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Effect of weeding management on the performance of local maize populations

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Abstract

One of the most important stress factors in maize (*Zea mays* L.) fields is weed competition, which reduces the crop yield. Weeds chiefly interfere with maize and establish considerable competition for light, water and nutrients. To avoid these harmful effects, there are different agronomic measures and factors among which, the most relevant are the interactions between crop and weed, weed management practices and type of germplasm. This study attempts to evaluate maize germplasm for tolerance to weed competition in order to achieve competitive ability and suitability for farming. Ten genotypes of maize, classified into two groups, *i.e.* improved populations and traditional cultivars, were grown under four types of weed management practices (mechanical harrowing control, chemical control, combination of harrowing and chemical control and untreated control as check) for three years (from 2009 to 2011) in Zaragoza (Spain). We found that the effect of weed management practices was not significantly different, whereas the genotype effect was highly significant, with genotype EZS34 (mean yield of 7.7 Mg ha^{-1}) showing the highest yield. Other traits, such as earliness, displayed a good behaviour under weed competition. On the other hand, harrowing management proved to be the most effective method of weed control although it did not show a significant response. The best results are associated with some maize genotypes that have a specific adaptation to local conditions, according to their genetic background.

Additional key words: *Zea mays* L; local cultivars; improved populations; weed interferences; weed competition.

Introduction

Maize (*Zea mays* L.) is an important crop in Spain, being planted in year 2012 in an area of 345,000 ha with an annual production of 3.5 million tons, and average of 10.1 Mg ha^{-1} (FAO, 2012). However, there are several stress factors responsible for reducing maize productivity, of which weeds are the most important, causing about 13% of global losses (Oerke *et al*., 1994). The most likely explanation for this phenomenon is competition between maize and weeds. Indeed, there are different practical reasons for removing weeds, but the most important is the competition for water, nutrients and sunlight. Also, weeds induce reductions of the maize root system and leaf area (Silva *et al*., 2009), thus diminishing yield (Tollenaar *et al*., 1997). Effective control of weeds in cereals must rely on both preventive (such as placement of fertilisers and crop rotation) and curative methods (*i.e.* harrowing) in an integrated way (Hansen *et al*., 2008). Moreover, an integrated weed management system must take all aspects of a cropping system into consideration, since they are influenced by multiple abiotic and biotic factors (Tollenaar *et al*., 1994). Crop rotation, tillage, cover crops, soil type, type of crop, the relative humidity, herbicide use and farming practices have been found to be relevant driving factors to explain the abundance of weeds (Derksen *et al*., 1993). Recent studies suggest that human management factors, such as sowing date, type of seeds, crop rotation, etc. are more important than environmental factors (Shrestha *et al*., 2002) or tillage managements (Swanton *et al*., 1999), with crop type being the main determining factor of weed population (Fried *et al*., 2008).

Over the last decades herbicides have simplified weed control and have been extensively used, replacing cultural weed control methods in several regions (Pardo *et al*., 2008). These products are commonly used in the

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Abbreviations used: RRS (reciprocal recurrent selection).

Spanish maize fields because of selectivity, fast action and their low cost in comparison with other methods. However, weed biotypes that are resistant to these products have been selected as a consequence of the intensive use of herbicides (Oliveira *et al*., 2011). Thus, the occurrence of resistant weeds in the Ebro valley maize fields has been significant. In the same context, another important problem is the contamination of rivers and aquifers with very soluble herbicides like atrazine and terbutilazine (Garrido *et al*., 1998). For these reasons, controlling weeds with less dependence on herbicides would be of interest. The use of cultivars that can tolerate or suppress weeds more effectively may be a suitable way to weed control (Christensen, 1994). Varietal differences in weed controlling capacity have been reported for many crops, including maize (Begna *et al*., 2001; Travlos *et al*., 2011) and winter cereals (Christensen, 1995; Dhima *et al*., 2000).

Weed ability to compete cannot be attributed to a single growth trait but to the total effect of several traits, such as quick emergence, high leaf area growth and rapid growth in height. In this sense, further studying on the response to stress of different maize genotypes, such as traditional and improved maize populations is essential, in order to increase the knowledge about different behaviors. The objective of this work was to evaluate the effects of weeds on ten maize genotypes under four weeding management practices (harrowing, herbicide, harrowing combined with herbicide, and untreated check-control).

Materials and methods

Plant materials and treatments

The trials included ten genotypes, grouped into two classes: 1) six local cultivars, 'Amarillo de Aragón', 'Rojo de Aragón', 'Castellote', 'Fino', 'Hembrilla/Queixalet', 'Rastrojero', and 2) four improved populations, EZS9, EZS33, EZS34, and EZS35 (Table 1). The geographical origin of the varieties or the type and criterion of selection in the genotypes are also reported in Table 1.

Four weed control methods were evaluated: (a) chemical control, which implied the application of herbicides; 0.5 L ha^{-1} sulcotrione (Mikado, Bayer CropScience) and 0.5 L ha^{-1} nicosulfuron (Samsom, Syngenta) were manually sprayed; (b) harrowing control, mechanical treatment at about 5 cm of depth; (c) combined chemical and harrowing management control; and (d) check control (weed-free control).

These treatments were carried out every 10 days since the sowing date until 60 days after sowing (period of major competition between weeds and maize), except the untreated control. The different types of weed management practices were allocated to main plots and the genotypes to sub-plots (8.25 m^2) of a split-plot design with three replications, leaving a 1.5 m wide border area under different weed management methods.

Evaluation trials

The genotypes were evaluated for three years (2009, 2010 and 2011) in Zaragoza, located in the region of Aragón, Spain (41° 44' N, 0° 47' W, 243 m asl). Suppl. Table 1 [pdf online] shows additional information about temperatures and rainfall. The soil type was a loamy texture (36% sand, 52% silt and 11% clay) with 2% organic matter and pH 8.4. The trials were irrigated through flooding throughout the growing seasons, and cultural practices and pest control were carried out according to the usual practices followed in the particular area (Suppl. Table 2 [pdf online]).

Table 1. Spanish maize populations, six adapted local cultivars and four improved populations, evaluated in 2009, 2010 and 2011 in Zaragoza (Spain)

Genotype	Reference	Type of germplasm	Grain type	Cycle
Amarillo de Aragón	—	Autochthonous population	Flint	Intermediate
Rojo de Aragón	—	Autochthonous population	Flint	Intermediate
Castellote	Djemel *et al.* (2012)	Autochthonous population	Semi dent	Late
Fino	Sánchez-Monge (1962)	Landrace	Flint	Late
Hembrilla/Queixalet	Sánchez-Monge (1962)	Landrace	Dent	Late
Rastrojero	Sánchez-Monge (1962)	Landrace	Dent	Intermediate
EZS9	Ruiz de Galarreta & Álvarez (2008)	Improved composite	Flint	Intermediate
EZS33	Djemel *et al.* (2012)	Improved composite	Flint	Late
EZS34	Djemel *et al.* (2012)	Improved composite	Dent	Late
EZS35	—	Improved composite	Flint	Late

All trials were machine-planted in mid-April in all three years. Each experimental plot consisted of two rows spaced 0.75 m apart, with 29 plant hills spaced 0.18 m apart, with stand density set at about 71,000 plants ha^{-1}. The entire plots were harvested manually.

The following traits were recorded on each plot: earliness, measured by early vigour (number of leaves at 30 days after sowing); anthesis; plant height; number of leaves; yield (Mg ha^{-1} adjusted at 140 g H_2O kg^{-1}); lodging (as % of plants showing either root or stalk); grain moisture (%); ear height (cm); ear length (mm); number of ear rows; ear weight, and ear health on a visual scale from 1 (= small ears with poor health and presence of damages for corn borers), to 9 (= big ears with excellent health and absence of damages). Data were recorded throughout the entire plot.

In addition, an inventory of the weeds in the untreated control was carried out with the aim of determining the presence of weeds. Subsequently they were classified according to their incidence. Weed samples were scored twice throughout the vegetative period of maize, mainly during the period of major competition between weeds and maize (30 and 45 days after sowing). The sampling consisted in identifying and enumerating the weeds found inside of a rectangle of 0.13 m^2 of area, with three replications per genotype.

Statistical analysis

Analyses of variance assessed the variation between weed management practices (treatments) and genotypes, and the genotypes × management interaction for the recorded traits according to the split-plot design with three replications. Differences between germplasm types, and germplasm type × management interactions, were tested by linear contrast, with the sum of squares and degree of freedom due to genotypes being partitioned orthogonally into the following sources of variation: local cultivars and improved populations. Differences between the treatment means were determined at a significance level of 0.05 (Steel *et al*., 1997). Means were compared by Fisher's protected LSD method using the genetic variation between improved populations and cultivars. Data analyses were conducted using the SAS (2005) software package.

Results

Regarding the inventory of the weeds, the most common species in the untreated control were *Cyperus rotundus* (24.6 plants m^{-2}), *Sorghum halepense* (3.6 plants m^{-2}), *Equisetum arvense* (1.5 plants m^{-2}), *Cynodon dactylon* (0.5 plants m^{-2}), *Xanthium strumarium* (0.5 plants m^{-2}), *Solanum nigrum* (0.2 plants m^{-2}), *Echinochloa crus-galli* (0.1 plants m^{-2}), *Digitaria sanguinalis* (0.1 plants m^{-2}) and *Setaria* spp. (< 0.1 plants m^{-2}).

The genotype source and its partition into local cultivars (1) and improved populations (2) was highly significant ($p < 0.01$) for all traits, indicating that there are differences between these two groups of genotypes for each one of the traits (Table 2). In contrast, weed management practices were only significant ($p < 0.05$) for three traits: earliness, leaves and ear health. The

Table 2. Mean squares for the agronomic traits under four types of weed control

Source[1]	df	Yield	Lodging	Earliness	Flowering	Grain moisture[2]	Plant height	Ear height	Leaves	Ear length	Ear rows	Ear weight	Ear health
G	9	$88 \cdot 10^6$**	1,249**	3.2**	918**	170**	11,175**	7,040**	57**	11,028**	186**	42,447**	0.9**
Cultivars	5	$56 \cdot 10^6$**	656**	3.8**	714**	111**	9,881**	6,532**	43**	14,014**	76**	29,655**	0.8**
Improved populations	3	$111 \cdot 10^6$**	593**	2.2**	1,544**	287**	16,441**	7,878**	99**	6,544**	179**	52,280**	0.5*
M	3	$0.4 \cdot 10^6$	87	2.7**	8	0.4	271	38	1**	26	0.1	165	0.6**
GM	27	$0.6 \cdot 10^6$	30	0.5**	4	2	53	54	0.3	184**	0.4	222	0.1
GE	18	$38 \cdot 10^6$**	571**	3.2**	313**	224**	6,455**	3,475**	18**	3,516**	59**	13,543**	0.7**
ME	6	$24 \cdot 10^6$**	313**	2.7**	65**	415**	7,779**	3,170**	0.7**	100**	2**	982**	1.5**
GME	54	$10 \cdot 10^6$**	173**	1.3**	79**	56**	1,637**	880**	5**	948**	15**	3,499**	0.3**
Error		$1.3 \cdot 10^6$	41.2	0.2	4.6	17.4	333	154	0.4	102	0.6	240	0.2
df error		320	320	320	320	320	320	320	320	320	320	320	320

[1] G, genotype; M, management; GM, genotype × management; GE, genotype × environment; ME, management × environment; GME, genotype × management × environment. [2] At harvest. *, ** Significant at the 0.05 and 0.01 probability level, respectively.

Table 3. Means for the agronomic traits for ten genotypes, six adapted local cultivars (1) and four improved populations (2)

Genotypes	Yield (Mg ha^{-1})	Lodging (%)	Earliness (No.)	Flowering (days)	Grain moisture[1] (%)	Plant height (cm)	Ear height (cm)	Leaves (No.)	Ear length (mm)	Ear rows (No.)	Ear weight (g)	Ear health[2] (1-9)
Amarillo de Aragón (1)	3.27	18.5	6.5	65	14.3	115	49	10.3	132	11.3	92	8.0
Rojo de Aragón (1)	3.63	21.8	7.2	64	15.1	112	51	10.8	134	10.3	89	8.4
Castellote (1)	6.54	13.6	7.0	73	19.2	155	84	12.7	179	10.8	169	8.3
Fino (1)	5.02	20.7	7.2	74	17.8	151	77	12.9	163	11.9	108	8.3
Hembrilla/Queixalet (1)	5.28	22.7	5.7	74	17.1	137	75	12.3	181	13.6	137	8.0
Rastrojero (1)	5.08	12.6	7.7	70	16.3	139	71	12.3	162	9.2	124	8.0
EZS33 (2)	6.79	7.2	5.7	73	20.1	133	65	12.7	185	15.0	165	8.0
EZS34 (2)	7.76	4.8	6.5	77	20.1	141	58	13.2	178	17.2	195	7.8
EZS35 (2)	6.95	12.0	7.2	70	17.4	145	70	12.5	170	12.5	137	8.1
EZS9 (2)	4.03	12.5	6.7	62	13.7	103	39	10.1	149	12.6	105	7.8
LSD ($p < 0.05$)	1.87	10.4	0.8	3	6.7	29	20	1.0	16	1.2	25	0.6

[1] At harvest. [2] Ear health: subjective scale (1-very poor to 9-excellent).

interaction management × genotypes was not significant, except for earliness and ear length. The interactions of environments with genotypes and managements were not relevant in the model due to the huge variability across environments.

Germplasm type comparisons for traits not subjected to the interaction management × genotype were based on data averaged across weed management practices. The improved populations had a significantly higher grain yield (6.38 Mg ha^{-1}) than cultivars (4.80 Mg ha^{-1}), and moreover, were significantly better in others traits like lodging (9.1% *vs.*18.3%), leaf number (12.1 *vs.*11.8), ear length (7% higher in improved populations than cultivars), number of ear row (27% higher in improved populations than cultivars) and ear weight (26% higher in populations than cultivars) (Table 3). However, cultivars were better than improved populations in grain moisture (7% higher in cultivars than improved populations), earliness (5% higher in cultivars than improved populations), plant height (3% higher in cultivars than improved populations) and ear height (15% higher in cultivars than improved populations). With respect to improved material, EZS34 was the best population with the highest mean yield (7.76 Mg ha^{-1}), total lodging (12.5%), flowering, leaves, number of ear row, ear weight and ear health (Table 3). In the group of cultivars, the best response came from ‘Castellote’, an Aragonese (local) variety, with a very high yield (34% higher than the mean of local varieties and 3% higher than the mean of improved populations). Moreover, ‘Castellote’ obtained the highest plant height (16% higher than the mean of local varieties and 19% higher than the mean of improved populations), with moderate-high values in other agronomic traits. In relation to weed management practices, the highest yield values corresponded to harrowing (1.3% higher than the mean of weed controls), and also, high values in other traits like earliness (3% higher than the mean of weed controls) and ear health (1.3% higher than the mean of weed controls), although these values were not significant ($p > 0.05$). On the other hand, the untreated control showed the lowest yield (3% less than the mean of weed controls) and ear health (1.3% less than the mean of weed controls) (Table 4).

Table 4. Means for the agronomic traits with four types of weed controls

Weed management practice	Yield (Mg ha^{-1})	Lodging (%)	Earliness (No.)	Flowering (days)	Grain moisture[1] (%)	Plant height (cm)	Ear height (cm)	Leaves (No.)	Ear length (mm)	Ear rows (No.)	Ear weight (g)	Ear health[2] (1-9)
Harrowing	5.51^{ns}	15.1^{ns}	7.0^{a}	70^{ns}	17.0^{ns}	133^{ns}	64^{ns}	12.1^{a}	163^{ns}	12.5^{ns}	131^{ns}	8.2^{a}
Chemical	5.49	13.5	6.6^{b}	70	17.2	131	64	11.6^{b}	163	12.4	133	8.1^{ab}
Harrowing/Chemical	5.46	15.2	6.6^{b}	70	17.0	132	63	12.1^{a}	161	12.5	129	8.1^{ab}
Control (no treatment)	5.28	14.7	6.9^{ab}	70	17.1	135	65	12.1^{a}	166	12.5	135	8.0^{b}

1 At harvest. [2] Ear health: subjective scale (1-very poor to 9-excellent). Different letters indicate significant differences. *ns*: not significant.

Other important traits showed high variability in their values and also a lack of significance as consequence of the environmental influence.

Discussion

In our study, the most abundant weeds under untreated control were *Cyperus rotundus* and *Sorghum halepense*. High sampling variability was revealed due to large climatological influence and soil conditions. These weed species had already been shortlisted in other studies of Spanish weeds. For instance, Cirujeda *et al*. (2011) only found four weeds species in more than half of the surveyed maize fields, showing that the weeds were adapted to specific conditions in the region of Aragón. In our work these weeds showed an adaptation to local weed management practices, in agreement with these authors. In addition, the types of weeds commonly found in this region significantly resembled maize plants, and hence it is a big challenge to remove them. Therefore, we propose the use of tolerant plants in farm weeding management.

The behaviour of maize populations combined with weed management practices under weed infestation is still unknown. Our model suggests that significant differences are mainly found among genotypes rather than among weed management practices. In particular, there were differences between varieties, especially between cultivars and improved populations. Our results confirmed that improved populations had higher yield than the cultivars under weed conditions. This was expected since the improved populations, such as EZS34 and EZS35, have been subjected to reciprocal recurrent selection (RRS) to improve grain yield. In contrast, the lowest yield was for EZS9, which was obtained through a mass selection, a method less effective than RRS. We suggest that varieties subjected to long improvement cycles should respond better. Local varieties, without improvements, showed low yields, although Castellote, a local variety, had an excellent performance under stress conditions (Romay *et al*., 2010). These results indicated some specific advantages of improved populations over the cultivars in concordance with other authors, suggesting that consecutive cycles of improvement provide a favourable accumulation of desirable genes in yield traits (plant height, number of leaves, ear length, ear rows, ear weight), that may contribute in ability to compete against weeds (Tollenaar *et al*., 1997).

In contrast, the lack of significance in weed management practices showed that these were not able to avoid the harmful effects from weeds. The non-existence of significant differences between weed management practices could reveal that the effect of competition was only relevant some time after the onset of competition (Seaver & Wright, 1995) and consequently, a minimum period of time between crop and weed is necessary for the effects of competition to be shown (Tollenaar *et al*., 1994). We hypothesize that under our trial conditions there was not enough effect of competition between weed and maize for water, light and nutrients (Carruthers *et al*., 1998), and for that reason we observed no differences. Although the statistical tests showed equal yields for all managements, the tendency seemed to decrease in grain yield for untreated control plot, in agreement with Karunatilake *et al*. (2000), and the highest maize yield seemed to be obtained with harrowing and chemical management, as reported by Oliveira *et al*. (2011) in maize via intercropping with gliricidia sown by broadcasting.

In general, the effect of weed management practices was not a determining factor, whereas the effect of genotypes was highly significant. A similar result was obtained by Govaerts *et al*. (2005) in wheat and maize and by Bakhtiar *et al*. (2011) in maize. The absence of significance in the interaction management × genotype was determined to confirm these results, concluding that a good method to control weeds are cycles of maize with outstanding behaviours such as EZS34 population, which showed strong persistence and established a direct competition with weeds by essential elements (water, sunlight, etc.). The interactions of environments with genotypes and managements showed a huge variability as a consequence of climatic parameters, indicating that there is no interaction and therefore, the management had a similar effect over all genotypes. Indeed Sibuga & Bandeen (1980) and Cavero *et al*. (1999) found that the relationship between crop-weed emergences for competition was very dependent on the climatic conditions.

With reference to the most influential traits under weed competition, earliness could be the most important one (Didon, 2002). It is essential to control weeds during the first growth stages of maize, and its competition depends on a higher relative growth rate, which enhances the plant's ability to compete for light (Berkowitz, 1988; Goudriann, 1988). Earliness did not suppose an advantage for competing with weeds as consequence of a short period of competition among maize and weeds, but in years of strong weed competition earliness could be especially advantageous. The variety with the highest earliness was 'Rastrojero', a local cultivar. It is likely that the higher variability and the best adaptation to local conditions gave it more capacity to develop in less time. Likewise, ear health is a trait that mainly depends on insect pest population, which usually takes refuge in weeds. Local cultivars had the best results for this trait. Probably these cultivars contained useful genes that conferred some type of resistance to protect the ear due to the adaptation of cultivars to local conditions that led to the best performance under weed conditions. Moreover, the majority of improvements in maize crop have been focused on yield and not on ear health, thus it is a weak point of improved populations. Besides, good ear conditions are highly correlated to a lower presence of mycotoxins, which could have toxic effects on humans or animals (Cao *et al*., 2013; Santiago *et al*., 2013). The rest of traits have been more satisfactory for the improved populations than for the local cultivars, owing to the yield effect that is pulling other related traits (lodging, plant height, leaf number, ear length, ear weight and ear rows). Regarding number of leaves, it could be said that a significant lower number of leaves was found in the chemical management than in the harrowing management. It would seem that the chemical management affected the growth of the maize plants, causing a decrease of the photosynthetic area. More studies should be made in this sense to avoid herbicide harmful effects on plant development. With respect to ear health, the worst value was obtained in the untreated control, where high density of weed could contribute to raise up pest's damages on the ears.

Other traits such as flowering, lodging, grain moisture, plant height, ear length, number of rows in ear and ear weight, achieved expected values according to background (improved population or local cultivar). No clear response to weed control in reference to light competition between plant structure traits, such as number leaves, plant height and ear height, has been found in barley (Didon, 2002).

In conclusion, the response of the evaluated varieties under weed competition depended mainly on the type of germplasm, such as traditional cultivars or improved populations, and, the type of specific adaptation to the evaluated region, autochthonous populations or foreign populations. We have pointed out that the best results were found in improved populations, where EZS34 had an excellent response in yield, lodging, and ear weight traits. It is likely that the use of improvement cycles in maize, with an accumulation of favourable genes, could help to reduce the weed damages due to strong competition with weeds during the growing. On the other hand, cultivars like 'Rastrojero' (an Aragonese landrace) showed very satisfactory values in earliness and ear health, as a result of their better adaptation to local conditions.

Finally, the most efficient weed management practice may be harrowing, although not clear findings were extracted due to the small effect of competition maize/weed and also due to the climatic factor. Consequently, the period of competence among crop and weed control would be larger to determine harmful effect of weed competition. In the future, more studies should be conducted to determine the effect of weed control over broaden collections of local and improved varieties.

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