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Tillage and Rotation effects on *Bromus diandrus* Roth: A Lesson Learned from Fields in Northern Spain

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Abstract

The aim of this research was to achieve a good understanding of the practices and environment conditions to control *Bromus diandrus* Roth, in the semi-arid drylands of northern Spain. We studied the effects of three crop systems: monoculture, cereal/fallow and cereal/legume on the density and biomass of B. diandrus over three seasons, under three soil tillage managements: conventional tillage (CT), minimum tillage (MT) and no-tillage (NT), at tillering and booting stages of cereal crops. The results showed B. diandrus significantly increased with cereal monoculture under conservation systems. Overall, NT presented highest infestation levels that increase from 89 plants m^{-2} to 342 plants m^{-2} between the first and the third experimental seasons. Followed by MT, that increased from 136 to 231 plants m^{-2}. Infestation levels in CT resulted lowest, with no weed plants in the first two seasons and only 5 plants m^{-2} in the third season. In conservation systems, yield was consistently lower under cereal monoculture because of B. diandrus competition. The introduction of legume crops in rotations decreased B. diandrus infestation and had a positive effect on cereal production. The inclusion of fallow in a cereal rotation scheme can be a good alternative if legume crops are not available.

Keywords

Rigput Brome, Conservation System, Cereal, Semi-Arid, Weed Biomass, Weed Density, Yield

1. Introduction

Farm management in northern Spain has changed a lot over the years for several reasons. There has been a move towards conservation agriculture to improve sustainability without compromising land, and at the same time is an effective way of reducing soil erosion and maintaining soil water content [1, 2, 3, 4]. However, conservation agriculture can lead to specific problems with weed control because without tillage farmers have no option but to rely on herbicides [5, 6, 7].

The high input systems of winter cereal, from northern Spain, under conservation tillage techniques need an efficient weed control programme in terms of efficacy and dosage of herbicides. Weed density has been shown to increase with tillage in some cases and in the long-term have resulted in a global decrease in crop yields [8, 9, 10, 11, 12]. However, this relationship between weed density and the tillage system is inconsistent and varies between years [13] for example, in a long-term field experiment with reduced tillage and non-tillage, conducted by Torrensen et al. [14], not only was the level of production lower, but also the weed infestations were greater compared to conventional tillage systems. Other studies found that weed density increased its abundance with conservation tillage techniques [15, 16]. However, Santín Montanyá et al. [17] did not observe differences in weed communities due to different tillage systems.

Bromus diandrus Roth. is a winter annual grass, problematic in conservation cereal systems [18, 19, 20, 21]. This is a common weed specially associated to no-tillage systems [22]. A previous hydrothermal emergence model developed for this species estimated the soil temperature and soil moisture seem to be the determinant factors driving emergence of B. diandrus [23]. Also, Del Monte and Dorado [24] found Bromus species emergence may be limited because light inhibition of germination. In this sense, Recasens et al. [25] showed that long-term conservation techniques (minimum tillage and no-tillage) affected to B. diandrus density due to changes to soil characteristics (photo-inhibition of germination, soil temperature, water availability). B. diandrus infestations in cereals (wheat and barley) are leading to a remarkable decrease of the economic profitability of crops due to the high herbicide costs [26, 27]. In the semi-arid region of Mediterranean Spain, Royo-Esnal et al. [28] found the combination of crop rotation (with dicotyledonous crops) and sowing delay contributed to an effective weed management that included an intensive herbicide programme.

Especially in monoculture cereal it has seen a notable presence of this weed which can lead to lower yield parameters [29, 22, 7, 21]. As a solution to yield reduction García et al. [30] have recommended the delayed crop sowing to optimize the control of B. diandrus in cereal fields, with no-tillage. But this measure even though useful can be limited by the crop sequence since in northern Spain is often sown a continuous cereal sequence (principally wheat and barley crops). Therefore, farmers who have seen the increased B. diandrus density in minimum and no-tillage systems abandon the conservation agriculture.

In previous studies, rotation systems have been proved an effective tool for maintaining weeds at manageable levels [31, 32, 33, 34, 35, 36]. It has been suggested that annual grass weeds such as B. diandrus are so difficult to control because they take advantage of a similar plant life cycle to the cereal crop [37, 22, 7]. Therefore, if the crop cycle is interrupted by using a rotation system, there is opportunity to reduce the impact of weed presence on crop yield. Although rotation systems have been used in Mediterranean agro-ecosystems to diversify and increase land outputs, considerable year-to-year variations in crop yield have also been recorded [38, 39, 40, 41]. In this paper, we show the field results from an assay which started may years ago (1999), even though the findings of this study have not been previously published, the data can provide valuable insight to winter cereal growers. Nowadays, there is great emphasis placed on the importance of conservation agriculture. In this respect, it is of great scientific interest to study the effects of rotation systems on weeds.

We are taking advantage of old data to hypothesise that a crop variety may reduce the emergence of a dominant weed, either by differences in morphological and physiological features between crop and weed, or from differences in the crop management requirements. In both cases, it would increase the crop ability to withstand the competition of a dominant weed.

However, in the farmlands of central Spain, there is no clear answer regarding the best rotation option to control B. diandrus specifically. Bearing this in mind, the overall objective of this study was to validate and gain insight into the effects of rotations on B. diandrus in conservation cereal fields.

2. Methods

The study was carried out in 1998/99, 1999/00 and 2000/2001 in an experiment regime that started in 1994. The land is located in Torrepadierne (Burgos, Spain), representative of the cereal zone of the Duero Basin. The soil is classified as Typic Calcixerolls with a clay texture, pH of 8.3 its bulk density 1.13 g/cm^3 and an organic matter content of 2.2%. The area has a Mediterranean-continental climate, according to Papadakis classification [42], with a frost-free period running from 3 May to 22 October, with average annual rainfall of 531 mm, and average annual temperature of 9°C. These climatic conditions are suitable for cereal grain production. The monthly rainfall and temperatures in the field are shown in Table 1.

The experimental design was a split plot with four repetitions where the assay consisted of 24 elementary plots of 450 m2. (15 x 30 m). The main plot was the tillage system, and the crop rotation was the variable in the sub-plot. Three tillage systems were used: conventional tillage (CT), at 45 cm, minimum tillage (MT), at 10 cm, and no-tillage. The preparatory work was according to each tillage system, CT (moldboard ploughing, cultivator, dredge, roller, and sowing), MT (chisel, dredge, roller and sowing) and NT (herbicide and sowing).

The following crop rotations were defined: cereal/cereal/cereal; cereal/fallow/cereal and cereal/legume/cereal. The fallow/cereal/fallow and legume/cereal/legume sequences were included to have all the same crops each year. Cereal crops used were barley (v. Tipper) and wheat (v. Marius) while the legume crop was vetch (v. Buza). In order to have cereal fields to study in each growing season, a duplicate regime starting on fallow or legume was also established. Sowing was carried out on the same day, and in all plots a grid seeding using the Sola Super 395-sd drill at a rate of 180 kg ha^{-1} of winter barley, 200 kg ha^{-1} of winter wheat and 160 kg ha^{-1} of vetch.

Table 1. Monthly rainfall (mm) and Temperatures (Tmax and Tmin) at Torrepadiernes, Spain, in growing seasons 1998-2001 and historic mean values

Precipitation (mm)	October	November	December	January	February	March	April	May	June	July	August	September	Total
1998/1999	7.1	19.8	45.5	43.5	2.4	16.6	37.4	52.4	4.7	34.2	26.3	39.8	329.7
1999/2000	79.5	34.7	23.1	16.8	4.9	35.8	117.4	25.9	25.3	33.7	14.3	40	451.4
2000/2001	48.1	109.9	83.2	86.5	16.9	111	12.8	36.7	1.1	57.4	14.1	24.5	602.2
30-year average	43.1	40.7	37.1	42.5	41.3	24.5	51.7	54.5	43.3	21.6	17.3	30	447.6
Tmax (°C)													
1998/1999	15.9	10.3	4.9	4.8	8.5	13.3	15.9	21.3	25.1	30.3	28.7	23.7	
1999/2000	16.8	8.1	6.6	5.1	12.7	14.1	12	22.4	27.1	27.6	28.3	25.3	
2000/2001	16.2	8	7.3	6.6	8.8	13.2	15.4	20.7	27.6	26.6	30.1	22.5	
30-year average	18.7	12.8	8.8	8.2	10.8	14.6	16.4	20.7	26.3	30.8	30.7	26.3	
Tmin (°C)													
1998/1999	3.8	0.1	-2.2	-1.3	-2.2	0.7	2.8	8.2	8.7	12.8	12.4	10	
1999/2000	6.1	0.3	-0.2	-3.6	-0.1	0.7	3.5	8.1	9.9	11	11.4	9	
2000/2001	4.8	2.3	3.3	1.5	0.5	5.9	3.3	6.9	10.5	12.6	14.4	8.6	
30-year average	7.1	3.4	1.3	-0.6	0.1	2.2	3.5	7.2	10.3	12.9	13	10.5	

Integrated fertilization was carried out, firstly, at the time of cereal sowing with 400 kg ha^{-1} of 8-24-8 (N-P-K). Secondly, at booting stage, 300 kg ha^{-1} of ammonium sulfate (27-0-0) was applied. Both fertilization rates were calculated according to the results of soil analysis and the needs of the crops.

At pre-sowing, the application of the 36% glyphosate herbicide (1 l/ha) was carried out in minimum tillage and no-tillage plots only. Post-emergence herbicides were applied to all cereal plots at the same rates: 2.5 l ha^{-1} of Oxitril (ioxinil 7.5% + mecoprop 37.5% + bromoxynil 7.5%) + 1.25 l ha^{-1} of Splendor (tralkoxidym 25%). In vetch, the post emergence treatment was 1.1 l ha^{-1} of Agil + 0.5 l ha^{-1} of Extravon (wetting oil).

The density of B. diandrus individuals was counted and their biomass removed in each crop rotation system, including fallow, and soil management, in four 0.25m^2 samples at tillering and booting stages of the cereal 24 and 59 respectively in Zadock's scale [43]. The remove biomass was brought to the laboratory, oven dried at 65°C for 48 hours, and weighted. Four-cereal grain and four-straw samples (0.5m^2) were taken per plot by hand. Crop production components were estimated for all samples.

Analysis of variance of B. diandrus measurements (density and biomass) was performed using the PROC MIXED routine, with tillage treatments and rotation considered as fixed effects and year as a random variable for Tillering and Booting stages. Means were compared by Tukey's HSD studentized range test at 0.05 probability level ($P \leqslant 0.05$). Weed measurements were log transformed prior to analysis to normalize residues. At harvest, the cereal yield means were compared by using the Tukey's HSD Test ($P < 0.05$). All statistical analysis was carried out using Statgraphics Plus 5.0 software package (Statgraphics Plus for Windows 1998).

3. Results

Precipitation levels have been different every year, in terms of total and monthly rainfall (Table 1). 1998-99 was extremely dry (329.7 mm), in 1999-00 precipitation levels (451.4 mm) were similar to historical mean. Last year, 2000-01, rainfall was the highest (602.2 mm); although cumulative precipitation recorded from April to June 2001 was extremely low (50.6 mm). Between December and March, we have seen that minimum temperature averages were higher last year of study than the first two years and the historical mean.

The results showed that B. diandrus data (density and biomass) were significantly affected by rotation but were not affected either by year or by tillage systems at Tillering and Booting stages of cereal (Table 2). Although, the climatic conditions made a difference to the weed parameters, and we have found significant effects of 'Year x Tillage' interaction on B. diandrus density and biomass parameters. The 'Tillage x Rotation' interaction was also found significant on weed data at both cereal stages.

Table 2. Analysis of variance results (F statistics and P-values) for Year, Tillage system and Rotation

		TILLERING		BOOTING	
Treatments	D. f.	Density (Plants/m^2)	Biomass (gr/m^2)	Density (Plants/m^2)	Biomass (gr/m^2)
Year (Y)	2	0.97	0.64	1.31	1.78
Tillage system (TS)	2	9.57 *	6.68	5.74	3.61
Rotation (Rot)	4	22.18 ***	18.77***	11.85**	13.76**
Y x TS	4	9.46 ***	9.62***	5.18**	7.89**
Y x Rot	8	1.8	2.07	2.59	1.87
TS x Rot	8	10.11 ***	9.86***	6.73***	6.06**
Y x TS x Rot	16	2.2 **	1.54	5.59***	4.78***

Note: Mean values for B. diandrus density (Plants/m^2) and Biomass (gr/m^2) at Tillering and Booting stages of cereal. All parameters were *log* transformed before analysis.

*Significant at P ≤0.05. **P ≤ 0.01. ***P ≤ 0.001.

Abbreviations: Y – year; TS – Tillage system; Rot – Rotation system.

At the cereal tillering stage, B. diandrus density and biomass results for each tillage system and rotation scheme varied during the three years of the study (Table 3). Regarding B. diandrus density, in the first year of the study (1998/1999) each tillage system had a significantly different value. MT showed the highest density, NT density was significantly lower than MT and higher than CT (which showed the lowest value). In the second and third years of the study (1999/2000 and 2000/2001), both conservation systems (MT and NT) showed higher density than CT, however, there was no significant difference between MT and NT. Comparing the effects of rotation on weed density, we have seen that B. diandrus density was consistently higher in cereal monoculture, followed by the cereal rotated with legume, all three years. Looking at B. diandrus biomass according to the tillage system, in the first year MT biomass was significantly higher than in NT and CT. In the two last years of the study, the conservation systems (MT and NT) showed significantly higher values of biomass than in CT plots. Biomass according to the rotation system showed results similar to those of density: in all three years B. diandrus biomass in cereal monoculture was consistently higher than the other rotation systems.

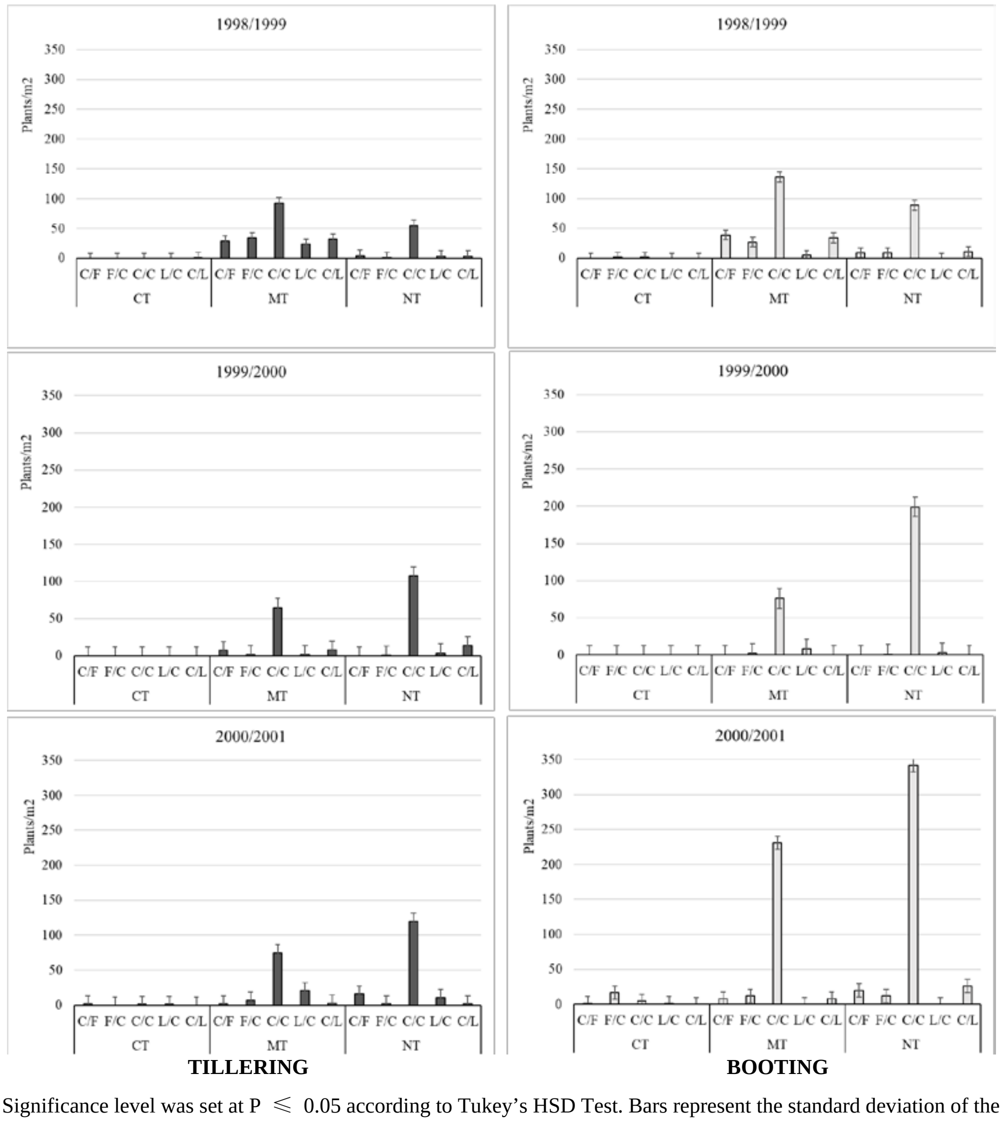
Table 3. Number of plants established and biomass of B. diandrusat tillering and booting stages of cereal in different tillage systems and rotations, over the years 1998/1999, 1999/00, and 2000/2001

	TILLERING						BOOTING					
Year	**1998/1999**		**1999/2000**		**2000/2001**		**1998/1999**		**1999/2000**		**2000/2001**	
	Plants/m^2	**Biomass (gr/m^2)**	**Plants/m^2**	**Biomass (gr/m^2)**	**Plants/m^2**	**Biomass (gr/m^2)**	**Plants/m^2**	**Biomass (gr/m^2)**	**Plants/m^2**	**Biomass (gr/m^2)**	**Plants/m^2**	**Biomass (gr/m^2)**
Tillage systems												
CT	0.12 c	0.01 c	0.05 b	0.00 b	0.28 b	0.06 b	0.15 c	0.12 c	0 .02 b	0.00 b	0.63 b	0.41 b
MT	3.02 a	0.92 a	1.30 a	0.35 a	1.82 a	0.52 a	2.77 a	2.74 a	1.05 a	0.69 a	1.59 ab	0.95 ab
NT	1.35 b	0.31 b	1.31 a	0.35 a	1.74 a	0.53 a	1.56 b	1.41 b	1.09 a	0.81 a	1.29 a	0.79 a
Rotation												
Cereal/Fallow/Cereal	1.16 b	0,27 b	0.39 c	0.13 bc	0.94 bc	0.26 b	1.63 b	1.68 b	0.00 c	0.00 c	1.12 b	0.67 ab
Fallow/Cereal/Fallow	1.03 b	0.32 b	0.23 c	0.00 c	0.80 cd	0.19 bc	0.88 c	1.00 c	0.24 bc	0.13 bc	1.46 b	1.07 a
Cereal/Cereal/Cereal	2.67 a	0.88 a	2.47 a	0.72 a	2.94 a	0.98 a	3.02 a	2.93 a	2.9 a	2.12 a	1.87 a	1.03 a
Legume/Cereal/Legume	1.30 b	0.31 b	0.44 c	0.04 c	1.35 b	0.38 b	0.21 d	0.15 d	0.44 b	0.26 b	0.92 b	0.47 b
Cereal/Legume/Cereal	1.34 b	0.28 b	0.92 b	0.28 b	0.39 d	0.04 d	1.72 b	1.35 bc	0.00 c	0.00 c	0.46 b	0.35 b

Note: Mean values for B. diandrus density (Plants/m^2) and Biomass (gr/m^2) at Tillering and Booting stages of cereal. All parameters were *log* transformed before analysis. Means values followed by different letters are significant differences at P ≤ 0.05.
Abbreviations: CT – Conventional tillage; MT – Minimum tillage; NT – No-tillage.

At booting stage of cereal B. diandrus density and biomass was affected by tillage system and rotation scheme over the three years of the study. Following the same pattern as the data for tillering stage (Table 3), B. diandrus density in the first year of the study (1998/1999) had a significantly different value in each tillage system. MT had the highest value, followed by NT and then CT. In the second and last years of the study, higher values were found in NT and MT systems than in CT systems. Last year of study, the NT systems values were significantly higher than CT. MT density values were the highest but were not significantly different from either NT or CT systems. We found that B. diandrus density was significantly higher in cereal monoculture compared to the rest of the rotation systems. B. diandrus biomass at the booting stage in all years followed the same pattern as density. The lowest values were found in CT, then NT and MT exhibited the highest biomass. Regarding the effect of rotation on B. diandrus biomass, at booting stage, in all three years cereal monoculture showed consistently higher B. diandrus biomass than the other rotation systems. In the first year of the study, legume/cereal rotation systems produced significantly lower levels of B. diandrus density and biomass at booting stage (not tillering stage).

B. diandrus density reported in Figure1 showed graphically, at tillering and booting stages, the interaction of tillage system and rotation each year of the study. In CT systems, all rotations presented very low density in all three years. In MT and NT systems, the cereal monoculture always showed the highest B. diandrus density.

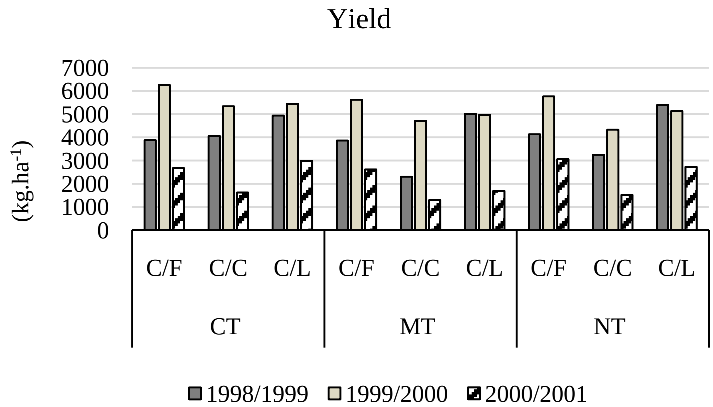


Note: Significance level was set at P ≤ 0.05 according to Tukey's HSD Test. Bars represent the standard deviation of the data.

Abbreviations: C/F=Cereal/Fallow; F/C= Fallow/Cereal; C/C= Cereal/Cereal; L/C= Legume/Cereal; C/L= Cereal/Legume; CT= Conventional Tillage; MT= Minimum Tillage; NT=No-tillage

Figure 1. Effects of Tillage and Rotation, over 3 years of study, on B. diandrus density, at Tillering and Booting stages of cereal.

With regard to cereal yield (Figure 2), there were no differences in yield observed between the tillage systems in all years of the study nor in the average of the yield per year in each tillage system. However, the year influenced the crop yield because the last year showed a significantly lower average (of all tillage systems) compared to the first two years. With regard to rotations, the cereal monoculture yield was significantly lower than the other rotations (with fallow or legume).



Abbreviations: C/F= Cereal/Fallow; C/C= Cereal/Cereal; C/L= Cereal/Legume; CT= Conventional Tillage; MT=Minimum Tillage; NT= No-Tillage

Figure 2. Cereal yield (Kg ha^{-1}) in each tillage system and rotations over the period of study.

4. Discussion

In general, our short-term study showed that there were consistent differences between the effects of conventional and conservation tillage techniques on *Bromus diandrus* Roth density and biomass. Previous studies have found that the overall effect of tillage on weed density depends primarily on the type of weed [44, 45]. Reduction of the soil disturbance (conservation agriculture) alters soil seed depth [46], and weed emergence period can vary depending on tillage technique. Some authors have found that annual monocotyledonous weeds tend to increase with reduced tillage [47, 48, 49, 50]. This can be explained, in part, because conservation tillage techniques (either MT or NT) keep the weed seed movements within the soil profile to the top layer, a more favourable condition for germination and seedling establishment of weed species dependent on light. Our study concurs with this idea, and B. diandrus, a monocotyledonous, was controlled by conventional tillage [51]. Although in some cases pre-sowing control of B. diandrus by tillage may be limited due to the weed seed reacts to light particularly [24]. This specie showed a noticeable sensitivity to light, especially at low temperatures; because of the light inhibition of B. diandrus germination is due in part to its negative photoblastism [24]. Light affects germination of many weeds, and tillage can help to initiate this process, especially with seeds on the soil surface layer [50]. This reaction has also been described in *Bromus rigidus* Roth and *Bromus sterilis* Her. [52, 53]. Conservation systems (MT and NT) favour the establishment of this species because the seeds remain on the surface layer which is not the case for conventional systems as the seeds are buried with the tillage [37, 19, 7, 27]. In our study, conservation techniques showed higher rates of B. diandrus infestation and lower yield parameters, especially in cereal monoculture. These results agree with those obtained by other author in similar conditions [7, 27, 54, 25]. The continuous cereal systems, in northern Spain, are common and weed control in these soil non-inversion conservation techniques (minimum tillage and no-tillage systems), is difficult to achieve because of these systems are dependent on herbicides [5]. Also, tillage system variant applied is crucial to weed species control [55]. The continuous use of cereal and the general lack of B. diandrus specific herbicides [26] has emphasized the spread of this species.

The weed management strategies focus their efforts to prevent the increase of a single dominant weed species. Weed species diversity in the field tends to be associated with the type of crop, due to levels of competition for resources during the crop and weed life cycles [33, 45, 56]. We have found lower B. diandrus density in vetch fields; legumes, as dicotyledonous species, have a different life cycle and rate of growth compared to monocotyledonous species such as barley and B. diandrus which gives legumes a competitive advantage over this species [28]. During the fallow period, different species of weeds compete for space, light, water and nutrients and a balance is usually established between dicotyledonous and monocotyledonous species. These conditions created in fallow lands act to avoid the dominance of B. diandrus and reduce its density and biomass compared to cereal monoculture. Previous studies of Thorne et al. [57] found that no-tillage cropping systems were effective controlling Bromus tectorum in cereal rotated with fallow. The results of our experiment, showing that cereal monoculture was the most affected by the B. diandrus infestation concur with these two ideas.

The second year of the study we found higher yield parameters than the historical average, probably due to weather conditions in winter which limited the development (biomass) of B. diandrus and in spring which affected the yield. Although the rainfall in October was higher than average, there was scarce rainfall over winter; only 79.5 mm accumulated between November and February. We can assume that the biomass of B. diandrus was decreased due to a reduced number of tillers per plant. There was also high spring rainfall (117.4 mm) which facilitated the crop growth and the conditions for the grain maturation. There are intricate connections between weather, weed parameters and crop production.

In this study, yield parameters were improved in plots with legume and fallow rotation systems. In conservation agriculture, where farm managers can protect the soil, rotation is important as an integrated management tool to reduce B. diandrus weed infestations and the impact on cereal production.

5. Conclusion

In Mediterranean arable fields, conservation tillage techniques are aimed to conserve soil and reduce tillage costs compared to conventional tillage, despite of their dependence on herbicides to control weeds. B. diandrus is a problematic weed in cereal crops in Spain as farmers turn to conservation agriculture. Tillage contributes to soil erosion, but on the other hand protects from B. diandrus infestations. Additionally, previous studies have demonstrated that soil tillage influences germination and emergence of B. diandrus due to, in part, the available light conditions created by each tillage technique. Then, a decision by a farmer to implement a certain tillage method needs to be based on predictive estimations of the climatic conditions and need a suitable crop rotation program. The results of our study show that crop rotation with legumes is an effective tool to protect against B. diandrus in conservation agriculture, and a period of fallow is a second alternative to legume rotation to prevent infestations of this weed.

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