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RESEARCH ARTICLE

Remarkable changes of weed species in Spanish cereal fields from 1976 to 2007

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Abstract Management practices, geographical gradients and climatic factors are factors explaining weed species composition and richness in cereal fields from Northern and Central Europe. In the Mediterranean area, the precise factors responsible for weed distribution are less known due to the lack of data and surveys. The existence of weed survey data of year 1976 in the Zaragoza province of the Aragón region, Spain, offered us the opportunity to compare present weed species with weed species growing 30 years ago. No detailed comparison of changes in weed species composition in cereal fields in that period of time has been conducted in the Mediterranean area. Here a survey was conducted in the Aragón region from 2005 to 2007. Weeds were surveyed in 138 winter cereal fields in ten survey areas where winter cereals are the main crops, using the same methodology applied 30 years ago. In the Zaragoza province, 36 fields were chosen in the same municipalities than in the previous survey. Several management, geographic and climatic variables of each field were recorded and related to weed species with multivariate analysis. Diversity index were calculated and related to survey area and altitude. Our results show that out of the 175 species only 26 species were found in more than 10% of the surveyed fields. The main species were *Papaver rhoeas*, *Lolium rigidum*, *Avena sterilis* and *Convolvulus arvensis* found in more than half of the surveyed fields. *L. rigidum* was related to dryland, while the other species were found overall. Furthermore, we found that management, geographical and climatic factors were significantly related to weed species distribution. In particular altitude, survey areas, irrigation and herbicide use in post-emergence were the most driving factors explaining weed species distribution. Species richness was higher in survey areas with extensive management practices and increased with altitude excepting a very productive area with intensive management practices at high altitude where richness was as low as in the irrigated lowlands. The main differences found between the 1976 and the 2005–2007 surveys were (1) the striking increase of grass weeds, (2) the high decrease of mean weed species number found in each field declining from 9 to 3 and (3) the frequency decrease of many weed species probably caused by agriculture intensification in that period of time. The growing importance of other weed species is probably related to their adaptation to minimum tillage, which is a widespread technique nowadays.

Keywords Biodiversity · Canonical correspondence analysis · Rare weeds · Weed diversity

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1 Introduction

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. Management practices, geographical gradients and climatic factors have been found to be the most driving factors to explain weed species composition and richness in Northern Europe (Salonen 1993) and in Central

Europe (Pysek et al. 2005; Lososova et al. 2004; Cimalova and Lososova 2009; Fried et al. 2008). The breadth of the environmental gradients considered is probably an important reason explaining discrepancies of the importance of these factors between studies (Fried et al. 2008). So far, no multivariate analysis of broad-scale gradients as altitude or management practices in cereal fields have been done on weed species composition in Mediterranean areas, but we hypothesize that both factors may be important in the Aragón region due to the broad extent of the altitude gradient and of the diverse management practices found.

Weed species are adapted to crops and to management techniques like soil disturbance by tillage or ploughing. However, intensification in the last decades with chemical fertilization, use of herbicides, sowing high-competitive cereal varieties, using seed-cleaning techniques etc. has reduced species richness (reviewed by Roschewitz et al. 2005). Studies have been conducted to analyse the individual impact of these techniques on weed communities' diversity and fertilization was found to be an important factor affecting weed community composition (Pysek and Leps 1991).

To assess the real scale of these intensification factors, recent surveys have been conducted in many countries to compare weed flora composition with those of previous surveys decades ago. Excepting Andreasen and Stryhn (2008) in Denmark, most of the authors describe an important decline in species number (Albrecht 1995, Germany; Sutcliffe and Kay 2000, United Kingdom; Lososova et al. 2004 and Pysek et al. 2005, Czech Republic and Slovakia). Detailed comparisons in the Mediterranean area are non-existing but Chamorro et al. (2007) in Spain and Speranza et al. (1990) in Italy observed an overall species decline in the last decades based on literature comparisons. We hypothesize that weed species number has also decreased in the most intensive areas of Aragón but may remain high in the extensive areas.

Attention on rare species is paid in many of the published surveys, which besides their intrinsic value, can play a role in agroecosystem functioning. These plants serve as habitat and food for insects, birds and other animals, as well as for soil life. The intense interest shown in some North European countries for rare arable weeds is less in Spain, and the Catalogue of Endangered Species of Flora in Aragón does not include rare weeds (Gobierno de Aragón 2007). As explained by Braun-Blanquet and de Bolós (1957), the semiarid regions of the occidental Mediterranean area are especially rich in weed species and there is a gradual decrease in weed species number towards the north of Europe. Perhaps intensification in agroecosystems has also been lower in Southern Europe than in North European countries so that we hypothesize to find in our survey more rare species than in other North European countries.

The most recent weed survey in cereal fields in the Aragón region was conducted in 1976 describing the flora of the Zaragoza province (Zaragoza and Maillet 1976; Zaragoza-Larios and Maillet 1980). The methodology was very similar to the one used in our study conducted in 2005–2007 allowing the comparison of the weed flora 30 years later in the same surveyed area. This way it was aimed to provide an insight into any changes that may have occurred. Because of lack of data of the rest of Aragón, it is not possible to compare the changes in the other two provinces. However, extending the survey to these regions where a generally more extensive agriculture is common can help determine which factors promote diversity of rare weed species. To our knowledge, this is the first study that establishes a detailed comparison of weed abundance 30 years ago with nowadays in cereal fields located very close to each other in the same municipalities in the Mediterranean region.

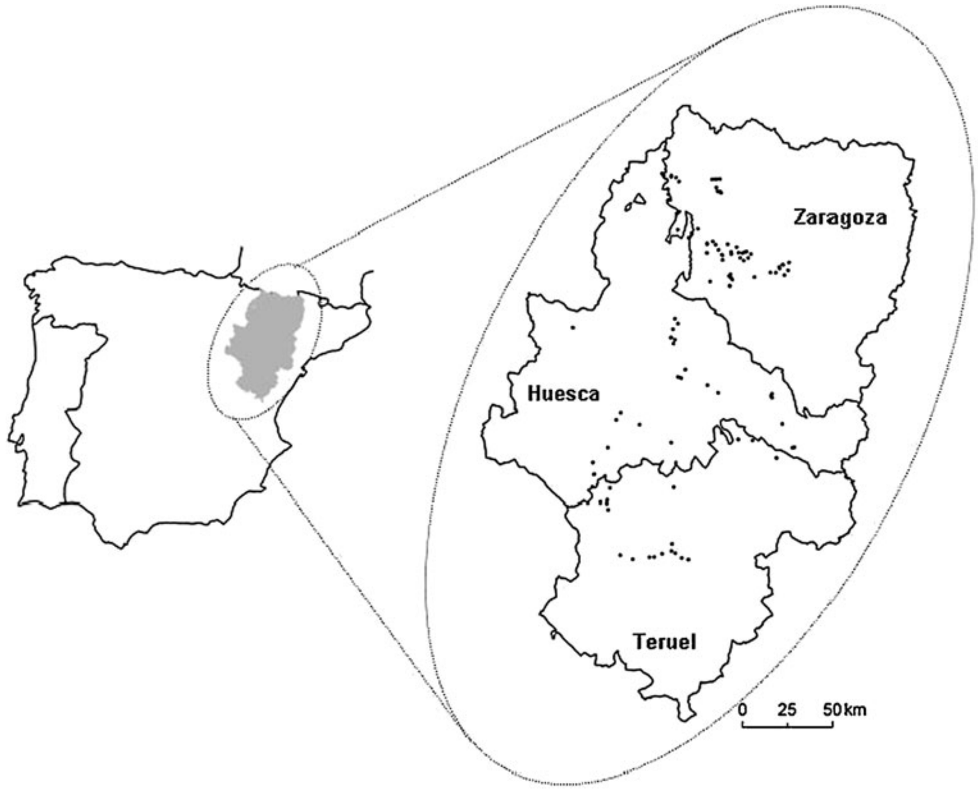
The aims of this study were (a) to describe the weed composition in cereal fields of the Aragón region in Spain and its relationship with climatic, geographic and agronomic management factors; (b) to find out which are the frequent and the rare weed species and (c) to compare weed species frequency in the same municipalities of the Zaragoza province 30 years after the survey conducted in 1976.

2 Material and methods

2.1 Field survey

Aragón is one of the 17 Autonomous Communities of Spain and is located in the north-eastern part of the country. It is comprised of three provinces: Zaragoza, Huesca and Teruel between latitude 42.852° N and 39.848° N and longitude 2.159° W and 0.744° E. The Aragón region has diverse landscapes and winter cereal is grown from 160 m altitude in the Ebro Basin to 1,400 m in the Pyrenees or in the Sistema Ibérico mountains. Agricultural intensification practices such as seed-cleaning techniques, synthetic fertilizers and the development of competitive crops are common throughout, but other techniques such as herbicides and crop rotations differ considerably within these areas. In some highlands of the Teruel and Huesca provinces, agriculture is still quite traditional with low-input management and the soil is left set-aside 1 of 2 years. In contrast, in the irrigated Ebro Basin (Zaragoza province), crop rotations, fertilizers and herbicides are common. To cover the high diversity of landscape and agricultural practices, the survey was organised by choosing different areas where cereal production is important (Fig. 1, Table 1). The number of surveyed winter cereal fields was 62, 21 and 55 in 2005, 2006 and 2007, respectively. In the Zaragoza province, 36

Fig. 1 Location of the surveyed fields in Aragón (Spain)



fields were chosen as close as possible to the 21 fields surveyed in 1976 (Zaragoza and Maillet 1976). Despite the amount of surveyed fields in 1976 is not huge, this information is very valuable and difficult to find even more because the person who gathered the data is still active and participated in the 2005–2007 survey.

The survey was done at the heading stage of cereal development in all cases, which occurred between April and June to avoid possible differences in vegetation caused by visiting the fields at different times. The fields were selected randomly in areas with important cereal production avoiding mixed crop areas where cereals are marginal crops following secondary roads and vegetation was described in zigzag transects by three trained persons including the field margin during at least 30 min until no more new species were found, which is a similar methodology as described by Poggio et al. (2004). Approximately 2 ha were surveyed if the whole field could not be covered in that period. One estimation of the observations was given globally and species appearing only in the margins were excluded. This method was preferred to counting weeds in frames, which is very inconvenient at heading stage of the crop, because

Table 1 Some characteristics of the surveyed areas in the Aragón region of Spain

Survey area	Number of samples	Irrigated fields	Set-aside is normal	Use of herbicides and fertilizers every year	Altitude	Mean altitude of the surveyed fields
1. Hoya Huesca I	15	10	No	Yes	377–627	502
2. Ayerbe area	13	0	No	Yes	488–847	667.5
3. Hoya Huesca II	14	0	No	Yes	484–740	612
4. Jacetania	20	1	No	Yes	609–1,068	838.5
5. Gállego valley	12	12	No	Yes	238–284	261
6. Ebro valley	12	9	No	Yes	166–340	253
7. Bajo Aragón and south Zaragoza	14	5	Yes	No	157–531	344
8. Bajo Teruel	11	1	Yes	No	800–1,047	924
9. Somontano and Graus	14	0	No	Yes	350–593	472
10. Cuencas Mineras and Teruel	14	0	Yes	No	790–1,390	1,090

more species are found this way and because weeds occurring in patches as described by Izquierdo et al. (2009) are taken into account more realistically with an overall assessment. Flora Europaea (Tutin et al. 1964–1980) was used for weed species identification. The abundance of all species found was recorded according to the visual CEB scale which relates plant density with weed soil cover, allowing a better estimation in the lower abundance categories. The CEB scale ranges from 1 to 10, which corresponds to categories of soil cover percentages of <1% (rare plants), 1–7% (<1 plant m^{-2}), 7–15% (> 1 plant m^{-2}), 15–30%, 30–50%, 50–70%, 70–85%, 85–93% and 93–100%.

Additional data was recorded during the survey: coordinates and altitude of the field, crop type, visual percentage of crop cover, data on possibility of irrigation of the field and data on evident use of herbicides in late post-emergence. Other parameters for each field were found in laboratory: field size (using the Sigpac database, http://sigpac.mapa.es/fega/visor/) and the official climatic variables used by the regional Agency of the Aragón Environmental Government (http://portal.aragon.es/portal/page/portal/MEDIOAMBIENTE/cclimatico/Atlas); climatic division of Aragón for each field following the criteria of Köppen (mean annual and monthly values of temperature and rainfall); the aridity index following the classification system of the United Nations Environmental Programme and the annual hidric balance. The phytoclimatic environment, which is the dominant vegetation community in the area, was given for each field following Villar and Sesé (2000). Table 2 summarizes the recorded explanatory variables.

2.2 Data analysis

The Gini–Simpson's diversity index $(1 - D)$ was calculated for each field following $(1-D)' = 1 - \sum (p_i)^2$ where $p_i = \frac{n_i}{N_i}$. Shannon's eveness index was calculated following $E = H'(\ln N)^{-1}$ (Magurran 1988).

Canoco 4.5 for Windows (ter Braak and Smilauer 2002) was used for direct gradient analysis. Weed data set was subjected first to a Detrended Correspondence Analysis from the CANOCO 4.5 package (ter Braak and Smilauer 2002). The length of the gradient bigger than three lead us to reduce the noise of the data set. For this purpose, the seven crop species occurring as weeds (wheat, barley, oats, rye, peas, alfalfa, sunflower) were excluded from the analysis as suggested by Hallgren et al. (1999). Rare species were downweighted with the same aim. In a first canonical correspondence analysis (CCA), nominal variables were coded as series of zero/one dummy variables and scaling was focused on inter-species distance with a biplot scaling. Year was found significant but did not contribute in a practical interpretation of results because different areas were surveyed in different years. Taking into account that the rest of explanatory variables explained significantly weed species composition, this variable was excluded from further analysis following Hallgren et al. (1999).

Gross and net effects of individual explanatory variables on weed species composition were tested using the Monte Carlo permutation tests with 999 permutations in CCA (ter Braak and Smilauer 2002), following the methodology of Lososova et al. (2004). The gross effect of an explanatory variable was tested using separate CCAs with a single explanatory variable. The net effect was tested using partial CCAs, each with a single explanatory variable and using the other variables as covariables. Net effects express the effect of a single variable after partialling out the effects shared with the other explanatory variables. We used the ratio of a particular canonical eigenvalue over the sum of all eigenvalues (total inertia) as a measure of the proportion of variation explained by each factor, respectively (Lososova et al. 2004; Fried et al. 2008).

To satisfy normality and variance homogeneity, the number of weed species and the total abundance needed $\sqrt(x)$ transformation and the diversity and eveness indexes $(x)^2$ transformation, following the indications of the Box–Cox Transformation (Bowley 1999). Data were submitted to a standard ANOVA using the SAS/STAT procedures PROC GLM (SAS version 8; SAS Institute 1991). Statistical significance between means was tested on the basis of the Student–Neumann–Keuls test at $P<0.05$. Altitude was divided in five groups with a similar number of samples in each group to allow conducting an ANOVA. Mean abundance as a measure of weediness was calculated by taking the median soil cover of each CEB scale value: 0.2%, 4%, 11%, 22.5%, 40%, 60%, 77.5%, 89% and 96.5% for the values 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively.

2.3 Comparison with the 1976 survey

In 2005–2007, 36 surveyed fields in the Zaragoza province were chosen in the same municipalities and as closed as possible to the fields sampled in 1976. The fields account for the survey areas 5, 6 and partly for areas 7 and 8. A similar methodology was used in both surveys, and the fields were also visited in the same period of the year.

3 Results and discussion

3.1 General results of the survey

We found 175 different weed species and seven volunteer crops in 138 fields, and 131 genera belonging to 26 families, which is a similar number of species compared

Table 2 Recorded explanatory variables

Variable	Method used	Range
Management variables		
Crop cover	FO	40–100%
Crop type	FO	Wheat, durum wheat, barley, oat, rye
Irrigation	FO	Irrigation, no irrigation
Herbicide use in late post-emergence	FO	Herbicide, no herbicide
Field size	AP	0.3–2 ha
Geographic variables		
Survey area	AP	Area 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Altitude	FO	157–1,390 m
Phytoclimatic environments	ADD[b]	*Quercus faginea*, *Quercus ilex*, *Quercus coccinea*, *Lygeum spartium*
Climatic variables		
Year	FO	2005, 2006, 2007
Annual hidric balance	ADD[a]	Less than −800 mm; −800 to −700 mm; −700 to −500 mm; −500 to −400 mm; −400 to −200 mm
Climatic division of Aragón	ADD[a]	Dry steppe, continental Mediterranean, transition mediterranean–oceanic, warm submediterranean continental, cold submediterranean continental
Aridity index (UNEP)	ADD[a]	Subhumid–moist (index 0.70–1), subhumid–dry (index 0.50–0.70), semiarid (index <0.30–0.50)

UNEP United Nations Environmental Programme, *FO* field observation, *AP* aerial photograph, *ADD* analysis of digital databas

[a] http://portal.aragob.es

[b] Villar and Sesé (2000)

to other surveys done in the Mediterranean area on a comparable number of cereal fields: Portugal, 278 species in 155 fields (Sá et al. 1992); Greece, 103 species in 86 fields (Damanakis 1983) and Morocco, 315 species in 218 fields (Taleb and Maillet 1994a). As expected from a phytosociological point of view (Braun-Blanquet and de Bolós 1957), these figures are higher than found in Northern Europe visiting a similar number of fields: South Central England, 46 species found in 100 fields (Sutcliffe and Kay 2000) and Denmark, 126 species in 165 fields (Salonen et al. 2001). Even studying many more fields, far fewer species were found in surveys done in Northern Europe: England, 87 species in 1,021 fields (Chancellor and Froud-Williams 1984) and Finland, 160 species in 690 fields (Salonen et al. 2001).

Only 26 species were found in more than 10% of the fields, and these were considered frequent weeds. Only four species (*Papaver rhoeas*, *Lolium rigidum*, *Avena sterilis* and *Convolvulus arvensis*) were found in more than half of the surveyed fields (Table 3). *P. rhoeas*, *L. rigidum* and *A. sterilis* were the most frequent and also the most abundant weed species (Table 3). Considering these parameters, *L. rigidum* was the most abundant weed but was concentrated in dryland areas found in 71% of the rainfed fields and only in 26% of the irrigated fields. Thus, *P. rhoeas* and *A. sterilis* likely can be considered the worst weeds of cereals in Aragón as they can be difficult to control and moreover may exhibit herbicide resistance (Centro de Protección Vegetal 2005). The next species of importance were *C. arvensis*, *Fumaria* spp. and *Polygonum aviculare*, which are less competitive due to their later emergence at the end of winter or early spring.

3.2 Relationship between weed species composition and environmental factors

The influence of the environmental variables on weed species composition overall was detected using CCA including only significant environmental variables one by one, from most significant to less significant, following the Monte Carlo permutation test. These significant variables were altitude, aridity index, irrigation, survey areas, herbicide use, annual hidric balance and crop type (Fig. 2). The first axis explained 16.2% of the variation and was mostly correlated with survey areas, altitude and irrigation. The second axis explained 11.3% of the total variation and was also mostly correlated with survey areas, altitude and with the crop type. Thus, altitude and survey areas were related to both axis. This fact and the relatively high eigenvalues of the third and fourth ordination axes

Table 3 Species with frequency higher than 10% and mean abundance values following the CEB scale

Species	Abbreviation	Frequency (%)	Mean abundance when present (% soil cover)	Mean total abundance (% soil cover)
Papaver rhoeas	PAPRH	69 (1)	3.1 (6)	2.2 (2)
Lolium rigidum	LOLRI	59 (2)	6.5 (2)	3.8 (1)
Avena sterilis	AVEST	55 (3)	3.7 (4)	2.0 (3)
Convolvulus arvensis	CONAR	53 (4)	0.8 (12)	0.4 (8)
Fumaria spp.	FUMSS	34 (5)	1.2 (10)	0.2 (10)
Polygonum aviculare	POLAV	32 (6)	0.8 (12)	0.3 (9)
Galium spp.	GALSS	31 (7)	1.6 (9)	0.2 (10)
Cirsium arvense	CIRAR	28 (8)	0.5 (14)	0.1 (11)
Chondrilla juncea	CHOJU	22 (9)	2.4 (7)	0.5 (7)
Buglossoides arvense	LITAR	22 (9)	0.2 (17)	0.04 (13)
Rumex spp.	RUMSS	21 (10)	1.2 (10)	0.1 (11)
Lactuca serriola	LACSE	21 (10)	0.6 (13)	0.1 (11)
Euphorbia serrata	EPHSR	20 (11)	0.8 (12)	0.1 (11)
Vicia sp.	VICSS	20 (11)	0.2 (17)	1.0 (6)
Fallopia convolvulus	POLCO	20 (11)	0.3 (16)	1.6 (4)
Anacyclus clavatus	ANYCL	20 (11)	2.0 (8)	0.4 (8)
Medicago sativa	MEDSA	18 (12)	1.1 (11)	0.2 (10)
Hypecoum procumbens	HCYPR	17 (13)	7.6 (1)	1.3 (5)
Rapistrum rugosum	RASRU	17 (13)	0.2 (17)	0.03 (14)
Bromus spp.	BROSS	17 (13)	0.4 (15)	0.1 (11)
Diplotaxis erucoides	DIPER	14 (14)	0.8 (12)	0.1 (11)
Avena fatua	AVEFA	14 (14)	3.1 (6)	0.4 (8)
Descurania sofia	DESSO	12 (15)	3.8 (3)	0.4 (8)
Herniaria hirsuta	HEQHI	12 (15)	0.4 (15)	0.1 (11)
Capsella bursa-pastoris	CAPBP	12 (15)	3.2 (5)	0.4 (8)
Malva sylvestris	MALSI	11 (16)	0.5 (14)	0.05 (12)

In parentheses, rank of the species

(10.1% and 8.2% respectively) indicated the complex nature of weed communities, which was difficult to explain with the chosen environmental variables as also observed by Salonen (1993).

Most of the species with highest fit to the two axes were indeed strongly related to high altitude (Fig. 2): *Cerastium perfoliatum* L., *Delphinium consolida* L., *Neslia paniculata* (L.) Desv., *Papaver argemone* L., *Androsace maxima* L., *Silene conoidea* L. and *Vaccaria pyramidata* Medik.. These are rare species found mainly in the highlands of Teruel in survey areas 10 and 8 at extensive management systems without irrigation. In this way, altitude was thus related to survey areas.

The importance of irrigation in our analysis is not surprising because weeds growing in irrigated areas and those growing in rainfed conditions form part from different orders in the phytosociological classification (Rivas-Martínez et al. 2002). Also Zaragoza-Larios and Maillet (1980) found irrigation to be the main factor explaining weed species distribution and to a lower extent soil type and altitude. Species mostly related to irrigation, following the weighted averages, were *Xanthium strumarium* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Picris echioides* L. and *Poa annua* L.. These weeds are typical in lucerne and maize crops and appear in irrigated cereal fields when farmers rotate with these crops. In the CCA, these species were also near to the centroids of the moist aridity index (of regions without irrigation) and to the most positive hidric balance −200 to −400 mm (again of regions without irrigation), which shows the relationship between these indexes (Fig. 2).

Species especially related to non-irrigated fields were *Glaucium corniculatum* (L.) J.H. Rudolph, *Malcolmia africana* (L.) W.T. Aiton, *Silybum marianum* (L.) Gaertn., *Euphorbia serrata* L., *Reseda phyteuma* L. and *Herniaria hirsuta* L. The troublesome species, *P. rhoeas* and *A. sterilis* were independent of irrigation (Fig. 2) whereas *L. rigidum* was more related to non-irrigated fields. This weed was

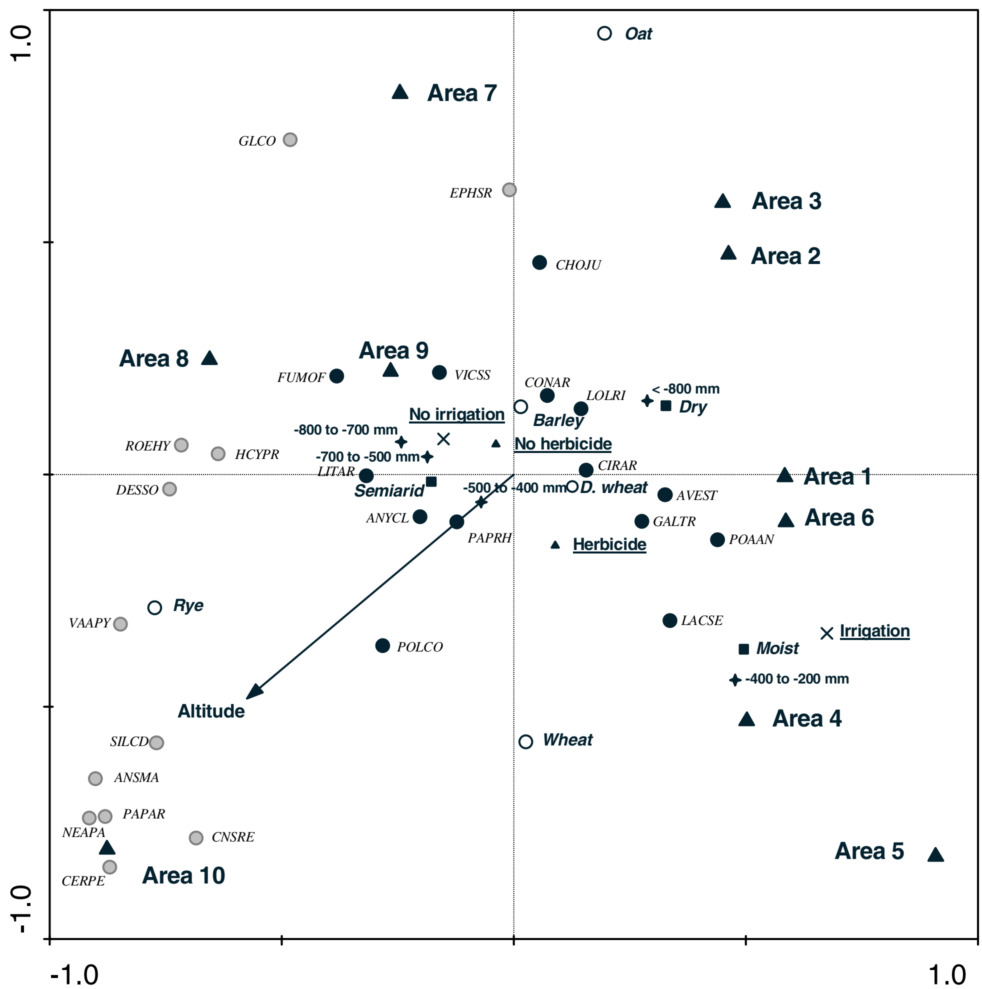


Fig. 2 Canonical correspondence analysis (CCA) ordination of the 15 most frequent weed species (*black circles*) and of the 12 species with highest fit (*grey circles*). HCYPR and EPHSR are included in both categories. Variables were added stepwise with a Monte Carlo permutation test, and only significant variables were taken into account. The first two axes explain 27.5% of the species–environment relations. The codes of the environmental variables are explained in Table 2. *ANSMA Androsace maxima* L., *ANYCL Anacyclus clavatus*, *AVEST Avena sterilis*, *CERPE Cerastium perfoliatum* L., *CHOJU Chondrilla juncea*, *CIRAR Cirsium arvense*, *CONAR Convolvulus arvensis*, *CNSRE Delphinium consolida* L., *DESSO Descurainia sofia*, *EPHSR Euphorbia serrata*, *FUMOF Fumaria officinalis*, *GALTR Galium tricornutum*, *GUCCO Glaucium corniculatum* (L.) Rudolph/Curt., *HCYPR Hypecoum procumbens*, *LACSE Lactuca serriola*, *LITAR Buglossoides arvensis*, *LOLRI Lolium rigidum*, *MALSI Malva sylvestris*, *NEAPA Neslia paniculata* (L.) Desv., *PAPAR Papaver argemone* L., *PAPRH Papaver rhoeas*, *POAAN Poa annua* L., *POLCO Fallopia convolvulus*, *ROEHY Roemeria hybrida* (L.) DC., *SILCD Silene conoidea* L., *VAPY Vaccaria pyramidata* Medik., *VICSS Vicia* spp.

found in 71% of the rainfed fields and only in 26% of the irrigated fields. All three species were quite independent of other environmental variables, located near to the origin of the ordination diagram, thus found in all the areas and crops similarly (Fig. 2). Taleb and Maillet (1994b) also found *P. rhoeas*, *C. arvensis* and *Fumaria parviflora* to be indifferent to the analysed edaphic and climatic parameters, demonstrating a high adaptation capacity. In the Mediterranean region, *P. rhoeas* is known to grow both in low intensification areas (Taleb and Maillet 1994b) and also in areas with herbicide use (Tanji 2000).

Following the weighted averages species mostly related to herbicide use in last post-emergence, which is normally used for broad-leaved weed control, were several non-frequent grass weeds and late emerging broad-leaved species as *Heliotropium europaeum* L. and *P. echioides* L., which probably emerged after treatment.

All environmental variables had a significant gross effect on species composition and most of the variation was explained by survey area (Table 4). Together, these variables explained 48% of the total variation. However, according to permutation tests, the net effects of only survey areas, irrigation, herbicide use and altitude were significantly linked to species composition (Table 4). The other environmental variables were not significant, showing an important correlation with the other variables.

Table 4 Percentage variation in species data attributed to the effects of explanatory variables calculated by partial Canonical Correspondence Analysis (CCA) for net effects and CCA with a single variable for gross effects

Factors	Gross effects		Net effects	
	%	*P*	%	*P*
Survey area	14.58	**	7.28	**
Climatic division	7.40	**	3.05	ns
Rainfall	5.76	**	3.01	ns
Phytoclimatic environment	4.41	**	2.06	ns
Crop	3.77	**	2.70	ns
Aridity index	3.29	**	1.47	ns
Altitude	2.97	**	0.98	*
Irrigation	2.48	**	1.33	**
Crop cover	1.07	*	0.71	ns
Herbicides	0.96	*	0.91	**
Field size	0.94	*	0.73	ns

The amount of variation explained by the net effects of particular variables, as detected by partial CCAs (Table 4) was also highest for *survey areas*. In our case, this variable includes the effect of geographic, climatic and factors related to management practices (Table 4) explaining the lack of significance of the net effect of several environmental factors of all three kinds. However, the remaining significant variables considering their net effect are both climatic and related to management and had a similar influence on weed species composition being correlated within each other, as also found by Pysek et al. (2005).

There are certain discrepancies between the importances of climatic, geographic and management factors on weed species composition in studies conducted in other parts of Europe. While Pysek et al. (2005), Fried et al. (2008) and Cimalova and Lososova (2009) found certain management practices to be more relevant than the climatic influence when the study area was relatively homogeneous, Lososova et al. (2004) observed a pronounced influence of climate in a more heterogeneous area. The range of the analysed variables explains these differences. In our case, the broad altitude gradient (157–1,390 m) is similar to the one of the survey area of Lososova et al. (2004; 97–1,100 m) and altitude had an important influence in weed species composition also in our study.

On the other hand, also the range of possibilities in the management practices in our study was very wide so that irrigation and herbicide use were also significant in our analysis. Thus, the pattern of weed species distribution in the Aragón region is complex and driven by a number of mutually correlated and interacting climatic, geographic and management factors as also found by Pysek et al. (2005) in Central Europe.

3.3 Species richness and diversity

Weed species richness, weediness and Gini–Simpson's (1 − *D*) diversity index were highest for survey area 10, where extensive agronomic practices are common located in the highlands of the Teruel province (Table 5). In the irrigated areas 5 and 6, richness, weediness and Gini–Simpson's (1 − *D*) diversity index were the lowest. Crop rotation and intensive herbicide use are probably responsible for this situation. Dominating weed species in those areas were the cosmopolitans *P. rhoeas*, *A. sterilis* and, to a lower extent, *L. rigidum*. However, Shannon's *E′* eveness index was not significantly different for any of the tested areas. Generally, species richness, weediness and Gini–Simpson's (1 − *D*) diversity index increased with altitude as found in Central Europe and France (Lososova et al. 2004, Pysek et al. 2005, Fried et al. 2008). In the case of the Aragón region, human activity and intensification degree decreases with altitude, which probably explains species richness increase with altitude (Table 5). However, there was an interruption of this gradient at the 631–870 m stripe, which includes mainly fields form survey areas 3 and 4, most of them located in a wide valley in the pre-Pyrenees where yield is high despite of the altitude. Management practices are intensive and, as a consequence, species richness, weediness and diversity were low and similar to the values of the lowland areas.

Generally, highest weediness was found in the most extensive area of Teruel (area 10) but also highest diversity (Table 5). It needs to be highlighted that the most serious weed control problem occurring in that area could be due to *Descurainia sophia* or *Hypecoum procumbens* which can appear at high density but which are not dangerous weeds and easily controlled with herbicides. No herbicide resistance is known in that area (Heap 2010) and high infestations of the high-competitive weeds *A. sterilis* L. or *L. rigidum* Gaud. are very rare. Indeed, in area 10, *L. rigidum* was found in 69% of the surveyed fields but at low mean abundance (0.6% cover) compared to 33% and 17% occurrence in areas 5 and 6 with a higher mean abundance (6.7% and 2.1% cover, respectively).

3.4 Rare weed species

One hundred forty-nine species, accounting for 85.3% of the total weed species were found at less than 10% of the fields demonstrating that many weed species should be considered as rare species in the Aragón cereal fields. Forty-five of them are characteristic species of the class *Stellarietea mediae* Tüxen, Lohmeyer & Preisling ex von Rochow (1951) and of their orders and alliances (Rivas-Martínez et al. 2002).

A complete list of all species found is available as supplementary information. Romero et al. (2008) compared

Table 5 Richness (number of species per field), weediness (total abundance), diversity (Gini-Simpson's diversity index $(1 - D)$) and eveness (Shannon's E index) of each area. Different letters within each parameter refer to statistical differences following Student–Neumann–Keuls test at $P<0.05$. Number of species and total abundance was $\sqrt{(x)}$ transformed, eveness was $(x)^2$ transformed. Values in parentheses indicate the transformed means corresponding to each of the back-transformed values

[a]Details on the survey areas are explained in Table 1

Survey area[a]	Richness	Weediness	Diversity	Eveness
1	2.84 (8.1)b	3.28 (10.8)bc	0.64b	0.66 (0.81)a
2	3.02 (9.1)b	3.27 (10.7)bc	0.73ab	0.85 (0.92)a
3	2.91 (8.5)b	3.06 (9.4)bc	0.69ab	0.73 (0.85)a
4	2.99 (8.9)b	3.25 (10.6)bc	0.69ab	0.82 (0.91)a
5	2.77 (7.7)b	2.96 (8.7)c	0.71ab	0.85 (0.92)a
6	2.83 (8.0)b	3.12 (9.7)bc	0.68b	0.79 (0.89)a
7	3.44 (11.8)b	4.04 (16.3)b	0.79ab	0.73 (0.85)a
8	3.71 (13.8)b	4.20 (17.6)b	0.79ab	0.77 (0.88)a
9	3.70 (13.7)b	4.05 (16.4)b	0.82ab	0.85 (0.92)a
10	4.66 (21.7)a	5.14 (26.4)a	0.87a	0.83 (0.91)a
Altitude				
157–283 m	2.87 (8.2)b	3.26 (10.6)b	0.69b	0.77 (0.87)a
284–488 m	3.17 (10.0)b	3.55 (12.6)b	0.71ab	0.76 (0.87)a
489–630 m	3.47 (12.0)ab	3.80 (14.4)ab	0.78ab	0.83 (0.91)a
631–870 m	2.91 (8.5)b	3.26 (10.6)b	0.67b	0.78 (0.88)a
871–1,390 m	3.91 (15.3)a	4.33 (18.7)a	0.81a	0.80 (0.90)a

species occurring in conventional and in organically managed farms in the nearby region of Catalonia, thus comparing a package of agronomic management practices. They found *H. procumbens* and *Roemeria hybrida* (L.) DC. Only in organic farms and *Papaver hybridum* L. and *Scandix pecten-veneris* L. more frequently in organic fields. In our case, *H. procumbens* and *R. hybrida* were mainly found in the low input dryland areas 7, 8 or 10 (78% and 92% of the scores, respectively). *P. hybridum* was also more frequent in these areas (50% of the scores) but *S. pecten-veneris* (a very rare species found in only 3% of the surveyed fields) was found in dryland but in quite intensive areas. The similarity in these results suggests that the extensive management practices adopted by organic farmers may have a similar influence on weed composition than the extensive practices of the farmers in Teruel.

3.5 Comparison with the 1976 survey on fields in the same municipalities of Zaragoza

Due to the small available sampling size (21 fields in 1976), only the most striking results can be discussed. The biggest change observed between the two surveys was the importance of grass weeds at present, especially *L. rigidum* and *Avena* spp. In 1976, these species were found at such a low frequency and abundance that the authors considered that their increase could still be avoided (Zaragoza and Maillet 1976). The shift from broad-leaved to grass weeds has been observed overall in Spain since the adoption of auxin-like herbicides so that these grass weed species were considered main weeds in most of the cereal areas of Spain already in 1984 (García-Baudin 1984).

Another important aspect is that weed species number in the fields decreased in these years from a mean of nine species in 1976 to only three species in 2005–2007. As a consequence, most weed species were found less times: 22 species were found in more than one third of the fields while in 2005–2007 only four species exceeded this figure, i.e. *C. arvensis* (58%), *P. rhoeas* (53%), *A. sterilis* (39%) and *P. aviculare* (39%). As an exception, *C. arvensis* frequency increased in these 30 years from 33% to 58%, probably due to the minimum tillage practices, which are widespread nowadays. Probably intensive management practices in the Zaragoza area are responsible for the disappearance of most of these species. High susceptibility to herbicides and a negative response to increased nitrogen rates as documented for *P. hybridum* and *P. argemone* by Wilson et al. (1990) are some of the most probable causes for frequency decrease. Similar decreases were reported in England comparing weed flora in the 1960s with year 1997 (Sutcliffe and Kay 2000).

Despite studying a greater survey area and visiting more fields than in 1976, eight species were not found in 2005–2007 in Aragón overall. Two of them were not frequent in 1976 either (present in only 5% of the fields: *Datura* sp. and *Festuca pratensis* Huds.) but *Allium* spp., *Ammi majus* L., *Lotus corniculatus* L., *Plantago coronopus* L., *Spergula arvensis* L. and *Urtica urens* L. were found in 10% or more of the fields. 21 more species were not found in the Zaragoza province any more but in the more extensive areas of Teruel, considered a reservoir of rare weed species, or in Huesca (Table 6). Weed species, whose frequency has declined most reaching values below 10% in the province of Zaragoza in 2005–2007 are *Daucus carota* L., *S. pecten-*

Table 6 Frequency (%) of weed species found in the 1976 survey (Zaragoza and Maillet 1976) but not in the 2005–2007 survey and vice-versa; next, species that show an important decline reaching a frequency lower than 10% were considered rare species and last, species that were rare in 1976 and have increased in frequency in 2005–2007

Species	1976 Zaragoza province	2005–2007 Zaragoza province	2005–2007 Whole Aragón
Agropyron repens	5	0	1
Anthemis arvensis	5	0	1
Centaurea cyanus	5	0	1
Thlaspi arvense	5	0	1
Biscutella auriculata	5	0	5
Cerastium glomeratum	5	0	6
Matricaria chamomila	5	0	9
Setaria spp.	10	0	1
Taraxacum officinalis	10	0	1
Linaria spp.	10	0	1
Conringia orientalis	10	0	2
Neslia paniculata	10	0	4
Androsace maxima	10	0	6
Trifolium spp.	14	0	2
Chenopodium vulvaria	14	0	2
Galium tricornutum	14	0	15
Papaver argemone	24	0	6
Ranunculus arvensis	29	0	6
Scandix pecten-veneris	33	0	3
Veronica agrestis	33	0	5
Daucus carota	38	0	4
Erucastrum nasturtiifolium	0	3	7
Heliotropium europaeum	0	3	1
Onopordum nervosum	0	3	5
Phalaris minor	0	3	1
Silybum marianum	0	3	7
Alyssum alyssoides	0	6	10
Atriplex patula	0	6	1
Calystegia sepium	0	6	1
Equisetum arvense	0	6	4
Eruca vesicaria	0	6	5
Filago spp.	0	6	9
Glyzhirriza glabra	0	6	1
Herniaria hirsuta	0	6	12
Cichorium intybus	0	8	4
Malva sylvestris	0	8	11
Senecio vulgaris	0	8	8
Hordeum murinum	0	11	5
Kochia scoparia	0	11	4
Xanthium strumarium	0	11	3
Sorghum halepense	0	14	4
Cirsium spp.	0	14	9
Phragmites australis	0	25	7
Chondrilla juncea	0	28	3
Lepidium draba	48	6	48
Galium aparine	43	3	6
Veronica hederifolia	38	6	10

Table 6 (continued)

Species	1976 Zaragoza province	2005–2007 Zaragoza province	2005–2007 Whole Aragón
Capsella bursa-pastoris	33	6	12
Papaver hybridum	33	3	9
Roemeria hybrida	29	8	9
Polygonum convolvulus	24	3	20
Rumex spp.	10	31	21
Lactuca serriola	10	28	21
Euphorbia serrata	10	25	20
Silene inflata	5	14	9

Sampled fields: 21 in 1976, 36 in the Zaragoza province in 2005–2007 and 138 in whole Aragón in 2005–2007

veneris L., *Veronica agrestis* L. (Table 6), *P. hybridum* (from 33% to 2%), *R. hybrida* (from 29% to 9%) and *H. procumbens* (from 38% to 11%). However, these species were still found in some areas of Teruel.

On the other hand, 22 species were found in 2005–2007 but not in 1976. Most of them were rare in 2005–2007 but *Chondrilla juncea* L., *P. australis* (Cav.)Trin., *Sorghum halepense* (L.) Pers. *X. strumarium* L., *Kochia scoparia* (L.) Schrad. and *Hordeum murinum* L. were surprisingly frequent species in 2005–2007. Several of these species are related to minimum tillage and direct drilling, techniques which are much more frequent nowadays and non-existing before 1980 in Aragón (Sopena 2007): *Alyssum alyssoides* (L.) L., *C. juncea* L. (Mas and Verdú 2003), *Cichorium intybus* L., *Cirsium* spp., *Filago* spp., *Glycyrrhiza glabra* L., *H. hirsuta* L., *H. murinum* L., *K. scoparia* (L.) A.J. Scott, *Onopordum nervosum* Boiss. and *S. marianum* (L.) Gaertn. Other species are tolerant to the commonly used herbicide glyphosate in pre-sowing, which was not used in 1976, and who require the addition of special surfactants or other compounds for their control (Monsanto 2010): *Equisetum arvense* L. and *Malva sylvestris* L. Another group of species found in 2005–2007 and not in 1976 need high temperatures to germinate and their earlier presence in cereal fields could be due to global warming: *Calystegia sepium* (L.) R. Br., *H. europaeum* L., *Phalaris minor* Retz., *S. halepense* (L.) Pers. and *X. strumarium* L. The presence of the Brassicaceae *Eruca vesicaria* (L.) Cav. and *Erucastrum nasturtiifolium* (Poir.) O. E. Schulz is difficult to explain, as well as the presence of *Atriplex prostrata* Bouchér ex DC., *Rumex pulcher* L., *Senecio vulgaris* L. and *P. australis.*

The most striking results are in agreement with the expected changes in time (Zaragoza, personal communication). Despite that only a relatively small area could be used for comparison (21 fields in 1976), probably the huge intensification of agriculture in that period of time and the fact that very near fields were surveyed both times with the same survey technique allowed to reflect the main changes occurred between 1976 and 2005–2007.

4 Conclusions

Only four species are found in more than half of the surveyed cereal fields of the Aragón region showing that there is still a big diversity in weed flora in Aragón. Thus, weed management problems are locally different and need specific advice to be solved.

Changes in agriculture between 1976 and 2005–2007 have had an influence in weed species frequency and abundance. The mean species number in each field has declined drastically showing that current management practices, globally, have a negative influence on weed biodiversity. On the other hand, the increase of other weed species adapted to the current minimum tillage techniques demonstrate the plasticity of plant species and their continuous adaptation to management practices. Higher diversity was found in areas with extensive management practices showing that regulations favouring the adoption of these practices could contribute increasing the presence of characteristic weed species which have declined in more intensive areas.

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Appendix

Table 7

Table 7 List of weed species found in the survey conducted between 2005 and 2007

	Species
1	*Adonis aestivalis*
2	*Agropyron repens*
3	*Agrostemma githago*
4	*Alopecurus myosuroides*
5	*Alyssum alyssoides*

Table 7 (continued)

	Species
6	*Alyssum* sp.
7	*Amaranthus blitoides*
8	*Anacyclus clavatus*
9	*Anagallis arvense*
10	*Anchusa azurea*
11	*Androsace maxima*
12	*Anthemis arvensis*
13	*Arrhenatherum bulbosum*
14	*Atriplex patula*
15	*Atriplex prostrata*
16	*Avena fatua*
17	*Avena sterilis*
18	*Beta vulgaris* var. *napus*
19	*Biscutella auriculata*
20	*Brassica napus*
21	*Bromus madritensis*
22	*Bromus rigidus*
23	*Bromus sterilis*
24	*Bromus tectorum*
25	*Bromus* sp.
26	*Buglossoides arvensis*
27	*Calendula arvensis*
28	*Calystegia sepium*
29	*Camelina sativa*
30	*Capsella bursa-pastoris*
31	*Cardaria draba*
32	*Caucalis platycarpos*
33	*Centaurea aspera*
34	*Centaurea cyanus*
35	*Centaurea melitensis*
36	*Centaurea solstitialis*
37	*Cerastium glomeratum*
38	*Cerastium perfoliatum*
39	*Chenopodium album*
40	*Chenopodium vulvaria*
41	*Chondrilla juncea*
42	*Cichorium intybus*
43	*Cirsium arvense*
44	*Cirsium vulgare*
45	*Cirsium* sp.
46	*Conryngia orientalis*
47	*Consolida pubescens*
48	*Convolvulus arvensis*
49	*Conyza* sp.
50	*Coronilla scorpioides*
51	*Crepis vesicaria*
52	*Cynodon dactylon*
53	*Cynoglossum creticum*
54	*Daucus carota*

Table 7 (continued)

	Species
55	*Descurainia sophia*
56	*Diplotaxis erucoides*
57	*Draba verna*
58	*Echinochloa* sp.
59	*Echium vulgare*
60	*Equisetum arvensis*
61	*Erodium ciconium*
62	*Erodium cicutarium*
63	*Eruca vesicaria*
64	*Erucastrum nasturtiifolium*
65	*Eryngium campestre*
66	*Euphorbia helioscopia*
67	*Euphorbia serrata*
68	*Fallopia convolvulus*
69	*Filago pyramidata*
70	*Filago* sp.
71	*Foeniculum vulgare*
72	*Fumaria officinalis*
73	*Fumaria parviflora*
74	*Fumaria* sp.
75	*Galium aparine*
76	*Galium parisiense*
77	*Galium tricornutum*
78	*Galium* sp.
79	*Geranium molle*
80	*Gladiolus segetum*
81	*Glaucium corniculatum*
82	*Glycyrrhiza glabra*
83	*Heliotropium europaeum*
84	*Herniaria hirsuta*
85	*Hordeum murinun*
86	*Hyoscyamus niger*
87	*Hypecoum procumbens*
88	*Iberis amara*
89	*Kochia scoparia*
90	*Lactuca saligna*
91	*Lactuca serriola*
92	*Lamium amplexicaule*
93	*Lathyrus odoratus*
94	*Linaria hirta*
95	*Linaria micrantha*
96	*Lolium multiflorum*
97	*Lolium rigidum*
98	*Malcolmia africana*
99	*Malva sylvestris*
100	*Marrubium vulgare*
101	*Matricacia chamomila*
102	*Medicago lupulina*
103	*Medicago orbicularis*

Table 7 (continued)

	Species
104	*Medicago polimorpha*
105	*Medicago* sp.
106	*Melilotus officinalis*
107	*Muscari comosum*
108	*Muscari neglectum*
109	*Neslia paniculata*
110	*Nigella galica*
111	*Ononis* sp.
112	*Onopordum nervosum*
113	*Papaver argemone*
114	*Papaver hybridum*
115	*Papaver rhoeas*
116	*Phalaris minor*
117	*Phragmites australis*
118	*Picris echioides*
119	*Plantago lanceolata*
120	*Plantago mayor*
121	*Poa annua*
122	*Poa trivialis.*
123	*Poa* sp.
124	*Podospermum laciniatum*
125	*Polygonum aviculare*
126	*Potentilla reptans*
127	*Ranunculus arvense*
128	*Raphanus raphanistrum*
129	*Rapistum rugosum*
130	*Reseda lutea*
131	*Reseda phyteuma*
132	*Roemeria hybrida*
133	*Rumex crispus*
134	*Rumex obtusifolius*
135	*Rumex pulcher*
136	*Rumex* sp.
137	*Salsola kali*
138	*Salvia sclarea*
139	*Sanguisorba minor*
140	*Scandix pecten-veneris*
141	*Scorzonera hirsuta*
142	*Senecio* sp.
143	*Senecio vulgaris*
144	*Setaria* sp.
145	*Silene conica*
146	*Silene conoidea*
147	*Silene vulgaris*
148	*Silybum marianum*
149	*Sinapis arvensis*
150	*Sisymbrium runcinatum*
151	*Sisymbrum irio*
152	*Solanum nigrum*
153	*Sonchus arvense*
154	*Sonchus asper*
155	*Sonchus oleraceus*
156	*Sonchus* sp.
157	*Sonchus tenerrimus*
158	*Sorghum halepense*
159	*Stellaria media*
160	*Taraxacum officinalis*
161	*Teucrium* sp.
162	*Thlaspi arvensis*
163	*Torilis nodosa*
164	*Trifolium repens*
165	*Vaccaria pyramidata*
166	*Veronica agrestis*
167	*Veronica arvensis*
168	*Veronica heredifolia*
169	*Veronica persica*
170	*Veronica polita*
171	*Veronica* sp.
172	*Vicia sativa*
173	*Viola arvensis*
174	*Vulpia unilateralis*
175	*Xanthium strumarium*
	Volunteer crop plants
1	*Avena sativa*
2	*Helianthus annua*
3	*Hordeum vulgare*
4	*Medicago sativa*
5	*Pisum sativum*
6	*Secale cereale*
7	*Triticum aestivum*

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