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Weed communities in Italian maize fields as affected by pedo-climatic traits and sowing time

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Abstract

This study examined relationships between weed communities and some pedo-climatic traits in Italian maize cultivation areas. A weed dataset was amassed from studies conducted independently by research groups during 1998-2013. Included were herbicide efficacy field trials and weed surveys from about 600 sites representing 175 northern and central Italy maize fields. The dataset was honed to results from untreated plots in which weed data were collected at least once (June/July) each season. For sites observed more often, only the survey with the highest weed species count was used.

Of the approximate 120 species found, just five were present on more than 50% of sites: *Chenopodium album*, *Echinochloa crus-galli*, *Amaranthus retroflexus*, *Solanum nigrum,* and *Persicaria maculosa*. Indices were calculated to describe weed community structure: total weed species count, monocotyledonous and dicotyledonous species counts, and total weed density. Additional soil and climate site data were collected or obtained from regional databases: pH reaction, texture, organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio, annual total precipitation, annual mean temperature, and Thornthwaite climate classification. Pedo-climatic traits and weed indices relationships were investigated using linear correlation analysis (CA), discriminant analysis (DA), and principal component analysis (PCA).

CA and PCA highlighted a weak bias (higher count and density) by monocotyledonous species for sand and alkaline soils, while clay and alkaline soils favored dicotyledonous species. DA classified the sites well based on weed indices using soil parameters as predictor variables, in particular for a Piemonte region (northwest Italy) data subset. Soil texture, CEC, pH, and some nutrient contents significantly predicted some weed indices.

This study pointed out that Italian maize field weed communities are influenced by some pedoclimatic traits; the weak relationships observed might be mitigated by the overall influence of crop practices on weed dynamics.

Keywords: weed community indices; soil traits; climatic data; weed diversity; discriminant analysis

1. Introduction

Weeds are one of the major constraints to maize cultivation that can affect crop yield based on their species composition and density (Kropff et al., 1992). Over the years, weeds typical to maize cultivation have evolved in reaction to cropping system changes and to agronomic practices changes, such as weed control. The heterogeneity of Italian maize systems and their agronomic histories has resulted in a particularly composite and unpredictable weed community (Zanin et al., 1988).

Maize (*Zea mays* L.) is one of the most important herbaceous crops in Italy and was cultivated on about 908,000 hectares in 2013 (ISTAT, 2014). Its cultivation is mainly concentrated in the Po River plain, where it represents upwards of 90% of the total Italian maize area (ISTAT, 2014). Soil fertility levels and environmental features that characterize different maize cultivation areas can affect both the crop and its related weeds. Indeed, weed communities vary with crop area pedological and climatic traits (Walter et al., 2002). Specific optimal growth ranges for some of these traits, such as soil pH or water availability, have been defined for certain weeds; some are considered indicator species of particular soils (such as, *Digitaria sanguinalis* for acid soil), environments, and crop managements (Buchanan et al., 1975; Albrecht, 2003). However, most weed species infesting maize and other crops are ubiquitous due primarily to their plasticity and absence of specific needs, which allow them to grow in different environments (Holzner, 1978). This contest begs verification of the possible relationships between weed infestation in a field and the pedo-climatic characteristics of the site. Such an exploration should consider not only the most widespread weed species, but also the entire floral composition of the weed infestation (Légère et al., 2005).

Studying arable field weed community composition appears useful to evaluate weed diversity. It provides ecological importance as a host habitat for natural weed enemies, it reduces the chance of selecting herbicide resistant or dominant weeds, and as an indicator of weed community stability (Miyazawa et al., 2004; Murphy et al., 2006). Weed community is usually considered stable when constituted of many species. Agronomic practices and environmental fluctuations of a particular cropping area may affect weed community dynamics (Smith and Gross, 2006).

Previous studies have shown the existence of a correlation between some weed species and soil characteristics, even at the field scale (Andreasen et al., 1991; Heisel et al., 1999; Albrecht and Auerswald, 2003). Some authors found that, for example, clay content was correlated with *Alopecurus myosuroides*, *Veronica hederifolia*, *Equisetum arvense*, and *Poa annua* densities (Nordmeyer and Dunker, 1999; Walter et al., 2002). The ability to confirm the presence of these relationships can be difficult, especially on a large scale, despite considerable information can be achievable on any infestation in a given territory. Data hurdle examples include the following: lack of soil nature information for all areas, soil property effects not easily discernable from those of other environmental factors, and limited knowledge of the agronomic practices applied in the years prior to survey (Zanin et al., 1988; Andreasen et al., 1991; Suárez et al., 2001).

This last aspect is probably the major limiting factor, but also one of the most important because the agronomic history of a particular site can strongly affect the relationships between weed community, soil, and climate (Buhler, 1995; Pyšek et al., 2005). Weed infestation changes due to management practices and to environmental conditions of a cultivated area make crucial the study of weed community composition to improve weed control (Saavedra et al., 1990). In fact, accurate knowledge on the weed community variability of a certain area may result in a more accurate tuning of sustainable weed management strategies (Davis et al., 2005; Smith and Gross, 2006). The spreading of particular agronomic techniques or the timing in which these are applied, may favor some weed species instead of others, modifying the composition of weed infestation (Smith, 2006). For instance, early maize sowing can stimulate the infestation of dicotyledonous species: microtherm, shade tolerant, and those that complete their life cycle after crop harvest (Zanin, 2000).

Previous studies have demonstrated the influence of environmental factors on the species constitution of weed communities to an area (Fried et al., 2008; Cimalová and Lososová, 2009). For example, annual precipitation and temperature are two important factors that may influence weed composition (Cimalová and Lososová, 2009). However, it has been established that management practices, such as soil tillage and crop rotation explain the majority of weed community variation across different soil typologies (Fried et al., 2008). Few weed surveys exist on Italian maize fields (Zanin et al., 1992; Zanin et al., 1997). Similarly, there is a dearth of knowledge on the change of its weed community composition in response to pedo-climatic factors. The aim of the present study was to verify the existence of relationships between weed communities and some pedological and climatic traits in different Italian maize cultivation areas. The influence of sowing time on weed community composition was also evaluated.

2. Materials and Methods

Weed data results of several independent studies carried out in the 1998-2013 period by different research groups were gathered and organized into a large dataset. Data referred to studies aimed at different purposes, including herbicide efficacy field trials and weed surveys, conducted on a total of about 600 sites, representing maize fields on 175 localities in northern and central Italy. Only data from untreated plots (size ranging from 10 to more than 100 m^2) were considered.

2.1 Data collection

Weed data were collected at least once in June or July of each year. In the case of multiple weed surveys on a single site, only the observation with the highest number of recorded weed species was used. The collected data were organized into two distinct datasets: one named “ITA” relative to fields located in the eight most important Italian maize cultivation regions (Piemonte, Lombardia, Veneto, Friuli Venezia Giulia, Emilia-Romagna, Lazio, Toscana, and Umbria), and another called “PIE,” which was limited to fields situated in the Piemonte region. The ITA dataset comprised data collected on 455 fields spread on 170 localities, while the PIE dataset involved 80 fields. For all sites, weed, soil, and climatic data were collected or obtained from regional databases.

Due to the large heterogeneity of data included in the ITA dataset, only weed community variables common to all sites and dates were considered, namely total weed species number and the number of monocotyledonous and dicotyledonous species in the fields.

The PIE dataset was generated principally from a weed survey program conducted using a common protocol. For this reason, some additional weed community data (such as, weed species density) was included.

For both datasets, weed data were obtained from counts carried out on four 0.5 x 0.5 m square areas randomly placed in each plot.

Soil properties were also considered in the study for each site; in particular, soil reaction (pH) and texture (relative proportions of sand, silt, and clay) were acquired for both surveys. For the fields comprising dataset PIE, a number of other soil properties, namely organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio were obtained from the Regione Piemonte soil database. For dataset PIE, some climatic parameters (annual total precipitation, annual mean temperature, and climate classification per Thornthwaite (1948)) were obtained from the Regione Piemonte Agrometeorological network.

2.2 Data analyses

At each site, some indices of weed species diversity were calculated (Table 1). For both datasets, the number of species (*nspec*), number of monocotyledonous (*nmono*) and dicotyledonous species (*ndico*), and the ratio between mono- and dicotyledonous species (*nmon_dic*) were determined. Additional indices relative to each weed species density were calculated for dataset PIE (Table 1). For each site in the survey, both the total number of species and the frequency of species-specific encounters (percentage of sites that included the species *n* over the total number of sites) were determined. For sites in which different maize sowing times were available, species frequency was calculated only for those species with a frequency above 25% (13 species).

The relationships between surveyed site weed species and pedo-climatic parameters were determined using three statistical methods. Initially, a series of linear correlations were determined for each pair of weed indices and pedo-climatic parameters, excluding the Thornthwaite climate categorical variable (*Thorn*). The significance of the correlation and Pearson's r correlation coefficient were calculated. Afterwards, the collected data were submitted to discriminant analysis to verify, through pedological and climatic parameters (predictors), the potential to classify sites as a function of the weed indices (discriminant variables). These indices, derived from continuous or categorical variables with a high number of categories, were transformed into new categorical variables with four, three, or two modalities, such that each site was classified by four, three, or two categories.

Considering the Thornthwaite climate classification (*Thorn*) as the discriminant variable and weed indices as the predictors allowed discriminant analysis performance. This procedure was necessary because the *Thorn* variable was already categorical. Another method, Principal Component Analysis (PCA), was applied only to the ITA dataset to identify variables capable of explaining most of the variability as well as the existence of any hidden structure underlying the variables. PCA was not applied to the PIE dataset because of its relatively limited observations. The correlation, discriminant, and principal component analyses were completed using the correlations, and discriminant and factor functions of statistical software SPSS, version 12.0.

3. Results

3.1 Weed community diversity

The total number of encountered species was similar for both surveys (ITA and PIE) and equaled approximately 120. However, among the species in the ITA dataset, only nine were present on more than 25% of the surveyed sites (Figure 1). Only five species were observed on more than 50% of the sites, and no species were found on more than 72% of the surveyed area. The most widespread species, ranked by diffusion (Table 2), were *Chenopodium album* and *Echinochloa crus-galli* (encounter frequencies above 70%), followed by *Amaranthus retroflexus*, *Solanum nigrum,* and *Persicaria maculosa*. As was true for encountered species, both dataset surveys showed similar trends in weed species frequency. Specifically, only a few species in Emilia Romagna region had high frequency values in dataset ITA, as opposed to Piemonte region where a high diffusion (95% frequency) of *C. album* was observed. In Lombardia a more homogeneous pattern of the most diffused weeds was detected, while in Veneto, and Friuli Venezia Giulia regions the trend were more intermediate in nature (Figure 2).

3.2 Weed infestation and maize sowing time

The large variation in maize growing conditions to which the ITA database referred allowed site comparison by classifying them into three maize sowing time groups: early sowing time (before March 20th), conventional sowing time (between March 20th and April 30th), and delayed sowing time (after April 30th). Infestation levels in fields sown at different times showed higher frequencies of *C. album*, *Abutilon theophrasti*, and *Fallopia convolvulus* at early sowing *versus* conventional sowing time, even though the three species had frequency variations below 10%. Moreover, fields at the early sowing time demonstrated remarkably lower frequency of encounters for *Panicum dichotomiflorum*, *Sorghum halepense*, *A. retroflexus,* and *Portulaca oleracea* (Figure 3). In general, observations at early sowing compared to late sowing found a greater presence of the species belonging to the Polygonaceae family (*P. maculosa*, *P. aviculare*, and *F. convolvulus*), in addition to *E. crus-galli*, *C. album*, and *S. nigrum*. In particular, frequency varied 21% for *P. maculosa* at early sowing time compared to delayed sowing time (Figure 3). Observations at conventional sowing compared to late sowing showed an even higher number of species occurring more frequently, including *P. dichotomiflorum*, *S. halepense* and *A. retroflexus* (Figure 3).

3.3 Weed species and pedo-climatic parameters

3.3.1. Linear correlation analysis

Linear correlation analysis identified some significant relationships between the pedological parameters *pH, sand, silt* and *clay* and some weed indices (Table 3). For the ITA dataset, height such correlations were found to be significant; five were identified in the PIE dataset. In ITA dataset, positive significant correlation was found between *sand* and *nmono* and between *sand* and *nmon_dic* (r =0.364, r =0.285, respectively). All the other correlations were negative. In PIE dataset, positive significant correlation was found only between *sand* and *dmono* (r = 0.324). In general, even though the correlations found were highly significant in some cases, the Pearson correlation coefficients were rather low, which indicated strong data variability.

3.3.2. Discriminant analysis

Among the pedo-climatic parameters, discriminant analysis detected some statistical predictors valid for both datasets (Table 4). The ITA dataset discriminant functions using soil property parameters *sand* and *clay* properly classified the sites (60-70% of correct site classification) and predicted based on variables *nmono* and *nmon_dic* which category the sites should have been included. Classification accuracy was quite constant considering that the two weed indices were subdivided in four, three, or two categories. However, when, the indices were subdivided into more than two categories, prediction accuracy was higher for the extreme classes. Indeed, the most accurate classification was observed for the sites with very high or very low numbers of monocotyledonous species. For this reason, the number of final categories was reduced to two. In the case of ITA dataset, a *nmono* threshold value of 1 was set to divide the dataset in the two categories: sites with up to one monocotyledonous species were classified in the first category, while sites with more than one monocotyledonous species were classified in the second category. In these conditions about 67% of sites (304) fall in the first category. The accuracy site classification considering only two categories comprised between 62% and 82% of both datasets.

Discriminant analysis in PIE produced the best results when each weed variable was composed of only two categories (i.e. high and low weed densities). Accurate predictions of classes to which the sites pertained was obtained using several variables and predictors: *SI and P. dichotomiflorum* density with *pH*, *dmono* with *sand*, *dmon_dic* with *Pass*, *P. maculosa* density with *Ntot*, *E. crus-galli* density with *Mg/K* and *CEC*, and *Stellaria media* density with *CEC* (Table 4). In the case of the ratio between monocotyledonous and dicotyledonous density (*dmon_dic*), the discriminant analysis correctly classified about 75% of sites in the lowest weed density category (data not shown). For most analyses, the discriminant function included only one pedological parameter as a valid predictor. When this was the case, only one pedological parameter was considered for site classification from one of the two categories in which a weed index was subdivided (i.e. high or low *SI*).

Among weed indices, only for *E. crus-galli* density were two predictors, *Mg/K* and *CEC,* used to classify sites. If the average value for *CEC* (13) among all PIE sites is used, then when *Mg/K* is above 6.5, the predicted *E. crus-galli* density was greater than 5 plants m^{-2} (Figure 4). For any given site, the farther the pair of *CEC* and *Mg/K* values is from the straight line, the more accurate is the site classification based on *E. crus-galli* density (Figure 4).

When used as a separation variable, parameter *Thorn* was reclassified by reducing the initial five categories to two categories into which the various sites could be classified. These were referred to more humid-tending sites (merging the sites falling into the categories B4B1rb3 and B4B2rb3) and less humid-tending sites (merging the sites falling into the categories C1B2sb3, C2B1rb3, C2B2rb3) according to the Thornthwaite climate classification (Thornthwaite, 1948). Using this classification, the weed indices *aden*, *SI*, and *nmon_dic* proved to be good predictors, with, about 60% and 70% of the sites correctly classified into generally more humid areas and generally less humid areas, respectively. In general, in the more humid sites both a higher number of weed species (low *SI* values) and a prevalence of monocotyledonous were observed, in contrast with what was recorded for the less humid sites.

3.3.3. Principal Component Analysis

The first three components calculated by PCA explained more than 80% of the variation in the original ITA dataset sites. The first component was positively correlated mainly with some weed indices, and in particular, with the number of monocotyledonous species (*nmono*) and with the mono-dicot ratio (*nmono_dic*) (Table 5). The second component correlated mostly with pedological parameters, and specifically as follows with those related to soil texture fraction: high positive correlation with *silt*, lower positive correlation with *clay*, and high negative correlation with *sand*. Figure 5 shows a representation in bi-dimensional space of these first two components, in which the sites were indicated with symbols referring to their actual soil texture (clay, silt, sand, and loam).

The majority of sites with clay soils were concentrated around near slightly negative values of the first component, indicating that in these sites the monocotyledonous species were less abundant, both in absolute and relative terms to the dicotyledonous species number. The cloud formed by sites with other soil textures (silt, sand, and loam) showed a more spread arrangement, moving from negative to positive values of first component. This suggests that in sites with soil different from clay, weed indices are basically not influenced by soil texture.

4. Discussion

4.1 Weed community diversity

Study results made it possible to characterize the weed vegetation of maize fields in the main Italian areas of crop cultivation, and in detail for the Piemonte region. The 120 total detected weed species fell within the range of 75-124 species found in previous studies for other summer crops (Frick and Thomas, 1992; Zanin et al., 1997; Viggiani et al., 1998). Since both the entire area and Piemonte region surveys recorded a similar number of species, this parameter seemed unrelated to survey area size. Despite the high simplification in Italian maize cropping systems currently, the number of observed weed species was great. A number of factors may contribute to this effect: high agronomic practice variation, even in maize mono-cropping, farm fragmentation, and pedological and climatic conditions that vary at both the farm and territory levels. A study conducted in France by Fried et al. (2008) showed weed species diversity and composition were particularly influenced by crop type and the crop preceding maize in the rotation.

Only some of the many species found were widespread. Indeed, only five weed species were recorded in more than 50% of the surveyed sites. Among these, only one grass weed was highly diffused (*E. crus-galli*); it is common to crop fields worldwide because of its ability to germinate and flower in different environmental conditions (Keeley and Thullen, 1989). This study found that grass weeds constituted one-third of the nine weed species present on more than 25% of the surveyed sites, which agreed with the prevalence of broad-leaved species seeds discussed in a previous study undertaken on the seedbank of an Italian field after five years of maize cultivation (Bàrberi et al., 1998). Many experiments associate high grass weed counts with reduced input cultivation systems, while broad-leaved species predominate in conventional plowed systems (Froud-Williams et al., 1983; Mohler, 1993; Bàrberi et al., 1998). Italian maize fields are typically plowed, which may explain broad-leaved weed preponderance; another explanation may be their higher seed longevity and persistence in soil compared to that of grass weeds (Burnside et al., 1996). For broad-leaved species, this survey confirmed the findings of previous studies (Viggiani et al., 1998) as it showed the ubiquitous characteristic of *C. album*. In fact, this species was the most dispersed probably due to its abundant seed production and longevity (Clements et al., 1996). In fact, *C. album* is one of the five most widespread weeds globally, the seventh most abundant in maize, and one of the most troublesome weeds in the U.S. corn belt (Forcella et al., 1992; Clements et al., 1996).

4.2. Weed infestation and maize sowing time

Maize sowing time showed it had an important effect on weed community composition—enhancing or reducing the presence of different species. In this study, early sowing of maize is a practice widely used in northern Italy. This study detected a different weed community composition depending on maize sowing time as other studies have demonstrated (Otto et al., 2009). At early sowing time some species were encountered more frequently than others. *E. crus-galli* was one such species, probably because it is able to emerge rapidly, even at temperatures characteristic of early March (about 15 °C) (Keeley and Thullen, 1989). The same holds for *F. convolvulus* and other Polygonaceae species, for which low temperatures induce high emergence flushes (Metzger, 1992).

4.3. Weed species and pedo-climatic parameters

The results of the study highlighted some relationships among the weed indices and pedo-climatic parameters of the surveyed sites, as observed in previous studies (Andreasen et al., 1991; Cimalová and Lososová, 2009). However, the correlations described in those studies were generally moderate and did not allow clarification of the precise relationships among the parameters. It is, nevertheless, possible to hypothesize that interactions may be hidden by agronomic practice effects, for which information was not available. Other studies have demonstrated effects from certain agronomic practices, such as soil fertilization or weed community tillage (Andersson and Milberg, 1998; Hyvönen and Salonen, 2002; Cimalová and Lososová, 2009).

The few significant relationships found among some macroscopic weed indices and pedo-climatic parameters (i.e., mono/dicot ratio and soil texture, Simpson indices and climatic classification) have importance. For example, soil reaction was proved to affect weed community composition either directly or indirectly by changing the availability of different soil nutrients (Buchanan et al., 1975; Dieleman et al., 2000). Correlation analysis results indicated that a higher and a lower number of monocots were found in sand and clay soils, respectively. In addition, a lower mono/dicots ratio was found in soils dealing with a higher pH value.

Both PCA and discriminant analysis also confirmed the existence of relationships among the weed indices and some pedo-climatic traits. For example, discriminant analysis provided a good classification of the surveyed sites on the basis of weed indices using soil parameters as predictor variables. In particular, soil texture, *CEC*, as well as pH and some nutrient contents, resulted significant predicting many weed indices. Furthermore, discriminant analysis successfully classified the sites based on the density of *E. crus-galli* using two soil parameters, namely *Mg/K* and *CEC*.

Finally, mean annual precipitation and mean annual temperature affected weed species composition as observed in previous studies, even though they appear not to be the main source of weed community variation (Cimalová and Lososová, 2009).

4.4 Conclusions

In general, many factors impact weed community dynamics; in particular, management practices, soil tillage, and crop type play important roles. This study highlighted not only the diversity of weed species in Italian maize, but also the importance of pedological and climatic factor contributions to weed species variation. Study analyses did establish some relationships between certain weed indices and pedo-climatic parameters, however, it also demonstrated the particular difficulty associated with distinguishing single factor effects. Weed community variation seems to result from an interaction of different cropping and pedo-climatic aspects. Further studies are needed to better clarify these relationships as this information may improve the predictability of weed flora composition based on the environmental characteristics of a certain area.

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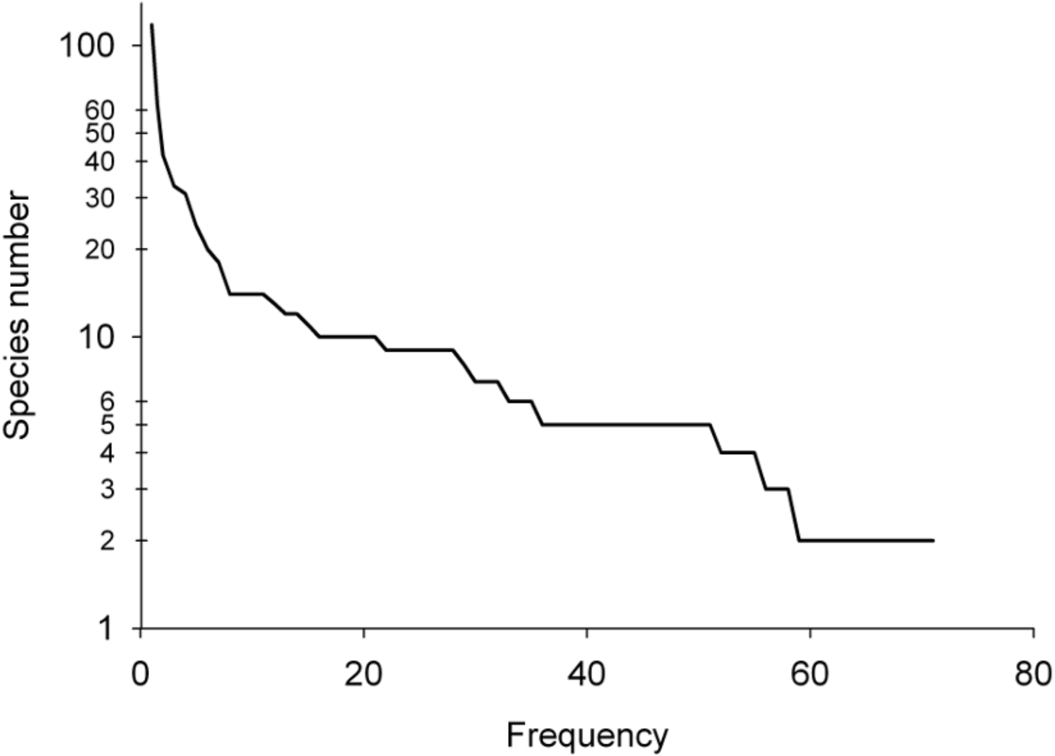
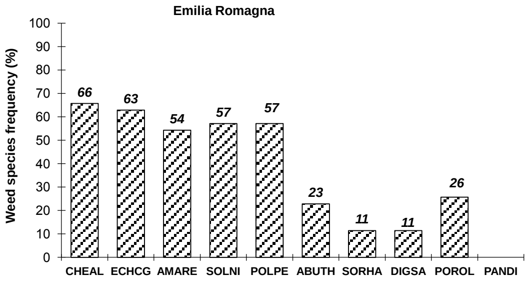
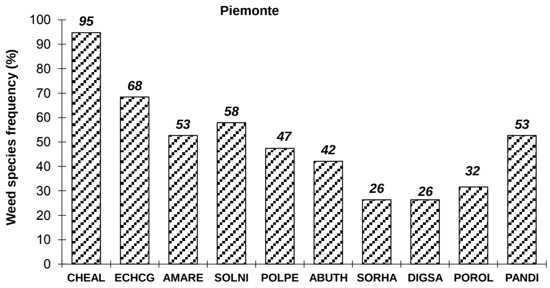
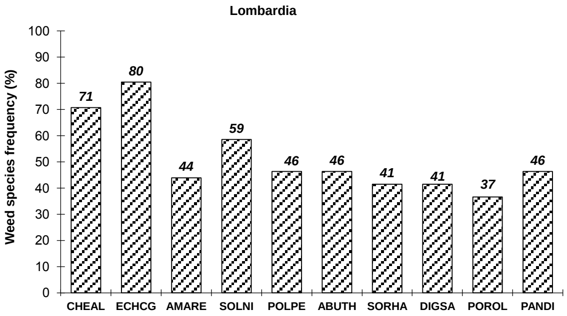
Figure


Species number
100
60
50
40
30
20
10
6
5
4
3
2
1
0
20
40
60
80
Frequency


Emilia Romagna
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
66
63
54
57
57
23
11
11
26
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI


Piemonte
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
95
68
53
58
47
42
26
26
32
53
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI


Lombardia
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
71
80
44
59
46
46
41
41
37
46
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI

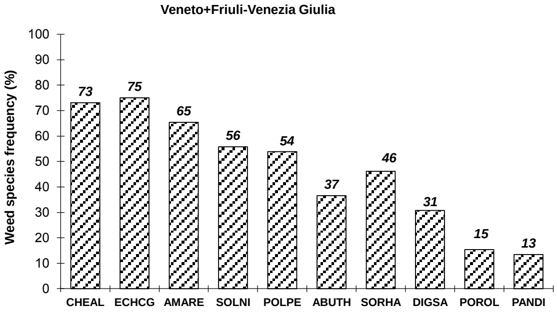
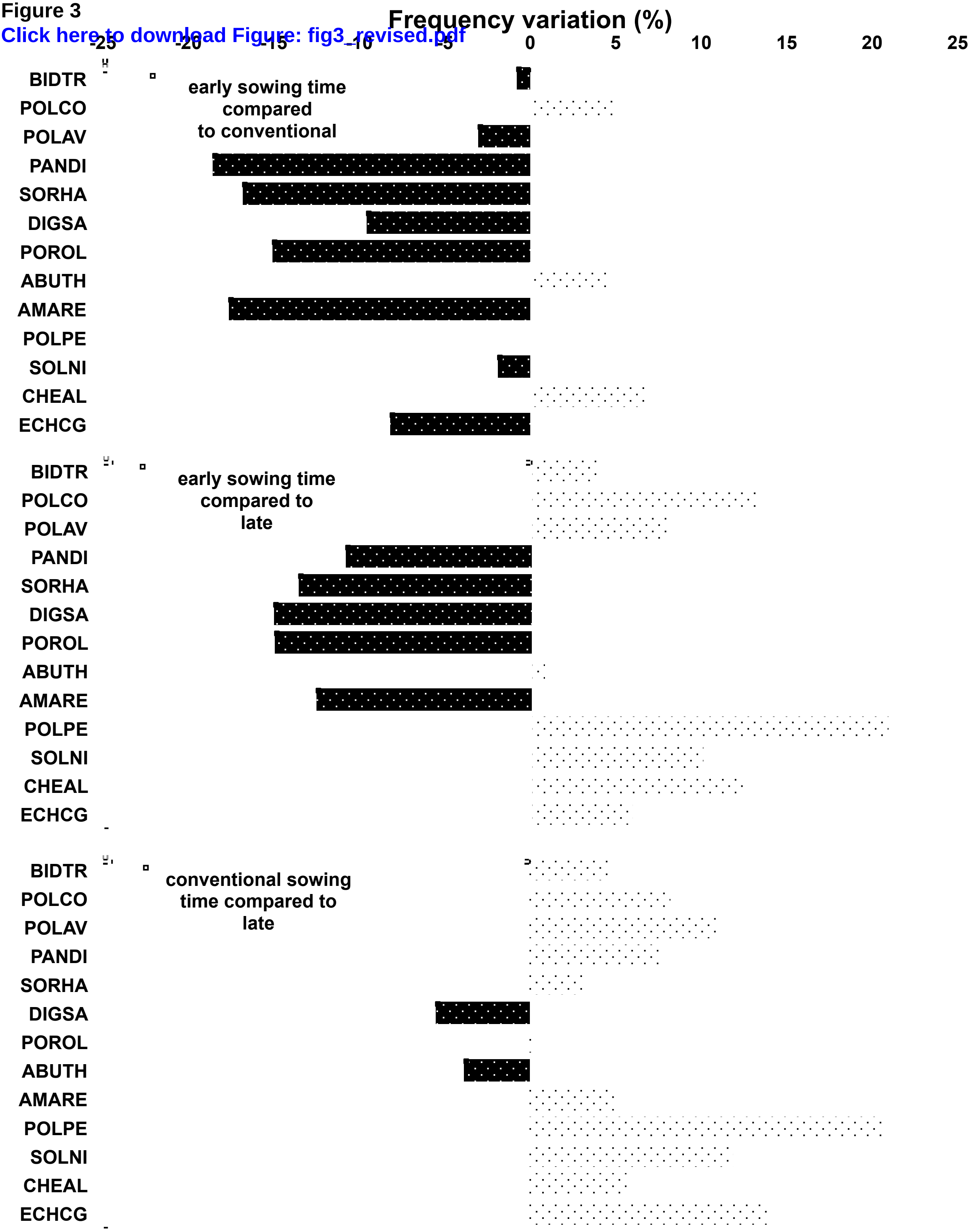

Veneto+Friuli-Venezia Giulia
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
73
75
65
56
54
37
46
31
15
13
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI

Figure 3


Frequency variation (%)
-25
-20
-15
-10
-5
0
5
10
15
20
25
early sowing time compared to conventional
early sowing time compared to late
conventional sowing time compared to late
BIDTR
POLCO
POLAV
PANDI
SORHA
DIGSA
POROL
ABUTH
AMARE
POLPE
SOLNI
CHEAL
ECHCG

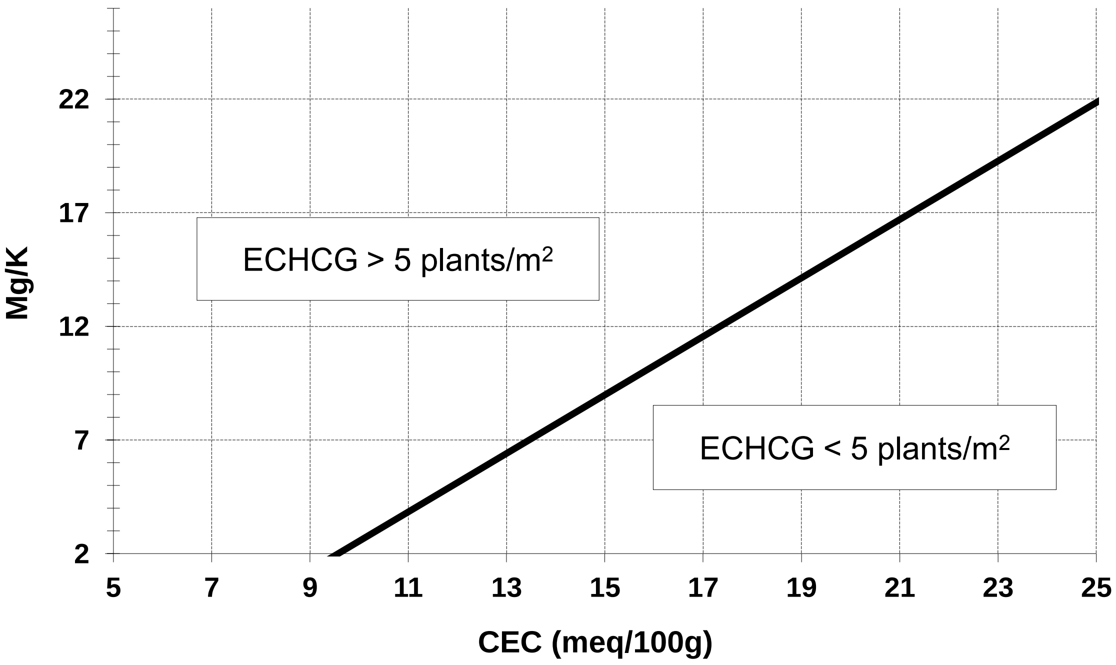

Mg/K
22
17
12
7
2
5
7
9
11
13
15
17
19
21
23
25
CEC (meq/100g)
ECHCG > 5 plants/m2
ECHCG < 5 plants/m2

Figure 5

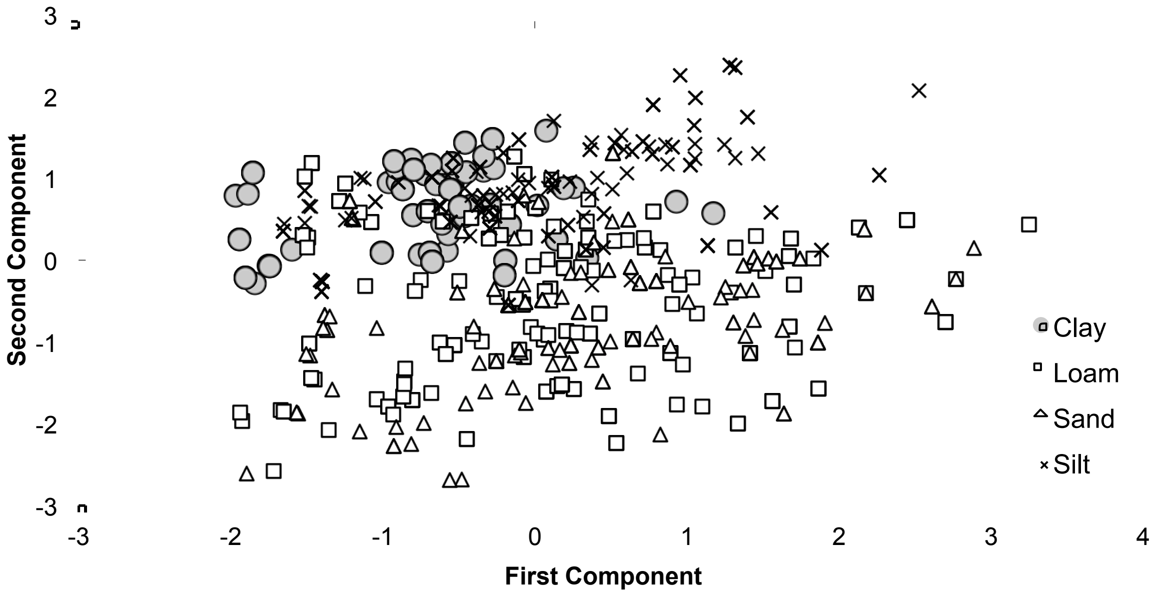

3
2
1
0
-1
-2
-3
Second Component
-3
-2
-1
0
1
2
3
4
First Component
Clay
Loam
Sand
Silt

Table 1. Weed, pedological, and climatic variables considered in the study.

variables	**code**	**Unit of measurement**	**dataset**		**Calculation method** $^{(1)}$
			ITA	**PIE**	
Weed indices					
Total weed density	*dentot*	plants/m^2		X	
Number of weed species	*nspec*	n^a	X	X	
Mean weed density of the present species	*aden*	plants/m^2		X	$dentot / nspec$
Weed density of the single species	n_i	plants/m^2		X	
Number of species contributing for more than 5% and 10%	*con*5 *con*10	n		X	$con5 = \sum{}^{\backprime} i$; for $n_i \geq (0.05 \cdot dentot)$ $con10 = \sum{}^{\backprime} i$; for $n_i \geq (0.10 \cdot dentot)$
Simpson index	*SI*	ad^b		X	$SI = \sum (n_i / dentot)$
Shannon index	*H'*	ad		X	$H' = -\sum [(n_i / dentot) \cdot \ln (n_i / dentot)]$
Numbers of MONOCOT species	*nmono*	n	X	X	
Numbers of DICOT species	*ndico*	n	X	X	
Number of MONCOT/DICOT species ratio	*nmon_dic*	ad	X	X	$nmono / ndico$
Total MONOCOT density	*dmono*	plants/m^2		X	
Total DICOT density	*ddico*	plants/m^2		X	
MONOCOT/DICOT density ratio	*dmon_dic*	ad		X	$dmono / ddico$
Pedological indices					
Sand	*sand*	%	X	X	
Silt	*silt*	%	X	X	
Clay	*clay*	%	X	X	
pH	*pH*		X	X	
Organic matter content	*SO*	%		X	
Total nitrogen	*Ntot*	%		X	
Mg/K ratio	*Mg/K*	ad		X	
Assimilable phosphorous	*Pass*	ppm		X	
Cation exchange capacity	*CEC*	meq/100g		X	
Carbon/Nitrogen ratio	*C/N*	ad		X	
Climatic indices					
Total annual precipitation	*Ptot*	mm		X	
Anuual mean temperature	*Tavg*	°C		X	
Thornthwaite climatic classification	*Thorn*	ad		X	

[a]n indicates number of species; [b]ad indicates adimensional

Table 2. Frequency of encounters for the most diffused weed species across all surveyed sites (site number in which a weed species was present relative to total surveyed sites).

Species	**Encounter frequency (%)**
Chenopodium album	71.6
Echinochloa crus-galli	71.6
Amaranthus retroflexus	58.6
Solanum nigrum	55.6
Persicaria maculosa	50.0
Abutilon theophrasti	35.5
Sorghum halepense	32.5
Digitaria sanguinalis	29.6
Portulaca oleracea	28.4
Panicum dichotomiflorum	21.3
Fallopia convolvulus	15.4
Polygonum aviculare	14.8
Setaria glauca	12.4
Bidens tripartita	11.8
Convolvolus arvensis	7.7

Table 3. Significance values (P) and Pearson correlation coefficients (r) (in brackets), of the relationships among some pedological parameters and weed indices for the ITA and PIE datasets (P≤0.05).

	ITA		*PIE*	
	nmono	*nmon_dic*	*dmono*	*dmon_dic*
pH	<0.001 (-0.299)	<0.001 (-0.330)	0.273 (-0.124)	0.001 (-0.352)
sand	<0.001 (0.364)	<0.001 (0.285)	0.003 (0.324)	0.086 (0.193)
silt	<0.001 (-0.150)	0.018 (-0.090)	0.045 (-0.224)	0.570 (-0.065)
clay	<0.001 (-0.364)	<0.001 (-0.303)	0.006 (-0.303)	0.025 (-0.251)

Table 4. Pedo-climatic variables for which significant relationships were found according to discriminant analysis and threshold value dividing the two categories.

Separation variables	**Estimators**	**Percentage of correct classification**[a]	**Threshold value**[b]
ITA dataset			
nmono	*sand*	61.9	1
nmon_dic	*clay*	69.0	25
PIE dataset			
SI	*pH*	71.4	0.25
dmono	*sand*	67.9	70
dmon_dic	*Pass*	64.3	50
POLPE density	*Ntot*	64.3	5
ECHCG density	*Mg/K; CEC*	75.0	5
STEME density	*CEC*	82.0	5
PANDI density	*pH*	64.3	5
Thorn	*aden, SI, nmondic*	76.0	

[a] Percentage of sites used for validation (sites not used to build the discriminant function) and percentage correctly classified.

[b] Values equal or below threshold belonged to category 1, values above belonged to category 2.

Table 5. Component matrix of the first two principal components relative to surveyed sites (pedological and weed indices) and their respective loads.

Variables	**Component**	
	1	**2**
pH	-0.465	0.425
sand	0.280	-0.942
silt	0.108	0.807
clay	0.470	0.589
nspec	0.204	-0.033
nmono	0.863	-0.122
ndico	-0.249	0.014
nmon_dic	0.871	-0.053

Weed communities in Italian maize fields as affected by pedo-climatic traits and sowing time

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Abstract

This study examined relationships between weed communities and some pedo-climatic traits in Italian maize cultivation areas. A weed dataset was amassed from studies conducted independently by research groups during 1998-2013. Included were herbicide efficacy field trials and weed surveys from about 600 sites representing 175 northern and central Italy maize fields. The dataset was honed to results from untreated plots in which weed data were collected at least once (June/July) each season. For sites observed more often, only the survey with the highest weed species count was used.

Of the approximate 120 species found, just five were present on more than 50% of sites: *Chenopodium album*, *Echinochloa crus-galli*, *Amaranthus retroflexus*, *Solanum nigrum,* and *Persicaria maculosa*. Indices were calculated to describe weed community structure: total weed species count, monocotyledonous and dicotyledonous species counts, and total weed density. Additional soil and climate site data were collected or obtained from regional databases: pH reaction, texture, organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio, annual total precipitation, annual mean temperature, and Thornthwaite climate classification. Pedo-climatic traits and weed indices relationships were investigated using linear correlation analysis (CA), discriminant analysis (DA), and principal component analysis (PCA).

CA and PCA highlighted a weak bias (higher count and density) by monocotyledonous species for sand and alkaline soils, while clay and alkaline soils favored dicotyledonous species. DA classified the sites well based on weed indices using soil parameters as predictor variables, in particular for a Piemonte region (northwest Italy) data subset. Soil texture, CEC, pH, and some nutrient contents significantly predicted some weed indices.

This study pointed out that Italian maize field weed communities are influenced by some pedoclimatic traits; the weak relationships observed might be mitigated by the overall influence of crop practices on weed dynamics.

Keywords: weed community indices; soil traits; climatic data; weed diversity; discriminant analysis

1. Introduction

Weeds are one of the major constraints to maize cultivation that can affect crop yield based on their species composition and density (Kropff et al., 1992). Over the years, weeds typical to maize cultivation have evolved in reaction to cropping system changes and to agronomic practices changes, such as weed control. The heterogeneity of Italian maize systems and their agronomic histories has resulted in a particularly composite and unpredictable weed community (Zanin et al., 1988).

Maize (*Zea mays* L.) is one of the most important herbaceous crops in Italy and was cultivated on about 908,000 hectares in 2013 (ISTAT, 2014). Its cultivation is mainly concentrated in the Po River plain, where it represents upwards of 90% of the total Italian maize area (ISTAT, 2014). Soil fertility levels and environmental features that characterize different maize cultivation areas can affect both the crop and its related weeds. Indeed, weed communities vary with crop area pedological and climatic traits (Walter et al., 2002). Specific optimal growth ranges for some of these traits, such as soil pH or water availability, have been defined for certain weeds; some are considered indicator species of particular soils (such as, *Digitaria sanguinalis* for acid soil), environments, and crop managements (Buchanan et al., 1975; Albrecht, 2003). However, most weed species infesting maize and other crops are ubiquitous due primarily to their plasticity and absence of specific needs, which allow them to grow in different environments (Holzner, 1978). This contest begs verification of the possible relationships between weed infestation in a field and the pedo-climatic characteristics of the site. Such an exploration should consider not only the most widespread weed species, but also the entire floral composition of the weed infestation (Légère et al., 2005).

Studying arable field weed community composition appears useful to evaluate weed diversity. It provides ecological importance as a host habitat for natural weed enemies, it reduces the chance of selecting herbicide resistant or dominant weeds, and as an indicator of weed community stability (Miyazawa et al., 2004; Murphy et al., 2006). Weed community is usually considered stable when constituted of many species. Agronomic practices and environmental fluctuations of a particular cropping area may affect weed community dynamics (Smith and Gross, 2006).

Previous studies have shown the existence of a correlation between some weed species and soil characteristics, even at the field scale (Andreasen et al., 1991; Heisel et al., 1999; Albrecht and Auerswald, 2003). Some authors found that, for example, clay content was correlated with *Alopecurus myosuroides*, *Veronica hederifolia*, *Equisetum arvense*, and *Poa annua* densities (Nordmeyer and Dunker, 1999; Walter et al., 2002). The ability to confirm the presence of these relationships can be difficult, especially on a large scale, despite considerable information can be achievable on any infestation in a given territory. Data hurdle examples include the following: lack of soil nature information for all areas, soil property effects not easily discernable from those of other environmental factors, and limited knowledge of the agronomic practices applied in the years prior to survey (Zanin et al., 1988; Andreasen et al., 1991; Suárez et al., 2001).

This last aspect is probably the major limiting factor, but also one of the most important because the agronomic history of a particular site can strongly affect the relationships between weed community, soil, and climate (Buhler, 1995; Pyšek et al., 2005). Weed infestation changes due to management practices and to environmental conditions of a cultivated area make crucial the study of weed community composition to improve weed control (Saavedra et al., 1990). In fact, accurate knowledge on the weed community variability of a certain area may result in a more accurate tuning of sustainable weed management strategies (Davis et al., 2005; Smith and Gross, 2006). The spreading of particular agronomic techniques or the timing in which these are applied, may favor some weed species instead of others, modifying the composition of weed infestation (Smith, 2006). For instance, early maize sowing can stimulate the infestation of dicotyledonous species: microtherm, shade tolerant, and those that complete their life cycle after crop harvest (Zanin, 2000).

Previous studies have demonstrated the influence of environmental factors on the species constitution of weed communities to an area (Fried et al., 2008; Cimalová and Lososová, 2009). For example, annual precipitation and temperature are two important factors that may influence weed composition (Cimalová and Lososová, 2009). However, it has been established that management practices, such as soil tillage and crop rotation explain the majority of weed community variation across different soil typologies (Fried et al., 2008).

Few weed surveys exist on Italian maize fields (Zanin et al., 1992; Zanin et al., 1997). Similarly, there is a dearth of knowledge on the change of its weed community composition in response to pedo-climatic factors. The aim of the present study was to verify the existence of relationships between weed communities and some pedological and climatic traits in different Italian maize cultivation areas. The influence of sowing time on weed community composition was also evaluated.

2. Materials and Methods

Weed data results of several independent studies carried out in the 1998-2013 period by different research groups were gathered and organized into a large dataset. Data referred to studies aimed at different purposes, including herbicide efficacy field trials and weed surveys, conducted on a total of about 600 sites, representing maize fields on 175 localities in northern and central Italy. Only data from untreated plots (size ranging from 10 to more than 100 m^2) were considered.

2.1 Data collection

Weed data were collected at least once in June or July of each year. In the case of multiple weed surveys on a single site, only the observation with the highest number of recorded weed species was used. The collected data were organized into two distinct datasets: one named “ITA” relative to fields located in the eight most important Italian maize cultivation regions (Piemonte, Lombardia, Veneto, Friuli Venezia Giulia, Emilia-Romagna, Lazio, Toscana, and Umbria), and another called “PIE,” which was limited to fields situated in the Piemonte region. The ITA dataset comprised data collected on 455 fields spread on 170 localities, while the PIE dataset involved 80 fields. For all sites, weed, soil, and climatic data were collected or obtained from regional databases.

Due to the large heterogeneity of data included in the ITA dataset, only weed community variables common to all sites and dates were considered, namely total weed species number and the number of monocotyledonous and dicotyledonous species in the fields.

The PIE dataset was generated principally from a weed survey program conducted using a common protocol. For this reason, some additional weed community data (such as, weed species density) was included.

For both datasets, weed data were obtained from counts carried out on four 0.5 x 0.5 m square areas randomly placed in each plot.

Soil properties were also considered in the study for each site; in particular, soil reaction (pH) and texture (relative proportions of sand, silt, and clay) were acquired for both surveys. For the fields comprising dataset PIE, a number of other soil properties, namely organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio were obtained from the Regione Piemonte soil database. For dataset PIE, some climatic parameters (annual total precipitation, annual mean temperature, and climate classification per Thornthwaite (1948)) were obtained from the Regione Piemonte Agrometeorological network.

2.2 Data analyses

At each site, some indices of weed species diversity were calculated (Table 1). For both datasets, the number of species (*nspec*), number of monocotyledonous (*nmono*) and dicotyledonous species (*ndico*), and the ratio between mono- and dicotyledonous species (*nmon_dic*) were determined. Additional indices relative to each weed species density were calculated for dataset PIE (Table 1). For each site in the survey, both the total number of species and the frequency of species-specific encounters (percentage of sites that included the species *n* over the total number of sites) were determined. For sites in which different maize sowing times were available, species frequency was calculated only for those species with a frequency above 25% (13 species).

The relationships between surveyed site weed species and pedo-climatic parameters were determined using three statistical methods. Initially, a series of linear correlations were determined for each pair of weed indices and pedo-climatic parameters, excluding the Thornthwaite climate categorical variable (*Thorn*). The significance of the correlation and Pearson's r correlation coefficient were calculated. Afterwards, the collected data were submitted to discriminant analysis to verify, through pedological and climatic parameters (predictors), the potential to classify sites as a function of the weed indices (discriminant variables). These indices, derived from continuous or categorical variables with a high number of categories, were transformed into new categorical variables with four, three, or two modalities, such that each site was classified by four, three, or two categories.

Considering the Thornthwaite climate classification (*Thorn*) as the discriminant variable and weed indices as the predictors allowed discriminant analysis performance. This procedure was necessary because the *Thorn* variable was already categorical. Another method, Principal Component Analysis (PCA), was applied only to the ITA dataset to identify variables capable of explaining most of the variability as well as the existence of any hidden structure underlying the variables. PCA was not applied to the PIE dataset because of its relatively limited observations. The correlation, discriminant, and principal component analyses were completed using the correlations, and discriminant and factor functions of statistical software SPSS, version 12.0.

3. Results

3.1 Weed community diversity

The total number of encountered species was similar for both surveys (ITA and PIE) and equaled approximately 120. However, among the species in the ITA dataset, only nine were present on more than 25% of the surveyed sites (Figure 1). Only five species were observed on more than 50% of the sites, and no species were found on more than 72% of the surveyed area. The most widespread species, ranked by diffusion (Table 2), were *Chenopodium album* and *Echinochloa crus-galli* (encounter frequencies above 70%), followed by *Amaranthus retroflexus*, *Solanum nigrum,* and *Persicaria maculosa*. As was true for encountered species, both dataset surveys showed similar trends in weed species frequency. Specifically, only a few species in Emilia Romagna region had high frequency values in dataset ITA, as opposed to Piemonte region where a high diffusion (95% frequency) of *C. album* was observed. In Lombardia a more homogeneous pattern of the most diffused weeds was detected, while in Veneto, and Friuli Venezia Giulia regions the trend were more intermediate in nature (Figure 2).

3.2 Weed infestation and maize sowing time

The large variation in maize growing conditions to which the ITA database referred allowed site comparison by classifying them into three maize sowing time groups: early sowing time (before March 20th), conventional sowing time (between March 20th and April 30th), and delayed sowing time (after April 30th). Infestation levels in fields sown at different times showed higher frequencies of *C. album*, *Abutilon theophrasti*, and *Fallopia convolvulus* at early sowing *versus* conventional sowing time, even though the three species had frequency variations below 10%. Moreover, fields at the early sowing time demonstrated remarkably lower frequency of encounters for *Panicum dichotomiflorum*, *Sorghum halepense*, *A. retroflexus,* and *Portulaca oleracea* (Figure 3). In general, observations at early sowing compared to late sowing found a greater presence of the species belonging to the Polygonaceae family (*P. maculosa*, *P. aviculare*, and *F. convolvulus*), in addition to *E. crus-galli*, *C. album*, and *S. nigrum*. In particular, frequency varied 21% for *P. maculosa* at early sowing time compared to delayed sowing time (Figure 3). Observations at conventional sowing compared to late sowing showed an even higher number of species occurring more frequently, including *P. dichotomiflorum*, *S. halepense* and *A. retroflexus* (Figure 3).

3.3 Weed species and pedo-climatic parameters

3.3.1. Linear correlation analysis

Linear correlation analysis identified some significant relationships between the pedological parameters *pH, sand, silt* and *clay* and some weed indices (Table 3). For the ITA dataset, height such correlations were found to be significant; five were identified in the PIE dataset. In ITA dataset, positive significant correlation was found between *sand* and *nmono* and between *sand* and *nmon_dic* (r =0.364, r =0.285, respectively). All the other correlations were negative. In PIE dataset, positive significant correlation was found only between *sand* and *dmono* (r = 0.324). In general, even though the correlations found were highly significant in some cases, the Pearson correlation coefficients were rather low, which indicated strong data variability.

3.3.2. Discriminant analysis

Among the pedo-climatic parameters, discriminant analysis detected some statistical predictors valid for both datasets (Table 4). The ITA dataset discriminant functions using soil property parameters *sand* and *clay* properly classified the sites (60-70% of correct site classification) and predicted based on variables *nmono* and *nmon_dic* which category the sites should have been included. Classification accuracy was quite constant considering that the two weed indices were subdivided in four, three, or two categories. However, when, the indices were subdivided into more than two categories, prediction accuracy was higher for the extreme classes. Indeed, the most accurate classification was observed for the sites with very high or very low numbers of monocotyledonous species. For this reason, the number of final categories was reduced to two. In the case of ITA dataset, a *nmono* threshold value of 1 was set to divide the dataset in the two categories: sites with up to one monocotyledonous species were classified in the first category, while sites with more than one monocotyledonous species were classified in the second category. In these conditions about 67% of sites (304) fall in the first category. The accuracy site classification considering only two categories comprised between 62% and 82% of both datasets.

Discriminant analysis in PIE produced the best results when each weed variable was composed of only two categories (i.e. high and low weed densities). Accurate predictions of classes to which the sites pertained was obtained using several variables and predictors: *SI and P. dichotomiflorum* density with *pH*, *dmono* with *sand*, *dmon_dic* with *Pass*, *P. maculosa* density with *Ntot*, *E. crus-galli* density with *Mg/K* and *CEC*, and *Stellaria media* density with *CEC* (Table 4). In the case of the ratio between monocotyledonous and dicotyledonous density (*dmon_dic*), the discriminant analysis correctly classified about 75% of sites in the lowest weed density category (data not shown). For most analyses, the discriminant function included only one pedological parameter as a valid predictor. When this was the case, only one pedological parameter was considered for site classification from one of the two categories in which a weed index was subdivided (i.e. high or low *SI*).

Among weed indices, only for *E. crus-galli* density were two predictors, *Mg/K* and *CEC,* used to classify sites. If the average value for *CEC* (13) among all PIE sites is used, then when *Mg/K* is above 6.5, the predicted *E. crus-galli* density was greater than 5 plants m^{-2} (Figure 4). For any given site, the farther the pair of *CEC* and *Mg/K* values is from the straight line, the more accurate is the site classification based on *E. crus-galli* density (Figure 4).

When used as a separation variable, parameter *Thorn* was reclassified by reducing the initial five categories to two categories into which the various sites could be classified. These were referred to more humid-tending sites (merging the sites falling into the categories B4B1rb3 and B4B2rb3) and less humid-tending sites (merging the sites falling into the categories C1B2sb3, C2B1rb3, C2B2rb3) according to the Thornthwaite climate classification (Thornthwaite, 1948). Using this classification, the weed indices *aden*, *SI*, and *nmon_dic* proved to be good predictors, with, about 60% and 70% of the sites correctly classified into generally more humid areas and generally less humid areas, respectively. In general, in the more humid sites both a higher number of weed species (low *SI* values) and a prevalence of monocotyledonous were observed, in contrast with what was recorded for the less humid sites.

3.3.3. Principal Component Analysis

The first three components calculated by PCA explained more than 80% of the variation in the original ITA dataset sites. The first component was positively correlated mainly with some weed indices, and in particular, with the number of monocotyledonous species (*nmono*) and with the mono-dicot ratio (*nmono_dic*) (Table 5). The second component correlated mostly with pedological parameters, and specifically as follows with those related to soil texture fraction: high positive correlation with *silt*, lower positive correlation with *clay*, and high negative correlation with *sand*. Figure 5 shows a representation in bi-dimensional space of these first two components, in which the sites were indicated with symbols referring to their actual soil texture (clay, silt, sand, and loam). The majority of sites with clay soils were concentrated around near slightly negative values of the first component, indicating that in these sites the monocotyledonous species were less abundant, both in absolute and relative terms to the dicotyledonous species number. The cloud formed by sites with other soil textures (silt, sand, and loam) showed a more spread arrangement, moving from negative to positive values of first component. This suggests that in sites with soil different from clay, weed indices are basically not influenced by soil texture.

4. Discussion

4.1 Weed community diversity

Study results made it possible to characterize the weed vegetation of maize fields in the main Italian areas of crop cultivation, and in detail for the Piemonte region. The 120 total detected weed species fell within the range of 75-124 species found in previous studies for other summer crops (Frick and Thomas, 1992; Zanin et al., 1997; Viggiani et al., 1998). Since both the entire area and Piemonte region surveys recorded a similar number of species, this parameter seemed unrelated to survey area size. Despite the high simplification in Italian maize cropping systems currently, the number of observed weed species was great. A number of factors may contribute to this effect: high agronomic practice variation, even in maize mono-cropping, farm fragmentation, and pedological and climatic conditions that vary at both the farm and territory levels. A study conducted in France by Fried et al. (2008) showed weed species diversity and composition were particularly influenced by crop type and the crop preceding maize in the rotation.

Only some of the many species found were widespread. Indeed, only five weed species were recorded in more than 50% of the surveyed sites. Among these, only one grass weed was highly diffused (*E. crus-galli*); it is common to crop fields worldwide because of its ability to germinate and flower in different environmental conditions (Keeley and Thullen, 1989). This study found that grass weeds constituted one-third of the nine weed species present on more than 25% of the surveyed sites, which agreed with the prevalence of broad-leaved species seeds discussed in a previous study undertaken on the seedbank of an Italian field after five years of maize cultivation (Bàrberi et al., 1998). Many experiments associate high grass weed counts with reduced input cultivation systems, while broad-leaved species predominate in conventional plowed systems (Froud-Williams et al., 1983; Mohler, 1993; Bàrberi et al., 1998). Italian maize fields are typically plowed, which may explain broad-leaved weed preponderance; another explanation may be their higher seed longevity and persistence in soil compared to that of grass weeds (Burnside et al., 1996). For broad-leaved species, this survey confirmed the findings of previous studies (Viggiani et al., 1998) as it showed the ubiquitous characteristic of *C. album*. In fact, this species was the most dispersed probably due to its abundant seed production and longevity (Clements et al., 1996). In fact, *C. album* is one of the five most widespread weeds globally, the seventh most abundant in maize, and one of the most troublesome weeds in the U.S. corn belt (Forcella et al., 1992; Clements et al., 1996).

4.2. Weed infestation and maize sowing time

Maize sowing time showed it had an important effect on weed community composition—enhancing or reducing the presence of different species. In this study, early sowing of maize is a practice widely used in northern Italy. This study detected a different weed community composition depending on maize sowing time as other studies have demonstrated (Otto et al., 2009). At early sowing time some species were encountered more frequently than others. *E. crus-galli* was one such species, probably because it is able to emerge rapidly, even at temperatures characteristic of early March (about 15 °C) (Keeley and Thullen, 1989). The same holds for *F. convolvulus* and other Polygonaceae species, for which low temperatures induce high emergence flushes (Metzger, 1992).

4.3. Weed species and pedo-climatic parameters

The results of the study highlighted some relationships among the weed indices and pedo-climatic parameters of the surveyed sites, as observed in previous studies (Andreasen et al., 1991; Cimalová and Lososová, 2009). However, the correlations described in those studies were generally moderate and did not allow clarification of the precise relationships among the parameters. It is, nevertheless, possible to hypothesize that interactions may be hidden by agronomic practice effects, for which information was not available. Other studies have demonstrated effects from certain agronomic practices, such as soil fertilization or weed community tillage (Andersson and Milberg, 1998; Hyvönen and Salonen, 2002; Cimalová and Lososová, 2009).

The few significant relationships found among some macroscopic weed indices and pedo-climatic parameters (i.e., mono/dicot ratio and soil texture, Simpson indices and climatic classification) have importance. For example, soil reaction was proved to affect weed community composition either directly or indirectly by changing the availability of different soil nutrients (Buchanan et al., 1975; Dieleman et al., 2000). Correlation analysis results indicated that a higher and a lower number of monocots were found in sand and clay soils, respectively. In addition, a lower mono/dicots ratio was found in soils dealing with a higher pH value.

Both PCA and discriminant analysis also confirmed the existence of relationships among the weed indices and some pedo-climatic traits. For example, discriminant analysis provided a good classification of the surveyed sites on the basis of weed indices using soil parameters as predictor variables. In particular, soil texture, *CEC*, as well as pH and some nutrient contents, resulted significant predicting many weed indices. Furthermore, discriminant analysis successfully classified the sites based on the density of *E. crus-galli* using two soil parameters, namely *Mg/K* and *CEC*.

Finally, mean annual precipitation and mean annual temperature affected weed species composition as observed in previous studies, even though they appear not to be the main source of weed community variation (Cimalová and Lososová, 2009).

4.4 Conclusions

In general, many factors impact weed community dynamics; in particular, management practices, soil tillage, and crop type play important roles. This study highlighted not only the diversity of weed species in Italian maize, but also the importance of pedological and climatic factor contributions to weed species variation. Study analyses did establish some relationships between certain weed indices and pedo-climatic parameters, however, it also demonstrated the particular difficulty associated with distinguishing single factor effects. Weed community variation seems to result from an interaction of different cropping and pedo-climatic aspects. Further studies are needed to better clarify these relationships as this information may improve the predictability of weed flora composition based on the environmental characteristics of a certain area.

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Figure

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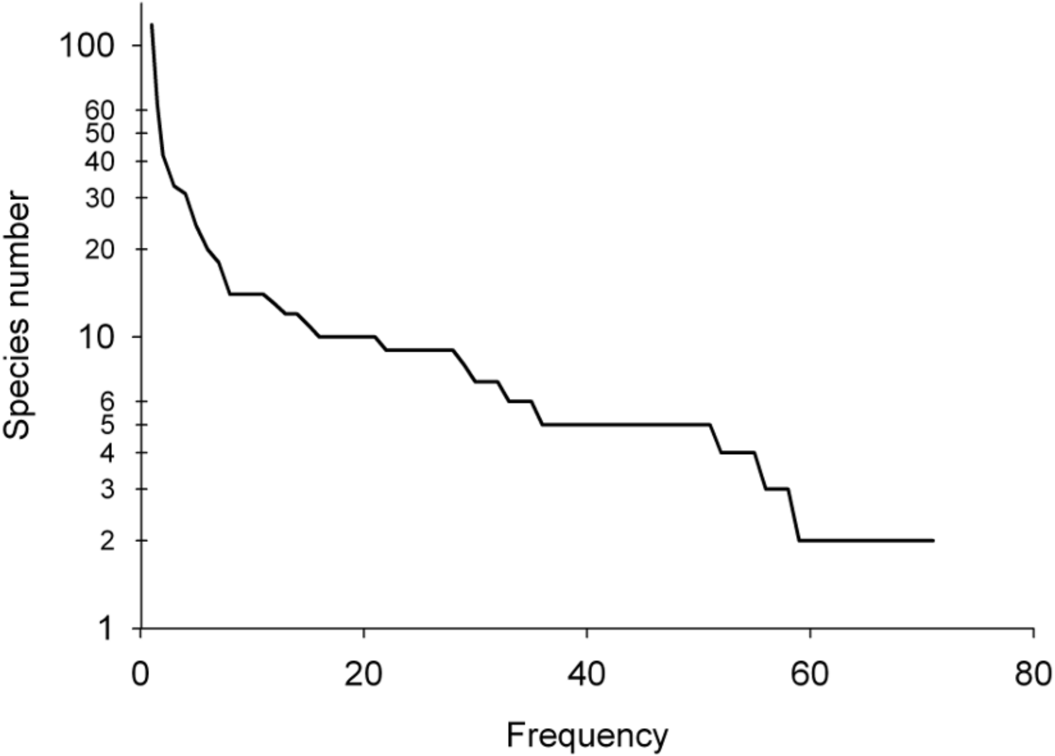

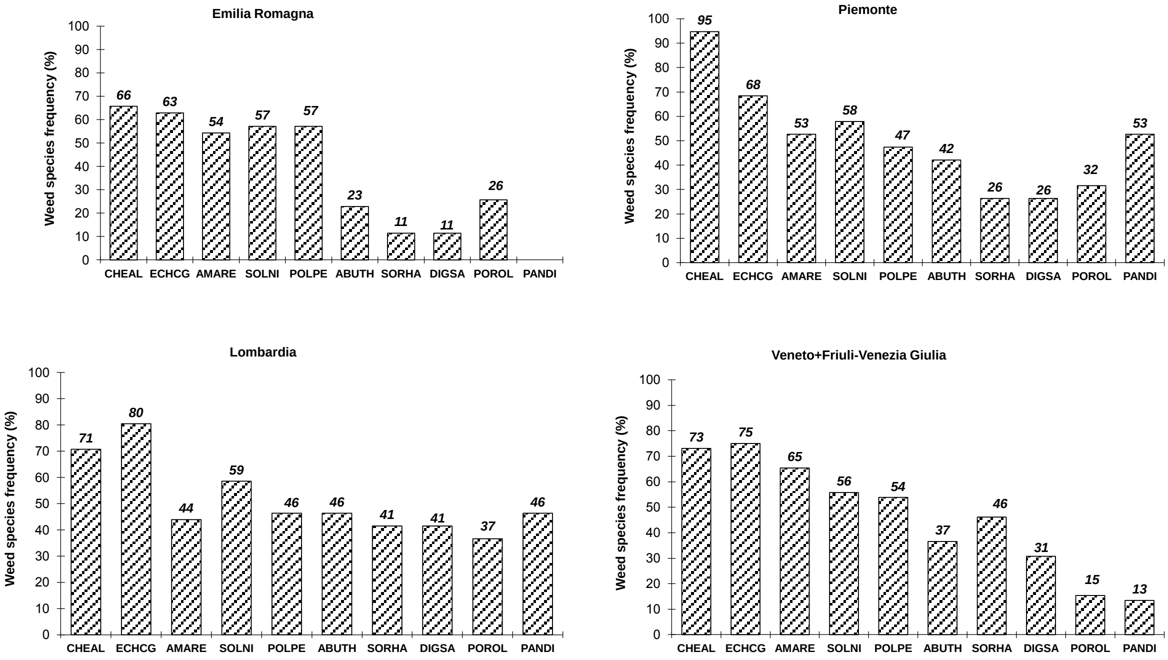
Emilia Romagna
Weed species frequency (%)
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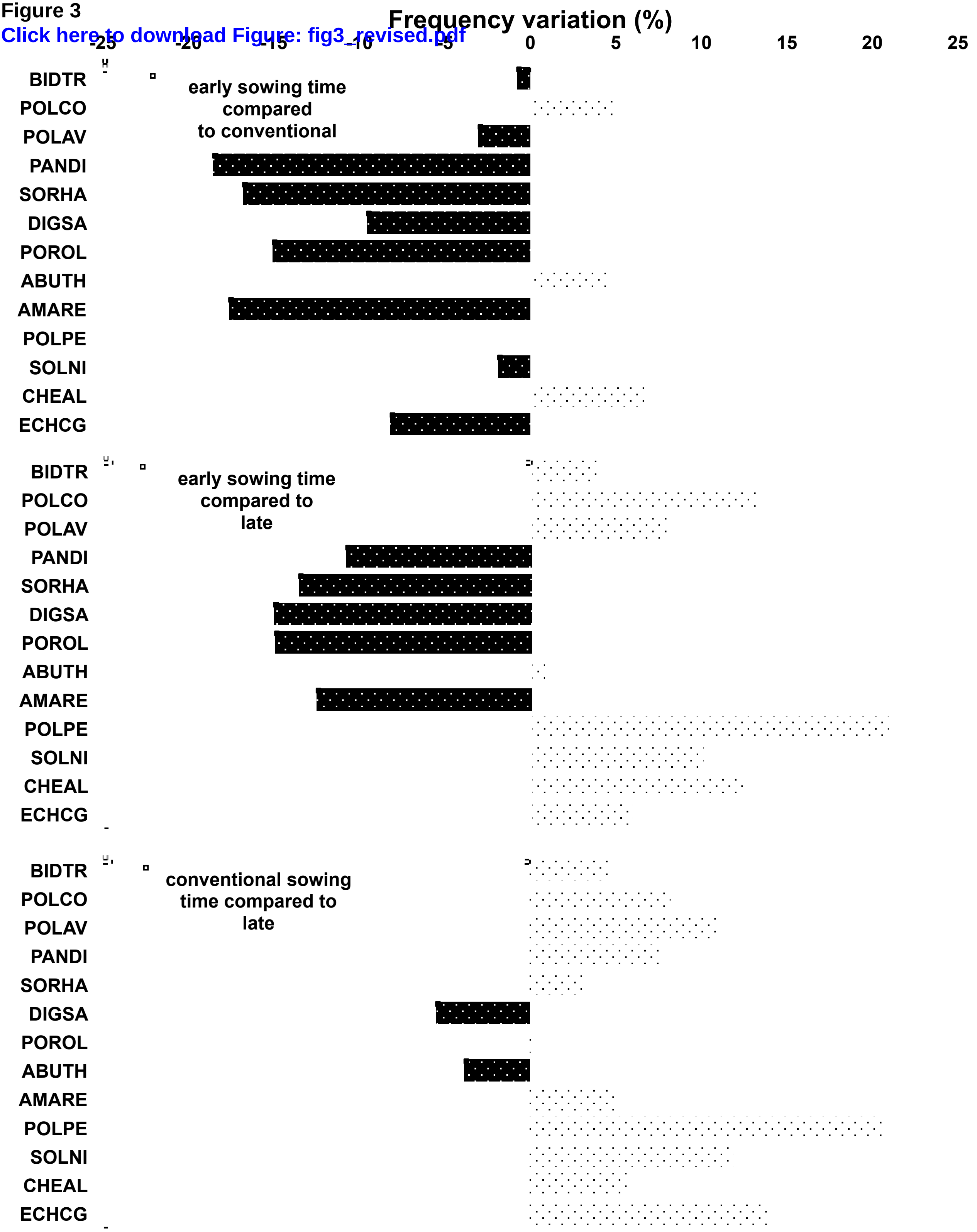
10
20
30
40
50
60
70
80
90
100
66
63
54
57
57
23
11
11
26
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI
Piemonte
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
95
68
53
58
47
42
26
26
32
53
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI
Lombardia
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
71
80
44
59
46
46
41
41
37
46
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI
Veneto+Friuli-Venezia Giulia
Weed species frequency (%)
0
10
20
30
40
50
60
70
80
90
100
73
75
65
56
54
37
46
31
15
13
CHEAL
ECHCG
AMARE
SOLNI
POLPE
ABUTH
SORHA
DIGSA
POROL
PANDI

Figure 3


Frequency variation (%)
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-20
-15
-10
-5
0
5
10
15
20
25
early sowing time compared to conventional
early sowing time compared to late
conventional sowing time compared to late
BIDTR
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POLAV
PANDI
SORHA
DIGSA
POROL
ABUTH
AMARE
POLPE
SOLNI
CHEAL
ECHCG

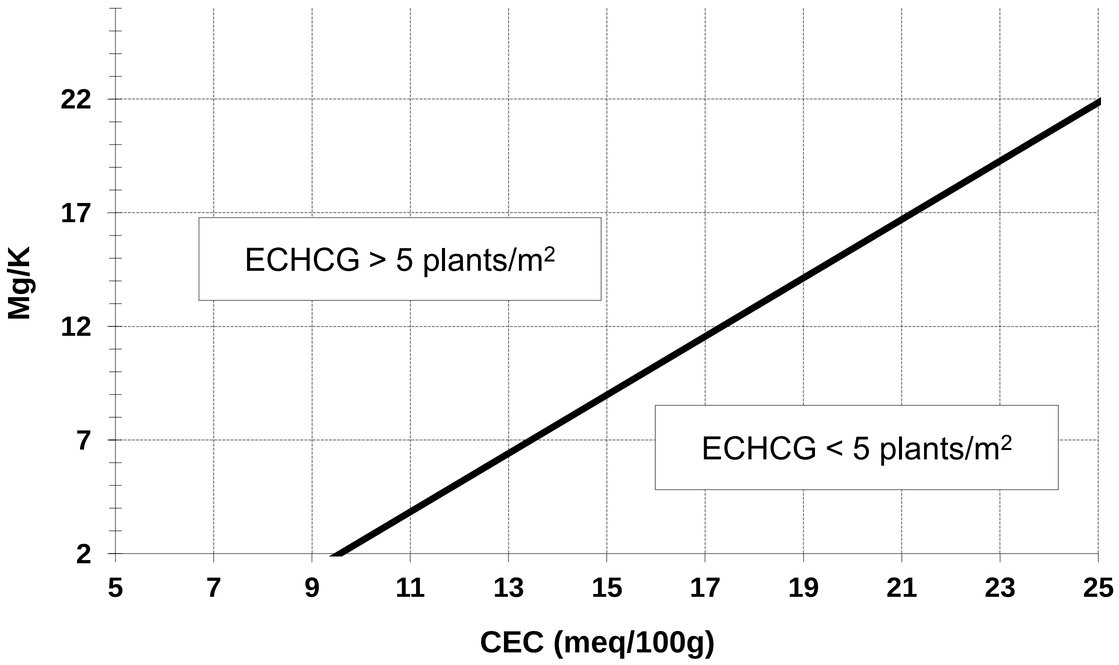
22
17
12
7
2
Mg/K
5
7
9
11
13
15
17
19
21
23
25
CEC (meq/100g)
ECHCG > 5 plants/m2
ECHCG < 5 plants/m2

Figure 5

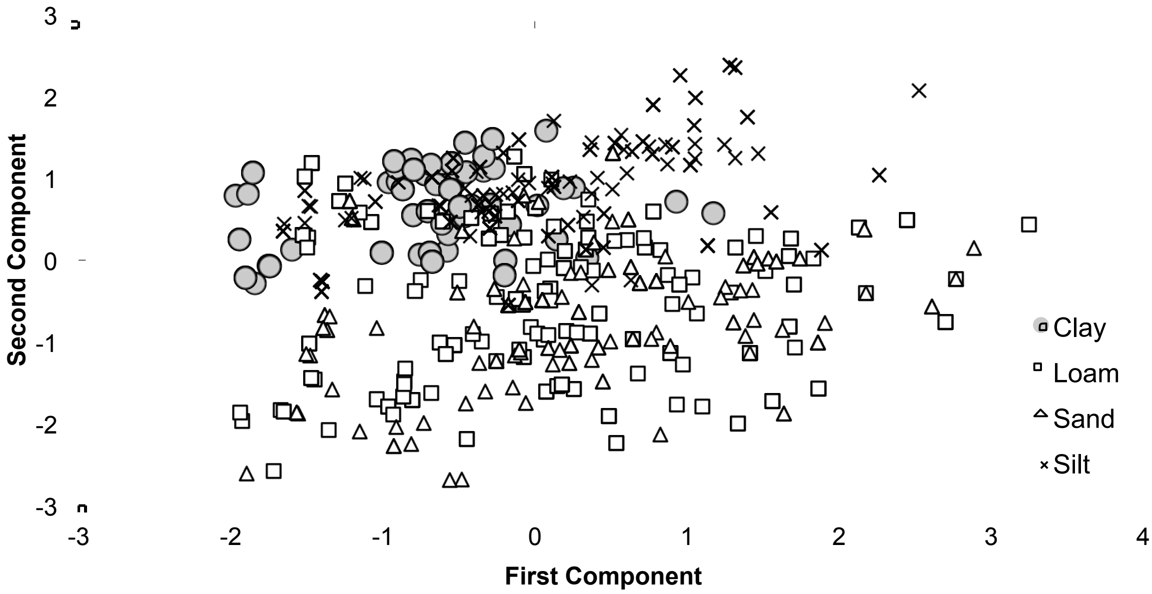
3
2
1
0
-1
-2
-3
Second Component
-3
-2
-1
0
1
2
3
4
First Component
● Clay
□ Loam
△ Sand
× Silt

Table 1. Weed, pedological, and climatic variables considered in the study.

variables	**code**	**Unit of measurement**	**dataset** **ITA**	 **PIE**	**Calculation method** [(1)]
Weed indices					
Total weed density	*dentot*	plants/m^2		X	
Number of weed species	*nspec*	n^a	X	X	
Mean weed density of the present species	*aden*	plants/m^2		X	$dentot/nspec$
Weed density of the single species	n_i	plants/m^2		X	
Number of species contributing for more than 5% and 10%	*con*5 *con*10	n		X	$con5=\sum ` i$ ; for $n_i \geq (0.05 \cdot dentot)$ $con10=\sum ` i$; for $n_i \geq (0.10 \cdot dentot)$
Simpson index	*SI*	ad^b		X	$SI=\sum(n_i/dentot)$
Shannon index	*H'*	ad		X	$H'=-\sum[(n_i/dentot)\cdot \ln(n_i/dentot)]$
Numbers of MONOCOT species	*nmono*	n	X	X	
Numbers of DICOT species	*ndico*	n	X	X	
Number of MONCOT/DICOT species ratio	*nmon_dic*	ad	X	X	$nmono/ndico$
Total MONOCOT density	*dmono*	plants/m^2		X	
Total DICOT density	*ddico*	plants/m^2		X	
MONOCOT/DICOT density ratio	*dmon_dic*	ad		X	$dmono/ddico$
Pedological indices					
Sand	*sand*	%	X	X	
Silt	*silt*	%	X	X	
Clay	*clay*	%	X	X	
pH	*pH*		X	X	
Organic matter content	*SO*	%		X	
Total nitrogen	*Ntot*	%		X	
Mg/K ratio	*Mg/K*	ad		X	
Assimilable phosphorous	*Pass*	ppm		X	
Cation exchange capacity	*CEC*	meq/100g		X	
Carbon/Nitrogen ratio	*C/N*	ad		X	
Climatic indices					
Total annual precipitation	*Ptot*	mm		X	
Anuual mean temperature	*Tavg*	°C		X	
Thornthwaite climatic classification	*Thorn*	ad		X	

[a]n indicates number of species; [b]ad indicates adimensional

Table 2. Frequency of encounters for the most diffused weed species across all surveyed sites (site number in which a weed species was present relative to total surveyed sites).

Species	**Encounter frequency (%)**
Chenopodium album	71.6
Echinochloa crus-galli	71.6
Amaranthus retroflexus	58.6
Solanum nigrum	55.6
Persicaria maculosa	50.0
Abutilon theophrasti	35.5
Sorghum halepense	32.5
Digitaria sanguinalis	29.6
Portulaca oleracea	28.4
Panicum dichotomiflorum	21.3
Fallopia convolvulus	15.4
Polygonum aviculare	14.8
Setaria glauca	12.4
Bidens tripartita	11.8
Convolvulus arvensis	7.7

Table 3. Significance values (P) and Pearson correlation coefficients (r) (in brackets), of the relationships among some pedological parameters and weed indices for the ITA and PIE datasets (P≤0.05).

	ITA		*PIE*	
	nmono	*nmon_dic*	*dmono*	*dmon_dic*
pH	<0.001 (-0.299)	<0.001 (-0.330)	0.273 (-0.124)	0.001 (-0.352)
sand	<0.001 (0.364)	<0.001 (0.285)	0.003 (0.324)	0.086 (0.193)
silt	<0.001 (-0.150)	0.018 (-0.090)	0.045 (-0.224)	0.570 (-0.065)
clay	<0.001 (-0.364)	<0.001 (-0.303)	0.006 (-0.303)	0.025 (-0.251)

Table 4. Pedo-climatic variables for which significant relationships were found according to discriminant analysis and threshold value dividing the two categories.

Separation variables	Estimators	Percentage of correct classification[a]	Threshold value[b]
ITA dataset			
nmono	*sand*	61.9	1
nmon_dic	*clay*	69.0	25
PIE dataset			
	pH	71.4	0.25
SI			
dmono	*sand*	67.9	70
dmon_dic	*Pass*	64.3	50
POLPE density	*Ntot*	64.3	5
ECHCG density	*Mg/K; CEC*	75.0	5
STEME density	*CEC*	82.0	5
PANDI density	*pH*	64.3	5
Thorn	*aden, SI, nmondic*	76.0	

[a] Percentage of sites used for validation (sites not used to build the discriminant function) and percentage correctly classified.

[b] Values equal or below threshold belonged to category 1, values above belonged to category 2.

Table 5. Component matrix of the first two principal components relative to surveyed sites (pedological and weed indices) and their respective loads.

Variables	**Component**	
	1	**2**
pH	-0.465	0.425
sand	0.280	-0.942
silt	0.108	0.807
clay	0.470	0.589
nspec	0.204	-0.033
nmono	0.863	-0.122
ndico	-0.249	0.014
nmon_dic	0.871	-0.053