Chapter 6

Weed Management in Cereals in Semi-Arid Environments: A Review

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Additional information is available at the end of the chapter

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1. Introduction

1.1. The weed problem on cereal arable fields

With growing concern about the environment, and the increased public interest in environmental conservation, traditional agriculture has led to profound changes in in recent years. Cereals are the most important crop in dry-land areas of southern Europe. In Spain, nearly 5.5 million ha of winter cereals are sown each year [1]. Research in agriculture has undergone a paradigm shift, favoring systems aimed at improving the performance of cropping systems without deleterious effects to the environment. To achieve this, weed managers continually develop comprehensive programs for crop protection, in which an essential component is the use of crops more competitive with weeds [2], in order to maintain the stability of agricultural production.

The selection of a crop is not an easy task and it involves the consideration of numerous environmental and socioeconomic factors. Additionally, in any cropping system, we always can observe the presence of weeds that invade, persist and survive. They are unwanted and we refer to them as plants "out of place". There are numerous definitions of a weed: a plant that is out of place and not intentionally sown; a plant that grows where it is not wanted or welcomed; a plant whose virtues have not yet been discovered; a plant that is competitive, persistent, pernicious, and interferes negatively with human activity. Weeds possess one or more of the following characteristics that allow them to survive and increase in nature: abundant seed production; rapid population establishment; seed dormancy; long-term survival of buried seed; adaptation for spread; presence of vegetative reproductive structures and ability to occupy sites disturbed by humans.

Therefore, to control effectively we should ask: *why do weeds emerge;* and *what factors limit their development?*. There is abundant evidence that the presence of weeds reduce crop yields; weeds compete for environmental resources, especially water, light and soil nutrients, resulting in decreased crop yield or reducing the crops quality by contaminating the commodity, interfering with harvest, serving as hosts for crop diseases or providing shelter for insects to overwinter, limiting the choice of crop rotation sequences and cultural practices. The most important parameters that characterize the infestation of weeds in a crop and that determine the competitive relationships between them are the density and time of weed competition. Their competitive ability is associated with the establishment of a dense infestation, and is caused by the different habits of growth of weeds and crops. Weeds have developed a number of features that allow them to survive and even dominate in adverse environmental conditions. Also, to learn more about competition exerted by weeds is necessary to know their life cycle, and we can observe three major life cycle groups in cereal arable fields:

Annuals

Summer annuals germinate in the spring, mature, produce seed, and die in one growing season.

Winter annuals germinate in late summer or fall, mature, produce seed, and then die the following spring or summer.

Biennials

Weeds grow from seed anytime during the growing season. They normally produce a rosette of leaves close to the soil surface the first year, then flower, mature, and die during the second year. A true biennial never produces flowers or seeds the first year. There are relatively few biennial weeds.

Perennials

Simple perennials form a deep taproot and spread primarily by seed dispersal.

Creeping perennials may be either herbaceous or woody and can spread by both vegetative structures as well as by seed.

When we study the competition process between species, we must consider what resources are limiting in the environment, which will account for more competition. Since weeds are so prevalent in many areas of the landscape, management techniques are necessary to maintain order. Weed management is most successful when it involves an integrated approach using a variety of methods. The common methods used to manage weeds include prevention and cultural, mechanical, biological, and chemical means.

Herbicides remain the predominant weed management tool with the greatest influence on weed selection over the last 60 years [3]. Reliance on chemicals for weed control has increased significantly in the last decades [4]. However, herbicide use also carries risks that include environmental, ecological, and human health effects. It is important to understand both the benefits and disadvantages associated with chemical weed control before selecting the appropriate control. Many factors determine when, where, and how a particular herbicide can be used most effectively. Understanding some of these factors enables you to use herbicides to their maximum advantage. Urzúa [5] recorded the following precepts:

1. When any plant is established and persists in a given area, it is likely to have established a presence of seeds, tubers, rhizomes or other means propagative in the place; that environmental conditions are favorable for reproductive success; and competes successfully with established plant populations. Furthermore, morphological and physiological differences between plants being constantly selected will likely be the most suited to climate, soil and agricultural management, for their establishment and persistence and will likely dominate [6]. Yenish [7] pointed out that it is not economical nor practical to try to eradicate the most problematic species already established, when the presence of them is high in the soil seed bank; in most cases, they can be kept under control with the application of herbicides. In a period of about five years we may reduce the seed bank to less than 5%, but we should also consider that in a single year without control, their seed production may be sufficient to exceed 50% of the original population [7].

2. The weed composition in different communities is not always the same, and it changes over time; this has been called succession. According to this theory, when the habitat remains relatively constant, we do not record considerable changes in the community. When the conditions are modified, the species adapted to the "original conditions" are replaced by those that the new environment is more conducive for their development. At the same time, the presence of new species modifies the new environmental conditions and favors the establishment of other species [8]. In agricultural land the succession process is different than in natural areas since agricultural practices constantly disrupt natural succession process, and the dynamic successional cycle begins. With the suspension of agricultural operations, successional processes in vegetative populations are restored [9].

3. The practices used by the farmers to produce their crops each year favor the development of certain species of weeds so that populations that occur in different plots reflect agricultural management provided to crops that year and previous years.

4. The competitive damage to the crop depends on the species, the density of each range, the proximity in which it is growing when they emerge to the crop plant and the duration of the competition. There are many species that do become problematic during a crop cycle in a particular field, depending on crop. However, it has been found that the early stages of crop development are more sensitive to competition by weeds.

5. Herbicides are available in the market, which when selected appropriately for each particular problem, can efficiently control weeds. To succeed, it is not enough to acquire and apply herbicides recommended for cultivation, it is necessary to take into account the factors that affect the efficiency of action of these herbicides, such as:

- In post-emergence applications, the species present, their size, age, growth rate and environmental conditions.
- In pre-emergence applications, soil type (texture, pH and organic matter content), soil moisture at the time of application and weed species to be controlled.

In addition, the selected herbicide must fulfill other requisites about their mode of action, which are:

- Control weeds with a sufficient dose.
- Penetrate into the weed.
- Move to where conduct its physiological action.
- Affect any vital function.

Herbicides provide a convenient, economical, and effective way to help manage weeds. They allow fields to be planted with less tillage, allow earlier planting dates, and provide additional time to perform the other tasks that farm or personal life require. However, if herbicides are not applied in a timely and appropriate manner in terms of dosage and coverage, or resistant weeds are present, they can have ineffective control.

In this context, long-term experiments, carried out for decades, are considered very important in agricultural research when evaluating the sustainability of crop systems in which are being developed programs of integrated crop protection, in order to maintain stability of agricultural production. The weed vegetation in an agricultural area can change quickly and vary greatly among fields and regions. The factors that influence the weed community are numerous and are difficult to evaluate each factor independently, in a culture system (Figure 1): climatic factors relevant to the persistence of plants, soil factors, which involved the physical and chemical properties of soil, human factors, which are involved in various legislative measures and the use and farm management and technological factors, where one is constantly innovating and researching systems tillage, crop rotation, herbicides, fertilization, and irrigation.

Intensification of land use has also been identified as a major cause of the current biodiversity decline in agro ecosystems [10, 11]. For instance, arable weeds have suffered a severe decline over all Europe, which has developed concerns over the sustainability and environmental consequences of the intensification of land use in agricultural systems [12]. Plant diversity in dry land Mediterranean cereal fields is affected by agricultural intensification at any of these abovementioned scales, as reflected by a decrease of plant species richness and changes in species composition [13]. But the ecological implications of these changes still remain uncertain, because in such agro systems there is a high variability in the local occurrence of plant species [14, 15].

Historically in central semiarid Spain, arable fields have been dominated by cereal production. In this region, tillage intensity has markedly decreased in order to decrease soil loss. There has been an increasing trend towards utilizing conservation tillage systems and the use of herbicides in winter cereals holds a prominent place in the overall use of pesticides in Spain. However, in recent years, climate change, grain prices, cost of

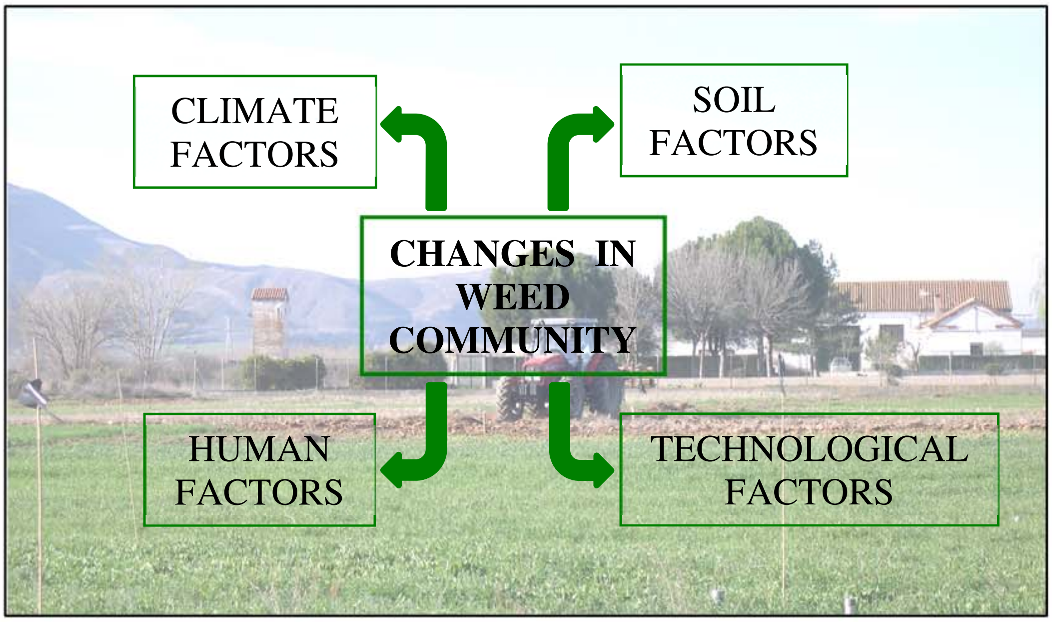

Figure 1. Factors involved in changes of weed community present in a field.

herbicides and the development of resistant weeds has led to seek integrated weed management systems more. Integrated weed management requires more knowledge on how weed community compositions respond to changing agronomic practices after one crop rotation cycle with different practices. Gerard [16] observed that the prediction of the distribution and abundance of weed infestations likely in each field could help to plan and carry out timely control measures in an efficient and economical manner, in accordance with ecology and the interests of the society. The above statement is framed within what is known as "integrated management of weeds", where the main objective is to cause displacement of species difficult to control, by others less problematic and / or reduce the density of populations of noxious weeds at levels that do not cause damage. Therefore, such rationalization goes through the realization of a good diagnosis of the situation, by using a series of agronomic practices that hinder the development of weed populations most problematic and the use of clear decision criteria based on scientific knowledge.

1.1.1. Weed ecology in dry land cereal agriculture

Cereals are the most important crop in dry-land areas of southern Europe. In Spain, nearly 5.5 million ha of winter cereals are sown each year [1]. In Mediterranean areas, weed species are adapted to crops and to management techniques like soil disturbance by tillage. However, the agricultural intensification in the last decades is a process occurring at different scales, which reduces biodiversity, simplifies communities, leads to a loss of ecosystem services [17- 19] and reduces species richness [20]. At the landscape scale, farming intensification has caused the replacement of most natural habitats with arable fields [21], which leads to large, uniformly cropped areas with low spatial heterogeneity [22, 23]. At the field scale, intensification is related to the farming practices performed: i.e., high amount of external inputs (mainly chemical fertilizers and herbicides), low complexity of crop-rotational schemes and improvements in seed-cleaning techniques [24].

In this sense, the patterns of weed species composition in cereal fields are often attributable to a complex number of interacting factors and multivariate analysis has been used in many studies to discuss them. The selection of weeds is constantly evolving in response to crop management practices; therefore, these practices have an important role in the flora composition and its fluctuations in the short and long term at the field level. Management practices, geographical gradients and climatic factors have been found to be the driving factors to explain weed species composition and richness in Northern Europe [25] and in Central Europe [26-29]. Thus, changes in flora may be the result, among other factors, of complex interactions between agronomic practices (choice of species, tillage systems, and strategies for weed control) and environmental factors (soil quality, temperature, and rainfall). It is well known that sometimes, the use of some methods of control, or changes in them by others, causes a change in the composition of the flora, and we can say that weed communities are not static, producing the phenomenon known as *Flora Inversion*.

Although major weeds can be quite different from one region to another, from one farm to another and even between different locations of the same farm, we can select a few species that are widespread throughout the Spanish geography which represent a serious threat by the competitiveness, by the difficulty of control and by the rapid expansion of their populations. Among them we can mention four annual grasses:

Avena sterilis L. and *A. fatua* L. ("Wild oats"), these weeds are found throughout the peninsula, has an almost identical cycle of cereals, germinating simultaneously with them and for a fairly long period of time and matures at the same time as grain crops. These attributes, combined with its ability to emerge from depths relatively high (up to 25 cm) and the prolonged persistence of seeds in the soil (over 3 years) facilitates the development and presence in tilled fields. However, the main reason for its spread is its ability to cause high losses in cereal yields.

Lolium rigidum Gaudin and *Lolium multiflorum* L. ("Ryegrass") are widespread geographically, being especially prevalent in cereals. These species germinate with the first rains of autumn, usually beginning their nascence before sowing of cereal. If the first plants were not completely destroyed by seedbed preparation tillage or pre-plant herbicides they can become great competitors with the crop. Most seeds germinate the following year of their production, making containment or eradication of their population easier than in the case of the other grass.

Bromus spp. and Phalaris spp. were a very common species in the margins of roads and cultivated fields until the arrival of conservation agriculture. With tillage reduction or elimination, they have been introduced in the fields quickly causing major problems. These species are well adapted to emerge from the soil surface zone. Its emergence period is very short, beginning with the first rains of autumn, and almost all seeds germinate the following year.

Besides the grasses mentioned above, there are some dicotyledonous annuals that are harmful, either because of their abundance, their competitiveness or difficulties involved in their control. In the case of the "poppy" (Papaver spp. and Hypecoum spp.) the problem is more

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due to their abundance (associated with a huge seed production and a high persistence of these seed on the soil surface) than competitiveness with the crop (relatively low). Similarly, the Cruciferae family (*Sinapis arvensis* L., *Diplotaxis erucoides* L. and Raphanus spp.) produces high numbers of seeds although the competition with the crop can be quite high. These species had adapted to conventional tillage, but the increasing use of herbicides has reduced their populations while favoring the presence of other species: "Cleavers" (*Galium aparine* L.), which are fast growing and can outcompete almost completely the cereal plants; “Speedwell” (*Veronica hederifolia* L. and *Veronica persica* L.), “Chamomile” (*Matricaria chamomilla* L.), *Polygonum aviculare* L., etc. Other species of the genus Tussilago, Epilobium, Conyza, Artemisia, Lactuca, etc., have problems in soils subjected to periodic disturbances, and they have also adapted to no-tillage fields. Also, the species Chenopodium spp., Amaranthus spp., Salsola spp., etc. can invade the cereal fallows, which can require investment in specific herbicides for control. Finally, perennial weeds base their success on their bodies’ underground reserves that enable rapid development at the beginning of spring. They are represented by the bindweed (Convolvulus spp.) and several thistles (Cirsium spp.).

In this paper, we will not create a weed inventory or abundance, but focus on identifying the most significant risks to which crop will face during its development. Before herbicide treatment, it is imperative to carry out a diagnosis as accurate as possible of the weed situation. This idea is according to the National Academy of Sciences (1980): "to induce population changes in response to agricultural management, it is necessary to know the biology of the species involved and environmental modifications that causes each agronomic practice”. This requires knowledge of the dynamics of weed populations that cause *a favorable succession* and it is necessary to know the majority of weed species present in the plots treated. In this sense, decisions regarding herbicide treatments should be based on four main points:

First, it is necessary to select the most appropriate treatments taking into account the efficacy and selectivity of the products available on the market. In view of the problems identified in each field, we will need to find which products adequately control all high-risk species. In Spain there are over 30 different active ingredients for use in cereal crops and over two times that many commercial products (with various formulations and/or combinations of active substances). The selection of products to be used will be dictated by the timing of treatments. Table 1 lists some of the most widely used herbicides in cereals and their application times. We should note that the application of these products is not always carried out in isolation, so it is important to know if there is a problem of incompatibility between products (relatively frequent event). There would also be possible to find problems of sensitivity of crops because not all products are equally safe for barley and wheat, and even within the same crop, there are differences in sensitivity in some varieties.

In the case of herbicides used in pre-emergence, this decision will have to be made based on the problems identified in previous years. In that sense, it is highly desirable to have some information about the history of the field, i.e. crops that were planted, cultural practices, herbicides used, and what kind of weed problems developed. This information will help us to identify the type and severity of the problem to be faced in the coming season. Since weed

Timing of herbicide application	Controlled weeds	Active substances
Pre emergence	Dicotyledonous	clortoluron, isoproturon, trifluralina, clorsulfuron, linuron, bifenox,pendimetalina, triasulfuron.
	Grass	isoproturon
Early post emergence	Dicotyledonous	clortoluron, diclofop-metil, fenoxaprop-etil, 2.4-D, MCPA, fluroxipir, bentazona, tifensulfuron-metil, tribenuron-metil.
	Grass	iodosulfuron-metil-sodio, pendimetalina, tralkoxidim.
Late post emergence	Dicotyledonous	clodinafop, tralkoxidim
	Grass	Fenoxaprop-p-etil,

Table 1. Herbicides used in cereal crops depending on the timing and type of weed.

infestations are often not distributed evenly throughout the field, it will also be useful to know the location of problematic weeds populations and if they are particularly aggressive species or found in very high densities. Pre-emergent herbicides act upon weed seeds, seedlings or form a barrier in the soil to prevent weed seed germination or establishment. These herbicides are usually used in the spring to prevent seeds establishing when the soil temperatures begin to warm up and a properly timed application can provide control for several months.

In the case of herbicides used in post-emergence (the most common use), it is desirable to perform the evaluation of the main weeds that are invading each field as soon as the cereal is established. This assessment should be made as soon as possible in order to plan and carry out early treatment, which is recommended due to their greater efficiency. Post-emergent herbicides work on actively growing weeds and can be further broken down into two categories:

- Selective herbicides can be applied to an area and target weeds (i.e. dicots or monocots) while having little or no effect on the crop or non-target weeds. Some products may require repeated applications for effective control.

- Non-selective herbicides kill all susceptible plants they come into contact with. The most used non-selective herbicide is glyphosate.

After choosing the herbicide, it is necessary to decide the dose to apply. Typically there is a relatively large dose range according to what weeds dominate; what is the stage of development (the higher development, the greater the dose needed to control them) and what is the texture and the organic matter content of soil (in cases of pre-sowing applications or pre-emergence, the higher the content of clay and organic matter, the greater the dose).

Second, one must consider the costs of treatments considered. There are large differences between the costs of different products. For example, while the cost of treatment with hormonal

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herbicides (2.4-D, MCPA, etc.) for overall control of dicots is almost negligible, the use of specific herbicides against Galium spp. or Avena spp. may be a considerable investment.

Third, it is necessary to estimate the economic benefits of a treatment application. This involves estimating the expected yields in the crop (and its sale value) and the losses that would be avoided by such treatment. In this sense, while the application of herbicides in areas of high productivity (yields higher than 4 t/ha) is usually economically profitable in more marginal areas (with an income below 2 t/ha) these benefits are rather dubious. Similarly, in meteorologically favorable years higher investments in inputs may provide higher profits. In relation to avoidable losses, we should consider the competitiveness of the dominant species (it´s not the same having a plot infested by Avena spp. or it infested by Papaver spp.), and the level of weed infestation of plot.

Finally, we must consider the potential side effects arising from the application of such treatment. This section is not only to consider the effects on the environment (pollution of waterways, loss of biodiversity) but also the risk of resistance. The emergence of resistance as a result of poor practices is increasingly common. Continued application of the same product (or products belonging to the same chemical family or families with the same mode of action) over a certain period of time leads, sooner or later, to the emergence of resistant weed biotypes. The best strategy to prevent the emergence of weed resistance is the integrated use of prevention and control of many methods as possible:

- Use of crop rotations, using spring crops needed to eliminate resistant biotypes before planting or use alternative herbicides not applicable in cereal crops.
- Employment of fallow and mechanical control practices.
- Avoid seeds with resistance movement from one field to another, carefully cleaning tillage and harvesting equipment.
- Using appropriate densities for a competitive cultivation.
- Herbicide use only when necessary, alternating herbicides belonging to different groups according to their mode of action.

1.1.2. The climate influence in an agro system with a semi-arid environment

The climatic factors more relevant to the persistence of the plants are: light, temperature, water, wind and seasonal characteristics of these factors:

The intensity, quality and duration of **ligh**t are important for determining the growth, reproduction and distribution of such plants. Light governs the photoperiodic response and determines the flowering time of seed maturation; therefore, it determines the latitudinal distribution limits of species.

The air and soil **temperature** and the duration of the frost, are important limits on the distribution of weeds. The soil temperature is directly related to the seed germination, and a drop in temperature will influence the same seed dormancy and survival of their underground parts. Therefore, temperature is a critical factor for the persistence and adaptation of annual and perennial weeds.

Water is the most important environmental factor in the habitat, with a marked morphological expression in the plant. The total water available in a location is related to both the initial supply with losses by runoff, evaporation and transpiration. The seasonal distribution of water is a key factor, since sometimes its scarcity at critical stages of the plant leads to lack of reproduction and survival.

The speed, **wind** direction and wind frequency defines the presence of all plants, including weeds. Also, it can produce transpiration losses of plants.

In summary, the weeds are primarily affected by the same factors as the crop: water, and the factors related to their availability (insolation and transpiration) and nutrients. If these parameters are not restricted, the weed growth will be higher than the crop.

On the other hand, when conditions are not suitable, the agronomic practices may be ineffective in inducing seed germination. In this sense, one of chief limiting factor of crop yield in cereal agro systems with a semi-arid environment is the scarce irregular rainfall distribution. For this reason, we initiated a field experiment, at the experimental farm of INIA "La Canaleja", located in Alcala de Henares (Madrid). The field trials were located in a semi-arid agro system of central Spain, with an average total annual rainfall of 470 mm, and rainfall distribution registered over fifteen years were used to assess the effects of environmental conditions on weed community.

Our results showed that seasonal distribution of rainfall did restrict the effectiveness of the weed management practices and it affected the weed density. In 2000-2001 and 2010-2011, it we recorded higher annual rainfall than the average for this area, and in accordance with the increase of water availability, the weed density, measured by sampling (size of each sample of 0,125 m^2), increased considerably. Between years 1995 and 2011 herbicides controlling dicotyledonous and / or against grass were used to control the weed community present in the field. In this situation, total weed density was maintained except in the 2009-2010 period, when weed density was large though the annual rainfall was below normal; this was mainly due to herbicides not being used in this period favoring the weed competition with the crops (Table 2 & Figure 2).

The community of weeds present in the field differed with the annual distribution of rainfall and may limit the effectiveness of the system used to control weeds, leading the specialization of some species under certain crop conditions. We observed in our field, that high rainfall occurring in the spring favored early-emergence weeds, such as *Papaver roheas* L. and high rainfall occurring in autumn favored late-emergence weeds such us *Lolium rigidum* Gaud. and *Hypecoum procumbens* L.; and weeds with extended patterns of emergence such as *Anacyclus clavatus* L. and Veronica spp.; or perennial weeds (Cardaria spp. and Convolvulus spp.) were favored by a general increase of annual rainfall in the area. Furthermore, increasing knowledge of how plants respond to different environmental conditions and the application of this knowledge allows more effective and efficient use of available tillage tools in combination with other weed control practices.

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Year	J	F	M	A	My	J	Jy	A	S	O	N	D	Annual
1994	18,4	33,4	9	18,2	76,8	10,8	3,6	0,8	40,6	52,2	26,8	4,6	295,2
1995	18,2	28,4	0,8	10,8	33,4	56,2	7,6	3,0	11,4	5,6	45,2	71,2	291,8
1996	84,6	24,2	16,4	9,4	94,4	5,8	1,4	6,8	12,4	4,0	58,4	86,6	404,4
1997	76,2	2,8	0,0	63,2	47,2	6,8	23,6	32,0	28,0	17,6	145,4	53,4	496,2
1998	28,5	45,1	15,9	27,6	14,2	1,6	2,0	0,4	0,2	1,0	29,6	20,0	186,1
1999	36,0	14,8	18,0	55,3	65,8	22,6	4,0	3,0	57,0	96,7	45,8	0,0	419,0
2000	64,0	0,8	30,0	103,8	69,6	25,0	10,0	0,0	18,2	26,5	70,0	129,7	547,6
2001	108,8	20,7	60,1	26,5	37,7	7,2	4,3	7,0	14,0	79,4	4,9	0,0	370,6
2002	54,0	5,7	46,2	41,5	76,7	12,3	12,0	5,1	32,5	50,6	86,0	48,2	470,8
2003	51,2	52,3	39,5	57,2	22,2	1,8	1,2	2,6	9,4	99,5	67,6	35,5	440,0
2004	4,2	74,7	55,1	43,7	102,2	5,3	46,1	18,5	5,4	99,4	20,4	17,8	492,8
2005	0,0	15,5	11,3	7,2	7,1	1,3	0,0	3,2	12,2	86,3	66,0	27,0	237,1
2006	40,2	45,5	20,0	37,0	14,0	34,8	1,5	5,7	15,9	84,6	98,3	20,5	418,0
2007	7,8	43,8	13,6	104,5	95,7	37,0	0,0	6,8	10,3	30,8	30,3	4,0	384,6
2008	27,6	32,6	2,1	80,1	106,0	36,9	0,0	0,0	22,2	56,7	25,2	42,0	431,4
2009	38,7	43,9	11,2	31,4	8,0	17,3	0,0	20,7	8,6	23,2	12,8	111,7	327,5
2010	70,2	84,8	51,3	47,5	33,5	58,1	17,5	2,8	40,6	31,0	41,0	62,9	541,2
2011	44,0	30,0	46,7	65,0	168,5	24,5	1,0	24,0	1,6	33,2	49,5	6,0	494,0
Historical Average	42,92	33,28	24,84	46,11	59,61	20,29	7,54	7,91	18,92	48,79	51,29	41,17	402,68

Table 2. Annual distribution of rainfall (mm) and historical average during years object of study.

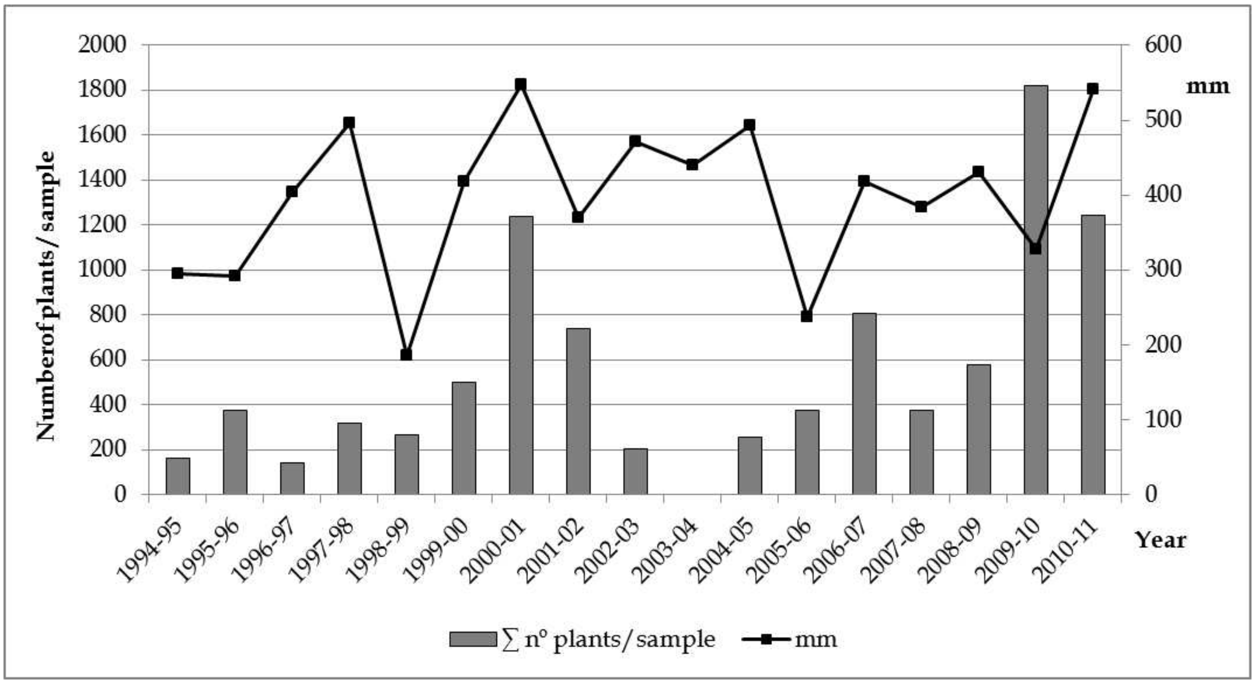

Figure 2. Total number of plants recorded per sample (0,125 m^2) and annual rainfall (mm) from 1995 to 2011.

2. The adoption of conservation tillage systems

The European agricultural situation is modifying quickly due to the pressure of economic factors and to the increased sensitivity of environmental problems. Nowadays, integrated weed management could be a possible solution to rationalize the inputs of herbicides and to increase the use of complementary methods of weed control forming an integral component of sustainable agriculture [30]. However, the adoption of these practices have a considerable impact on communities of weeds, and therefore, their management should be different from that undertaken in a conventional system [31-33]. The benefits of conservation tillage include reducing soil erosion, increasing organic matter, improving soil structure, and reducing fuel consumption and some tillage machinery. As a result of these agronomic and economic incentives, direct seeding practices have been adopted in many regions. Weed control is often cited as the main challenge in minimum tillage systems and no-tillage, and often leads to increased herbicide use, so we must pay special attention to this system. Otherwise, conservation tillage systems are believed to worsen weed problems with higher weed emergence promoted by higher concentrations of seed in the surface soil and shifts of the weed community towards increased abundance of troublesome species, e.g. grasses and perennials [34].

In summary, minimum tillage, particularly no-tillage, may favor a relative emergence of weeds over crops. Moreover, the increase of prior crop residues in these systems can alter the competitive ability of crops with weeds at early stages, increasing production losses thereof [35]. Thus, it appears that common tasks tend to select annual weeds and little work allows the dominance of perennial or biennial species. However, these predictions are strongly influenced by cultural practices and environmental conditions used in a specific area. Currently, insufficient information exists about the processes associated with changes in weed communities; such information is crucial in managing weeds. As a means of control it is necessary to assess the presence of weeds, setting thresholds for treatment of major species in crops and the adequate product selection, dose and time of application best suited among those authorized, while taking into account the environmental conditions.

Development of improved weed management systems requires more knowledge on how weed species respond to changing agronomic practices. In order to monitor weed development subjected to different agronomic practices, one experiment was conducted to determine weed population response to various tillage intensities in a cereal agro system in central Spain (Figure 3A). Field trials under a cold semi-arid environment were conducted in successive growing seasons from 1995 to 2011, to assess the effects of management practices on the weed community with three tillage systems: (1) conventional tillage (CT); (2) minimum tillage (MT) and (3) no-tillage system (NT). The experiment consisted of a field divided in four randomized complete blocks with three different tillage systems and four replications. To study the effectiveness of different managements, we performed a first identification of the flora present in the field where the experiment was developed.

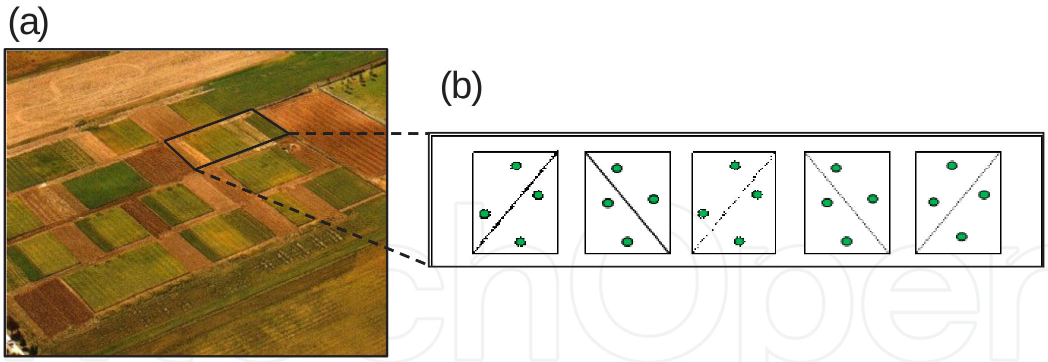

Figure 3. A) Field trials in the experimental farm "La Canaleja", and B) Weeds sampling scheme realized it in each tillage system.

The natural community of weeds present in the assay is comprised by dicotyledonous weed species and grasses, annual and perennial species typical of crop fields in the area (Table 3). Later, during all years of the study, weeds were counted by species with a similar methodology based on the selection of four random samples in the field with a quadrant of 0,125m^2, taken in zigzag on the diagonal of a rectangle defined in each sub-plot (Figure 3B), which were identified and quantified in situ, the weed species present. Total density of weeds referred to the unit area (1m^2).

Adonis annua	Chondrilia juncea	Hordeum murimus	Scabiosa spp.
Amaranthus albus	Chrozopera tinctoria	Hypecoum pendulum	Scorzonera laciniata
Amaranthus blitoides	Cichorium intybus	Hypecoum procumbens	Senecio vulagaris
Amaranthus retroflexus	Cirsium arvense	Lactuca serriola	Setaria viridis
Anacyclus clavatus	Cnicus benedictus	Lamium amplexicaule	Silybum marianum
Anchusa azurea	Convulvulus arvensis	Lavatera spp.	Sisymbrium iria
Andryala integrifolia	Conyza spp.	Linaria micranha	Sisymbrium orientale
Asperugo procumbens	Datura stramonium	Lolium rigidum	Solanun rigidum
Avena spp.	Descurania Sophia	Medicago spp.	Sonchus spp.
Belladia trixago	Diplotaxis erucoides	Melilotus spp.	Stellaria media
Biscutella auriculata	Echallium elaterium	Papaver hybridum	Torilis nodosa
Bromus rigidus	Echium spp.	Papaver rhoeas	Tragopogum psp.
Bromus rubens	Epilolium brachycarpum	Plantago spp.	Trifolium angustifolium
Buglossoides arvensis	Eruca vessicaria	Polygonum aviculare	Trigonella polyceratia
Campanula erimus	Eryngium spp.	Portulaca aleracea	Veccaria pyramidata
Capsella burs-pastori	Filago spp.	Rapistrum rugosum	Veronica hederifolia
Cardaria draba	Fumaria officinalis	Reseda phyteuma	Vicia spp.
Centaurea aspera	Galium murale	Roemeria híbrida	Xanthium spinosum
Chenopodium album	Heliotroium europaeum	Salsola kali	

Table 3. Initial weed community in the farm "La Canaleja".

The herbicides employed in the trials were post emergence against dicotyledonous weeds from 1994 to 2000; against dicotyledonous and grasses from 2004 to 2009; in 2009 we did not employ any herbicide and afterward, we used post emergence herbicide against dicotyledonous weeds. Also, in the NT system, the crops were seeded each year after an application of glyphosate at 2 $l.ha^{-1}$. Within the time frame of this research, weed density and species composition were affected by year, which differs in environmental conditions, and by tillage intensity, indicating fluctuations in changes of weed community composition associated with changes in agronomic practices and environmental conditions are complex and difficult to predict, especially in semiarid regions with low and / or irregular rainfall.

Specific research regarding the impact of crop production systems on weed communities is lacking and currently, there is not a common position among authors about which system produces the best weed control. Several researchers have described the effect of the tillage system on weed flora composition and valued the long term dependence on the crop system used and their studies showed changes in weed species composition as a consequence of tillage practices [36]. According with this idea, we observed that the community of weeds present in a field differs with the tillage system employed (Figure 4). Minimum tillage systems (MT) and no-tillage (NT) showed higher weed densities compared to conventional tillage (CT).

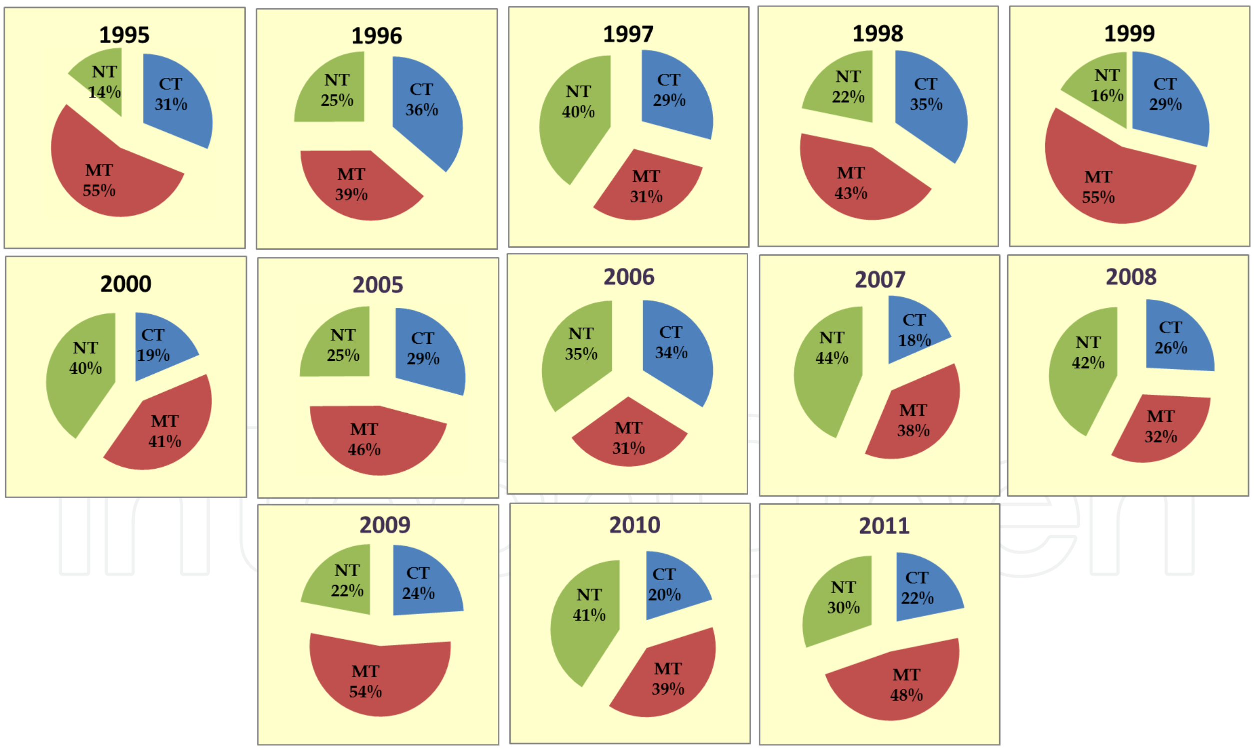

Figure 4. Percentage of total weeds observed in each tillage system studied from 1995 to 2011.

Other researchers have described the predominant weeds of different tillage systems, such as Lolium spp. in minimum tillage system [37]; Poligonum spp. in conventional tillage [38, 39], or *Fumaria officinalis* L. and *Lamium amplexicaule* L., also favored in conventional tillage [40].

Some species display greater capacity of infestation when the intensity of tillage is reduced [41-44].These species shifts generally resulted in the emergence of species tolerant to existing weed management practices [45, 46]. In this sense, Froud-Williams [47] also predicted that annual and perennial grasses, perennial dicotyledonous species, wind-disseminated species, and volunteer crops would increase and annual dicotyledonous weeds would decrease in association with MT systems; although, these predictions were strongly influenced by the agronomic practices employed within a specific study; and Liebman & Davis [48] suggested a possible solution for weed problems would be the combination of different soil tillage systems. Nevertheless, other authors have suggested that tillage did not produce any selective effect in the composition of weed flora [49].

In this context, it is very important to identify which are the most troublesome weeds, because they are the most difficult to control. Also, we should follow those species maintained in the seed bank of soil without an initial risk because they present low density, but one change in the crop system and /or the environmental conditions can favor their propagation and convert them into a dominant species of the field. The specific objectives of the work reported here were to determine if decreasing tillage is accompanied by a predicted increase in the presence of annual and perennial grasses, perennial dicot species, wind disseminated species, and volunteer crops, but a decrease in annual dicotyledonous weeds.

In order to realize the following of several weed species along the year's object of study, we determined the relative weed density in the field each five years for representative species (Figure 5). In general, years with high rainfall in fall, 1995 and 2005, favoured later-emergence weeds and perennial species to escape suppression by the crops. Many weeds had patterns of emergence that peak in October and November such as *Fumaria officinalis* L.; *Lolium rigidum* Gaudin and *Hypecoum procumbens* L., as well as the perennial weed *Cardaria draba* L. Desraux, which increased the year where higher than average rainfall was received in fall. However, years with high rainfall occurring in April and May, 2000 and 2010, they favoured early-emergence weeds such as Papaver spp. At the same time, in our experiment, we noted a reduction of dicotyledonous weeds *Cardaria draba* L. and *Fumaria officinalis* L., and the increase of Papaver spp., *Lamium amplexicaule* L. and Veronica spp. in sub-plots with NT system. Also, we could observe a clear tendency of increasing of *Lolium rigidum* L. and *Hypecoum procumbens* L. density in MT sub-plots and another perennial species such as Cirsium spp. and Convolvulus spp., which we typically found in field margins, appeared frequently within NT sub-plots.

The decrease in soil water evaporation due to the residual cover in both NT and MT could have increased the soil water content compared with CT, and this could be one of the reasons for the increase in the density of weeds within these systems [50]. Also, the annual distribution of rainfall may limit the effectiveness of the system used to control weeds, predisposing the specialization of some species under certain crop conditions. Generally, no-till systems can be difficult to maintain over a long period of time without adequate weed management, and knowledge of the emergence process of weeds will increase the effectiveness of a post-emergence herbicide, assuming an important qualitative advance in the integrated control of weed populations.

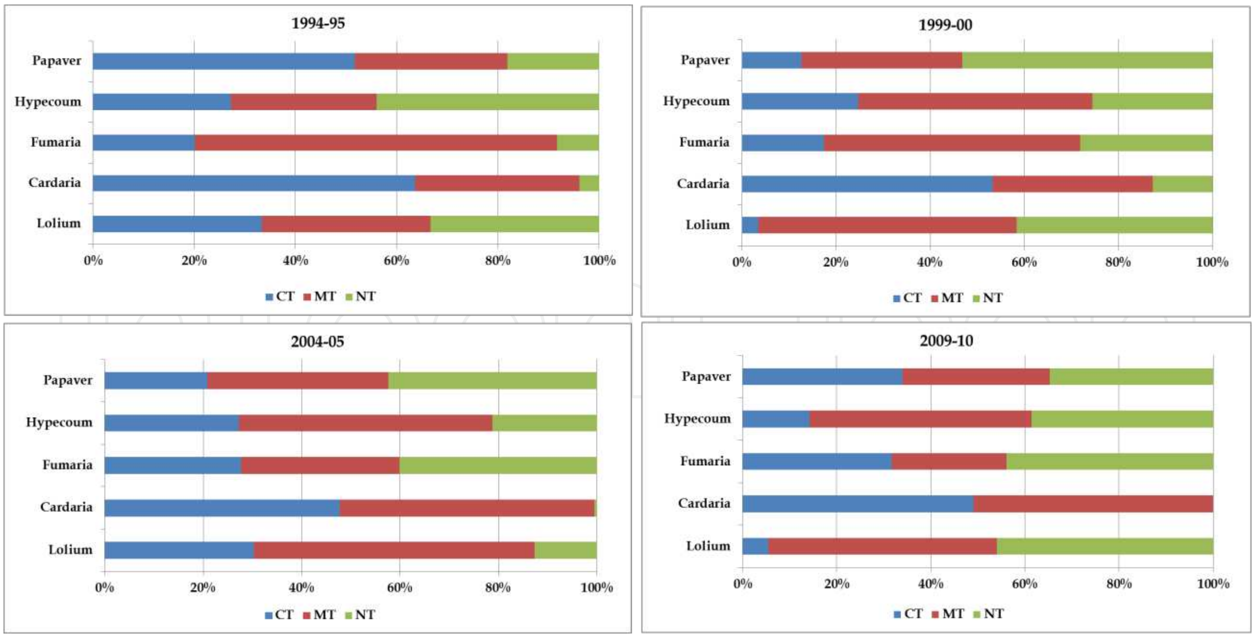

Figure 5. Relative density of weed species more representative in the field object of study.

3. Conclusion

At the moment, sustainable agriculture is being promoted in Europe, and its industrialization using technologies that help to increase crop production should be designed in order to protect the environment. In this context, the increasing awareness of the farmers requires the adoption and adaptation of techniques that, without undermining the economic benefit of farms, could be also accepted by the environment.

Sometimes we ignore the ecological processes that occur in agro systems, and weed control problems associated with herbicide selectivity and changes occurring in weed communities within MT and NT systems have been reported by numerous authors. In this sense, changes in agricultural technologies, such as the employment of selective herbicides, require reevaluation of assumptions regarding the nature of weed communities in MT and NT systems and the information on the association of weeds species with tillage systems and herbicides are key in determining directions of future research in weed management.

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