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UNIVERSITÀ DEGLI STUDI DI TORINO

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

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12 Abstract

32

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.

20 Of the approximate 120 species found, just five were present on more than 50% of sites:

21 Chenopodium album, Echinochloa crus-galli, Amaranthus retroflexus, Solanum nigrum,

22 and *Persicaria maculosa*. Indices were calculated to describe weed community structure:

23 total weed species count, monocotyledonous and dicotyledonous species counts, and total

24 weed density. Additional soil and climate site data were collected or obtained from regional

25 databases: pH reaction, texture, organic matter content, total nitrogen, Mg/K ratio,

assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio, annual total

27 precipitation, annual mean temperature, and Thornthwaite climate classification. Pedo-

28 climatic traits and weed indices relationships were investigated using linear correlation

analysis (CA), discriminant analysis (DA), and principal component analysis (PCA).

30 CA and PCA highlighted a weak bias (higher count and density) by monocotyledonous

31 species for sand and alkaline soils, while clay and alkaline soils favored dicotyledonous

33 predictor variables, in particular for a Piemonte region (northwest Italy) data subset. Soil

species. DA classified the sites well based on weed indices using soil parameters as

34 texture, CEC, pH, and some nutrient contents significantly predicted some weed indices.

35 This study pointed out that Italian maize field weed communities are influenced by some

36 pedoclimatic traits; the weak relationships observed might be mitigated by the overall

37 influence of crop practices on weed dynamics.

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

40 **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).

47 Maize (Zea mays L.) is one of the most important herbaceous crops in Italy and was 48 cultivated on about 908,000 hectares in 2013 (ISTAT, 2014). Its cultivation is mainly 49 concentrated in the Po River plain, where it represents upwards of 90% of the total Italian 50 maize area (ISTAT, 2014). Soil fertility levels and environmental features that characterize 51 different maize cultivation areas can affect both the crop and its related weeds. Indeed, 52 weed communities vary with crop area pedological and climatic traits (Walter et al., 2002). 53 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 54 55 particular soils (such as, *Digitaria sanguinalis* for acid soil), environments, and crop 56 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 57 of specific needs, which allow them to grow in different environments (Holzner, 1978). This 58 59 contest begs verification of the possible relationships between weed infestation in a field 60 and the pedo-climatic characteristics of the site. Such an exploration should consider not 61 only the most widespread weed species, but also the entire floral composition of the weed 62 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).

70 Previous studies have shown the existence of a correlation between some weed species 71 and soil characteristics, even at the field scale (Andreasen et al., 1991; Heisel et al., 1999; 72 Albrecht and Auerswald, 2003). Some authors found that, for example, clay content was 73 correlated with Alopecurus myosuroides, Veronica hederifolia, Equisetum arvense, and 74 Poa annua densities (Nordmeyer and Dunker, 1999; Walter et al., 2002). The ability to 75 confirm the presence of these relationships can be difficult, especially on a large scale, 76 despite considerable information can be achievable on any infestation in a given territory. 77 Data hurdle examples include the following: lack of soil nature information for all areas, soil 78 property effects not easily discernable from those of other environmental factors, and 79 limited knowledge of the agronomic practices applied in the years prior to survey (Zanin et 80 al., 1988; Andreasen et al., 1991; Suárez et al., 2001).

81 This last aspect is probably the major limiting factor, but also one of the most important 82 because the agronomic history of a particular site can strongly affect the relationships 83 between weed community, soil, and climate (Buhler, 1995; Pyšek et al., 2005). Weed 84 infestation changes due to management practices and to environmental conditions of a 85 cultivated area make crucial the study of weed community composition to improve weed 86 control (Saavedra et al., 1990). In fact, accurate knowledge on the weed community 87 variability of a certain area may result in a more accurate tuning of sustainable weed 88 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).

94 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, 95 96 2009). For example, annual precipitation and temperature are two important factors that 97 may influence weed composition (Cimalová and Lososová, 2009). However, it has been 98 established that management practices, such as soil tillage and crop rotation explain the 99 majority of weed community variation across different soil typologies (Fried et al., 2008). 100 Few weed surveys exist on Italian maize fields (Zanin et al., 1992; Zanin et al., 1997). 101 Similarly, there is a dearth of knowledge on the change of its weed community composition 102 in response to pedo-climatic factors. The aim of the present study was to verify the 103 existence of relationships between weed communities and some pedological and climatic 104 traits in different Italian maize cultivation areas. The influence of sowing time on weed 105 community composition was also evaluated.

106

107 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 m²) were considered.

114

115 2.1 Data collection

116 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 117 118 recorded weed species was used. The collected data were organized into two distinct 119 datasets: one named "ITA" relative to fields located in the eight most important Italian 120 maize cultivation regions (Piemonte, Lombardia, Veneto, Friuli Venezia Giulia, Emilia-Romagna, Lazio, Toscana, and Umbria), and another called "PIE," which was limited to 121 122 fields situated in the Piemonte region. The ITA dataset comprised data collected on 455 123 fields spread on 170 localities, while the PIE dataset involved 80 fields. For all sites, weed, 124 soil, and climatic data were collected or obtained from regional databases. 125 Due to the large heterogeneity of data included in the ITA dataset, only weed community 126 variables common to all sites and dates were considered, namely total weed species 127 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 128 129 common protocol. For this reason, some additional weed community data (such as, weed 130 species density) was included. 131 For both datasets, weed data were obtained from counts carried out on four 0.5 x 0.5 m 132 square areas randomly placed in each plot. 133 Soil properties were also considered in the study for each site; in particular, soil reaction 134 (pH) and texture (relative proportions of sand, silt, and clay) were acquired for both 135 surveys. For the fields comprising dataset PIE, a number of other soil properties, namely 136 organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation 137 exchange capacity (CEC), and C/N ratio were obtained from the Regione Piemonte soil 138 database. For dataset PIE, some climatic parameters (annual total precipitation, annual 139 mean temperature, and climate classification per Thornthwaite (1948)) were obtained from

140 the Regione Piemonte Agrometeorological network.

141

142 2.2 Data analyses

143 At each site, some indices of weed species diversity were calculated (Table 1). For both 144 datasets, the number of species (nspec), number of monocotyledonous (nmono) and 145 dicotyledonous species (ndico), and the ratio between mono- and dicotyledonous species 146 (*nmon dic*) were determined. Additional indices relative to each weed species density 147 were calculated for dataset PIE (Table 1). For each site in the survey, both the total 148 number of species and the frequency of species-specific encounters (percentage of sites 149 that included the species *n* over the total number of sites) were determined. For sites in 150 which different maize sowing times were available, species frequency was calculated only 151 for those species with a frequency above 25% (13 species).

152 The relationships between surveyed site weed species and pedo-climatic parameters were 153 determined using three statistical methods. Initially, a series of linear correlations were 154 determined for each pair of weed indices and pedo-climatic parameters, excluding the 155 Thornthwaite climate categorical variable (*Thorn*). The significance of the correlation and 156 Pearson's r correlation coefficient were calculated. Afterwards, the collected data were 157 submitted to discriminant analysis to verify, through pedological and climatic parameters 158 (predictors), the potential to classify sites as a function of the weed indices (discriminant 159 variables). These indices, derived from continuous or categorical variables with a high 160 number of categories, were transformed into new categorical variables with four, three, or 161 two modalities, such that each site was classified by four, three, or two categories. 162 Considering the Thornthwaite climate classification (*Thorn*) as the discriminant variable 163 and weed indices as the predictors allowed discriminant analysis performance. This 164 procedure was necessary because the *Thorn* variable was already categorical. Another 165 method, Principal Component Analysis (PCA), was applied only to the ITA dataset to 166 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.

- 171
- 172 3. Results

173 *3.1 Weed community diversity*

174 The total number of encountered species was similar for both surveys (ITA and PIE) and 175 equaled approximately 120. However, among the species in the ITA dataset, only nine 176 were present on more than 25% of the surveyed sites (Figure 1). Only five species were 177 observed on more than 50% of the sites, and no species were found on more than 72% of 178 the surveyed area. The most widespread species, ranked by diffusion (Table 2), were 179 Chenopodium album and Echinochloa crus-galli (encounter frequencies above 70%), 180 followed by Amaranthus retroflexus, Solanum nigrum, and Persicaria maculosa. As was 181 true for encountered species, both dataset surveys showed similar trends in weed species 182 frequency. Specifically, only a few species in Emilia Romagna region had high frequency 183 values in dataset ITA, as opposed to Piemonte region where a high diffusion (95% 184 frequency) of C. album was observed. In Lombardia a more homogeneous pattern of the 185 most diffused weeds was detected, while in Veneto, and Friuli Venezia Giulia regions the 186 trend were more intermediate in nature (Figure 2).

187 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

190 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

192 showed higher frequencies of *C. album*, *Abutilon theophrasti*, and *Fallopia convolvulus* at

193	early sowing versus conventional sowing time, even though the three species had
194	frequency variations below 10%. Moreover, fields at the early sowing time demonstrated
195	remarkably lower frequency of encounters for Panicum dichotomiflorum, Sorghum
196	halepense, A. retroflexus, and Portulaca oleracea (Figure 3). In general, observations at
197	early sowing compared to late sowing found a greater presence of the species belonging
198	to the Polygonaceae family (P. maculosa, P. aviculare, and F. convolvulus), in addition to
199	E. crus-galli, C. album, and S. nigrum. In particular, frequency varied 21% for P. maculosa
200	at early sowing time compared to delayed sowing time (Figure 3). Observations at
201	conventional sowing compared to late sowing showed an even higher number of species
202	occurring more frequently, including P. dichotomiflorum, S. halepense and A. retroflexus
203	(Figure 3).
204	
205	3.3 Weed species and pedo-climatic parameters

- 206 3.3.1. Linear correlation analysis
- 207 Linear correlation analysis identified some significant relationships between the
- 208 pedological parameters *pH, sand, silt* and *clay* and some weed indices (Table 3). For the
- 209 ITA dataset, height such correlations were found to be significant; five were identified in
- 210 the PIE dataset. In ITA dataset, positive significant correlation was found between sand
- 211 and *nmono* and between *sand* and *nmon_dic* (r =0.364, r =0.285, respectively). All the
- 212 other correlations were negative. In PIE dataset, positive significant correlation was found
- 213 only between sand and dmono (r = 0.324). In general, even though the correlations found
- 214 were highly significant in some cases, the Pearson correlation coefficients were rather low,
- 215 which indicated strong data variability.
- 216 3.3.2. Discriminant analysis

217 Among the pedo-climatic parameters, discriminant analysis detected some statistical 218 predictors valid for both datasets (Table 4). The ITA dataset discriminant functions using 219 soil property parameters sand and clay properly classified the sites (60-70% of correct site 220 classification) and predicted based on variables *nmono* and *nmon* dic which category the 221 sites should have been included. Classification accuracy was guite constant considering 222 that the two weed indices were subdivided in four, three, or two categories. However, 223 when, the indices were subdivided into more than two categories, prediction accuracy was 224 higher for the extreme classes. Indeed, the most accurate classification was observed for 225 the sites with very high or very low numbers of monocotyledonous species. For this 226 reason, the number of final categories was reduced to two. In the case of ITA dataset, a 227 *nmono* threshold value of 1 was set to divide the dataset in the two categories: sites with 228 up to one monocotyledonous species were classified in the first category, while sites with 229 more than one monocotyledonous species were classified in the second category. In these 230 conditions about 67% of sites (304) fall in the first category. The accuracy site 231 classification considering only two categories comprised between 62% and 82% of both 232 datasets. 233 Discriminant analysis in PIE produced the best results when each weed variable was 234 composed of only two categories (i.e. high and low weed densities). Accurate predictions 235 of classes to which the sites pertained was obtained using several variables and 236 predictors: SI and P. dichotomiflorum density with pH, dmono with sand, dmon dic with 237 Pass, P. maculosa density with Ntot, E. crus-galli density with Mg/K and CEC, and 238 Stellaria media density with CEC (Table 4). In the case of the ratio between 239 monocotyledonous and dicotyledonous density (*dmon dic*), the discriminant analysis 240 correctly classified about 75% of sites in the lowest weed density category (data not 241 shown). For most analyses, the discriminant function included only one pedological 242 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).

251 When used as a separation variable, parameter Thorn was reclassified by reducing the 252 initial five categories to two categories into which the various sites could be classified. 253 These were referred to more humid-tending sites (merging the sites falling into the 254 categories B4B1rb3 and B4B2rb3) and less humid-tending sites (merging the sites falling into the categories C1B2sb3, C2B1rb3, C2B2rb3) according to the Thornthwaite climate 255 256 classification (Thornthwaite, 1948). Using this classification, the weed indices aden, SI, 257 and *nmon_dic* proved to be good predictors, with, about 60% and 70% of the sites 258 correctly classified into generally more humid areas and generally less humid areas, 259 respectively. In general, in the more humid sites both a higher number of weed species 260 (low SI values) and a prevalence of monocotyledonous were observed, in contrast with 261 what was recorded for the less humid sites.

262

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

- 269 with *clay*, and high negative correlation with *sand*. Figure 5 shows a representation in bi-
- 270 dimensional space of these first two components, in which the sites were indicated with
- 271 symbols referring to their actual soil texture (clay, silt, sand, and loam).
- 272 The majority of sites with clay soils were concentrated around near slightly negative values
- 273 of the first component, indicating that in these sites the monocotyledonous species were
- 274 less abundant, both in absolute and relative terms to the dicotyledonous species number.
- 275 The cloud formed by sites with other soil textures (silt, sand, and loam) showed a more
- 276 spread arrangement, moving from negative to positive values of first component. This
- 277 suggests that in sites with soil different from clay, weed indices are basically not influenced
- 278 by soil texture.
- 279

280 4. Discussion

281 4.1 Weed community diversity

282 Study results made it possible to characterize the weed vegetation of maize fields in the 283 main Italian areas of crop cultivation, and in detail for the Piemonte region. The 120 total 284 detected weed species fell within the range of 75-124 species found in previous studies for 285 other summer crops (Frick and Thomas, 1992; Zanin et al., 1997; Viggiani et al., 1998). 286 Since both the entire area and Piemonte region surveys recorded a similar number of 287 species, this parameter seemed unrelated to survey area size. Despite the high 288 simplification in Italian maize cropping systems currently, the number of observed weed 289 species was great. A number of factors may contribute to this effect: high agronomic 290 practice variation, even in maize mono-cropping, farm fragmentation, and pedological and 291 climatic conditions that vary at both the farm and territory levels. A study conducted in 292 France by Fried et al. (2008) showed weed species diversity and composition were 293 particularly influenced by crop type and the crop preceding maize in the rotation.

294 Only some of the many species found were widespread. Indeed, only five weed species 295 were recorded in more than 50% of the surveyed sites. Among these, only one grass weed 296 was highly diffused (E. crus-galli); it is common to crop fields worldwide because of its 297 ability to germinate and flower in different environmental conditions (Keeley and Thullen. 298 1989). This study found that grass weeds constituted one-third of the nine weed species 299 present on more than 25% of the surveyed sites, which agreed with the prevalence of 300 broad-leaved species seeds discussed in a previous study undertaken on the seedbank of 301 an Italian field after five years of maize cultivation (Barberi et al., 1998). Many experiments 302 associate high grass weed counts with reduced input cultivation systems, while broad-303 leaved species predominate in conventional plowed systems (Froud-Williams et al., 1983; 304 Mohler, 1993; Bàrberi et al., 1998). Italian maize fields are typically plowed, which may 305 explain broad-leaved weed preponderance; another explanation may be their higher seed 306 longevity and persistence in soil compared to that of grass weeds (Burnside et al., 1996). 307 For broad-leaved species, this survey confirmed the findings of previous studies (Viggiani 308 et al., 1998) as it showed the ubiquitous characteristic of C. album. In fact, this species 309 was the most dispersed probably due to its abundant seed production and longevity 310 (Clements et al., 1996). In fact, *C. album* is one of the five most widespread weeds 311 globally, the seventh most abundant in maize, and one of the most troublesome weeds in 312 the U.S. corn belt (Forcella et al., 1992; Clements et al., 1996).

313 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).

323 *4.3. Weed species and pedo-climatic parameters*

324 The results of the study highlighted some relationships among the weed indices and pedo-325 climatic parameters of the surveyed sites, as observed in previous studies (Andreasen et 326 al., 1991; Cimalová and Lososová, 2009). However, the correlations described in those 327 studies were generally moderate and did not allow clarification of the precise relationships 328 among the parameters. It is, nevertheless, possible to hypothesize that interactions may 329 be hidden by agronomic practice effects, for which information was not available. Other 330 studies have demonstrated effects from certain agronomic practices, such as soil 331 fertilization or weed community tillage (Andersson and Milberg, 1998; Hyvönen and 332 Salonen, 2002; Cimalová and Lososová, 2009).

333 The few significant relationships found among some macroscopic weed indices and pedo-

334 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

337 soil nutrients (Buchanan et al., 1975; Dieleman et al., 2000). Correlation analysis results

338 indicated that a higher and a lower number of monocots were found in sand and clay soils,

339 respectively. In addition, a lower mono/dicots ratio was found in soils dealing with a higher

340 pH value.

341 Both PCA and discriminant analysis also confirmed the existence of relationships among

342 the weed indices and some pedo-climatic traits. For example, discriminant analysis

343 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 *Ma/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).

351 *4.4 Conclusions*

352 In general, many factors impact weed community dynamics; in particular, management 353 practices, soil tillage, and crop type play important roles. This study highlighted not only 354 the diversity of weed species in Italian maize, but also the importance of pedological and 355 climatic factor contributions to weed species variation. Study analyses did establish some 356 relationships between certain weed indices and pedo-climatic parameters, however, it also 357 demonstrated the particular difficulty associated with distinguishing single factor effects. 358 Weed community variation seems to result from an interaction of different cropping and 359 pedo-climatic aspects. Further studies are needed to better clarify these relationships as 360 this information may improve the predictability of weed flora composition based on the 361 environmental characteristics of a certain area.

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Figure 3 Click here	Freq یو down/gad Figyte: fig3_7evised.	uency variation (%)
BIDTR	early sowing time	8
POLCO	compared	
POLAV	to conventional	
PANDI		
SORHA		
DIGSA		
POROL		
ABUTH	_	
AMARE		
POLPE		
SOLNI		
CHEAL		<u></u>
ECHCG		
BIDTR	early sowing time	2011 - 11 - 11 - 11 - 11 - 11 - 11 - 11
POLCO	compared to	
POLAV	late	
PANDI		
SORHA		
DIGSA		
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ABUTH		
AMARE		
POLPE		
SOLNI		
CHEAL		
ECHCG	-	
BIDTR	<u>و،</u> conventional sowing	
POLCO	time compared to	
POLAV	late	141414141414141414141414141
PANDI		
SORHA		
DIGSA	1	
POROL		
ABUTH		
AMARE		
POLPE		
SOLNI		
CHEAL		
ECHCG	_	





			data	aset	
variables	code	Unit of measurement	ITA	PIE	Calculation method ⁽¹⁾
Weed indices					
Total weed density	dentot	plants/m ²		Х	
Number of weed	nspec	n ^a	Х	Х	
Mean weed density of the present species	aden	plants/m ²		Х	dentot / nspec
Weed density of the	n _i	plants/m ²		Х	
Number of species	con5	n		Х	$con5 = \sum i$; for
than 5% and 10%	contu				$n_i \ge (0.05 \cdot dentot)$
					$con10 = \sum i$; for
Simpson indev	SI	odb		V	$n_i \ge (0.10 \cdot dentot)$
Simpson index	31	au		^	$SI = \sum (n_i/dentot)$
Shannon index	H'	ad		Х	$H' = -\sum [(n_i/dentot) \cdot \ln(n_i/dentot)]$
Numbers of MONOCOT species	nmono	n	Х	Х	
Numbers of DICOT	ndico	n	Х	Х	
Number of MONCOT/DICOT	nmon_dic	ad	Х	Х	nmono/ ndico
Total MONOCOT	dmono	plants/m ²		Х	
Total DICOT density	ddico	plants/m ²		Х	
MONOCOT/DICOT density ratio	dmon_dic	ad		Х	dmono/ddico
Pedological indices					
Sand	sand	%	Х	Х	
Silt	silt	%	Х	Х	
Clay	clay	%	Х	Х	
рН	рĤ		Х	Х	
Organic matter	SO	%		Х	
Total nitrogen	Ntot	%		Х	
Mg/K ratio	Ma/K	ad		х	
Assimilable	Pass	ppm		X	
Cation exchange	CEC	meq/100g		Х	
Carbon/Nitrogen ratio	C/N	ad		Х	
Total annual	Ptot	mm		Х	
Anuual mean	Tavg	°C		Х	
temperature Thornthwaite climatic classification	Thorn	ad		Х	

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

^an indicates number of species; ^bad 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 (%) 71.6
	71.0
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

- 1 Table 3. Significance values (P) and Pearson correlation coefficients (r) (in brackets), of
- 2 the relationships among some pedological parameters and weed indices for the ITA and
- 3 PIE datasets (P≤0.05).
- 4
- 5

	רו	⁻ A	P	IE
<mark>рН</mark>	<mark>nmono</mark> <0.001 (-0.299)	<mark>nmon_dic</mark> <0.001 (-0.330)	<mark>dmono</mark> 0.273 (-0.124)	<mark>dmon_dic</mark> 0.001 (-0.352)
sand	<mark><0.001 (0.364)</mark>	<mark><0.001 (0.285)</mark>	<mark>0.003 (0.324)</mark>	<mark>0.086 (0.193)</mark>
<mark>silt</mark>	<mark><0.001 (-0.150)</mark>	<mark>0.018 (-0.090)</mark>	<mark>0.045 (-0.224)</mark>	<mark>0.570 (-0.065)</mark>
<u>clay</u>	<mark><0.001 (-0.364)</mark>	<mark><0.001 (-0.303)</mark>	<mark>0.006 (-0.303)</mark>	<mark>0.025 (-0.251)</mark>

- 6 Table 4. Pedo-climatic variables for which significant relationships were found according to
- 7 discriminant analysis and threshold value dividing the two categories.
- 8

Separation variables	Estimators	Percentage of correct classification ^a	Threshold value ^ь
ITA dataset			
nmono	sand	61.9	1
nmon_dic	clay	69.0	25
PIE dataset			
	pН	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	pН	64.3	5
Thorn	aden, SI, nmondic	76.0	

9 ^aPercentage of sites used for validation (sites not used to build the discriminant function) and

10 percentage correctly classified.

^bValues 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	Compo	Component	
	1	2	
pН	-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	

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

- 2 sowing time
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12 Abstract

32

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.

20 Of the approximate 120 species found, just five were present on more than 50% of sites:

21 Chenopodium album, Echinochloa crus-galli, Amaranthus retroflexus, Solanum nigrum,

22 and *Persicaria maculosa*. Indices were calculated to describe weed community structure:

23 total weed species count, monocotyledonous and dicotyledonous species counts, and total

24 weed density. Additional soil and climate site data were collected or obtained from regional

25 databases: pH reaction, texture, organic matter content, total nitrogen, Mg/K ratio,

assimilable phosphorus, cation exchange capacity (CEC), and C/N ratio, annual total

27 precipitation, annual mean temperature, and Thornthwaite climate classification. Pedo-

28 climatic traits and weed indices relationships were investigated using linear correlation

analysis (CA), discriminant analysis (DA), and principal component analysis (PCA).

30 CA and PCA highlighted a weak bias (higher count and density) by monocotyledonous

31 species for sand and alkaline soils, while clay and alkaline soils favored dicotyledonous

33 predictor variables, in particular for a Piemonte region (northwest Italy) data subset. Soil

species. DA classified the sites well based on weed indices using soil parameters as

34 texture, CEC, pH, and some nutrient contents significantly predicted some weed indices.

35 This study pointed out that Italian maize field weed communities are influenced by some

36 pedoclimatic traits; the weak relationships observed might be mitigated by the overall

37 influence of crop practices on weed dynamics.

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

40 **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).

47 Maize (Zea mays L.) is one of the most important herbaceous crops in Italy and was 48 cultivated on about 908,000 hectares in 2013 (ISTAT, 2014). Its cultivation is mainly 49 concentrated in the Po River plain, where it represents upwards of 90% of the total Italian 50 maize area (ISTAT, 2014). Soil fertility levels and environmental features that characterize 51 different maize cultivation areas can affect both the crop and its related weeds. Indeed, 52 weed communities vary with crop area pedological and climatic traits (Walter et al., 2002). 53 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 54 55 particular soils (such as, *Digitaria sanguinalis* for acid soil), environments, and crop 56 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 57 of specific needs, which allow them to grow in different environments (Holzner, 1978). This 58 59 contest begs verification of the possible relationships between weed infestation in a field 60 and the pedo-climatic characteristics of the site. Such an exploration should consider not 61 only the most widespread weed species, but also the entire floral composition of the weed 62 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).

70 Previous studies have shown the existence of a correlation between some weed species 71 and soil characteristics, even at the field scale (Andreasen et al., 1991; Heisel et al., 1999; 72 Albrecht and Auerswald, 2003). Some authors found that, for example, clay content was 73 correlated with Alopecurus myosuroides, Veronica hederifolia, Equisetum arvense, and 74 Poa annua densities (Nordmeyer and Dunker, 1999; Walter et al., 2002). The ability to 75 confirm the presence of these relationships can be difficult, especially on a large scale, 76 despite considerable information can be achievable on any infestation in a given territory. 77 Data hurdle examples include the following: lack of soil nature information for all areas, soil 78 property effects not easily discernable from those of other environmental factors, and 79 limited knowledge of the agronomic practices applied in the years prior to survey (Zanin et 80 al., 1988; Andreasen et al., 1991; Suárez et al., 2001).

81 This last aspect is probably the major limiting factor, but also one of the most important 82 because the agronomic history of a particular site can strongly affect the relationships 83 between weed community, soil, and climate (Buhler, 1995; Pyšek et al., 2005). Weed 84 infestation changes due to management practices and to environmental conditions of a 85 cultivated area make crucial the study of weed community composition to improve weed 86 control (Saavedra et al., 1990). In fact, accurate knowledge on the weed community 87 variability of a certain area may result in a more accurate tuning of sustainable weed 88 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).

94 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, 95 96 2009). For example, annual precipitation and temperature are two important factors that 97 may influence weed composition (Cimalová and Lososová, 2009). However, it has been 98 established that management practices, such as soil tillage and crop rotation explain the 99 majority of weed community variation across different soil typologies (Fried et al., 2008). 100 Few weed surveys exist on Italian maize fields (Zanin et al., 1992; Zanin et al., 1997). 101 Similarly, there is a dearth of knowledge on the change of its weed community composition 102 in response to pedo-climatic factors. The aim of the present study was to verify the 103 existence of relationships between weed communities and some pedological and climatic 104 traits in different Italian maize cultivation areas. The influence of sowing time on weed 105 community composition was also evaluated.

106

107 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 m²) were considered.

114

115 2.1 Data collection

116 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 117 118 recorded weed species was used. The collected data were organized into two distinct 119 datasets: one named "ITA" relative to fields located in the eight most important Italian 120 maize cultivation regions (Piemonte, Lombardia, Veneto, Friuli Venezia Giulia, Emilia-Romagna, Lazio, Toscana, and Umbria), and another called "PIE," which was limited to 121 122 fields situated in the Piemonte region. The ITA dataset comprised data collected on 455 123 fields spread on 170 localities, while the PIE dataset involved 80 fields. For all sites, weed, 124 soil, and climatic data were collected or obtained from regional databases. 125 Due to the large heterogeneity of data included in the ITA dataset, only weed community 126 variables common to all sites and dates were considered, namely total weed species 127 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 128 129 common protocol. For this reason, some additional weed community data (such as, weed 130 species density) was included. 131 For both datasets, weed data were obtained from counts carried out on four 0.5 x 0.5 m 132 square areas randomly placed in each plot. 133 Soil properties were also considered in the study for each site; in particular, soil reaction 134 (pH) and texture (relative proportions of sand, silt, and clay) were acquired for both 135 surveys. For the fields comprising dataset PIE, a number of other soil properties, namely 136 organic matter content, total nitrogen, Mg/K ratio, assimilable phosphorus, cation 137 exchange capacity (CEC), and C/N ratio were obtained from the Regione Piemonte soil 138 database. For dataset PIE, some climatic parameters (annual total precipitation, annual 139 mean temperature, and climate classification per Thornthwaite (1948)) were obtained from

140 the Regione Piemonte Agrometeorological network.

141

142 2.2 Data analyses

143 At each site, some indices of weed species diversity were calculated (Table 1). For both 144 datasets, the number of species (nspec), number of monocotyledonous (nmono) and 145 dicotyledonous species (ndico), and the ratio between mono- and dicotyledonous species 146 (*nmon dic*) were determined. Additional indices relative to each weed species density 147 were calculated for dataset PIE (Table 1). For each site in the survey, both the total 148 number of species and the frequency of species-specific encounters (percentage of sites 149 that included the species *n* over the total number of sites) were determined. For sites in 150 which different maize sowing times were available, species frequency was calculated only 151 for those species with a frequency above 25% (13 species).

152 The relationships between surveyed site weed species and pedo-climatic parameters were 153 determined using three statistical methods. Initially, a series of linear correlations were 154 determined for each pair of weed indices and pedo-climatic parameters, excluding the 155 Thornthwaite climate categorical variable (*Thorn*). The significance of the correlation and 156 Pearson's r correlation coefficient were calculated. Afterwards, the collected data were 157 submitted to discriminant analysis to verify, through pedological and climatic parameters 158 (predictors), the potential to classify sites as a function of the weed indices (discriminant 159 variables). These indices, derived from continuous or categorical variables with a high 160 number of categories, were transformed into new categorical variables with four, three, or 161 two modalities, such that each site was classified by four, three, or two categories. 162 Considering the Thornthwaite climate classification (*Thorn*) as the discriminant variable 163 and weed indices as the predictors allowed discriminant analysis performance. This 164 procedure was necessary because the *Thorn* variable was already categorical. Another 165 method, Principal Component Analysis (PCA), was applied only to the ITA dataset to 166 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.

- 171
- 172 3. Results

173 *3.1 Weed community diversity*

174 The total number of encountered species was similar for both surveys (ITA and PIE) and 175 equaled approximately 120. However, among the species in the ITA dataset, only nine 176 were present on more than 25% of the surveyed sites (Figure 1). Only five species were 177 observed on more than 50% of the sites, and no species were found on more than 72% of 178 the surveyed area. The most widespread species, ranked by diffusion (Table 2), were 179 Chenopodium album and Echinochloa crus-galli (encounter frequencies above 70%), 180 followed by Amaranthus retroflexus, Solanum nigrum, and Persicaria maculosa. As was 181 true for encountered species, both dataset surveys showed similar trends in weed species 182 frequency. Specifically, only a few species in Emilia Romagna region had high frequency 183 values in dataset ITA, as opposed to Piemonte region where a high diffusion (95% 184 frequency) of C. album was observed. In Lombardia a more homogeneous pattern of the 185 most diffused weeds was detected, while in Veneto, and Friuli Venezia Giulia regions the 186 trend were more intermediate in nature (Figure 2).

187 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

190 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

192 showed higher frequencies of *C. album*, *Abutilon theophrasti*, and *Fallopia convolvulus* at

193	early sowing versus conventional sowing time, even though the three species had
194	frequency variations below 10%. Moreover, fields at the early sowing time demonstrated
195	remarkably lower frequency of encounters for Panicum dichotomiflorum, Sorghum
196	halepense, A. retroflexus, and Portulaca oleracea (Figure 3). In general, observations at
197	early sowing compared to late sowing found a greater presence of the species belonging
198	to the Polygonaceae family (P. maculosa, P. aviculare, and F. convolvulus), in addition to
199	E. crus-galli, C. album, and S. nigrum. In particular, frequency varied 21% for P. maculosa
200	at early sowing time compared to delayed sowing time (Figure 3). Observations at
201	conventional sowing compared to late sowing showed an even higher number of species
202	occurring more frequently, including P. dichotomiflorum, S. halepense and A. retroflexus
203	(Figure 3).
204	
205	3.3 Weed species and pedo-climatic parameters

- 206 3.3.1. Linear correlation analysis
- 207 Linear correlation analysis identified some significant relationships between the
- 208 pedological parameters *pH, sand, silt* and *clay* and some weed indices (Table 3). For the
- 209 ITA dataset, height such correlations were found to be significant; five were identified in
- 210 the PIE dataset. In ITA dataset, positive significant correlation was found between sand
- 211 and *nmono* and between *sand* and *nmon_dic* (r =0.364, r =0.285, respectively). All the
- 212 other correlations were negative. In PIE dataset, positive significant correlation was found
- 213 only between sand and dmono (r = 0.324). In general, even though the correlations found
- 214 were highly significant in some cases, the Pearson correlation coefficients were rather low,
- 215 which indicated strong data variability.
- 216 3.3.2. Discriminant analysis

217 Among the pedo-climatic parameters, discriminant analysis detected some statistical 218 predictors valid for both datasets (Table 4). The ITA dataset discriminant functions using 219 soil property parameters sand and clay properly classified the sites (60-70% of correct site 220 classification) and predicted based on variables *nmono* and *nmon* dic which category the 221 sites should have been included. Classification accuracy was guite constant considering 222 that the two weed indices were subdivided in four, three, or two categories. However, 223 when, the indices were subdivided into more than two categories, prediction accuracy was 224 higher for the extreme classes. Indeed, the most accurate classification was observed for 225 the sites with very high or very low numbers of monocotyledonous species. For this 226 reason, the number of final categories was reduced to two. In the case of ITA dataset, a 227 *nmono* threshold value of 1 was set to divide the dataset in the two categories: sites with 228 up to one monocotyledonous species were classified in the first category, while sites with 229 more than one monocotyledonous species were classified in the second category. In these 230 conditions about 67% of sites (304) fall in the first category. The accuracy site 231 classification considering only two categories comprised between 62% and 82% of both 232 datasets. 233 Discriminant analysis in PIE produced the best results when each weed variable was 234 composed of only two categories (i.e. high and low weed densities). Accurate predictions 235 of classes to which the sites pertained was obtained using several variables and 236 predictors: SI and P. dichotomiflorum density with pH, dmono with sand, dmon dic with 237 Pass, P. maculosa density with Ntot, E. crus-galli density with Mg/K and CEC, and 238 Stellaria media density with CEC (Table 4). In the case of the ratio between 239 monocotyledonous and dicotyledonous density (*dmon dic*), the discriminant analysis 240 correctly classified about 75% of sites in the lowest weed density category (data not 241 shown). For most analyses, the discriminant function included only one pedological 242 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).

251 When used as a separation variable, parameter Thorn was reclassified by reducing the 252 initial five categories to two categories into which the various sites could be classified. 253 These were referred to more humid-tending sites (merging the sites falling into the 254 categories B4B1rb3 and B4B2rb3) and less humid-tending sites (merging the sites falling into the categories C1B2sb3, C2B1rb3, C2B2rb3) according to the Thornthwaite climate 255 256 classification (Thornthwaite, 1948). Using this classification, the weed indices aden, SI, 257 and *nmon_dic* proved to be good predictors, with, about 60% and 70% of the sites 258 correctly classified into generally more humid areas and generally less humid areas, 259 respectively. In general, in the more humid sites both a higher number of weed species 260 (low SI values) and a prevalence of monocotyledonous were observed, in contrast with 261 what was recorded for the less humid sites.

262

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

- 269 with *clay*, and high negative correlation with *sand*. Figure 5 shows a representation in bi-
- 270 dimensional space of these first two components, in which the sites were indicated with
- 271 symbols referring to their actual soil texture (clay, silt, sand, and loam).
- 272 The majority of sites with clay soils were concentrated around near slightly negative values
- 273 of the first component, indicating that in these sites the monocotyledonous species were
- 274 less abundant, both in absolute and relative terms to the dicotyledonous species number.
- 275 The cloud formed by sites with other soil textures (silt, sand, and loam) showed a more
- 276 spread arrangement, moving from negative to positive values of first component. This
- 277 suggests that in sites with soil different from clay, weed indices are basically not influenced
- 278 by soil texture.
- 279

280 4. Discussion

281 4.1 Weed community diversity

282 Study results made it possible to characterize the weed vegetation of maize fields in the 283 main Italian areas of crop cultivation, and in detail for the Piemonte region. The 120 total 284 detected weed species fell within the range of 75-124 species found in previous studies for 285 other summer crops (Frick and Thomas, 1992; Zanin et al., 1997; Viggiani et al., 1998). 286 Since both the entire area and Piemonte region surveys recorded a similar number of 287 species, this parameter seemed unrelated to survey area size. Despite the high 288 simplification in Italian maize cropping systems currently, the number of observed weed 289 species was great. A number of factors may contribute to this effect: high agronomic 290 practice variation, even in maize mono-cropping, farm fragmentation, and pedological and 291 climatic conditions that vary at both the farm and territory levels. A study conducted in 292 France by Fried et al. (2008) showed weed species diversity and composition were 293 particularly influenced by crop type and the crop preceding maize in the rotation.

294 Only some of the many species found were widespread. Indeed, only five weed species 295 were recorded in more than 50% of the surveyed sites. Among these, only one grass weed 296 was highly diffused (E. crus-galli); it is common to crop fields worldwide because of its 297 ability to germinate and flower in different environmental conditions (Keeley and Thullen. 298 1989). This study found that grass weeds constituted one-third of the nine weed species 299 present on more than 25% of the surveyed sites, which agreed with the prevalence of 300 broad-leaved species seeds discussed in a previous study undertaken on the seedbank of 301 an Italian field after five years of maize cultivation (Barberi et al., 1998). Many experiments 302 associate high grass weed counts with reduced input cultivation systems, while broad-303 leaved species predominate in conventional plowed systems (Froud-Williams et al., 1983; 304 Mohler, 1993; Bàrberi et al., 1998). Italian maize fields are typically plowed, which may 305 explain broad-leaved weed preponderance; another explanation may be their higher seed 306 longevity and persistence in soil compared to that of grass weeds (Burnside et al., 1996). 307 For broad-leaved species, this survey confirmed the findings of previous studies (Viggiani 308 et al., 1998) as it showed the ubiquitous characteristic of C. album. In fact, this species 309 was the most dispersed probably due to its abundant seed production and longevity 310 (Clements et al., 1996). In fact, *C. album* is one of the five most widespread weeds 311 globally, the seventh most abundant in maize, and one of the most troublesome weeds in 312 the U.S. corn belt (Forcella et al., 1992; Clements et al., 1996).

313 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).

323 *4.3. Weed species and pedo-climatic parameters*

324 The results of the study highlighted some relationships among the weed indices and pedo-325 climatic parameters of the surveyed sites, as observed in previous studies (Andreasen et 326 al., 1991; Cimalová and Lososová, 2009). However, the correlations described in those 327 studies were generally moderate and did not allow clarification of the precise relationships 328 among the parameters. It is, nevertheless, possible to hypothesize that interactions may 329 be hidden by agronomic practice effects, for which information was not available. Other 330 studies have demonstrated effects from certain agronomic practices, such as soil 331 fertilization or weed community tillage (Andersson and Milberg, 1998; Hyvönen and 332 Salonen, 2002; Cimalová and Lososová, 2009).

333 The few significant relationships found among some macroscopic weed indices and pedo-

334 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

337 soil nutrients (Buchanan et al., 1975; Dieleman et al., 2000). Correlation analysis results

338 indicated that a higher and a lower number of monocots were found in sand and clay soils,

339 respectively. In addition, a lower mono/dicots ratio was found in soils dealing with a higher

340 pH value.

341 Both PCA and discriminant analysis also confirmed the existence of relationships among

342 the weed indices and some pedo-climatic traits. For example, discriminant analysis

343 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 *Ma/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).

351 *4.4 Conclusions*

352 In general, many factors impact weed community dynamics; in particular, management 353 practices, soil tillage, and crop type play important roles. This study highlighted not only 354 the diversity of weed species in Italian maize, but also the importance of pedological and 355 climatic factor contributions to weed species variation. Study analyses did establish some 356 relationships between certain weed indices and pedo-climatic parameters, however, it also 357 demonstrated the particular difficulty associated with distinguishing single factor effects. 358 Weed community variation seems to result from an interaction of different cropping and 359 pedo-climatic aspects. Further studies are needed to better clarify these relationships as 360 this information may improve the predictability of weed flora composition based on the 361 environmental characteristics of a certain area.

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363

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Figure 3 Click here	Freq یو down/gad Figyte: fig3_7evised.	uency variation (%)
BIDTR	early sowing time	8
POLCO	compared	
POLAV	to conventional	
PANDI		
SORHA		
DIGSA		
POROL		
ABUTH	_	
AMARE		
POLPE		
SOLNI		
CHEAL		<u></u>
ECHCG		
BIDTR	early sowing time	2011 - 11 - 11 - 11 - 11 - 11 - 11 - 11
POLCO	compared to	
POLAV	late	
PANDI		
SORHA		
DIGSA		
POROL		
ABUTH		
AMARE		
POLPE		
SOLNI		
CHEAL		
ECHCG	-	
BIDTR	<u>و،</u> conventional sowing	
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SORHA		
DIGSA	1	
POROL		
ABUTH		
AMARE		
POLPE		
SOLNI		
CHEAL		
ECHCG	_	





			data	aset	
variables	code	Unit of measurement	ITA	PIE	Calculation method ⁽¹⁾
Weed indices					
Total weed density	dentot	plants/m ²		Х	
Number of weed	nspec	n ^a	Х	Х	
Mean weed density of the present species	aden	plants/m ²		Х	dentot / nspec
Weed density of the single species	n _i	plants/m ²		Х	
Number of species	con5	n		Х	$con5 = \sum i$; for
than 5% and 10%	contu				$n_i \ge (0.05 \cdot dentot)$
					$con10 = \sum i$; for
Simpson indev	SI	odb		V	$n_i \ge (0.10 \cdot dentot)$
Simpson index	31	au		^	$SI = \sum (n_i/dentot)$
Shannon index	H'	ad		Х	$H' = -\sum [(n_i/dentot) \cdot \ln(n_i/dentot)]$
Numbers of MONOCOT species	nmono	n	Х	Х	
Numbers of DICOT	ndico	n	Х	Х	
Number of MONCOT/DICOT	nmon_dic	ad	Х	Х	nmono/ ndico
Total MONOCOT	dmono	plants/m ²		Х	
Total DICOT density	ddico	plants/m ²		Х	
MONOCOT/DICOT density ratio	dmon_dic	ad		Х	dmono/ddico
Pedological indices					
Sand	sand	%	Х	Х	
Silt	silt	%	Х	Х	
Clay	clay	%	Х	Х	
рН	рĤ		Х	Х	
Organic matter	SO	%		Х	
Total nitrogen	Ntot	%		Х	
Mg/K ratio	Ma/K	ad		х	
Assimilable	Pass	ppm		X	
Cation exchange	CEC	meq/100g		Х	
Carbon/Nitrogen ratio	C/N	ad		Х	
Total annual	Ptot	mm		Х	
Anuual mean	Tavg	°C		Х	
temperature Thornthwaite climatic classification	Thorn	ad		Х	

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

^an indicates number of species; ^bad 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 (%) 71.6
	71.0
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

- 1 Table 3. Significance values (P) and Pearson correlation coefficients (r) (in brackets), of
- 2 the relationships among some pedological parameters and weed indices for the ITA and
- 3 PIE datasets (P≤0.05).
- 4
- 5

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

- 6 Table 4. Pedo-climatic variables for which significant relationships were found according to
- 7 discriminant analysis and threshold value dividing the two categories.
- 8

Separation variables	Estimators	Percentage of correct classification ^a	Threshold value ^ь
ITA dataset			
nmono	sand	61.9	1
nmon_dic	clay	69.0	25
PIE dataset			
	pН	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	pН	64.3	5
Thorn	aden, SI, nmondic	76.0	

9 ^aPercentage of sites used for validation (sites not used to build the discriminant function) and

10 percentage correctly classified.

^bValues 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	
pН	-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	