ACTA AGRONOMICA ÓVÁRIENSIS VOL. 46. NO. 2.

Composition of weed floras in different agricultural management systems within a north-south European climatic gradient

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SUMMARY

Current paper presents the first results of field investigations on weed flora compositions along a climate gradient from South to North Europe. The field investigations have been carried out between 1999 and 2003 in eight regions situated in a climate gradient which reached from South Italy, via Hungary, Germany and Sweden up to Finland. The investigations on the weed flora were designed to characterise i.) the regional differences in the weed flora composition along the climate gradient, not only in terms of species diversity and weed flora composition but also for the dominance structure and some functional groups within the weed flora and ii.) to analyse the influence of different land use types on it. For identifying the impact of land use, we have included weed surveys on three types of arable fields within every region: i.) cereals under conventional/integrated farming; ii.) cereals under extensive use/ecological farming and iii.) fallow fields/set aside fields.

We have found at all nearly 700 weed species in the eight selected regions. The number of weed species decreased from more than 400 in South Europe to 130 in Northern Europe. Species richness on fields under extensive use/ ecological farming was in average higher by 50–70% than on fields under conventional/ integrated use. Beside the differences in diversity, we have observed different patterns of species response on climate conditions.

One group of them, probably one of the most problematic from the land users point of view, were species occurring on the whole length of the climate transect. This group was mainly related to cereal fields under conventional/integrated land use. Species of special interest for nature protection or for plant genetic resources were mostly restricted to particular regions or fields of extensive/ecological land use type.
Keywords: diversity, weeds, land use type, climate gradient, climate change.

Introduction

Arable land is been used by nearly 10–15% of the overall plant diversity as main habitat (*Hanf* 1982). Decreases in flora diversity on arable land have been observed throughout Europe in the last three decades (*Erviö* and *Salonen* 1987, *Hilbig* and *Bachthaler* 1992, *Andreasen et al.* 1996, *Tóth et al.* 1999, *Montemurro* and *Viaggiani* 2000). In some regions, more than one-third of the entire species inventory has been categorised as extinct, endangered or rare (*Schneider et al.* 1994, *Györffy et al.* 1995). Despite of a different perception within the society, this rate of decline is comparable to that rate, we can notice in overall biodiversity (*Wilcove et al.* 1998). Species, which are most dramatically impacted, are often specialists, e.g. – those adapted to chalky, acidic and wet soil conditions (*Hilbig* and *Bachthaler* 1992) or species with specific climatic or site requirements as well as species with limited dispersal abilities. As species richness decreases through a loss of specialists, the average cover of wildlife plants may remain unchanged due to the increased dominance of a few species (*Györffy et al.* 1995) or the invasion of new species (neophytes). Both trends, the disappearance of site adapted species or species with regional limited occurrence and the introduction of new species may lead to a loss in regional specificity and a homogenisation of floras on arable land across Europe.

The occurrence of many of the weed species depend on specific farming systems to maintain suitable habitat conditions. Taking into account the technical, cultural and societal development over time, the choice of technology in agriculture is still the most important tool to prevent wildlife floras diversity and nativeness on arable land. A number of studies have shown the benefits of e.g. organic farming systems on the diversity of wildlife plants on arable land (*Moreby* and *Aebischer* 1994, *Frieben* and *Köpke* 1996). Using proper land use systems and adjusting land use practices will support first those plants, which have significantly declined in the recent years (*Azeez* 2000).

To balance ecological effects against economic restrictions on arable land, comparative studies about the interactions between environmental conditions (e.g. changing climate) and different land use intensity are lacking. Complex ecological assessments need to be firmly based on reliable, consistent, comprehensive data. Determining the status of floras on arable land is the necessary basis for further analyses and evaluations as well as for create awareness and call the attention of decision makers, stakeholders and society on the degree of vulnerability of arable ecosystems. Focusing on further investigations mainly

on the interactions between land use and climate changes, we have started field investigations in climatically different regions in Europe in 1999. Our first aims were to get impressions on the general trends in Europe by creating comparable datasets. Based on this, we have tried to identify species or communities characteristics, which might be used as indicators for specific climatic and land use conditions. Further on the data should be analysed with regard on site requirements, ecological importance, weed control relevance and functional aspects of the single species. This paper presents only some first results and trends.

Material and Methods

Area selection: The stations for investigations were pre-selected in a way to be situated on locations with differences in average annual air temperature in steps of 1.5 °K (in 2 metres height). According to the predictions from the *IPCC* (1996) for a temperature increase of between 1.3–4.5 °K in the next 100 years, we have decided to use the lower value of these predictions as basis for the pre-selection of investigational areas. Estimates on possible effects of climate change should be achieved based on this design by using the space-for-time-substitution-method (*Figure 1., Table 1.*).

Figure 1. Arrangement of the investigation areas on the north-south climatic gradients (for details see *Table1.*)

Table 1. Short description of the investigation areas
by climatic data and geographical situation
(data and name from their corresponding meteorological stations)

Location	Country	Latitude	Longitude	Height above sea level	Annual average temperature	Average rainfall
Vaasa	Finnland	63.1 °N	21.7 °E	5 m	3.5 °C	514 mm
Uppsala	Sweden	59.9 °N	17.6 °E	15 m	5 1 °C	541 mm
Osby	Sweden	56.4 °N	13.9 °E	83 m	6.9 °C	627 mm
Müncheberg	Germany	52.4 °N	14.2 °E	64 m	8.3 °C	527 mm
Magyaróvár	Hungary	47.9 °N	17.3 °E	121 m	9.7 °C	594 mm
Milano-Udine	Italy	45.6 °N–46.0 °N	8.7 °E–13.1 °E	100–211 m	11.8 °C	790 mm
Roma	Italy	41.8 °N	12.6 °E	129 m	15.0 °C	793 mm
Lecce	Italy	40.2 °N	18.2 °E	61 m	16.4 °C	556 mm

Soil type: To ensure comparability between the investigated regions, weed releves were carried out only on loamy-sandy soil, sandy-loamy soil and soddy-alluvial soil. The sites for plant releves were pre-selected by using regional soil maps.

Weed flora releves: For every survey station, we have analysed nine fields among them six cereal fields (winter barley, winter wheat), three of them under extensive use/organic farming (further on in the text only "extensive") and three under conventional farming (further on only "intensive") and three one-year fallows (further on only "fallow"). The fallows were chosen to gain any information about the potential weed flora composition within the different regions. Investigations were carried out in the same state of culture development before and shortly after flowering of the cereals (BBCH 59-71).

According to the main focus of our investigations, field investigations aimed on the observation of the whole species inventory (species list) accompanied by assessments on the dominance structure within the weed flora. Therefore four persons inspected the area of 0,5–1 ha of every single field and did assessments on the abundance of single species. The classification of abundance was based on the following scale, including their intermediate values: Sh – most frequent (occurring on at least 50% of the field), H – frequent (occurring on at least 25% of the field), Z – scattered/diffuse (occurring on at least 10% of the field), S – rare/infrequent (occurring only with a few species), Ss – most rare (not more than 1–3 individuals on the field). Identification of weed species was following the nomenclature of the national flora for every country, included in the investigation.

The floristic data were captured in a databank together with some descriptive information about the observed fields. Species nomenclature was tested against synonymity based on

standard species list for Germany (*Wisskirchen* and *Haeupler* 1998), supplemented by using Mediterranean nomenclature (*Pignatti* 1997) and Scandinavian nomenclature (*Mossberg et al.* 1992). The species nomenclature was combined with classifications for their systematics and ecological behavior. The following classifications for the ecological behavior were included in the data analysis: affiliation to plant families (*Ellenberg* 1996) and life forms (*Ellenberg* 1996). These classifications were created for central European conditions and therefore cross validated by using information from Mediterranean and Scandinavian floras (*Pignatti* 1997, *Mossberg et al.* 1992).

Data analysis: The data delivered by the comparative investigations were analysed in a holistic way. We used multivariate analyses to identify i.) major dissimilarities (also interpretable as characteristics) between the European regions, ii.) key parameters (species) for different climatic conditions using two-way indicator species analysis and several methods of multivariate variance analysis (e.g. PCA) to analyse iii.) the relative importance of climate factors on variance in species occurrence for the analysed investigation stations. The following multivariate statistical valuation methods were used: i.) Multiple Cluster Analysis (TWINSPAN program), ii.) Multiple Discriminant Analysis (SPSS 8.0 program), iii.) Canonical Correspondence Analysis (CANOCO program) and iiii.) Canonical Correlation Analysis (SYN-TAX 5.1 program).

A number of species occurred rare and/or with only low dominance in the single regions. These species were decisive in influencing the characteristics of those regions. Hereinafter these species were included in the valuation of ecological group. In the valuation of single species occurrence, we concentrated only on frequent species because of statistical reasons.

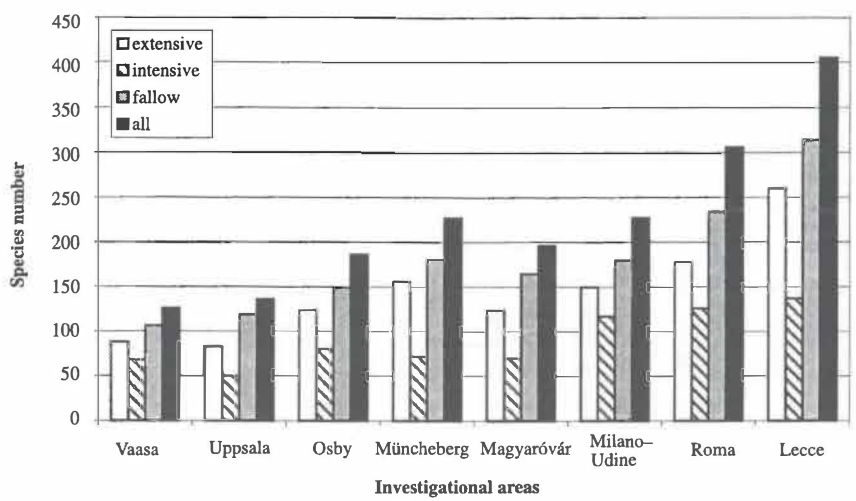
Results

Species richness: During our field work, we have visited every investigational area there times and we have made weed surveys at nine fields every year. That makes 210 surveys on different arable fields in total. As result of these field investigation, we have found at all 768 plant species growing on arable land, 550 of them were occurring on more than one single field, occurring more than once. Between the different land use types this number was divided as follow: the total species number on fallow fields was 634, on fields under extensive use 554 and under intensive use 346. Nearly two third of the total species number occurred rarely, only on less than 10% of the observed fields. This trend was nearly the same for all land use types.

Taking into account the relatively low number of fields at every particular investigational area, and the random selection of the fields for the survey, the number seems to be rather high. Despite the fact, that we could use at all stations support by local experts in species identification, we estimate the success in detecting the whole species occurrence by our own as to be underestimated by about 10–15%.

The spatial distribution of the whole species number we have found is shown in *Figure 2*. As expected, we have found a clear increasing south-north trend in total species number. The species number varied from maximum 405 species at all in the southernmost investigational area Lecce (Italy) up to the minimum of 126 species in the northernmost area Vaasa (Finland). In the middle sector of the gradient, from North Italy via Hungary up to northeast Germany the total species number was nearly equal (237 in north Italy, 196 in Hungary, 227 in Germany).

Figure 2. Spatial distribution of the total species number along the climate transect from North to South Europe related to different land use types (fallow, extensive, intensive)
(N = 27 for every area, N = 9 for every land use type in a particular area)



The differences between the land use types are also shown in *Figure 2*. The general trend was that nearly 80% (variation between 70–85% in the single regions) of the species richness on fallow fields could be found on fields under extensive use and only about 50% (40–65%) on fields under intensive land use.

Patterns of species occurrence: Analysing the occurrence of single species along the European transect, we could identify at least three different groups of single species response to the climate gradient. *Pictures 1–3.* show 3 attractive examples.

The first group includes those species, that are occurring mainly under Scandinavian climate with high frequencies. The most frequent species belonging into this first group are summarised in *Table 2*. In this group, we can find species of alluvial, partly moist soils, which are typical for large areas in northern Europe, for instance *Galeopsis bifida*, *Galeopsis speciosa*, *Erysimum cheiranthoides*, *Alopecurus geniculatus* and *Tussilago farfara*. Some of the species in the first group are also known as indicators for acid soil conditions, like f.i. *Spergula arvensis*.

Picture 1. Galeopsis speciosa was found with high abundances mainly in Northern Europe (example from Uppsala – Sweden)

Picture 2. Gladiolus segetum is a typical and very attractive representative of the bulbous plants, which were a typical requisite of the weed floras in Southern Europe (example from Lecce – Italy)

Picture 3. Convolvulus arvensis is one of those species occurring along the whole climate transect from South Italy up to middle of Sweden, it reached high abundances mainly in fields under intensive use (with herbicide use) (example from Roma – Italy)

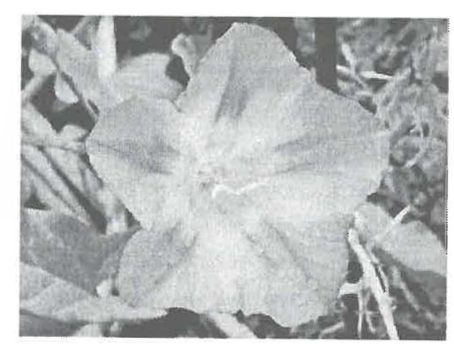


Table 2. Group of weed species more common and abundant in Northern Europe (mean abundance (%) over all land use types for every particular investigational area on the climate transect, N = 27 for every single area)

Species name	Northern Europe				Southern Europe			
	Vaasa	Uppsala	Osby	München-berg	Magyar-óvár	Milano–Udine	Roma	Lecce
Galeopsis speciosa	81.48	62.96	39.15	0.00	0.00	0.00	0.00	0.00
Phleum pratense	51.85	40.74	42.33	3.70	0.00	0.00	0.00	0.00
Alopecurus geniculatus	51.85	3.70	43.92	3.70	0.00	0.00	0.00	0.00
Spergula arvensis	51.85	7.41	38.10	11.11	0.00	0.00	3.70	0.00
Erysimum cheiranthoides	77.78	55.56	20.63	18.52	0.00	0.00	0.00	0.00
Galeopsis bifida	74.07	33.33	73.02	0.00	3.70	0.00	0.00	0.00
Matricaria discoidea	74.07	18.52	62.96	14.81	7.41	0.00	0.00	0.00
Tussilago farfara	11.11	48.15	26.98	3.70	22.22	3.70	0.00	0.00
Sonchus arvensis	7.41	48.15	19.58	11.11	25.93	0.00	0.00	7.41
Thlaspi arvense	33.33	74.07	34.39	44.44	29.63	0.00	0.00	0.00
Lapsana communis	48.15	62.96	59.26	7.41	0.00	11.57	0.00	0.00
Polygonum lapathifolium	51.85	25.93	69.84	33.33	37.04	35.19	0.00	0.00
Epilobium angustifolium	51.85	0.00	13.23	7.41	0.00	11.57	4.76	0.00
Taraxacum officinale	70.37	77.78	77.78	59.26	44.44	26.85	8.47	0.00
Gnaphalium uliginosum	44.44	11.11	47.62	3.70	0.00	0.00	9.52	0.00
Ranunculus repens	48.15	59.26	44.97	7.41	0.00	4.17	13.23	0.00
Galium spurium	59.26	33.33	0.00	3.70	0.00	0.00	14.29	0.00
Tripleurospermum perforatum	96.30	85.19	96.30	70.37	74.07	54.17	39.68	3.70
Viola arvensis	92.59	85.19	92.59	66.67	81.48	69.91	56.61	0.00
Elymus repens	88.89	92.59	80.42	81.48	88.89	37.96	27.51	11.11
Stellaria media	88.89	81.48	71.96	55.56	70.37	61.57	17.99	25.93

The second group covers just the opposite, the species preferring Mediterranean climate. There we found numerous legume species like f.i. *Medicago polymorpha*, *Trigonella corniculata* and *Vicia pseudocracca*. Beside of this, there are concentrated in this group (*Table 3.*) some grasses f.i.: *Lolium rigidum*, *Lolium multiflorum* and *Bromus sterilis* also. Additional to this, there usually could be detected some very attractive flowering species, f.i.: *Legousia speculum-veneris* and *Chrysanthemun segetum* too.

The last group differ from the species in other groups by showing no climate preferences and occurring with high abundances along the whole gradient (*Table 4.*). Looking at this group, we can easily consider, that most of the well known and very common weeds belong into this group. Species like *Galium aparine*, *Chenopodium album*, *Cirsium arvense*

and *Avena fatua* have been targets for weed control since decades. Actually these species are widely distributed all over the investigated countries and show high frequencies of occurrence. The difference between the investigated land use types related to the occurrence of these species is, that in fields under intensive use, this group dominates. Compared with this on fields under extensive use, the occurrence of species of this group is limited or supplemented by species of only local occurrence.

Noteable is also the wide introduction and high frequency of *Brassica napus* within the weed flora across all of the observed countries.

Table 3. Group of weed species more common and abundant in Southern Europe (mean abundance (%) over all land use types for every particular investigational area on the climate transect, N = 27 for every single area)

Species name	Northern Europe				Southern Europe			
	Vaasa	Uppsala	Osby	München-berg	Magyar-óvár	Milano–Udine	Roma	Lecce
Arenaria serpyllifolia	0. 00	14.81	8.47	40.74	37.04	23.15	9.52	66.67
Sonchus asper	0.00	7.41	21.69	11.11	25.93	26.39	53.97	44.44
Raphanus raphanistrum	0.00	3.70	3.70	3.70	7.41	7.87	50.26	48.15
Daucus carota	0.00	0.00	9.52	11.11	37.04	22.69	34.92	51.85
Vicia sativa	0.00	0.00	8.47	11.11	3.70	53.70	39.68	55.56
Anagallis arvensis	0.00	0.00	4.76	29.63	77.78	73.61	64.02	81.48
Papaver rhoeas	0.00	0.00	3.70	74.07	88.89	88.89	90.48	100.00
Bromus sterilis	0.00	0.00	0.00	55.56	14.81	38.43	51.85	11.11
Anthemis arvensis	0.00	0.00	3.70	3.70	14.81	19.44	52.91	74.07
Chrysanthemum segetum	0.00	0.00	3.70	0.00	0.00	0.00	68.78	62.96
Legousia speculum-veneris	0.00	0.00	0.00	0.00	0.00	42.13	53.97	55.56
Anagallis foemina	0.00	0.00	0.00	0.00	25.93	19.91	25.40	74.07
Lolium multiflorum	3.70	0.00	0.00	0.00	14.81	45.83	52.91	11.11
Ranunculus arvensis	0.00	0.00	0.00	0.00	3.70	50.46	43.39	11.11
Calystegia sepium	0.00	0.00	0.00	0.00	25.93	54.17	14.29	0.00
Calendula arvensis	0.00	0.00	0.00	0.00	0.00	0.00	22.75	70.37
Medicago polymorpha	0.00	0.00	0.00	0.00	0.00	0.00	14.29	59.26
Trigonella corniculata	0.00	0.00	0.00	0.00	0.00	0.00	9.52	62.96
Lolium rigidum	0.00	0.00	0.00	0.00	0.00	0.00	4.76	66.67
Campanula erinus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.37
Bellardia trixago	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.85
Melilotus sulcatus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.85
Vicia pseudocracca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.85

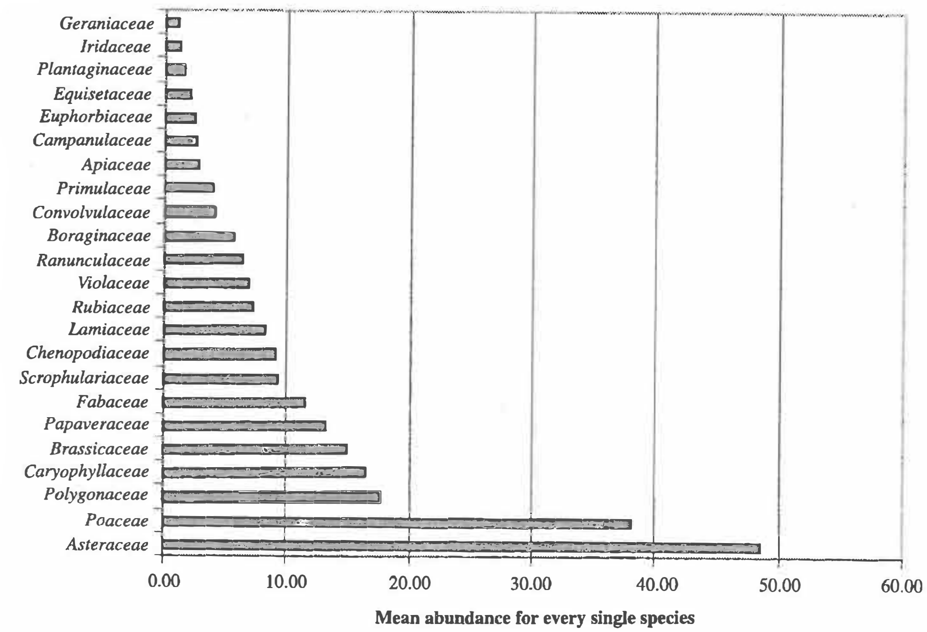
Table 4. Group of weed species with high abundances along the whole investigated transect and with no preferences to specific climate conditions (mean abundance (%) over all land use types for every particular investigational area on the climate transect, N = 27 for every area)

Species name	Northern Europe					Southern Europe		
	Vaasa	Uppsala	Osby	Müncheberg	Magyaróvár	Milano–Udine	Roma	Lecce
Polygonum aviculare	81.48	85.19	86.77	77.78	81.48	76.39	84.13	29.63
Fallopia convolvulus	81.48	88.89	95.24	96.30	81.48	62.04	64.02	18.52
Chenopodium album	85.19	77.78	88.89	81.48	85.19	61.57	53.97	40.74
Cirsium arvense	74.07	88.89	80.42	77.78	88.89	54.17	39.68	25.93
Capsella bursa-pastoris	51.85	59.26	88.89	74.07	70.37	84.72	61.38	29.63
Galium aparine	7.41	59.26	60.85	59.26	96.30	45.37	74.60	18.52
Myosotis arvensis	85.19	92.59	81.48	55.56	14.81	31.02	32.28	0.00
Convolvulus arvensis	0.00	33.33	3.70	48.15	88.89	63.89	70.90	81.48
Sonchus oleraceus	66.67	77.78	57.14	7.41	29.63	38.89	33.86	62.96
Fumaria officinalis	51.85	88.89	30.69	7.41	3.70	46.76	77.25	59.26
Avena fatua	14.81	3.70	0.00	22.22	44.44	69.44	85.71	77.78
Equisetum arvense	37.04	62.96	67.20	55.56	48.15	16.20	14.29	0.00
Poa trivialis	55.56	18.52	65.61	11.11	11.11	76.85	50.26	0.00
Poa annua	48.15	11.11	91.53	25.93	11.11	50.00	31.22	14.81
Euphorbia helioscopia	0.00	40.74	51.32	44.44	44.44	35.19	19.05	48.15
Artemisia vulgaris	11.11	22.22	69.31	62.96	62.96	42.59	4.76	0.00
Trifolium repens	51.85	55.56	60.85	18.52	3.70	31.94	31.22	3.70
Sinapis arvensis	14.81	51.85	43.92	18.52	29.63	31.48	40.74	14.81
Senecio vulgaris	11.11	33.33	55.56	11.11	3.70	23.15	49.21	48.15
Lactuca serriola	0.00	14.81	4.76	33.33	66.67	50.00	41.80	11.11
Brassica napus	40.74	62.96	36.51	22.22	11.11	0.00	20.63	7.41
Cerastium holosteoides	14.81	14.81	49.74	22.22	0.00	57.87	37.04	3.70

In a first attempt, we have tried to analyse the importance of different species groups in weed floras. *Figure 3.* shows the ranking of the average abundance of the occurring particular species related to their taxonomical affiliation for the whole transect. According to this result, species of the *Asteraceae* and *Poaceae* families are the most abundant within the overall species inventory. This trend could be observed over all single investigational areas. Regional differences between the abundance of the particular regions could be found for the plant species of *Papaveraceae* and *Fabaceae,* which were more abundant in the south and the *Lamiaceae,* which prevailed in the north.

Beside the most abundant 5–7 plant families, there are numerous plant families with only sporadic or less dominant occurrence.

Figure 3. Importance of different plant families as weeds on the investigated transect in general (mean value for the abundance (%) of single species per family, list of plant families is reduced to the most dominant ones)



Discussion

In the period between 1999 and 2003, we have examined the species composition in the respect of macro-climate and land use intensity. Our investigations focused in a first approach on the characterisation of the regional differences within the weed flora along a climate gradient in Europe. From our first results, we can make the following statements: The main objective of our fieldwork was to gain comparable data for a large European part. This work was restricted by our resources and methods to a detail of the overall weed flora of every region. To get a more complex and complete picture about the state of weed floras in Europe, more investigations or a network of investigations are needed. Field investigations for such a large regions are a necessary supplement to existing expert assessments (*Williams* 1982, *Hunyadi* and *Williams* 1987, *Hanf* 1982) and models. Despite the fact, that we were able to look at only a detail of the overall weed flora of the investigated regions, the number of plant species, we have found was rather high. The number of plant species, which uses arable fields at least as temporal habitat, seems to be much more higher, than actually assumed. As a consequence of this general perception, the role of arable land as habitat for weeds and other e.g. pioneer plants seems to be underestimated. From our results we want to encourage other experts and colleagues to initiate similar ecologically oriented surveys to validate the habitat function of arable fields.

Species richness of weeds is positively correlated with average temperature. Most of the species could be found on fallow fields. This finding underpin the importance of sucessional fallows for re-vitalising species inventory, mainly for species with rare and unstable occurrence under recent cropping conditions. If we regard the spontaneous vegetation on young fallows as "potential" weed flora for the given site conditions, regional diversity of weed flora was limited by about 20% in extensively used fields and by nearly 50% in intensively used fields by the land use practice in general. As most of the species surplus in extensive fields have shown a rare occurrence or low abundances, most of the species in intensively used fields were common or have had high abundances.
Warming of climate, theoretically conduces an increasing of species diversity, as *Saetersdal* (1998) modelled beside a south-north climate gradient in Scandinavia. This could not happen if we decrease the populations of most of species to the smallest value and create unique weed flora with a predomination of a few species. Under these conditions a large number of species hardly has chance of spreading in other areas. Our examinations showed that the specialised species were very rare or rare in the abundance scale, so populations of many of those species reached the indicatory value and their state needs protection. Much rather species number will be reduced in the case of climate warming by disappearance of specialists, the homogenisation of habitats and frequent herbicide use.
Related to the climate requirements of weeds we have detected three different pattern of response of weeds to the macro-climate. Species indicating the southern character and limited in their occurrence to this area are e.g.: legume species like f.i. *Medicago polymorpha*, *Trigonella corniculata* and *Vicia pseudocracca,* grasses like *Lolium rigidum*, *Lolium multiflorum* or *Bromus sterilis*, some very attractive flowering species, f.i.: *Legousia speculum-veneris* or *Chrysanthemun segetum* and bulbous species like f.i. *Gladiolus segetum*, *Allium sp.* or *Leopoldia comosa*. Other species are attached rather to 5–8 °C annual average temperature or colder and occurred mainly in Northern Europe. Examples for this group are e.g. species of moist alluvials like *Galeopsis bifida*, *Galeopsis speciosa*, *Erysimum cheiranthoides, Alopecusrus geniculatus* and *Tussilago farfara* or species of acid soil conditions, like f.i. *Spergula arvensis* and others like f.i.: *Lapsana communis*. We have found also as a third group species, which are not correlated to the climate, which occurre everywhere in Europe. Most of them are common, dangerous weeds e.g. *Galium aparine*, *Chenopodium album*, *Cirsium arvense* and *Avena fatua.*
Our work in this form can be evaluated only as a previous exposure. After all we know that our work should be extended in several important directions, so we would like to develop that in an international team to stress particularly the interactions between land use systems or cultural practices and climate on weed flora, as well as the flexibility of current inventories with respect to climate change, the role of intrinsic factors for the processes of invasion of new species and the ecological evaluation of possible climate induced changes within the weed flora.