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Weed management in winter wheat (*Triticum aestivum* L.) influenced by different soil tillage systems

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In this study, weed management in winter wheat influenced by different soil tillage systems was investigated. The experiment was carried out under Mediterranean conditions on a Luvisol, during two growing seasons (1996/1997 and 1999/2000). Two factors (different soil tillage systems and post-emergence weed control) were studied, with two levels each: Two soil tillage systems and two levels of post-emergence weed control. The conventional soil tillage system, performed for seedbed preparation after the emergence of a high percentage of weeds, increases the appearance of monocotyledons, especially *Lolium rigidum* Gaud. in wheat crops, when compared to their establishment in no-till system. As a consequence of the higher number of monocotyledons there is an increase in weed-crop competition. Without post-emergence herbicide treatment, the wheat crop yield is lower in the treatments with the conventional soil tillage system and yield reduction is less under no-till system compared to the respective treatments with post-emergence herbicide application.

Key words: No-till system, weeds, wheat, herbicides.

INTRODUCTION

It is known that tillage, carried out by mouldboard plough, was accepted, traditionally, as a principal means for guaranteeing a clean seedbed for cereal crops (Attwood et al., 1977). On the other hand, it can also be fundamental for controlling weeds (Attwood et al., 1977; Gruber and Claupein, 2009).

Substituting mouldboard plough by other tillage equipments can, under some conditions, avoid an increase in weed pressure, as observed by Bàrberi and Cascio (2001), with regard to rotary harrow (reduced tillage).

An increase in the weeds in reduced tillage systems, can be attributed to the direct effect of tillage on the weeds, their seed production, the seed bank, survival during certain periods and spreading, as a consequence of the propagating weed parts that are cut by the equipment (Tørresen and Skuterud, 2002). For example, soil tillage for preparation of autumn-winter cereal seedbed can improve the conditions for germination of weeds (Attwood et al., 1977; Fenster and Wicks, 1982; Bräutigam and Tebrügge, 1997; Mirsky et al., 2010; Morris et al., 2010), which will increase the population density of the weeds in the crop (Fenster and Wicks, 1982; Bräutigam and Tebrügge, 1997).

With regard to no-till systems, which are characterized by depositing seeds on the topsoil (Locke et al., 2002; Morris et al., 2010), it is necessary to follow an appropriate procedure, to avoid high weed densities and prevent unacceptable problems (Brainard et al., 2013). Therefore, in no-till and reduced tillage systems, the application of pre-sowing herbicides is a common practice. This application substitutes tillage, which cause

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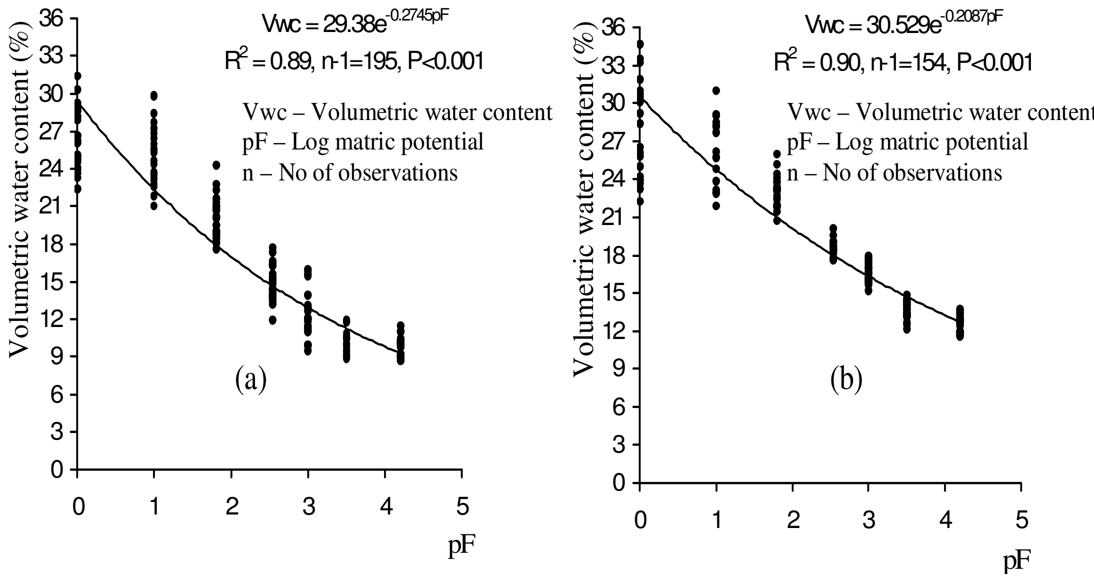

Figure 1. Water retention curve for the topsoil (0 - 10 cm; samples of the Luvisol collected during field work, (a) 1996/1997 and (b) 1999/2000.

great soil disturbances, and can have advantages with regard to water storage and increase wheat grain yield (Fenster and Wicks, 1982; Wicks et al., 1988; Mikha et al., 2013).

During the past two decades Portuguese farmers are searching increasingly for alternatives to the traditional system for the establishment of autumn-sown cereals, based predominantly on plough tillage. In reduced tillage and especially no-till systems they are looking for options able to provide environmental but mainly economical sustainability in a region where natural conditions strongly limit wheat productivity levels. For the adoption of conservation agriculture systems and their wide-spread uptake, weed flora and its dynamics must be understood (Brainard et al., 2013; Han et al., 2013). The knowledge and study of these dynamics is essential to define best management practices for weed control under given environmental conditions. There are differences in the infestation dynamics between traditional tillage based and no-till systems, because soil disturbance can both promote germination of the seeds of the existing seed bank in the soil as well as destroy the weeds that are already established (Forcella, 1986). Thus, this paper studies weed management in common wheat as a function of soil disturbance.

MATERIALS AND METHODS

The experiment was carried out at Revelheira farm in the Évora district of Portugal (38° 27' 54'' N; 7° 28' W) on a Luvisol during 1996/1997 and 1999/2000 seasons in a field where winter wheat was direct drilled. The areas were submitted to sheep grazing during the summer period until the establishment of the crop. This type of management was chosen to simulate the conditions of a wheat crop established in a rotation of cereals and natural pasture, commonly used under rainfed Mediterranean conditions.

Soil and climate conditions

The physical and chemical characteristics of the topsoil (0 to 10 cm) of Luvisol in 1996/1997 were 36.5% sand, 41.6% silt, 21.9% clay, with a bulk density of 1.6 (g cm^{-3}), available P and K of 10.5 ppm P_2O_5 and 69 ppm K_2O, pH 5.8 and 1.1% of organic matter. In 1999/2000 these characteristics were: 68.9% sand, 13.6% silt, 17.5% clay, with a bulk density 1.7 (g cm^{-3}), available P and K of 20.7 ppm P_2O_5 and 64 ppm K_2O, pH 5.6 and 1.2% of organic matter. Water retention characteristics are presented in Figure 1.

The monthly rainfall values and the average minimum, medium and maximum air temperatures are presented in Figure 2. These values were registered at the Reguengos de Monsaraz weather station, located at Revelheira farm, where the field work was carried out. The 30 year monthly average precipitation was obtained through the Instituto Nacional de Meteorologia e Geofísica (1991), based on the values registered at the Reguengos de Monsaraz pluviometric station.

Treatments and experimental design

The experimental model was two factors randomized complete block design for the main factor, which were soil tillage systems with a split with regard to the second factor of post-emergence weed control (subplot factor). There were two soil tillage systems (with and without soil disturbance), two levels of post-emergence weed control (with and without post-emergence weed control) and four replications.

Each main plot was 3 m wide and 25 m long, and divided into 2 subplots of 12.5 m length. Two tillage operations were performed in the treatment with conventional tillage (with soil disturbance), consisting of a tine cultivator followed by an offset disc harrow working at a depth of 15 cm. In the herbicide treatment, a post-emergence mixture of two herbicides (diclofop-methyl + tribenuron-methyl, trade name: Illoxan + Granstar) were applied at a

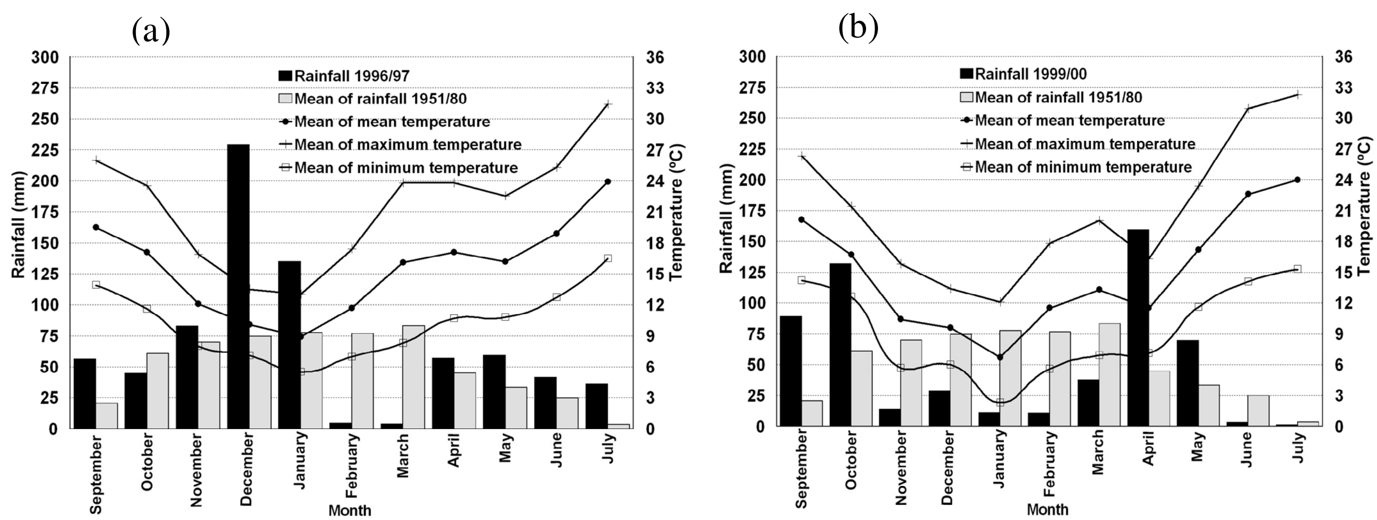

Figure 2. Thermopluviometric conditions in 1996/97 (a) and 1999/00 (b) and the 30-year average rainfall (1951/1980).

Table 1. Cultural practices used in the experiment of weed management in winter wheat influenced by different soil tillage systems.

Cultural practices	Years	
	1996/1997	1999/2000
Soil tillage: tine cultivator followed by an offset disc harrow working at a depth of 15 cm in the treatment with soil disturbance	20/11/1996	04/11/1999
Removing weeds before planting (pre-plant herbicide application, glyphosate 900 g a.i. ha^{-1}) in the treatment without soil disturbance		
Basic dressing: 36 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}	22/11/1996	12/11/1999
Wheat sowing. Variety: Centauro - 170 kg ha^{-1}	22/11/1996	12/11/1999
Application of active ingredient diclofop-methyl (900 g a.i. ha^{-1}) + tribenuron-methyl (13.5 g a.i. ha^{-1}) in the treatment with post-emergence weed control (recommended doses).	22/01/1997	19/01/2000
1st top dressing	27/01/1997 40 kg N ha^{-1}	12/01/2000 42 kg N ha^{-1}
2nd top dressing	10/02/1997 30 kg N ha^{-1}	Not applied
Harvest	June	

recommended doses, normally used by Portuguese farmers in wheat fields (Table 1), for an efficient control of the monocotyledon and dicotyledon weeds. The post-emergence herbicide mixture was applied when about 90% of the monocotyledons weeds, particularly *Lolium rigidum* Gaud., were at the beginning of tillering and dicotyledons were at the two to four true-leaf stages. Sowing density, fertilization and plant protection measures were done according to common local practice (Table 1). Herbicides were applied by a plot sprayer equipped with flat-fan nozzles (110° - 12) and an application volume of 200 L ha^{-1}. Winter wheat was sown with a mechanical drill with single disc openers. The harvest was carried out using a self propelled combine harvester in the small parcels (working width of 1.5 m) and manually in the 0.5 m^2 area.

Observations

In each of the subplots an area of 0.5 m^2 was chosen for the counting and identification of the weeds. This sampling method for carrying out weed readings was used according to Colbach et al. (2000). The total number of monocotyledons, dicotyledons and some dominant weed species on the trial site (individually) were monitored before and after the post-emergence herbicide application for each date and growth stage of wheat (stages 12 to 20 and 53 to 59) according to Zadoks et al. (1974) scale. Wheat yield and the respective components (number of ears, number of grains ear^{-1} and kernel weight) and the dry matter weight of weeds at wheat harvest time were recorded. Wheat grain and the weed biomass were dried in an oven at 65°C, until a constant weight was obtained (approximately 48 h).

The average values and standard errors of differences between means for the parameters observed were calculated using the MSTAT-C programme (v. 1.42) (Freed et al., 1991). Due to the not "normal distribution" pattern of weed species' populations in the field (Gonzalez-Andujar and Saavedra, 2003), the standard error of the means was used as it helps to estimate the uncertainty of the true value of the population mean, indicating the accuracy of the mean. The relative wheat yield was calculated in relation to the

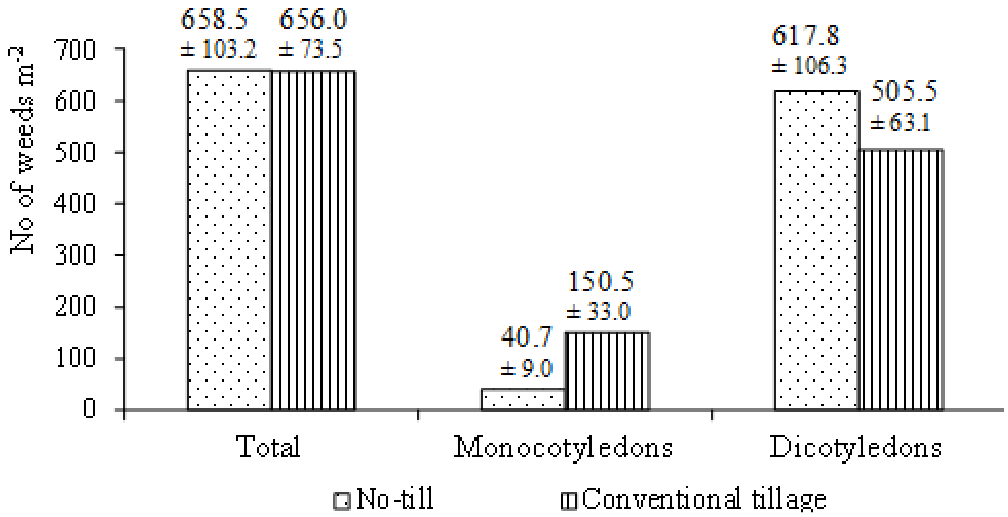

Figure 3. Number of weeds per square metre at tillering stage of the wheat under conventional tillage and no-till (average values of two years (1996/97 and 1999/00) ± standard error, region - Évora, Portugal).

yield obtained from disturbed soil with post-emergence herbicide.

Linear regressions were calculated between monocotyledons at heading stage of the wheat and the grain yield of the wheat as well as the weed dry matter at harvest and the wheat grain yield using Microsoft Excel (v. 2003) and Statistical Package for Social Sciences (SPSS) 15.0.

RESULTS

Effects of different soil tillage systems

The conventional soil tillage system increased the number of grass weeds at the beginning of the tillering stage of the wheat (stage 15). During this period, the no-till system is characterised by the occurrence of less monocotyledons (Figure 3). The counting of the weeds carried out at the heading stage of the wheat (stages 53 to 59), showed that the average number of the monocotyledon weeds continues to be less under no-till, with 13.0 plants m^{-2} in 1996/1997 and 38.8 plants m^{-2} in 1999/2000, against 26.8 plants m^{-2} in 1996/1997 and 49.3 plants m^{-2} in 1999/2000, in the conventional tillage system (Table 2). Therefore, conservation agriculture, especially no-till system, can contribute to decrease grass weeds in the cereal crops.

As we can see from Table 3, the weeds dry matter was less at harvest in no-till system, as compared to that in disturbed soil, especially in 1996/1997 (57.0 g m^{-2} in no-till and 157.0 g m^{-2} in conventional tillage, without post-emergence herbicide application). With regard to wheat yield and the respective components, it is noted that grain yield was greater when there was no-till (no soil disturbance) (Table 3). Also, there was a smaller difference between yield with post-emergence herbicide application and yield without post-emergence herbicide application in no-till system (413 kg ha^{-1} in 1996/1997 and 570 kg ha^{-1} in 1999/2000) than in conventional tillage system (762 kg ha^{-1} in 1996/1997 and 820 kg ha^{-1} in 1999/2000). Higher grain yield achieved in no-till systems resulted, mainly, in formation of a larger number of grains. The conventional tillage also affected negatively the grain weight when post-emergence herbicide was not applied (Table 3).

Influence of the post-emergence herbicide application on weeds and wheat yield components

As it is demonstrated in Table 4, application of post-emergence herbicides affect the number of weeds observed at the heading stage of the crop (stages 53 to 59). As a consequence of the decrease in the number of weeds with application of post-emergence herbicides, a lower weed dry matter weight was obtained at harvest, which was different from the weight obtained in the treatments without post-emergence herbicide application (Table 3). Due to the influence of herbicide application on weeds, it was noted that without post-emergence herbicide application, there was a decrease in the number of wheat grains, the determining component of wheat yield, under Mediterranean conditions. In turn, there was a decrease in the weight of the grain, without herbicide application in conventional tillage, but in the no-till system there was no difference in the average values of the kernel weight in the two treatments, with and without post-emergence herbicide (Table 3).

Wheat yield influenced by weeds infestation

As mentioned previously, the density of monocotyledon

Table 2. Effect of soil tillage systems on weed plant density (No m^{-2}) at heading stage of the wheat (average values (1996/1997 and 1999/2000) ± standard error, region - Évora, Portugal).

No. of plants m^{-2}	Year 1996/1997		Year 1999/2000	
	No-till	Conventional tillage	No-till	Conventional tillage
Total	129.3 ± 47.3	71.5 ± 25.1	52.5 ± 20.6	60.0 ± 23.2
Monocotyledons	13.0 ± 6.6	26.8 ± 8.7	38.8 ± 15.9	49.3 ± 19.4
Dicotyledons	116.3 ± 42.3	44.8 ± 17.9	13.8 ± 8.5	10.8 ± 5.1
Lolium spp.	0.5 ± 0.3	6.0 ± 3.5	38.3 ± 15.7	48.5 ± 19.0
Phalaris spp.	11.3 ± 5.9	15.8 ± 8.7	0.3 ± 0.3	0.3 ± 0.3
Coleostephus myconis (L.) Reincheb.	0.0 ± 0.0	11.8 ± 8.7	0.0 ± 0.0	0.0 ± 0.0
Chamaemelum spp.	1.3 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Calendula arvensis L.	0.8 ± 0.8	3.3 ± 2.2	0.0 ± 0.0	0.0 ± 0.0
Anagallis arvensis L.	74.3 ± 32.1	16.8 ± 6.5	0.0 ± 0.0	0.0 ± 0.0
Polygonum aviculare L.	18.3 ± 8.9	7.5 ± 3.0	0.8 ± 0.8	2.3 ± 1.5
Spergularia purpurea (Pers.) G. Don fil.	20.3 ± 11.9	2.0 ± 1.3	8.5 ± 5.7	3.3 ± 3.3

Table 3. Wheat yield, yield components and weed dry matter at harvest, under conventional tillage and no-till and with and without post-emergence herbicide (average values (1996/1997 and 1999/2000) ± standard error, region - Évora, Portugal).

Parameter	Year 1996/1997				Year 1999/2000			
	No-till		Conventional tillage		No-till		Conventional tillage	
	Post-emergence herbicide							
	With	Without	With	Without	With	Without	With	Without
Tillers $plant^{-1}$	0.365 ± 0.10	0.396± 0.11	0.293± 0.10	0.069 ± 0.11	0.719 ± 0.14	0.273± 0.16	0.301 ± 0.09	0.162 ± 0.06
No of ears m^{-2}	356.0 ± 21.0	299.5± 22.9	359.0± 28.4	286.5 ± 23.5	369.5 ± 15.1	310.0± 20.1	346.0 ± 29.0	331.0 ± 29.2
No of grains m^{-2}	7836 ± 526	6619± 494	6897± 619	4773± 1091	7981± 431	6113± 152	7278± 255	5385± 262
Kernel weight (mg)	31.85 ± 0.35	31.53± 0.77	31.32± 0.56	29.31 ± 0.15	31.28 ± 0.81	31.64 ± 0.89	31.33 ± 0.39	29.77 ± 0.71
Yield (kg ha^{-1})	2492 ± 149	2079± 129	2162± 201	1400± 322	2503± 185	1933± 63	2424± 77	1604± 91
Harvest índex	0.425 ± 0.01	0.400± 0.02	0.380± 0.0	0.325 ± 0.04	0.352 ± 0.01	0.360 ± 0.03	0.356 ± 0.02	0.352 ± 0.03
Dry matter of weeds (g m^{-2})	2.0 ± 1.4	57.0± 16.2	39.00± 33.1	157.0 ± 27.8	0.3± 0.2	222.0 ± 19.4	1.9± 0.8	235.6 ± 17.2

weeds, especially *Lolium rigidum* Gaud., was higher under conventional tillage carried out for seedbed preparation for wheat when compared to no-till. Increasing of weeds population caused an increase in competition for limited resources such as water and consequently a negative influence on yield and the respective components of the wheat crop. This can be verified in Figure 4, which shows the relationship between the number of monocotyledon weeds and wheat yield. In fact, there is a clear tendency towards a drop in the average yield values when the average number of these weeds increases. Figure 4 demonstrates that a weed population of up to 40 monocotyledon plants per square metre is related to wheat grain yields of over 2000 kg ha^{-1}. When the number of monocotyledon weeds moves towards zero, grain production increases to 2500 kg ha^{-1}, while a

Table 4. Effect of post-emergence mixture herbicide application on weed plant density (No m^{-2}) at heading stage of the wheat (average values (1996/97 and 1999/00) ± standard error, region - Évora, Portugal).

No. of plants m^{-2}	Year 1996/1997		Year 1999/2000	
	Post-emergence herbicide			
	With	Without	With	Without
Total	11.3 ± 4.0	189.5 ± 28.6	2.5 ± 0.8	110.0 ± 11.9
Monocotyledons	5.0 ± 3.4	34.8 ± 7.5	0.3 ± 0.3	87.8 ± 9.6
Dicotyledons	6.3 ± 1.7	154.8 ± 29.9	2.3 ± 0.8	22.3 ± 8.3
Lolium spp.	0.0 ± 0.0	6.5 ± 3.4	0.3 ± 0.3	86.5 ± 9.2
Phalaris spp.	3.0 ± 2.1	24.0 ± 8.7	0.0 ± 0.0	0.5 ± 0.3
Coleostephus myconis (L.) Reincheb.	0.0 ± 0.0	11.8 ± 8.7	0.0 ± 0.0	0.0 ± 0.0
Chamaemelum spp.	0.0 ± 0.0	1.3 ± 0.8	0.0 ± 0.0	0.0 ± 0.0
C. arvensis L.	0.0 ± 0.0	4.0 ± 2.2	0.0 ± 0.0	0.0 ± 0.0
Anagallis arvensis L.	6.0 ± 1.8	85.0 ± 29.3	0.0 ± 0.0	0.0 ± 0.0
P. aviculare L.	0.3 ± 0.3	25.5 ± 7.2	0.5 ± 0.5	2.5 ± 1.5
S. purpurea (Pers.) G. Don fil.	0.0 ± 0.0	22.3 ± 11.5	0.0 ± 0.0	11.8 ± 5.9

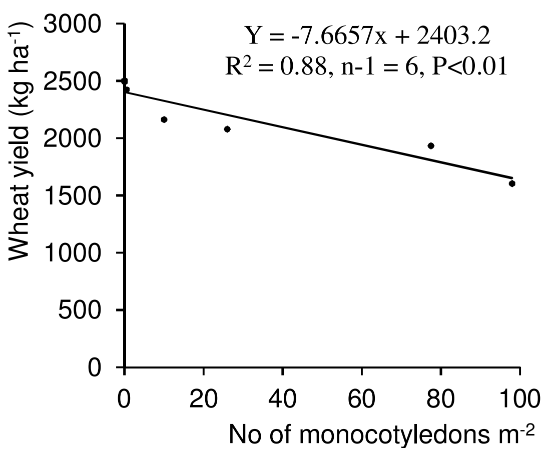

Figure 4. Relationship between the number of monocotyledons at heading stage of the wheat and the wheat yield (average values of two years).

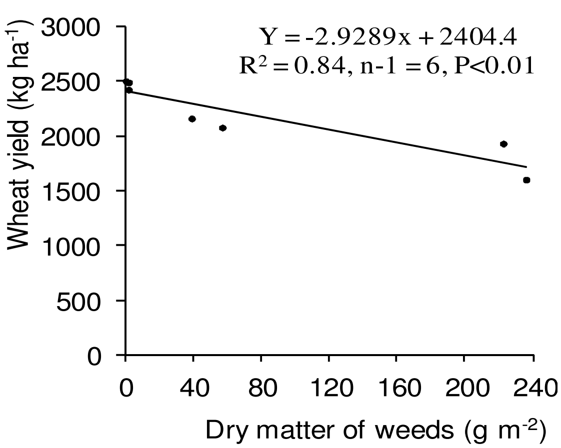

Figure 5. Relationship between the weed dry matter at harvest and the wheat yield (average values of two years).

population of 25 monocotyledon plants per square metre corresponds to a wheat yield of 2250 kg ha^{-1}.

With regard to weed dry matter at wheat harvest period, a negative linear relationship is observed between weed dry matter weight and wheat yield (Figure 5). Weed dry matter weight variations of 0 to 50 gm^{-2} correspond to wheat yields of 2500 to 2000 kg ha^{-1}. Due to the greater density of monocotyledon weeds that are present after soil tillage for seedbed preparation, there is a great decrease in crop yield without herbicide application, compared with post-emergence herbicide application, than that in the no-till system (Figure 6). Therefore, there is a greater relative yield in no-till system, without post-emergence herbicide application, which is another benefit of conservation agriculture systems.

DISCUSSION

Soil tillage enhanced the emergence of monocotyledon weeds, mainly *L. rigidum* Gaud., the dominant species in the region of the study. Therefore, despite the elimination of weeds through tillage performed for seedbed preparation, an increase in weed emergence can be expected after crop establishment (Bräutigam and Tebrügge, 1997; Marginet et al., 2000; Rahman et al., 2000), due to more favourable conditions for weed germination created by the tillage operations (Attwood et al., 1977; Fenster and Wicks, 1982; Bräutigam and Tebrügge, 1997; Mirsky et al., 2010). There are various studies that refer to the negative impact of *L. rigidum* Guad. (the dominant type in the conditions of this study) on wheat grain yield (Lemerle et al., 1995, 1996). According to Lemerle et al. (1996), competition between *L. rigidum* Guad. and wheat plants affected formation of the heading and the crop grain.

In competition between weeds and crops, it is important

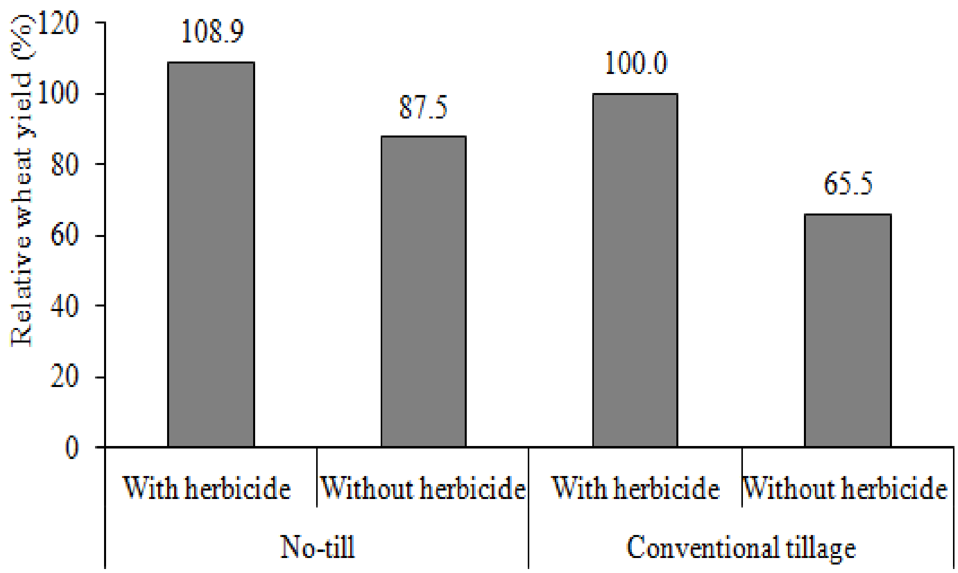

Figure 6. Wheat yield under conventional tillage and no-till and with and without post-emergence herbicide relative to the yield obtained from disturbed soil with post-emergence herbicide (% calculated from average values of two years (1996/1997 and 1999/2000), region - Évora, Portugal).

to analyse the threshold values (Swanton et al., 1999; Munier-Jolain et al., 2002; Gherekhloo et al., 2010), when is it possible to verify and control crop infestation (Swanton et al., 1999; Colbach et al., 2000). As also observed in our field trials, wheat yields under Mediterranean rainfed conditions frequently are around 2500 kg ha^{-1}. From our results we can also conclude that wheat grain losses due to grass weed infestation remain below 10% of this average wheat yield if the number of monocotyledon weeds at wheat heading stage below 25 per square metre.

As different studies have demonstrated that post-emergence herbicide has a significant influence on weed density and as a consequence on wheat yield and its components (Buhler et al., 2000; Han et al., 2013). However, the effect of post-emergence mixture herbicide application on the achievement of acceptable wheat yields depends on the given conditions (Calado et al., 2010). As a result of this study it appears that under Mediterranean conditions the post-emergence herbicide application is more important when crop establishment is based on the conventional tillage system, especially when compared to the no-till system. Considering the relative yield values (Boström, 1999; Colbach et al., 2000; Munier-Jolain et al., 2002), the observed loss in wheat yield without application of post-emergence herbicide, compared to the yield obtained with application of post-emergence herbicide is less in no-till systems than in soil tillage systems. Thus, if the registered autumn precipitation before sowing allows for maximizing emergence of potential weeds (Grundy and Mead, 2000; Froud-Williams, 2001), this is controlled in the no-till system through application of pre-sowing herbicide (Calado et al., 2010), without significant disturbance of the topsoil layer. In these conditions, the weed population emerging after crop sowing causes less harm to the plants, compared to the soil tillage system, and given the cost benefit results, there is no clear justification for applying post-emergence herbicide. Therefore, it can be concluded that in no-till wheat, in addition to environmental benefits, achieved through the improvement of soil physical, chemical and biological conditions (Mikha et al., 2013), and the benefits resulting from lower costs for crop establishment, it is possible to reduce or avoid the use of post-emergence herbicides.

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