is no influence of no-till direct seeding on bees that change nest location annually. Tschanz el al. (2023) conducted a study in which they found no significant differences, and even noted a slight increase in nests on tilled ground (Figure 5.9).

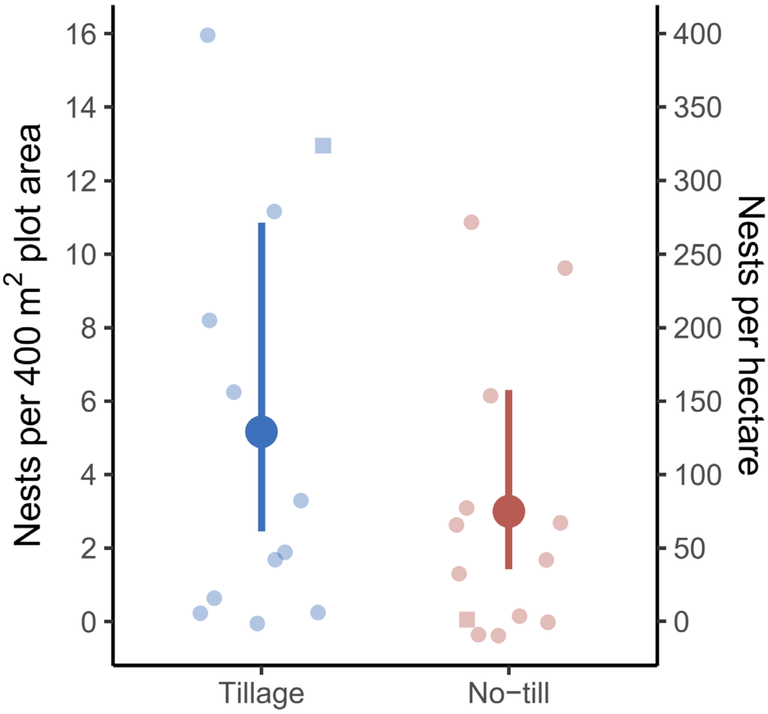


Figure 5.9. Number of nests per 400 m² plot area and per hectare. Source: Tschanz et al., 2023.

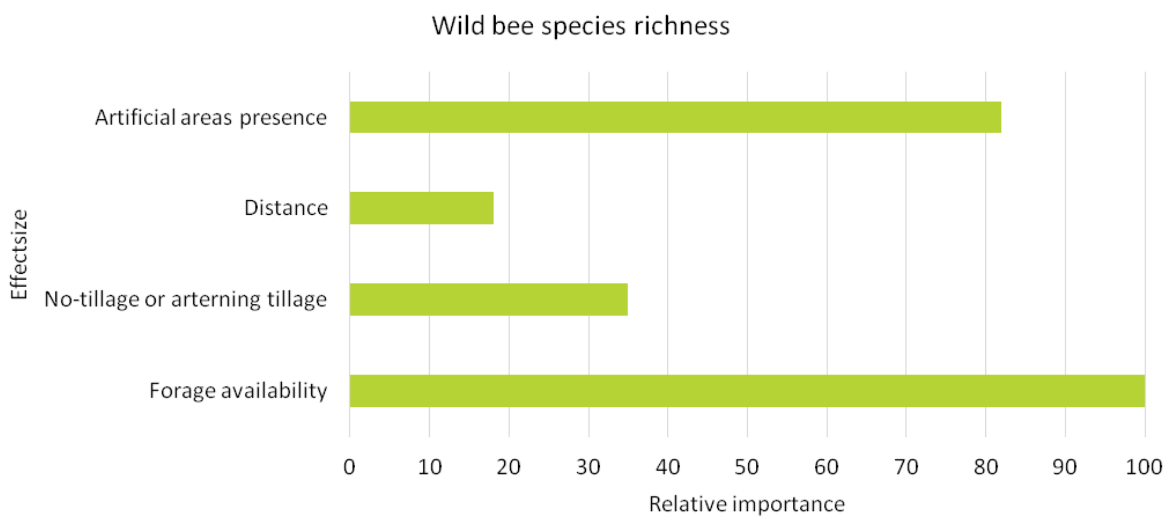
In this case, it has to be noted that the nesting of pollinating insect communities may be associated with different soil management systems. While some species prefer to nest in soils that are little disturbed and more resistant (Wuellner, 1999), others prefer lighter soils (Sardiñas & Kremen, 2015). Despite these variations in soil type preference for nesting, it is possible to state that, once nests are established, mechanical disturbance of the soil can affect them. Some species are more tolerant of such disruption of the soil surface than others, depending on the depth of nesting and the depth of tillage (Harmon-Threatt, 2020; Ullmann et al., 2016). Therefore, the more intensive and deeper the tillage of agricultural soils, the more the detrimental effect on the maintenance of established nests increases considerably.

The number of studies on the nesting capacity of pollinating insects according to different soil disturbances is scarce. Nonetheless, it can be assumed that the application of CA principles provides favourable soil conditions for nesting and emergence for a large majority of ground-nesting insect pollinators which, although little known (Antoine & Forrest, 2021), play an essential role in pollination processes.

5.3 IMPORTANCE OF CONSERVATION AGRICULTURE IN AGRICULTURAL LANDSCAPE MANAGEMENT TO ENSURE THE CONSERVATION OF POLLINATING INSECTS

Pollinating insects and the ecosystem services they provide to agricultural landscapes make their conservation a global priority, with the preservation of habitat continuity being one of the major challenges for the maintenance of pollinator communities. There are only few studies quantifying the effect of landscape and Agricultural ecosystems degradation and fragmentation on pollinator communities. These studies analyse various factors such as distance (Carvalheiro et al., 2010; Saunders & Luck, 2014) or the number of native habitats (Brosi et al., 2008; Le Féon et al., 2010). However, there are still not enough studies interrelating habitat shaping factors with pollinator population dynamics in agricultural ecosystems (Saturni et al., 2016).

In line with the above, Kratschmer et al. (2018) modelled the relationship of different landscape factors (floral or forage resources, distance, type of land management and presence of artificial or urban areas) with respect to the abundance and diversity of pollinator species in different vineyards in Austria (Figure 5.10).



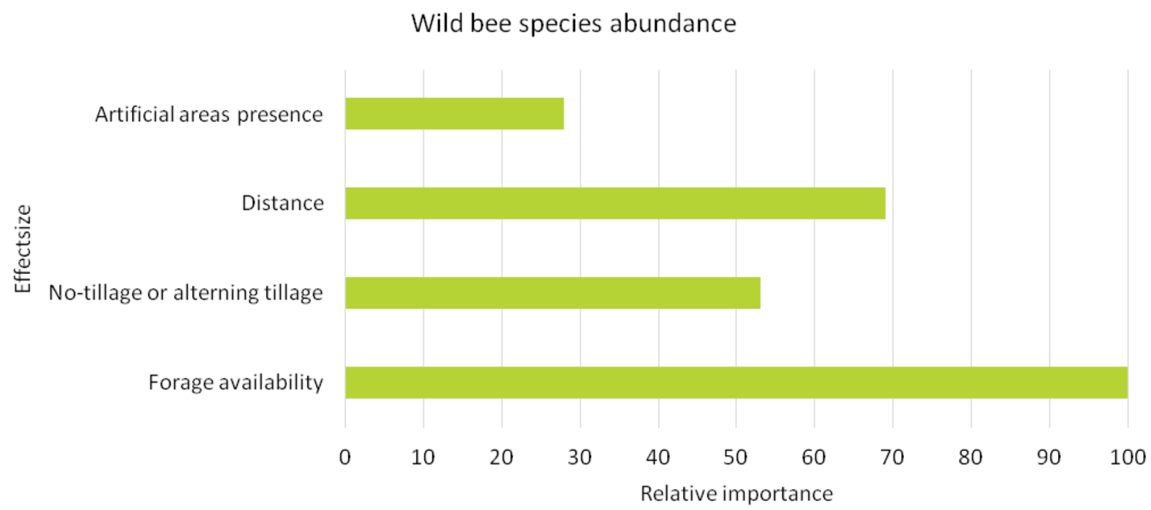


Figure 5.10. Parameters affecting (a) wild bee species richness and (b) wild bee abundance. Source: Kratschmer et al., 2018.

These models highlighted that the availability and variability of floral and forage resources in the landscape is the most influential factor with respect to the abundance and diversity of pollinating bees. The presence of artificial areas, which provide a greater variety of nesting spaces (such as lawns, gardens, human-made constructions, etc.), is shown to be the second most important factor with respect to species diversity. The distance to the refuge area is the third most important relative factor with respect to the abundance of bees present. The model also highlighted the importance of soil management as the fourth most important factor in terms of the richness and abundance of pollinator species. Thus, the elimination of tillage or shallow tillage in alternate lanes of the vineyards is an important factor in terms of the abundance of bees found. However, soil management is not as important a factor in terms of species diversity, as it is more important to include resource diversity in the landscape than to maintain continuity of soil structure. It is true that the alternation of tillage in the alleys can favour the nesting of species that prefer lighter soils, so that in such case the relative importance of soil management system in terms of the variety of species must be considered. Another factor that determines the presence or absence of pollinating bees in terms of abundance is distance. Depending on the pollinating insect species, pollinating insects can have a range of 100 m or even several kilometres. Pollination services and crop production decrease with increasing distance from natural habitats (Garibaldi et al., 2011), and production and profit can even be maximised by up to 30% in extensive crops within 750 m of pollinator refuge areas (Morandin & Winston 2006).

Another aspect highlighted by this study is the presence of artificial areas, pointing out that the variability of the landscape favours species enrichment. This is because it provides a diversity of nesting spaces that can lead to the appearance of other pollinating species that are typical of non-agricultural landscapes.

Therefore, integrated agricultural landscape management for the conservation and enhancement of pollinator species should consider various strategies that contribute to landscape continuity to favour pollinating insect dynamics. In agricultural areas, where plant resources as a refuge for pollinators are at risk due to intensification of tillage, introduction of large areas without soil cover and monoculture, the introduction of practices based on CA principles are key to providing these key resources without jeopardising the profitability of the crops. Key factors for the conservation and enhancement of pollinating insect species are: (a) the continued maintenance of groundcover, both with living cover (woody crops with groundcover or cover crop planting in annual crop rotations and associations) and pruned biomass; and (b) minimum mechanical disturbance of the soil surface. Other complementary practices, such as the introduction of vegetative margins or biodiversity islands which have beneficial effects on pollinator populations can be considered as they favour the maintenance of these key factors for the conservation and enhancement of pollinating insect species.

5.4 SUMMARY AND CONCLUSIONS

Ecosystem services provided by pollinating insects are threatened by intensive tillage agricultural. Adoption of the following practices based on the three principles of CA, provides key benefits for the conservation and enhancement of pollinator species in agricultural landscapes:

- Maintenance of vegetative ground cover benefits the shelter of pollinating species, providing soil with favourable characteristics for the breeding of nesting bees.
- Non-disturbance of the soil surface to maintain vegetation between crops, as well as crop rotation and the introduction of cover crops in woody crops, provide sufficient floral resources for nesting and maintenance of pollinator species.
- The avoidance of tillage favours the nesting and rearing of pollinating species which nest on the ground and are species of great importance in agricultural ecosystems.

Adoption of CA principles and practices therefore bring important benefits, both to soil health and to the provision of necessary resources to pollinators. Agricultural landscape management must integrate these practices to ensure the future of pollinators, and thus the sustainability and profitability of farms.

CHAPTER 6

IMPROVEMENT OF SMALL MAMMAL BIODIVERSITY IN CONSERVATION AGRICULTURE

6.1 INTRODUCTION

The Conservation Agriculture (CA) system and its practices pay special attention to maintaining a healthy ecological base to underpin sustainability, promoting biodiversity, and strengthening the resilience of the system.

Farmland supports a wide range of wildlife, including vertebrates. Although many species depend on natural habitat for food and shelter, production areas provide essential forage and breeding habitat for many species (Holland, 2004). CA supports small vertebrate biodiversity in different ways. For example, crop biomass cover including stubble provides cover in winter and breeding habitat in spring. Crop biomass and weeds, if allowed to remain after harvest, provide seeds that serve as food.

The increase in soil organic matter favours the biodiversity of arthropods that can serve as food. Avoiding or minimizing mechanical soil disturbance maintains burrows that may be established in crop fields. Undisturbed soil conditions also provide the best possible environment for biodiversity to reach its full potential. Tillage does not exist in nature; nature has evolved to thrive in the least disturbed soil possible (Day et al., 2020).

As an example, hares (fig 6-1) can benefit from stubble as a food source, and small rodents and insectivores can feed on weed seeds and arthropods. With CA, the landscape is more conducive to allowing predators the opportunity to encounter small rodents (Day et al., 2020). The number of predatory birds actually increases, in response to the increase in small mammals (Arthur et al., 2004). Also, prey behaviour may vary in relation to existing cover, to avoid the risk of predation by birds (Arthur & Pech, 2003).

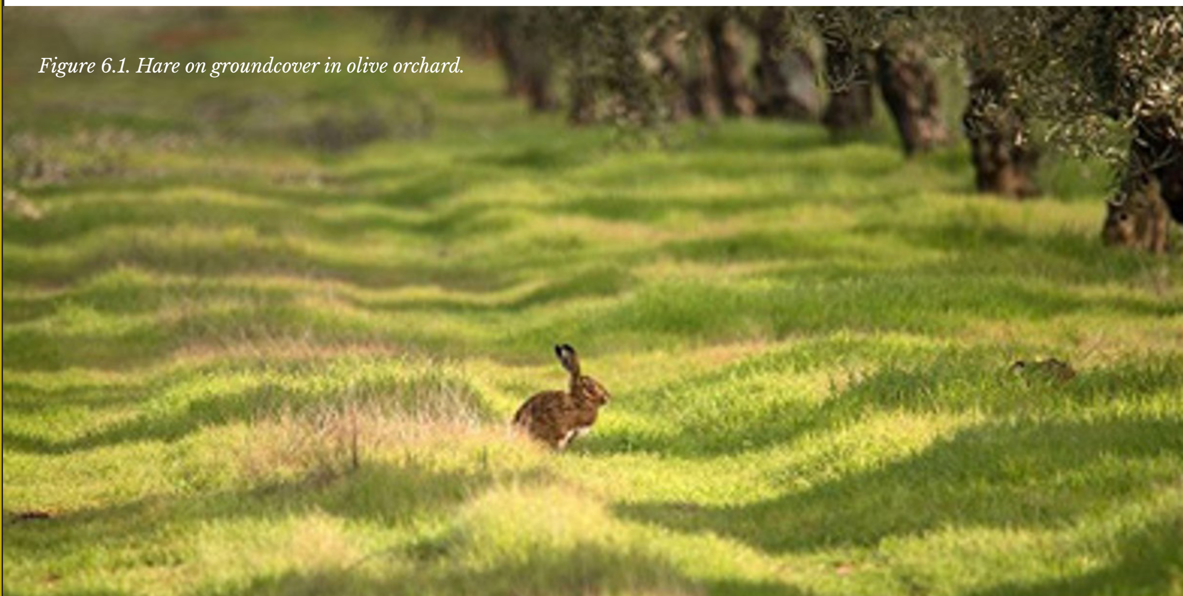


Figure 6.1. Hare on groundcover in olive orchard.

6.2 BIODIVERSITY OF SMALL MAMMALS IN ANNUAL CROPS IN CONSERVATION AGRICULTURE

CA enhances soil properties unlike conventional tillage agriculture by producing with minimum soil disturbance and maintaining biomass cover in diversified cropping. This also leads to changes in the quality and quantity of food sources as well as shelter for small mammals. Overall, habitat for wildlife is improved and biodiversity is increased in CA systems.

As there no-tillage in CA, no burrows are destroyed, which helps to maintain the population of small mammals, such as some rodents, which can cause damage to seedlings. Johnson (1986), in his review of field studies in the USA, states that populations of small mammals in no-till fields are generally no higher than in conventionally tilled fields but they are more diverse and possibly more stable. The same author underlines the benefits of these small mammals, such as the consumption of cutworms harmful to the crop. Getz & Brighty (1986) highlighted the potential of some species to combat weeds and control cutworms and budworms in corn and soybean fields in Illinois. Up to 64% of the annual weed seed production could be consumed by rodent species *Peromyscus maniculatus* and *Mus musculus*. Crotty et al. (2022) state that cover crops and mulches increase predation of weed seeds by invertebrates and small mammals compared to bare soil. Figure 6.2 compares seed predation of *Chenopodium album* by invertebrates and small mammals on bare soil and on clover-covered soil in soybean fields. Birthisel et al. (2015), in their studies highlight vertebrates as responsible for a higher proportion of weed seed predation than invertebrates and highlight cover crops as a strategy to encourage seed predation.

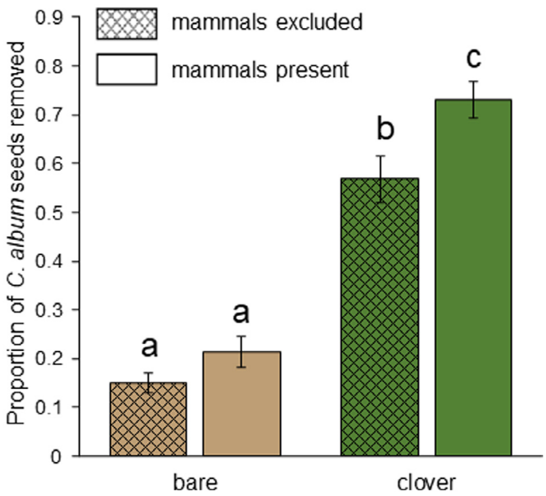


Figure 6.2. Mean (±SE) proportion of Chenopodium album seeds removed by invertebrates only (crosshatched bars) and invertebrates and vertebrates (open bars) on bare ground (left) and in cover plots (right) during week-long assays. Different lowercase letters indicate significant differences across all groups indicated by Tukey HSD posthoc tests. N=10 for each group repeated for 4 sampling periods in 2013 and 7 sampling periods in 2014 (440 total replicates). Source: Widick et al., 2022.

Studies carried out in CA systems in Argentina indicated that small mammals are sensitive to spatial variations in microhabitat, which can affect their distribution and abundance in crops (Bilenca et al., 2007). A study on armadillo presence (Zufiaurre et al., 2021) indicated a higher number of signs of armadillo presence (burrows and foraging holes) in CA systems compared to conventional tillage systems. Avoiding or minimizing soil disturbance provides a more suitable habitat for semi-fossorial mammals, such as armadillos, which also find greater feeding opportunities in stubble mulch cover with more fallen seeds scattered than in tilled systems. The effect of organic agriculture was also studied in Argentina but no difference in species richness and abundance was found compared to the normal land use management of the area, which is mostly CA (Coda et al., 2015).

CA involves a change in management of agricultural land that alters the habitat of small mammals that thrive in crop fields. CA system can also encourage mammal populations that may become a pest. In certain environments, there may be a conflict between CA and rodent pest control (Ruscoe et al., 2022).

By using cover crops in soybean CA fields, Prieur & Swihart (2020) observed an improvement in the biodiversity of small mammals as they can incorporate cover crops into their diet. However, an increase in vole (Microtus) populations may reduce production. One strategy to reduce the negative consequences of excess vole populations is to plant less palatable cover crops. Prieur & Swihart (2020) indicated red clover, alfalfa and hairy vetch as preferred by voles, and oilseed rape as the most avoided.

6.3 BIODIVERSITY OF SMALL MAMMALS IN WOODY CROPS UNDER CONSERVATION AGRICULTURE

Differentiated management with green groundcovers and/or biomass mulching in permanent crops, allows for an increase in small mammal biodiversity, especially as these provide shelter and more feeding possibilities than a soil without cover.

In mature woody crop plantations, increase in rodents does not constitute a production loss. Smallwood (1996), in a study conducted with groundcovers in vineyards and orchards in California, reported few cases of crop damage due to an increase in vertebrates, which might only affect vines and young trees up to 3 years old. In addition, it was indicated that groundcovers attract vertebrate predators that can control potential damage by small mammals, while helping to conserve biodiversity. Modifying soil management between crop rows, by providing more cover, increases predators of forage-eating individuals. Thus, mulching with biomass increases prey resources which promotes predator populations because of the increased physical cover and microclimate (Tworkoski & Glenn, 2008).

In general, plant species diversity and structural diversity are positively related to small mammal biodiversity (Sullivan & Sullivan, 2006). Cabodevilla et al. (2021), in their study on vineyards, underline the importance of groundcovers, as they facilitate access to food and provide shelter for the biodiversity of fauna, as well as maintaining natural enemies and avoiding possible pests. Similarly, higher populations of rodent species were observed in vineyards in California when a clover groundcover was used (Ingels et al., 2005). Caudill et al. (2015) in coffee agroforestry systems found a higher number of species and higher abundance in systems shaded by tree canopy cover, indicating canopy cover as a key factor in increasing the number and species richness of small mammal species.

Soil management strategies such as green groundcovers and biomass mulching benefit tree growth, nutrition, weed control and soil quality, especially in organic systems (Granatstein & Sanchez, 2009). However, such strategies may also increase the risk of rodent damage in young plantations. Thus, Wiman et al. (2009) noted that groundcovers improve soil health and increase vole numbers, but this may pose a risk. These authors found in their trials that *Galium odoratum* species and mulch cover of chopped pruned biomass reduced the presence of voles and reduced the risk of potential damage to crops.

6.4 SUMMARY AND CONCLUSIONS

The main practices of CA system such as no-tillage and groundcovers benefit small mammal fauna. The principle of no or minimum soil disturbance, implemented in annual crops through no-tillage practices prevents the destruction of burrows, thereby promoting small mammal populations. Similarly, maintaining a continuous soil cover with crop biomass and cover crops, provides shelter and food due to the increased seed availability and soil improvement, which enhances the supportive fauna that serves as food. Crop diversity and rotation introduce heterogeneity and complexity to the agricultural landscape, resulting in flora biodiversity, including root system diversity. This also favours fauna biodiversity by providing various habitats for species diversification.

Studies reflect the ecosystem services provided by the enhanced biodiversity of small mammal fauna, such as weed seed predation and the control of certain crop pests. However, CA system can promote an increase in small mammal abundance, particularly in annual crops, which could potentially lead to infestation. The rise in bird predator diversity and abundance in CA system can contribute to population control, as well as incorporating cover crop species that aid in small mammal population control due to their lower palatability. With woody crops, the risk of infestations is lower in mature tree plantations. While there might be a risk of damage to roots and seedlings in young populations, this could also be managed by implementing groundcovers species and mulches that help control small mammal populations. Moreover, mulching and groundcovers enhance predator populations, further contributing to small mammal control.

CHAPTER 7

ENHANCEMENT OF AVIFAUNA BIODIVERSITY IN CONSERVATION AGRICULTURE

7.1 INTRODUCTION

Birds are part of the natural heritage of the agricultural ecosystem in which they provide a set of services that serve to regulate it and help maintain its balance, thus being an essential part of it. The presence of birds on farms helps, among other things, with seed dispersal, biological pest control, by acting as predators, and pollination, and together with bees and bats, they assist in 35% of global agricultural production, increasing to around 75% of the world's main food crops (SEO BirdLife, 2023).

Over the last 40 years, bird population linked to agricultural ecosystems in Europe has declined by 60% (PECBMS, 2023), and there is evidence from numerous studies that the decline has been closely linked to agricultural intensification (Chamberlain et al., 2000, Donald et al., 2001, Newton 2004). The magnitude of change in agricultural ecosystems, is such that food resources and habitat quality for birds have been completely transformed (Wilson et al. 1999).

Source: Day et al., 2020.

One of the characteristics of agricultural intensification is the increase in soil tillage. The increased availability on the market of more powerful tractors and a wider range of farming implements has favoured deeper and more aggressive soil tillage. The consequence of this is the destruction of habitats for ground nesting birds, and the presence of bare soils, with less food available for birds (seeds or invertebrate fauna) or without the presence of plant biomass cover which often serve as shelter for some bird species. In this regard, Wilson et al. (1996) found that birds preferred to frequent plots where stubble remained as opposed to plots with bare soil. Hart et al. (2001) found that, even when there were plots with bare soils with a higher density of seeds than plots with plant biomass, birds preferred to frequent the latter.

However, intensification of agriculture is often linked to increased use of plant protection products (Fuller 2000). This can impact on bird population in several ways if practice is inadequate. It can also lead to a reduction in the auxiliary fauna that serves as food for the birds because of the use of insecticides or in the reduction of adventitious weeds that serve as hosts for this auxiliary fauna. Herbicides reduce weed populations that sometimes directly provide food for herbivorous and granivorous species, thus decreasing the survival of birds that depend on these foods (Boatman et al., 2004). Köhler & Triebskorn (2013) found a reduction in insecticide use of almost 80% between 1964 and 2010 (for US farms with soybean, corn, cotton, wheat, critics, apple trees, other fruit trees) leading to decreased in recent decades of cases of acute lethal poisoning in birds. However, agricultural malpractice continues to pose a risk to birds.

Another reason that Fuller (2000) argues has implications for the decline of bird populations is the simplification of agricultural systems through the proliferation of monoculture as opposed to diversified crop rotations and associations. This is because monoculture offers fewer opportunities for birds for nesting, feeding, breeding, and breeding, as detailed below, thus reducing the fidelity of birds to certain territories that have been greatly altered by human action.

In this scenario, through the application of the three principles of CA (i.e. no-tillage, groundcover or biomass mulch and crop rotation or association) represents an integral solution to the above-mentioned issues. CA is a land management system that can be used in combination with complimentary good practices aimed at optimising the use of phytosanitary products, reducing the risk to birdlife, and providing a better habitat for their development while maintaining a productive and sustainable agriculture.

7.2 HABITAT EFFECTS OF CONSERVATION AGRICULTURE: IMPROVING CONDITIONS FOR THE DEVELOPMENT OF BIRD POPULATIONS

Most of the studies reviewed on the subject agree that the conditions for the development of birdlife linked to agricultural ecosystems are improved in those plots where CA is implemented. Specifically, both no-till direct seeding and groundcovers or mulch covers in agricultural ecosystems have an impact on three aspects --food, habitat structure and environmental heterogeneity-- that are fundamental for maintenance of bird population.

i. Increased availability, quantity, and quality of feed.

In an agricultural ecosystem, birds can find three types of food: seeds of cultivated species, seed of spontaneous vegetation and invertebrates. The type of management system fundamentally affects each of these resources.

In the case of cultivated seeds, there are many factors that can influence the availability of unharvested grain from the crop, one of them being the soil management system employed. In general, those agricultural practices that leave more plant biomass on the ground surface will also leave more grain in the soil. This greater food quantity, together with the protection provided by the presence of plant biomass, contributes to a greater abundance in the density and number of bird species (Søby 2020, Valera-Hernández et al., 1997).

Regarding the availability of seeds from spontaneous vegetation, there are two situations depending on whether the crop under consideration is herbaceous (annual) or woody (perennial). While the aim in annual species is to eliminate all possible competition to ensure the viability of the crop, irrespective of the management system used, in woody crops in CA, the use of a groundcover between the alleys, which in many cases is made up of indigenous species, is encouraged. In the case of annual crops, there is evidence that the abundance of scattered grain and weed seeds is higher in CA fields (Kaur et al., 2017; Baldassarre et al., 1983), although there are other studies whose results indicate the opposite (Valera-Hernández et al., 1997), probably due to the greater and more effective control of weed vegetation with the use of herbicides in integrated weed management in CA systems. Muñoz-Cobo (2009) found that breeding birds select their territories in olive groves according to the availability of food resources such as seeds and arthropods, preferring those with groundcover (Castro-Caro et al., 2014).

Regarding the presence of invertebrates, studies confirm that the maintenance of groundcover on the ground has a positive effect on epigean fauna. For example, Soby (2020) observed that in no-till direct seeded plots in Denmark, there was up to a 10-fold increase in arthropod populations compared to tilled plots. Dulaurent et al. (2023), on test plots in France, found that total earthworm abundance was 4.8 times greater in CA systems compared to tilled systems.

ii. Habitat structure

In general, a bird seeks a habitat that has the appropriate characteristics for feeding, roosting, breeding, and sheltering, as well as hiding from predators. These characteristics are enhanced by the presence of biomass mulch cover on the soil surface. This means that habitats in CA are more suitable for birds at any time of the year (Valera-Hernández et al., 1997).

Numerous studies have shown that during breeding season no-tillage fields host higher densities of birds and are used by a greater variety of species than fields under conventional tillage (Van Beek et al., 2014; Basore et al., 1986). Similar results were obtained in studies on woody crops with groundcover crops. Thus, the conditions of these habitats in CA fields allowed the entry of ground-nesting species such as ptarmigan - *Alecotoris rufa*, nightjar - *Caprimulgus ruficollis*, woodlark - *Lullula arborea*, crested lark - *Galerida cristata*, and corn bunting - *Miliaria calandra* that were not present in the ploughed fields (Valera Hernández, 1992).

In winter, birds use crops mainly for food. As mentioned above, greater groundcover generally facilitates greater food sources. Thus, the frequency of occurrence of bird species and the number of individuals is generally higher in CA systems than in tillage-based systems (Castrale 1985). However, there are some species, such as towhee lark - *Lullula arborea*, rock dove - *Zenaida macrocura*, and scaly-tailed warbler - *Callipepla squamata* which prefer to feed on bare ground, either because of the ease of finding food on such soils or because birds may have been excluded from unploughed habitats by competition with mice and ants, the other important seed-eating animals in open habitats. Changes in land use can also lead to a decrease in the attractiveness of the area to birds, due to their effect on resource-dependent factors such as accessibility to food and risk of predation) (Best 1985; Díaz & Tellería 1994).

Finally, the structural change made by CA to agricultural ecosystems favours opportunities for adult and young birds to shelter from predators and harsh weather. In line with the above, Castro-Caro et al. (2014) explained the reasons for the lower rate of nest predation in olive groves with groundcover being the greater complexity of the system which favours the appearance of food alternatives to predators and the presence of meso-predators which controls the populations of nest-predator species.

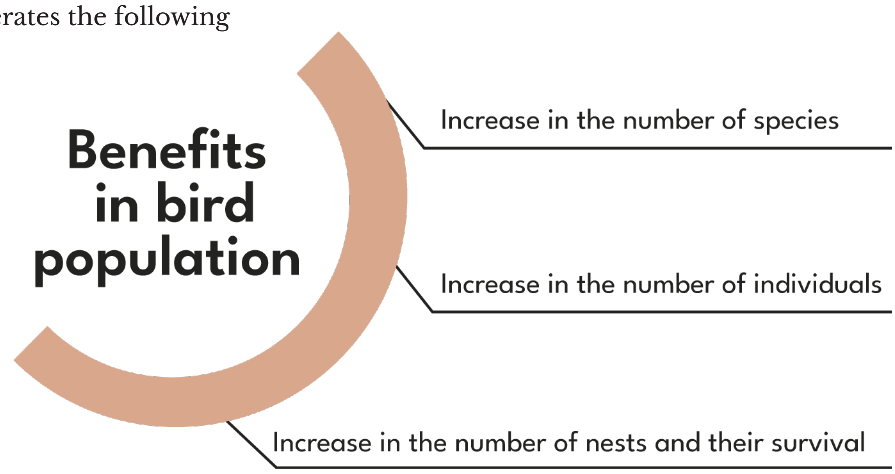
iii. Heterogeneity of the environment

The simplicity of agricultural ecosystems has been considered by many researchers to be the cause of the low diversity of avifauna (Arnold, 1983; Best et al., 1995, Tellería et al., 1988). Thus, adoption of management practices that bring complexity and heterogeneity to the environment, such as the establishment of groundcovers, the implementation of crop rotations that make the mosaic more varied, or the establishment of multifunctional margins, has an impact on increasing biodiversity (Fahrig et al., 2011).

CA promotes the presence of a variety of groundcover, either through biomass mulch, cover crops, companion plants or natural vegetation. This provides different structures, sizes, habitats and resources for the fauna and flora present in the agricultural ecosystem. This also increases the complexity and diversity of the system, thus promoting the establishment of a high number of species, particularly those associated with the soil and landscape (Brown et al., 2018), which also provide an important source of food for bird population.

7.3 EFFECTS OF CONSERVATION AGRICULTURE ON AVIFAUNA: EVIDENCE OF BIRD POPULATION IMPROVEMENT

Improvement of habitats brought about by the practice of CA is reflected in avifauna linked to agricultural ecosystems. There is evidence in scientific literature that the practice of no-till direct seeding or mulching generates the following benefits in bird population:



The following sections provide the evidence which demonstrates the increase in biodiversity in the avifauna linked to agricultural ecosystems due to the practice of CA.

i. Increase in the number of species

CA management system promotes the presence of permanent groundcover with crop biomass, cover crops and natural vegetation which provides shelter, food, and breeding sites for a variety of birds. This results in a greater number of bird species in CA fields than in fields managed under tillage system.

Thus, Søby (2020) in a study in northern Europe comparing bird species diversity in conventional agriculture fields organic agriculture fields and in CA fields, found that farm management significantly affected bird diversity. CA had a significant positive relationship with bird diversity, while the relationships for conventional tillage and organic tillage farming were negative (Figure 7.1), with a higher number of species observed in plots managed under CA system (Tables 7.1 and 7.2).

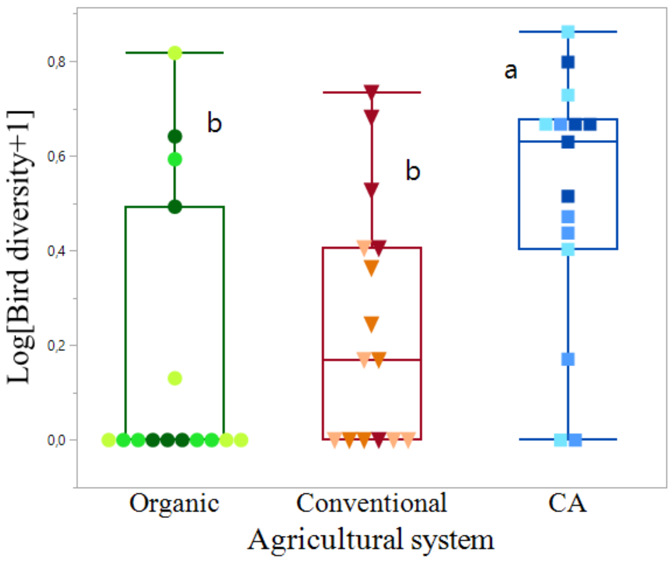


Figure 7.1. Bird diversity in the three agricultural systems. Significant difference between groups in (Tukey-Kramer HSD test results) are described with different letters. Source: Søby, 2020.

Table 7.1. Species richness of birds identified and observed in Søby (2020). Percentages of total species are shown in parentheses. Source: Søby, 2020.

	Total species	Organic Farming	Conventional Agriculture	Conservation Agriculture
Birds	**17**	**8 (47%)**	**11 (65%)**	**14 (82%)**
Before sowing/tillage	9	4 (44%)	7 (78%)	8 (89%)
After sowing/tillage	11	2 (18%)	4 (36%)	8 (73%)
Difference (before, after)		-92%	-29%	-20%
February	10	4 (40%)	3 (30%)	8 (80%)
Difference (after, February)		44%	-88%	-19%

Table 7.2. Observed bird species in agricultural systems. Source: Søby, 2020.

Latin name	Common name	Organic Farming	Conventional agriculture	Conservation Agriculture
I. Farmland specialists				
Alauda arvensis	Skylark	X	X	X
Perdix perdix	Grey partridge	X	X	X
Falco tinnunculus	Krestel	X	X	
Hirundo rustica	Barn swallow	X	X	X
II. Intermediate specialists				
Corvus frugilegus	Rook	X		X
Corvus cornix	Hooded crow	X	X	X
Passer montanus/ Passer domesticu	Tree sparrow/ house sparrow		X	X
II. Intermediate habitat use farmland species				
Chroicocephalus ridibundus	Black-headed gull		X	
Anser anser	Greylag goose			X
Pica pica	Eurasian magpie			X
Buteo buteo	Common buzzard	X	X	X
Coloeus monedula	Western jackdaw			X
Columba palumbus	Common wood pigeon	X	X	X
III. Other farmland species				
Oenanthe oenanthe	Northern wheatear		X	X
IV. Not farmland species				
Phasianus colchicus	Common pheasant		X	X
Accipiter gentilis	Northern goshawk			X
Chloris chloris	European greenfinch			X

This study concluded that the farm operation that most affected bird diversity was tillage, with significantly higher diversity when no-tillage was practiced. In this case, the effects of plant protection products were not significant in terms of diversity.

However, the study by Kaur et al. (2017) assessed the effect of CA system on bird diversity in two no-till direct sowing crops (wheat and rice). Bird species recorded in wheat and rice crops were 23 and 21 respectively. Seven species of omnivorous birds and five species of granivorous birds were recorded as overlapping species in both crops. These results highlight the capacity of no-tillage management to increase bird biodiversity in the agroecosystem, in contrast to studies conducted in the same areas in wheat and rice crops managed with tillage (Kler & Singh, 2007; Kler, 2010) which recorded 19 and 15 different species respectively, i.e., 17% fewer species in tilled wheat and 29% fewer species in tilled rice.

Finally, Bassore et al. (1986) studied the diversity of bird species based on the presence of nests in maize fields under no-till direct seeding and in fields under conventional tillage. A total of 12 species nested in the no-till fields. Four of these species also nested in ploughed fields (Table 7.3). Except for one case where the number of nests per 100 hectares was similar in both management systems, in the rest, the number of nests per 100 hectares was lower in ploughed fields, from 50% to 75% fewer nests per 100 hectares depending on the species considered.

Table 7.3. Nests of bird species observed in agricultural systems. Adapted from Bassore et al. (1986).

Species	No tillage			Tilled corn	Strip cover
	Corn-corn	Corn-sod	Soybean-corn		
Ring-necked pheasant	X	X	X		X
Killdeer	X	X	X	X	X
Mourning dove	X		X		X
Brown thrasher					X
American robin	X				X
Common yellowthroat					X
Bobolink		X			
Western meadowlark		X	X		X
Red-winged blackbird	X			X	X
Brown-headed cowbird	X	X	X	X	X
American goldfinch					X
Dickcissel		X			X
Savannah sparrow		X			
Grasshopper sparrow		X			X
Vesper sparrow	X	X	X	X	X
Field sparrow			X		X
Song sparrow					X
Unknown sparrow		X			

Similar conclusions were obtained in studies on woody crops, specifically in olive groves in southern Spain (Valera Hernández, 1992). In this case, a conventionally tilled field harboured 46% less species and 21% less diverse communities than a field under no-tillage (Table 7.4).

Table 7.4. Species observed in olive grove plots under no tillage and conventional tillage. Source: Valera Hernández, 1992.

Species		No tillage	Conventional Tillage
Latin name	**Common name**		
Calumba palumbus	Wood pigeon		X
Streptopelia turtur	European Turtle Dove	X	X
Caprimulgus ruficollis	Nightjar	X	
Upupa epos	Hoopoe	X	
Galerida cristata	Crested Lark	X	
Lullula arborea	Totovia	X	
Sylvia hortensis	Warbler	X	
Parus major	Great Tit	X	X
Certhia brachydactyla	Agateador	X	X
Lanius senator	Northern grey shrike	X	
Fringilla coelebs	Common chaffinch		X
Serinus serinus	Serin	X	X
Carduelis chloris	Greenfinch	X	X
Carduelis carduelis	Goldfinch	X	X
Milaria calandra	Corn bunting	X	
Maximum number of species		13	7
Shanon diversity index[1]		2.68	2.12

Faria & Morales (2019) concluded that the tillage system and frequency of tillage operations have a moderate overall influence on avifauna, compared to other important factors influencing bird abundance, such as grazing and the annual weather regime. Although this study does not report specific values, an interesting finding is that CA fields had similar levels of bird abundance as permanent pastures where herbicides were not used and limited use of other agrochemicals was made.

Further, while some studies have found a positive correlation between CA and bird species diversity, others found that CA had little effect on species richness and total bird abundance, which was probably related to the large variability in response to these variables between species. Boscutti et al. (2015) stated that no-till direct seeding affects floristic and carabid species composition, but not species diversity, which seems to be the case for birds. Filippi-Codaccioni et al. (2009) obtained

[1] An index reflecting the heterogeneity of a community based on two factors: the number of species present and their relative abundance (Shannon & Weaver, 1949).

similar heterogeneous results in northern France, where farmland specialised bird species were less abundant on CA farms than on conventional tillage farms, while granivorous and insectivorous species showed opposite trends. Other studies also show opposite results. For example, Lokemoen & Beiser (1997) and Martin & Forsyth (2003) observed high densities of birds on minimally tilled land in North America. In contrast, Barré et al. (2018) reported lower bird abundance in no-tillage fields with herbicide application in northern France.

In the case of woody crops, García-Navas et al. (2022) examined the effects of landscape complexity and intensive management practices in 40 olive orchards in southern Spain on the functional[1] and phylogenetic diversity[2] of the animal communities inhabiting these ecosystems, including birds. The study compared two management systems, one intensive, based on tillage and the use of herbicides, both pre-emergence and post-emergence, and the other extensive, with the presence of mechanically controlled groundcover. The conclusions of the study were that neither management type nor landscape complexity had an effect on phylogenetic diversity indices when the area used for production and the area not used for production on the farm were considered together. However, when restricting the analysis to area used for production, it was found that farms with groundcover supported more functionally diverse bird populations than those in conventionally managed farms without groundcover.

ii. Increase in the number of individuals birds

The reasons why CA favours an increase in bird density in fields where crops are planted under no-till direct sowing or cover crops are similar to those favouring species diversity. This is why the presence of ground cover, the absence of tillage and the heterogeneity produced by crop rotation promote the creation of habitats and refuges for birds, providing places for nesting, feeding (more seeds and auxiliary fauna), resting and shelter from predators.

Several studies have documented higher abundance and species richness of birds in no-tillage fields compared to conventional tilled fields (Castrale, 1985; Walk et al., 2010). Other studies, conducted in different areas of the US on different crops (wheat, sunflowers, fallow, etc.), have also documented the benefits of no-tillage for duck breeding (Duebbert & Kantrud, 1987) and the higher density of birds in no-tillage crop fields compared to conventional tilled crop fields (Lokemoen & Beiser, 1997; Martin & Forsyth, 2003). Van Beek et al. (2014) found that no-till direct sowing plots had 109% greater bird densities than tilled fields, and the species identified had a 58% higher conservation value[3].

An example of this is the study by Søby (2020), who, comparing CA, organic and conventional farming plots, observed a greater number of birds in CA (Table 7.5). Bird density in CA fields was greater for almost all species identified than on organic agriculture fields and conventional tillage agriculture fields (Figure 7.2). This density also always remained greater than the rest in the CA fields when measurements were made. Thus, bird density in CA fields was twice as high as that in conventional agriculture fields, and 21 times greater than that in organic agriculture fields (Table 7.6).

[1] Parameter describes the magnitude of functional differences between species in a community based on "functional traits", which are biological (physiological, morphological, anatomical, anatomical, biochemical, or behavioural) characteristics of individuals or species, directly or indirectly related to their development and fitness or to the structure and functioning of the ecosystem (McGill et al., 2006; Weiher et al., 2011).

[2] Measurement of biodiversity, which is based on measuring the set of characteristics and the time that has passed for species to acquire and accumulate those qualities that make them different from each other.

[3] Conservation value: this is understood as the importance of conserving a certain species in an area. For this purpose, the "Avian conservation significance" parameter, which is calculated based on the relative density of species and a score given by the "Partners in Flight" entity to each species according to their conservation concern in a region are used.

Table7.5. Total number birds identified and observed. Source: Søby, 2020.

	Total individuals	Organic Farming	Conventional Agriculture	Conservation Agriculture
Birds	**484**	**45 (9%)**	**155 (32%)**	**284 (59%)**
Before sowing/tillage	201	35 (17%)	100 (50%)	66 (33%)
After sowing/tillage	127	4 (3%)	49 (39%)	74 (58%)
February	156	6 (4%)	6 (4%)	144 (92%)

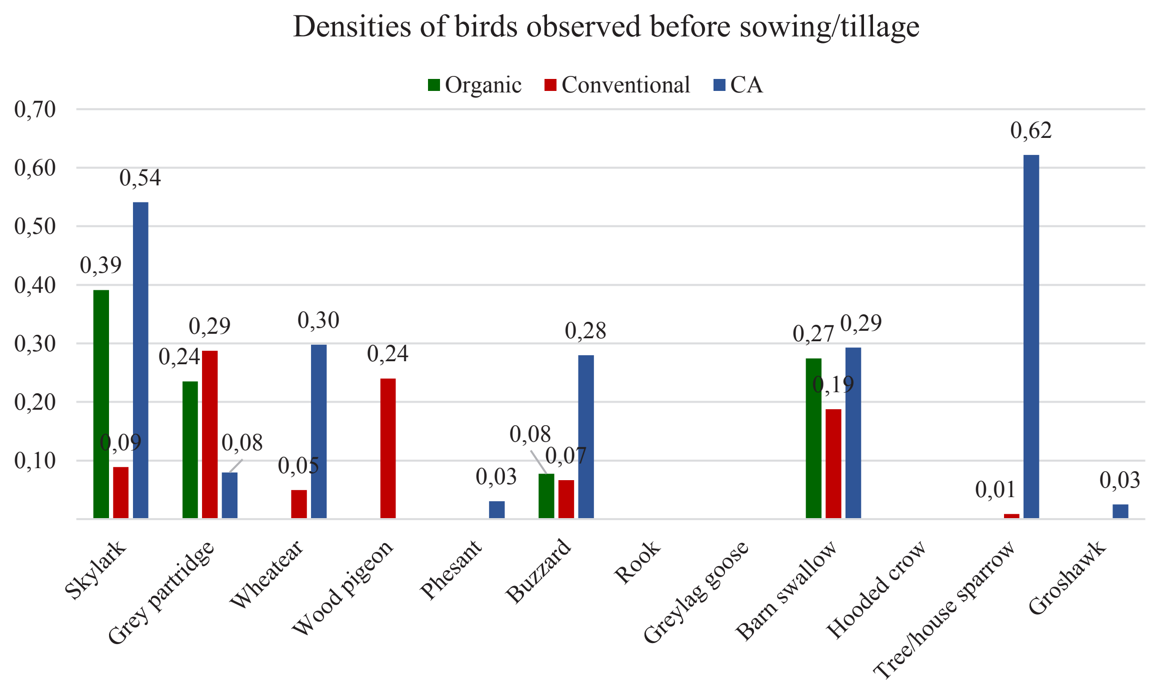


Figure 7.2. Densities of the nine bird species observed before sowing/ tillage, sorted in agricultural system. Source: Søby, 2020.

Table 7.6. Average densities of birds in the three agricultural systems, at the two sampling times: before and after sowing/tillage, respectively. Source: Søby, 2020.

	Organic Farming	Conventional Agriculture	Conservation Agriculture
Before sowing/tillage	0.98	0.93	2.17
After sowing/tillage	0.08	0.66	1.74
February	0.11	0.08	1.42

As stated at the beginning of this chapter, the reason for the greater population density in birds is due to better conditions in agricultural ecosystems under CA. Birds only reside in fields in non-breeding season if resources are available (Newton, 2017). Above-ground stubble mulch is important, particularly for granivorous birds, as they tend to prefer this type of habitat, due to the greater availability of weed seeds and grain scattered on the surface (Wilson et al., 1996; Moorcroft et al., 2002). In addition, stubble is important for predator avoidance, especially for smaller species such as passerines (Butler et al., 2005). Gillings et al. (2005) observed farmland birds in summer and winter and found that winter stubble mulch was positively associated with bullfinch - *Pyrrhula pyrrhula*, chaffinch - *Fringilla coelebs*, greenfinch - *Chloris chloris*, linnet - *Linaria cannabina*, skylark - *Alauda arvensis*, and house sparrow - *Passer domesticus*. The presence of stubble mulch on the soil surface could explain the higher density and diversity of birds in CA fields, as this cover is available during winter months.

Belmonte (1993), in a study carried out in southern Spain, showed how no-till direct sowing techniques favoured the bird community during the nesting season, not so much in terms of diversity, but quantitatively (Table 7.7). Birds nesting on the ground are the most favoured, they have more camouflage for predators and there is no risk of the nest being damaged by tillage operations, unlike in tillage fields. Migratory birds, and even birds accidental to the habitat, also have a certain preference for settling in CA fields.

Table 7.7. Species present in no-tillage and tillage plots (f: frequency, a/10: birds per 10 ha). Source: Belmonte, 1993.

Species		No tillage		Tillage	
Latin name	**Common name**	**f**	**a/10**	**f**	**a/10**
Bubulcus ibis	Cattle egret	1			
Circus pygargus	Montagu's harrier	7		5	
Falco tinnunculus	Kestrel	1			
Alectoris rufa	Red-legged Partridge	23	1.12	13	0.55
Coturnix coturnis	Quail	5	0.14		
Otis tetrax	Little Bustard	4			
Melanocorypha calandra	Common lark	202	8.45	86	3.19
Calandrella brachydactyla	Greater short-toed lark	6	0.14		
Galerida cristata	Crested Lark	119	5.07	60	2.08
Anthus campestris	Tawny pipit	1	0.14		
Motacilla flava	Western yellow wagtail	51	2.67	19	1.38
Saxicola torquata	African stonechat	3	0.14		
Oenanthe oenanthe	Wheatear	1			
Oenanthe hispanica	Black-eared wheatear			2	
Cisticola juncidis	Vulture	22	0.14	8	0.13
Hippolais plyglotta	Melodious warbler			2	
Passer domesticus	House Sparrow	7		5	
Carduelis carduelis	Goldfinch	3			
Carduelis cannabina	Linnet	9	0.56	3	
Miliaria calandra	Corn bunting	26	0.14	18	
Undetermined		14		10	
No. of species		18		12	

In this particular study, no evidence was found on the influence of herbicide use on birds populations. Herbicides are used not only in CA systems but also in conventionally tilled systems.

Field et al. (2007a) found that population densities of birds increased and decreased in each management system employed depending on the species considered and the season, suggesting that other environmental or food availability factors may be at play. In this case, the crop studied was corn at two locations in Hungary. In one of them, they observed a positive response in starlings throughout the three study seasons (Figure 7.3), while in the other, results were inconclusive.

For woody crops, the presence of an herbaceous groundcover is likely to increase and provide structural complexity and resources for foraging birds (Wilson et al. 1999, Vickery et al. 2009). In this regard, Martínez-Núñez et al. (2020) found that extensive management in olive grove fields in southern Spain (maintenance of herbaceous groundcover) clearly increased the abundance and richness of insectivorous birds (see also Castro-Caro et al., 2014; Rey et al., 2019). It is also known that the presence of groundcover during most of the year favours the presence of alternative prey (Álvarez et al., 2019; Paredes et al., 2019), providing these birds with more resources. As a result, birds prefer to settle in fields with groundcover, and bird density in fields with this type of management can be at least twice as high as in bare soil plots (Muñoz-Cobo, 2009, Castro-Caro et al., 2014).

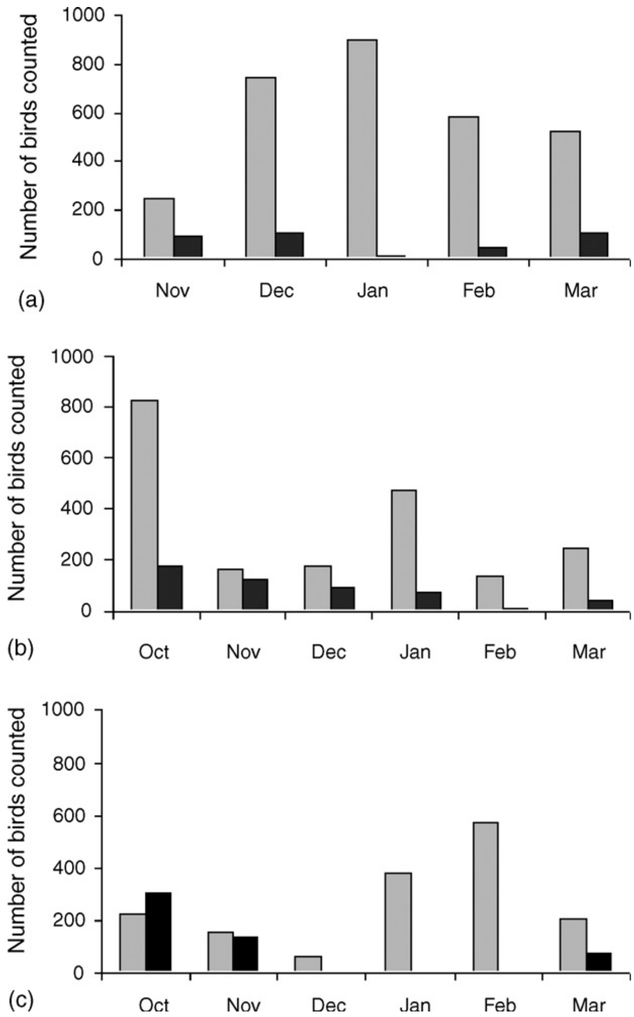


Figure 7.3. Monthly total bird numbers in Conservation Agriculture (CA) and mouldboard ploughed (P) fields summed for winters (a) 2003-2004, (b) 2004-2005 and (c) 2005-2006. Greybars CA, black bars P. Source: Field et al., 2007.

While most studies find a positive relationship between the use of CA practices and bird density, in some studies, listed below, this relationship is less clear.

Thus, Filippi-Codaccioni et al. (2009) detected no differences in the abundance of species linked to agricultural habitats between CA and conventional tillage management. In addition, they observed for their particular conditions, that some farmland specialised bird species were less abundant in CA fields than in conventional tillage fields, including some emblematic farmland species, such as the skylark (*Alauda arvensis*).

Barré et al. (2018), in a study comparing fields in direct sowing with cover crops, plots in direct sowing without cover crops and ploughed plots, found that bird abundance was highest in the first case and lowest in the second case. These results suggest that the more groundcover present in the field and the lower the herbicide use, the higher the bird density. The implementation of cover crops is not always viable in some areas where rainfall is scarce and summer temperatures can be high, as is the case in regions with a semi-arid Mediterranean climate. In such situations, it seems that the optimum solution, that combines the viability of the system from a productive point of view and the improvement in bird populations, is one that includes no-till direct sowing with an optimisation in the use of phytosanitary products.

In woody crops, Valera Hernández. (1997), in their trials of olive groves with groundcover, observed that only one of the majority species in the communities linked to this type of ecosystem (*Serinus serinus*, greenfinch – *Carduelis chloris* and goldfinch - *Carduelis carduelis*) reached a higher population density in no-tillage fields (Figure 7.4).

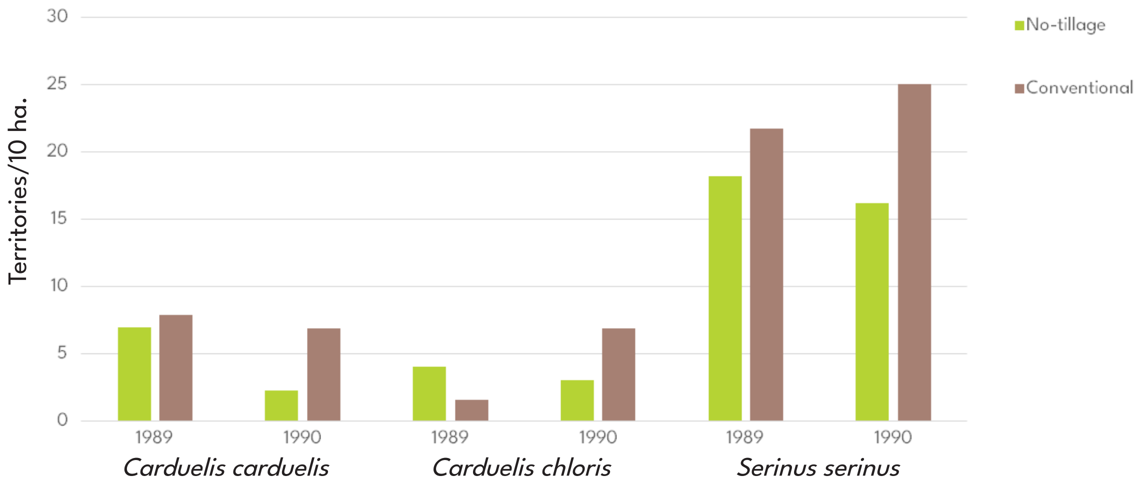


Figure 7.4. Density of three species of granivorous birds in no-tillage and conventional olive groves during the nesting season. Green: no tillage, Brown: conventional tillage. Source: Valera Hernández, 1997.

iii. Increased number and survival of nests

Soil tillage operations have a negative effect on nesting birds, destroying nests, or causing disturbance and forcing birds to abandon their nests. Such effects were extensively documented some time ago by several authors, both in annual and woody crops (Rodenhouse & Best, 1983; Rodgers, 1983; Valera Hernández, 1992). In addition to the above, Best (1986) was able to show that the effects will be more or less severe depending on nest location, nesting period, tendency to nest after failure and nesting dates in the breeding season.

As is well known, CA eliminates tillage practices, providing a high benefit in terms of nest establishment and survival and reducing the rate of nest predation as will be seen below.

Van Beek et al. (2014) compared nesting success and bird communities in tillage and no-tillage soybean fields in Illinois (USA). Nesting density was higher in no-tillage (4.5 nests/100 ha) than in conventional tillage farming (1.6) (Figure 7.5). The most common nesting species were canaries, sparrows, and turtle doves. Nest success, calculated from next-day survival rates, was 19.4% in direct sowing and 9.4% in tilled plots. In this study, it was found that predation was the main cause of nest failure, although 24.4% of failures caused by agricultural machinery was not negligible, suggesting that avoiding tillage operations in direct sowing would have a positive impact on reducing nest failures.

Authors concluded that the higher abundance of herbaceous plants in no-till direct sowing was the cause of both higher nesting and foraging activity and higher nest survival success, due to a better opportunity for nest concealment compared to tilled fields.

Another study, conducted by Field et al. (2007b), tested the influence of the tillage method on several parameters of Barn Lark breeding success, including the number of nests present in each management system and nesting attempts within 23 days of laying the first egg. The results obtained clearly show how no-till direct sowing provided better nesting conditions for birds. Thus, of the 32 skylark nests identified, 75% were found in no-till direct sowing fields (Table 7.8). The first nest in no-till direct sowing started 39 days earlier than the first nest in a ploughed field. Ten nests were initiated in no-till fields (41.7% of all nests in no-till) before any nesting was initiated in the tillage fields.

In woody crops, Castro-Caro et al. (2014) studied the percentage of nest predation in olive groves comparing fields with groundcover and ploughed fields. These authors found that nest predation was lower in covered plots than on bare ground, especially in tree nests. This decline in tree nest predation is attributed to the fact that main nest predators are small mammals that inhabit the area. With the presence of groundcover, food availability is improved for these mammals, which would prefer to forage in covered microhabitats with a higher proportion of seeds, probably because they were less visible to potential predators. An alternative is known as the "meso-predator release hypothesis", according to which the presence of groundcover favours the presence of larger predators that control nest predators' population (Terborgh et al., 1999).

However, nests are not exempt from various problems linked to the application of phytosanitary products, an operation that is carried out both in CA and in conventional tillage agriculture. Thus, the greatest risk is to the developing embryos inside the eggs and to the hatchlings which, because of their immobility, may be unable to avoid contact with the herbicide. In this sense, Best (1985) pointed out that its use is not related to the soil management system but to the cropping sequence. In other words, a no-tillage system would use no more insecticide than a conventional one.

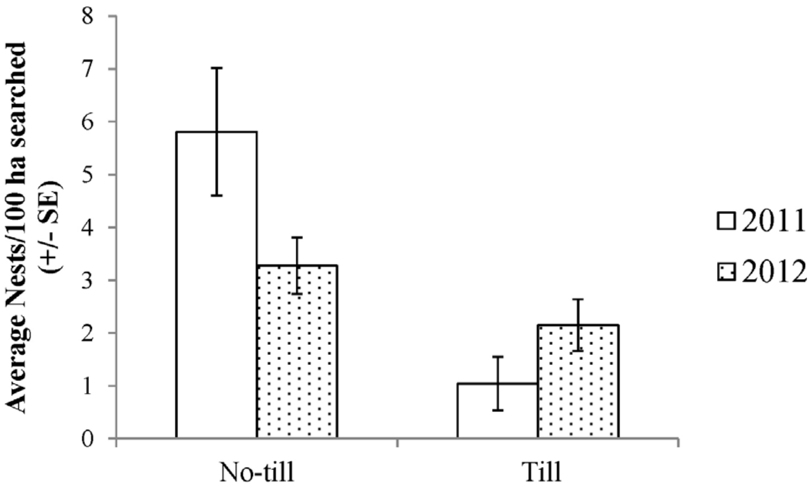


Figure 7.5. Average nest density (±SE) averaged across sites and based on search effort per site in no-till and tilled fields of east-central Illinois, 2011–2012. Source: Van Beek et al., 2014.

Table 7.8. Distribution of Skylark nests with respect to tillage. Source: Field et al., 2007b.

Field	Area (ha)	Tillage	No. of nests
CA1	13.1	No till	9
CA2	11.7	No till	15
P1	9.6	Conventional tillage	4
P2	12.5	Conventional tillage	4

7.4 SUMMARY AND CONCLUSIONS

The intensification of agriculture in recent decades, has led to a simplification of the agricultural landscape, leading to monocultures and a homogenisation of the landscape. This has meant, on many occasions, the disappearance of certain habitats suitable for the development of birdlife such as marshes, hedgerows, undergrowth, etc., contributing to a reduction in the diversity of the agricultural ecosystem. In this sense, the increase in heterogeneity brought about by CA systems through the introduction of crop diversification through groundcovers or crop rotations and associations, increases the structural complexity of the environment and benefits the diversity of birds in the agricultural ecosystem.

The application of the three principles of CA is essential for the improvement of avifauna biodiversity:

- Continuous elimination of tillage means that ground nesting birds are encouraged to settle, lay and breed.

- Permanent maintenance of biomass groundcover on the ground, not only provides shelter for the birds, but also improves the biological conditions of the soil, increasing the availability of seeds and auxiliary fauna that serves as food for the birds.

- Finally, crop diversification through rotations and associations brings heterogeneity and complexity to the agricultural landscape, offering different alternatives to bird populations linked to this ecosystem. Thus, the presence of winter and spring crops in the area, favours the existence of habitats capable of supporting different types of bird species.

Although it has been shown that the increased attractiveness of no-till fields as nesting and breeding habitat may have potential exposure to plant protection products, Little (1987) pointed out that increased use of plant protection products was not necessarily required in CA. A study conducted by the European Conservation Agriculture Federation (ECAF, 2020) based on a survey of 1,667 farmers in 21 European countries, concluded that the herbicide doses applied by no-till farmers were even lower from the doses applied by farmers practising conventional tillage farming.

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