Environmental and land-use variables determining the abundance of *Ambrosia artemisiifolia* in arable fields in Hungary

Vliv faktorů prostředí na abundanci *Ambrosia artemisiifolia* na zemědělské půdě v Maďarsku

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Ambrosia artemisiifolia is the most noxious invasive species of weed in Hungary. The aim of this study was to quantify the environmental and land-use factors that explain the variance in its abundance in arable fields. A survey of 243 arable fields was carried out across Hungary, and 19 environmental and 12 land-use factors were measured. These were used as explanatory variables in classification and regression tree models. The abundance of *A. artemisiifolia* was significantly higher at the edges than at the centres of fields. The most important land-use variables explaining the variance in abundance of *A. artemisiifolia* were crop type and crop cover, with the highest abundance recorded in sunflower fields and fields with low crop cover. The following explanatory environmental variables were associated with significantly higher *A. artemisiifolia* abundance: sandy or acidic soils, mean April precipitation > 39 mm, mean annual precipitation > 592 mm and mean May temperature < 15.5 °C. *Ambrosia artemisiifolia* was significantly less abundant in fields with soils containing high concentrations of Na, K and Mn. Both farmers and nature conservationists should be made aware of the conditions and practices that favour ragweed so that they can develop effective and selective ragweed control practices, particularly in arable habitats with a high diversity of weeds.

K e y w o r d s: agriculture, arable fields, decision trees, invasion, invasive plants, ragweed, weed distribution, weed ecology

Introduction

Common ragweed (*Ambrosia artemisiifolia* L.), an annual alien plant of North American origin, is one of the most noxious invasive species in Europe, particular because it produces large quantities of allergenic pollen, which causes severe health problems (Kazinczi et al. 2008b). The invasiveness of *A. artemisiifolia* is attributed to several features of the plant. Firstly, it has a wide ecological tolerance and can colonize a large range of disturbed habitats (Fumanal et al. 2008b). Its invasion is also facilitated by its large persistent seed bank (Fumanal et al. 2008a), huge plasticity in seed mass (Fumanal et al. 2007), resistance to certain herbicides (Kazinczi et al. 2008c), allelopathic effect (Kazinczi et al. 2008b), arbuscular mycorrhizal fungal symbiotic interactions (Fumanal et al. 2006), the lack of natural enemies (MacKay & Kotanen 2008), the high genetic variability of invasive populations (Genton et al. 2005, Chun et al. 2010) and the high incidence of out-crossing in colonizing populations (Friedman & Barrett 2008).

Ambrosia artemisiifolia is dispersed predominantly by human activities, via agricultural machines, soil or seed transport, but water dispersal along river corridors and dispersal by birds are also documented (Bassett & Crompton 1975, Bohren et al. 2006, Lavoie et al. 2007). This species was introduced into Europe in various ways in the late 19th century, mainly as a contaminant of crop (Chauvel et al. 2006) and bird seed (Brandes & Nitzsche 2007). It colonizes mostly disturbed habitats such as road margins, riverbanks, wasteland and cultivated fields (Fumanal et al. 2008b). Currently *A. artemisiifolia* severely adversely affects the health of people and reduces crop yields in many European countries, including France, Italy, Hungary, Croatia, Ukraine and Romania (Song & Prots 1998, Fumanal et al. 2008b, Hodisan 2008, Kazinczi et al. 2008b). Global warming might enhance its naturalization in more northerly countries (Dullinger et al. 2009, Essl et al. 2009).

The invasion of the Carpathian-basin began in the 1920s, after the First World War, when cereal seed contaminated with seed of *A. artemisiifolia* was imported through the seaports of the former Austro-Hungary Monarchy (Szigetvári & Benkő 2008, Csontos et al. 2010). This was followed by a slow northward spread accompanied by sporadic long-distance dispersal events, which resulted in it becoming naturalized in most agricultural areas in the Carpathian Basin. According to Hungarian national weed surveys, ragweed occupied the 21st position on the list of the most abundant arable weeds in 1950, then 8th in 1970, 4th in 1988 and first in 1997. The spread of this species was probably favoured by both the socialist-type large-scale agriculture (~1960–1990) and the less intensive farming practices in the post-communist period, after 1990 (Kiss & Béres 2006).

According to the latest Hungarian national weed survey, *A. artemisiifolia* still retains its primacy among species of agricultural weeds and is still increasing in abundance and spreading into the north-western parts of the country (Novák et al. 2009). Hungary is not homogeneously infested with ragweed; some regions are highly (mean cover above 10%), while others are less (mean cover under 0.5%) infested, suggesting that certain environmental and land-use factors might influence the abundance of *A. artemisiifolia* in arable fields. There are several recent papers on the distribution, habitat preferences and methods used to control *A. artemisiifolia* (e.g. Balogh et al. 2008, Kazinczi et al. 2008a, b, c, Szigetvári & Benkő 2008), but there are no complex broad-scale (e.g. country-level) studies on the links between different factors and ragweed abundance. The aim of this study was to identify those environmental and land-use variables that determine ragweed colonization of arable fields and the appropriate statistical methodology. The identification of the factors positively or negatively associated with the abundance of *A. artemisiifolia* might provide new information about the ecology of this species, which could be used to optimise the methods used to control this weed.

Materials and methods

Data collection

The territory of Hungary was divided into 56 grid cells between 45°30'–49°00' N latitude and 16°00'–23°00' W longitude (Fig. 1). In each cell, farmers were identified who permitted access to their fields and were willing to be interviewed about land-use factors. In each cell, five arable fields belonging to one or two farmers were randomly chosen. In grid cells crossing the country borders, where the greater part of the cell is in a neighbouring state, usually only three fields were selected. This procedure resulted in a set of 243 arable fields evenly distributed across Hungary (Fig. 1). The weeds growing in these fields were

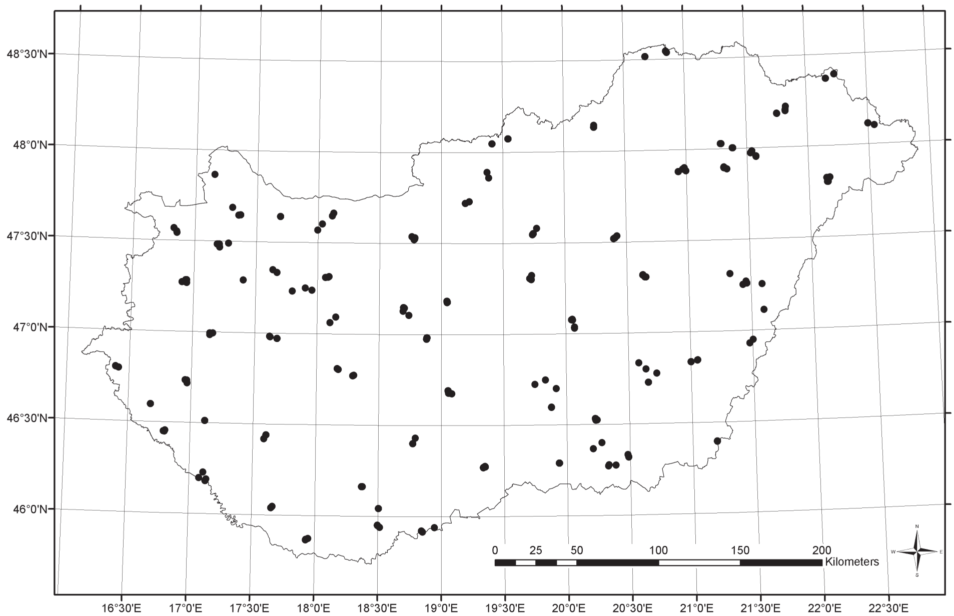

Fig. 1. –The locations, in the geographic grid cells used for stratification, of the 243 fields surveyed across Hungary. At this scale individual points may represent a number of fields.

assessed in four 50 m^2 plots, which were selected at random. One plot was located at the edge of the field, but within the cultivated area, and three plots were located at different distances (between 10 and 300 m) from the edge of the field. Percentage plant covers of *A. artemisiifolia*, other weeds and crop species in the plots were estimated visually between 27 July and 25 August 2009, when *A. artemisiifolia* was fully grown. In total, 972 plots were sampled (four plots in each of 243 fields). This survey focused on fields with crops that are regularly grown throughout Hungary. Accordingly, the crops in the selected fields were either maize (*Zea mays* L.) or sunflower (*Helianthus annuus* L.), or the stubble of different cereals: wheat (*Triticum aestivum* L.), triticale (*Triticosecale rimpaui* Wittm.), barley (*Hordeum vulgare* L. and *Hordeum distichon* L.), oats (*Avena sativa* L.) and oilseed rape (*Brassica napus* L.). Soil samples (~1000 cm^3 from the upper 10 cm layer) were collected, after removing the surface litter, in each field in the same area as the weed data. The samples from the four plots in each field were mixed thoroughly and analysed in a laboratory (belonging to UIS Ungarn GmbH) accredited by DAP (German Accreditation System for Testing).

Information on crop management (land use) was collected directly from the farmers using a dedicated questionnaire in which the following characteristics of their practice were recorded: sowing date, preceding crop, organic manure, the type and amount of fertilizer and herbicide, mechanical weed control, tillage system, tillage depth and field size. In total 12 groups of land-use variables were included in the analysis (as shown in brackets below). The variable (1) 'crop type' included maize, sunflower and stubble. In order to reduce the number of categories and avoid rare factors, the stubble of the different cereals and oilseed rape were placed in one group, 'stubble'. (2) Crop cover (%) and (3) sowing date were also included in the analysis. The variable (4) 'preceding crop' included all the above and some additional crops: alfalfa (*Medicago sativa* L.), potato (*Solanum tuberosum* L.), soybean (*Glycine soja* L.) and bean (*Phaseolus vulgaris* L.). The different cereal species were here also placed in one group, 'cereal'. (5) Organic manure ($t \cdot ha^{-1}$), (6) the type (N, P_2O_5, K_2O, MgO, CaO) and amount ($kg \cdot ha^{-1}$) of fertilizer and (7) the type (53 active ingredients) and amount ($g \cdot ha^{-1}$ or $l \cdot ha^{-1}$) of herbicide, (8) mechanical weed control (times), (9) field size (ha), (10) tillage system (conventional tillage, minimum tillage, no-tillage) and (11) tillage depth (cm) were also included in the analysis. In addition, (12) the location of the plot (edge or field centre) was also included. Due to the great variety of herbicides used this factor was later excluded from the statistical analysis.

For each field investigated 19 environmental variables were compiled, including (a) soil properties, such as (1) soil pH (KCl), (2) soil texture (coarse sand, sand, sandy loam, loam, clay loam, clay), assessed on the basis of Stefanovits et al. (2005), (3) the content (m/m%) of salt, refering to the total amount of salt in the soil that can be dissolved in water, (4) humus and (5) $CaCO_3$, (6) the content ($mg \cdot kg^{-1}$) of P_2O_5, (7) K_2O, (8) Na, (9) Mg, (10) NO_2-NO_3-N, (11) SO_4, (12) Cu, (13) Mn, (14) Zn; (b) climatic conditions, represented by (15) mean annual and monthly (from April to August) temperatures and (16) mean annual and monthly (from April to August) rainfall, obtained from the Hungarian Meteorological Service (HMS 2001) and WorldClim Databases (Hijmans et al. 2005); (c) geographic position (measured using a GPS receiver) in terms of (17) site longitude, (18) latitude and (19) altitude. Geographic coordinates were included in the analysis as surrogates of unmeasured environmental variables (e.g. climate). Furthermore, longitude and latitude are also related to the residence time of *A. artemisiifolia*, as it is continuing to slowly spread from south-west to north and east in Hungary. The ranges and categories of environmental and land-use gradients used in this study are given in Tables 1 and 2.

Data analysis

The abundance (percent cover) of ragweed at the edges of fields and the average abundance in the three plots in each field were compared using a Wilcoxon paired test.

Next, the land-use and environmental variables were used as explanatory predictors in a series of statistical models. The response variables in this analysis were either the (i) plant cover values of *Ambrosia artemisiifolia*, or (ii) three simplified cover categories, which were none (0), low (< 10%) or high (> 10%), or (iii) its presence/absence status. Results for field edges and fields were analysed separately, but data for the three plots from the same field were averaged prior to analysis. The different simplifications of the response variables (i.e. cover, cover categories and presence-absence data) may be affected by different environmental and land-use factors, and their analysis may highlight different aspects of ragweed's dependence on environmental conditions and land-use. As a raw measure of ragweed abundance, estimated cover values seem to convey the most information about the environmental preferences of this species. Nevertheless, above a certain threshold the exact cover value may be (i) more related to stochastic events than the factors studied and (ii) practically irrelevant with respect to the negative effects of this species. Presence/absence data, on the other hand, can be used to focus directly on the conditions associated with the absence of ragweed.

Table 1. – Ranges and categories of environmental variables used in this study.

Factor	Min	Max
Geographical position		
Altitude (m)	82	415
Latitude (N)	45°52'09"	48°32'59"
Longitude (EO)	16°49'57"	22°32'95"
Climatic conditions		
Mean annual precipitation (mm)	470	766
Mean April precipitation (mm)	33	63
Mean May precipitation (mm)	51	81
Mean June precipitation (mm)	62	92
Mean July precipitation (mm)	49	97
Mean August precipitation (mm)	46	93
Mean annual temperature (°C)	8.8	11.2
Mean April temperature (°C)	9.2	11.9
Mean May temperature (°C)	13.9	16.6
Mean June temperature (°C)	17.3	19.7
Mean July temperature (°C)	19.0	21.5
Mean August temperature (°C)	18.5	21.1
Soil properties		
Soil pH (KCl)	3.48	7.85
Soil texture (coarse sand, sand, sandy loam, loam, clay loam, clay)	–	–
Salt (m/m%)	0	1.14
Humus (m/m%)	0.5	6.43
$CaCO_3$ (m/m%)	0.01	37.3
P_2O_5 ($mg \cdot kg^{-1}$)	44.8	2810
K_2O ($mg \cdot kg^{-1}$)	57.8	1310
Na ($mg \cdot kg^{-1}$)	19.0	650
Mg ($mg \cdot kg^{-1}$)	19.5	1660
NO_2-NO_3-N ($mg \cdot kg^{-1}$)	0.49	390
SO_4 ($mg \cdot kg^{-1}$)	6.25	774
Cu ($mg \cdot kg^{-1}$)	0.31	13.1
Mn ($mg \cdot kg^{-1}$)	8.39	506
Zn ($mg \cdot kg^{-1}$)	0.1	22.8

Table 2. – Ranges and categories of land-use variables used in this study.

Factors	Min	Max
Crop type (maize, sunflower, stubble)	–	–
Crop species (8 species)	–	–
Crop cover	0	100
Date of sowing (3 January 2008–30 November 2009)	–	–
Preceding crop type (maize, sunflower, cereal, others)	–	–
Preceding crop species (12 species)	–	–
Organic manure ($t \cdot ha^{-1}$)	0	60
Amount of fertilizer ($kg \cdot ha^{-1}$)		
N	0	261
P_2O_5	0	104
K_2O	0	150
MgO	0	24.5
CaO	0	43
Mechanical weed control (number of treatments)	0	2
Field size (ha)	0.24	524
Tillage system (conventional tillage, minimum tillage, no tillage)	–	–
Tillage depth (cm)	0	60
Plot location (field edge, field core)	–	–

Decision tree models were used to establish relationships between the predictors and the response variables. Decision trees (also known as classification and regression trees) are non-parametric statistical methods that estimate the response variable as a piecewise constant function of the predictors by splitting the sample using the most influential predictor variable and assigning constant values to each resulting sub-domain in a recursive process (Breimann et al. 1984). Accordingly, such models can handle nonlinear relationships, very large sets of mixed type (i.e. both categorical and continuous) predictors, and the results are easy to interpret and indicate the variable that significantly discriminates between classes (Crawley 2007). Furthermore, as they handle the predictors one by one, they are essentially free from problems caused by multicollinearity. Decision tree models are frequently used to study the distribution of invasive organisms (Usio et al. 2006, Hejda et al. 2009, Pyšek et al. 2010) and analyse the factors affecting arable ecosystems (Ferraro et al. 2009).

Decision tree models were fitted using the party add-on package (Hothorn et al. 2006) in the R 2.9.2 environment (R Development Core Team 2009). The function *ctree* generates a binary decision tree through recursive partitioning and applies simple permutation tests based on the conditional inference framework of Strasser & Weber (1999) at each recursive step. Accordingly, the *ctree* framework is free of the variable selection bias, common to most other classification or regression tree algorithms. Furthermore, permutation tests provide a statistically sound inherent stopping rule for the model building process, which eliminates problems of under- and over-fitting.

Results

Ambrosia artemisiifolia was not recorded in 29 fields and in 48 it occurred only at the edges of the fields. Its maximum cover was 70% at the edges and 60% at the centre of the fields. Its mean cover was 11.9% at the edges and 5% at the centres of the fields, respectively. The abundance of *A. artemisiifolia* was significantly higher at the edges than at the centres of fields when all fields were analysed together. The same results were obtained when the different crop types were analysed separately (Table 3).

Table 3. – Comparison of *Ambrosia artemisiifolia* cover at the edges and centres of fields using Wilcoxon paired tests.

Studied subset of data	Test statistic	Number of fields	Type I error rate (P value)
All fields	19094.5	243	$< 2.2 \times 10^{-16}$
Maize fields only	3487	102	1.588×10^{-14}
Sunflower fields only	2016	71	3.405×10^{-11}
Stubble only	1150.5	70	0.02272

Classification and regression trees for edges of fields

Using cover values, crop type was the predictor variable that determined the first split in the regression tree (Fig. 2). Sunflower fields were separated from maize and stubble fields. For sunflower subsequent splits were determined by soil pH and mean May temperature; sunflower fields with a soil pH < 5.03 or with soil pH > 5.03 and a mean May temperature < 15.5 °C were associated with the highest cover values of *A. artemisiifolia*. Using cover

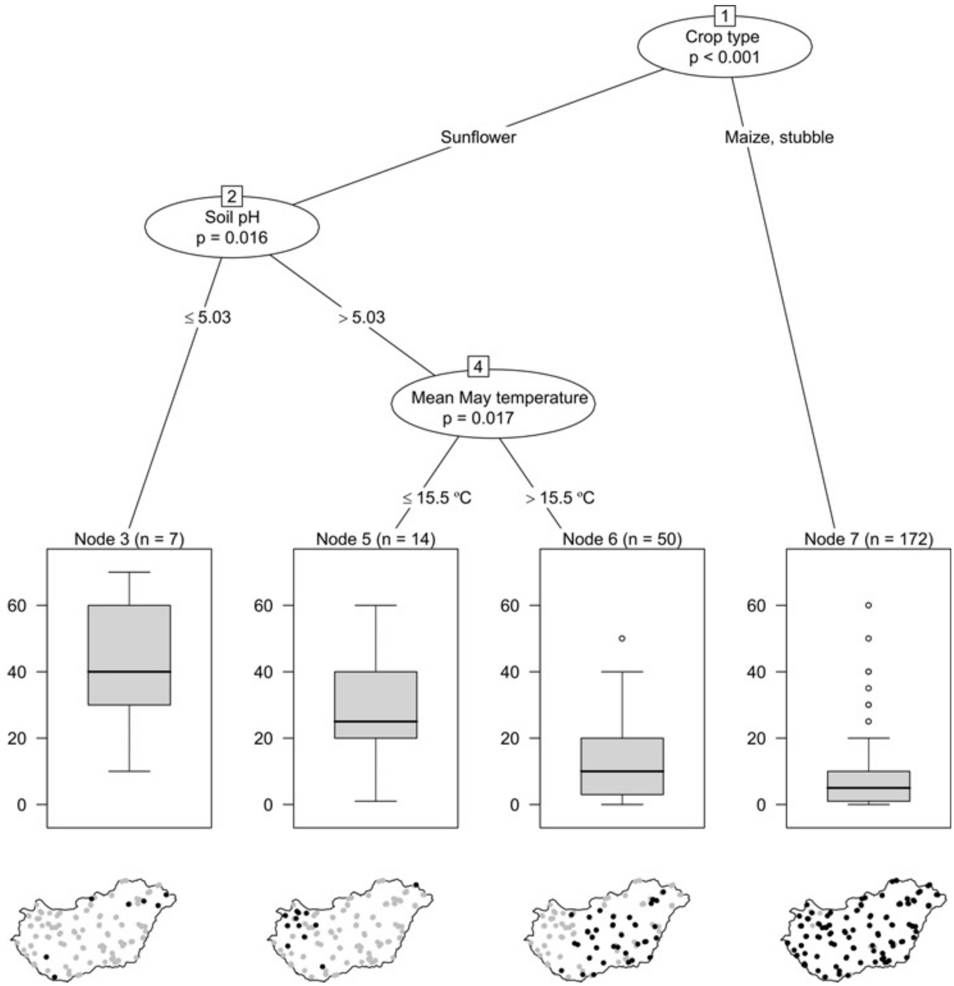

Fig. 2. – Regression tree model of the cover values of *Ambrosia artemisiifolia* recorded at the edges of fields. Each split is described with the predictor used at the split, the Bonferroni-corrected significance (P-value) of the split and the values at which the split occurs. At each terminal node the number of observations (n) is given along with the values of the response variables (vertical axes of the box plots showing median, upper and lower quartile, minimum and maximum) and their geographic locations (black dots on the small maps).

categories at field edges, soil K content was the most important explanatory factor, indicating higher infestation of *A. artemisiifolia* in fields where K_2O was < 429 mg (Fig. 3). The subsequent splitting variables were geographical longitude and field size, suggesting the lowest infestation are recorded at longitudes > 20°13' and in fields > 7 ha. At the presence/absence level soil Na content was the only significant predictor, showing that *A. artemisiifolia* was less frequently present at the edges of fields with a Na content > 66.9 mg (Fig. 4).

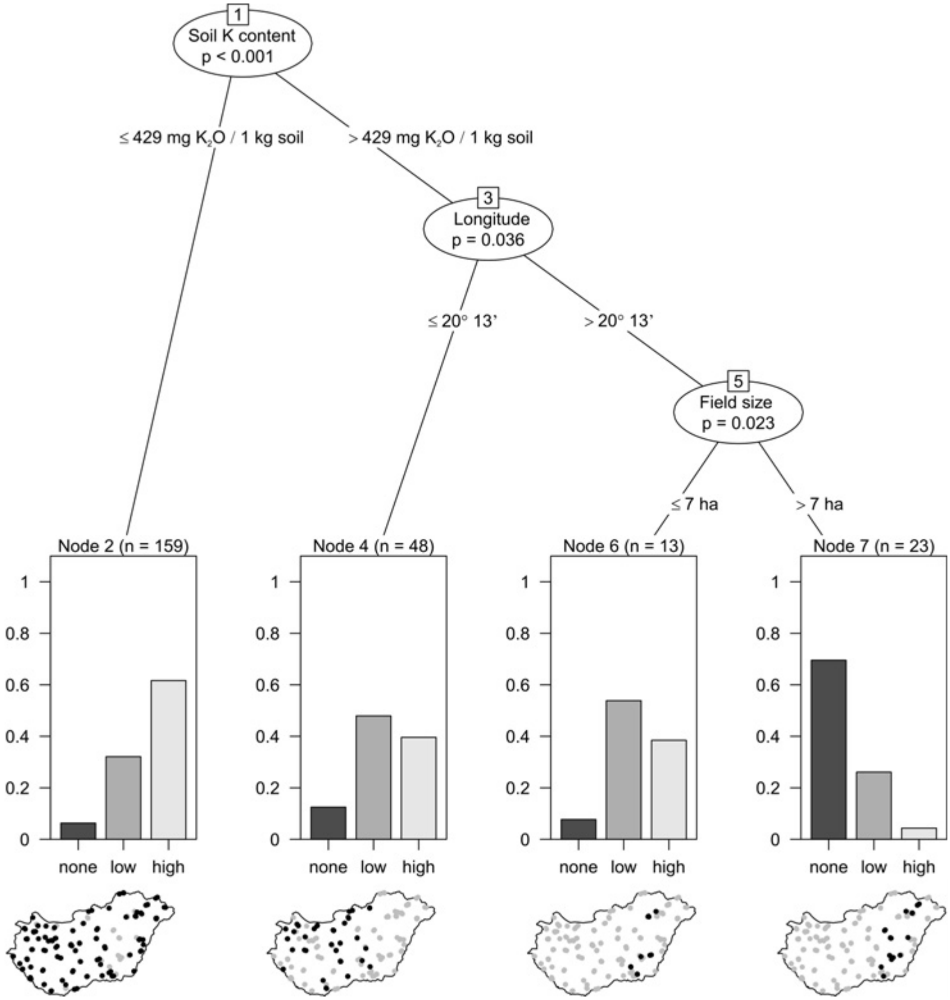

Fig. 3. – Classification tree model of the cover categories of *Ambrosia artemisiifolia* recorded at the edges of fields: none (0), low (< 10%) high (> 10%). Each split is described with the predictor used at the split, the Bonferroni-corrected significance (P-value) of the split and the values at which the split occurs. At each terminal node the number of observations (n) is given along with the values of the response variables (bar charts showing the proportions of observations of the different cover categories) and their geographic locations (black dots on the small maps).

Classification and regression trees for the centres of fields

Using the raw cover values for *A. artemisiifolia*, crop cover was the primary splitting variable for the centres of fields (Fig. 5). Fields with a crop cover ≤ 31.7% were then segregated on the basis of soil texture, indicating a higher abundance of *A. artemisiifolia* on sandy soils. Fields with crop cover > 31.7% were subsequently separated with respect to altitude, indicating higher infestation above 220 m a.s.l. Soil texture was also the most

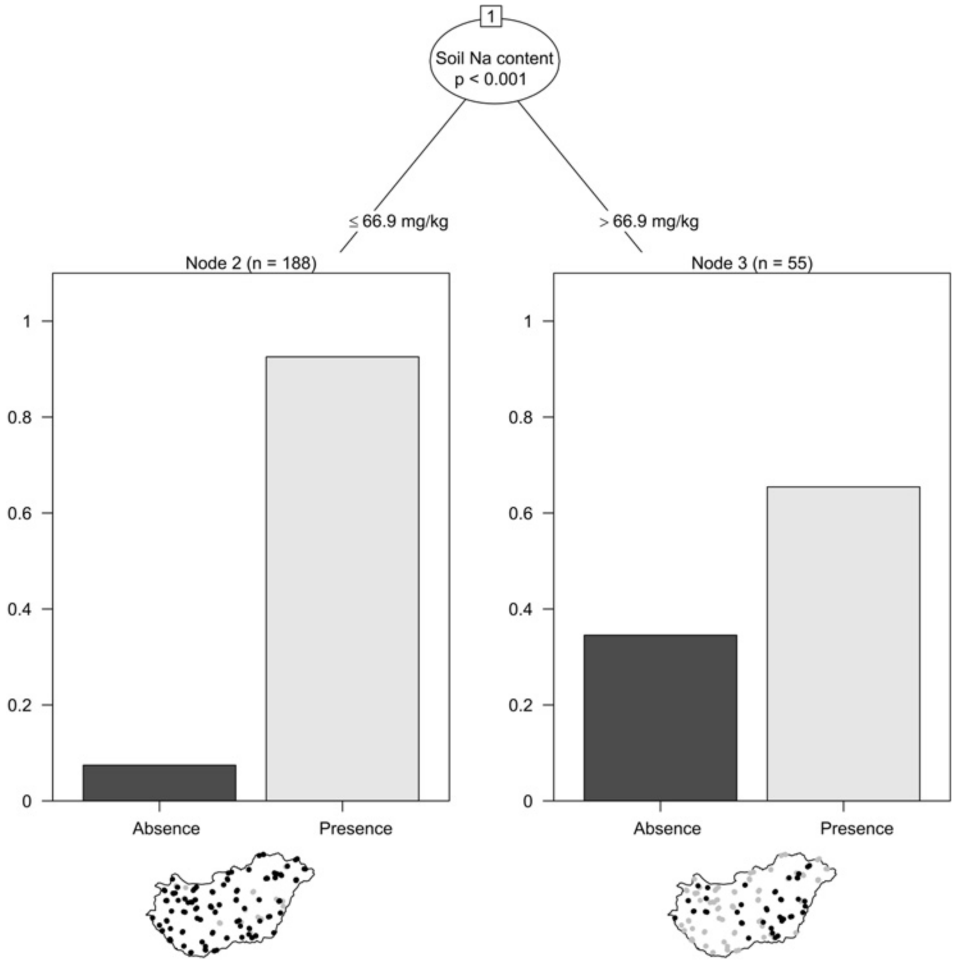

Fig. 4. – Classification tree model for the presence/absence data of *Ambrosia artemisiifolia* at the edges of fields (see Fig. 3 for details).

important factor when the data were analysed in cover categories, with higher infestations recorded in fields with coarse sand and sandy soils (Fig. 6). On other types of soil (sandy loam, loam, clay loam and clay), mean April rainfall was the second most important factor associated with high infestations if the mean April rainfall was > 39 mm. For the presence/absence data, the occurrence of *A. artemisiifolia* was primarily associated with soil K content at the centres of fields (Fig. 7). Fields with a soil K content < 279 mg were then separated with respect to soil Mn content, indicating a low occurrence of *A. artemisiifolia* in fields where the soil Mn content was > 214 mg. Fields with a soil K content > 279 mg were then segregated on the basis of mean annual rainfall, with a high occurrence of *A. artemisiifolia* associated with a mean annual rainfall > 592 mm.

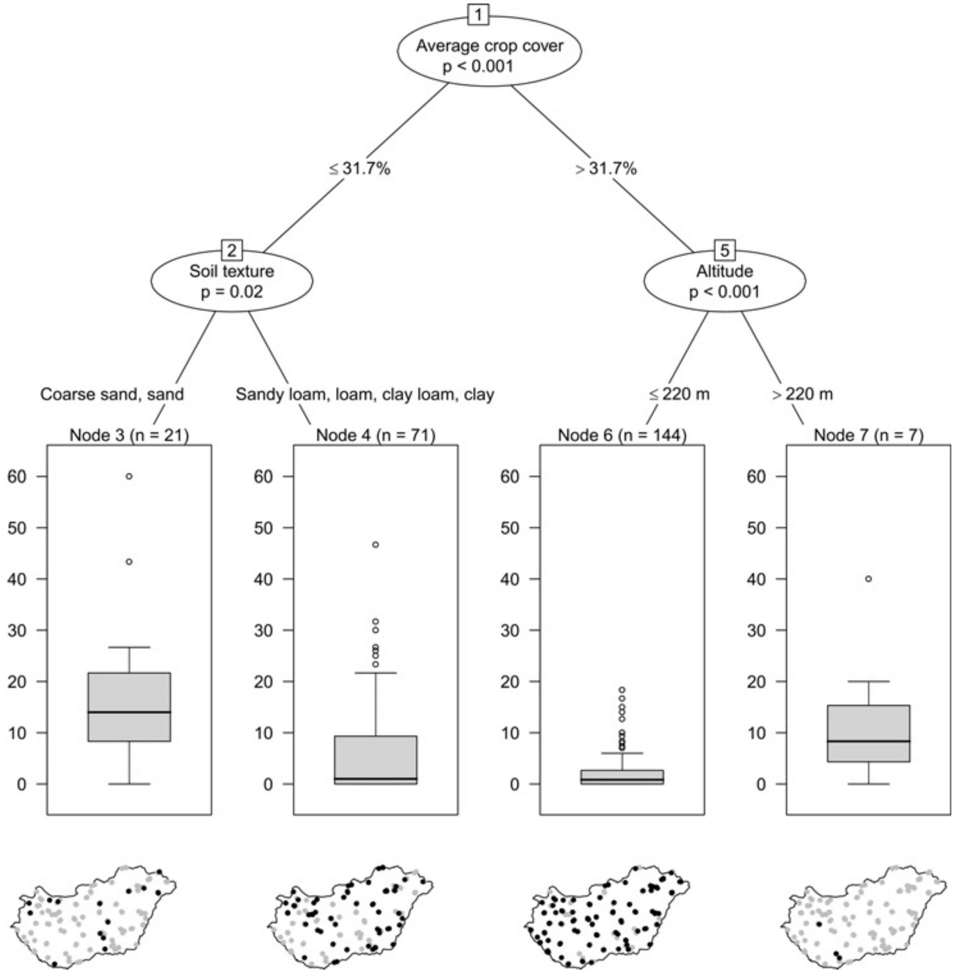

Fig. 5. – Regression tree model for the cover values of *Ambrosia artemisiifolia* at the centres of fields (see Fig. 2 for details).

Discussion

Field edge effect

This study indicates that the abundance of *A. artemisiifolia* is significantly higher at the edges than the centres of fields. Herbicides and fertilizers are often less efficiently applied near the edges of fields and the light conditions there are also usually more favourable (Wilson & Aebischer 1995). Accordingly, this habitat is a refugium for several rare species of arable land (Fried et al. 2009), but can also become heavily infested with noxious weeds, such as *A. artemisiifolia*, as shown by the current study. The cover values of *A. artemisiifolia* were significantly higher at the edges than in the centres of fields for all the crops studied (sunflower, maize and stubble fields). One possible explanation for this is that *A. artemisiifolia* is less competitive in dense crop stands because it requires high

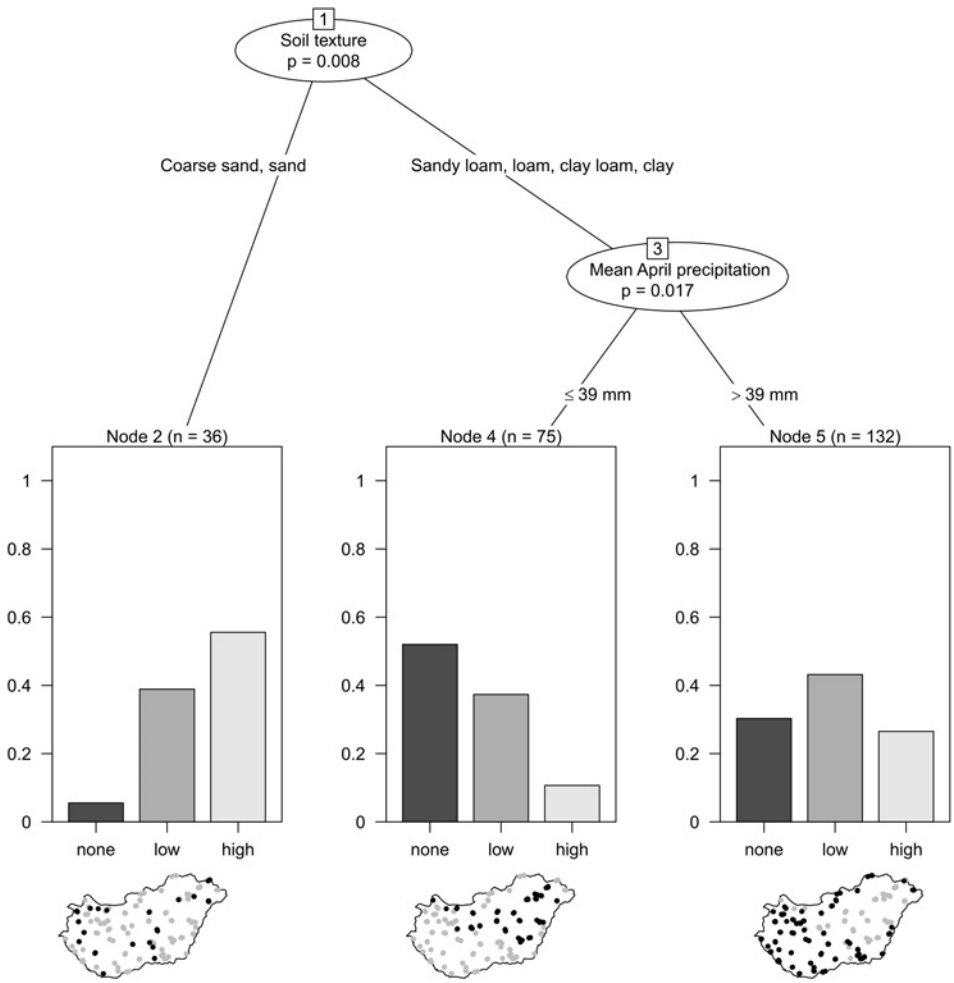

Fig. 6. – Classification tree model for the cover categories of *Ambrosia artemisiifolia* at the centres of fields: none (0), low (< 10%) high (> 10%) (see Fig. 3 for details).

light intensities when growing (Szigetvári & Benkő 2008). However, other factors might also contribute to this edge effect, as it was also detected in stubble fields that lacked any significant crop cover (with the possible exception of crop volunteers) at the time of the field surveys (July–August). For example, frequent growing of sunflower and maize in a crop rotation may result in a greater accumulation of *A. artemisiifolia* seeds in the soil seed bank at the edges than in the centres of fields.

Land-use factors

At the coarse scale of this study, crop type and crop cover were the only important land-use factors associated with the abundance of *A. artemisiifolia*, with field size having a minor

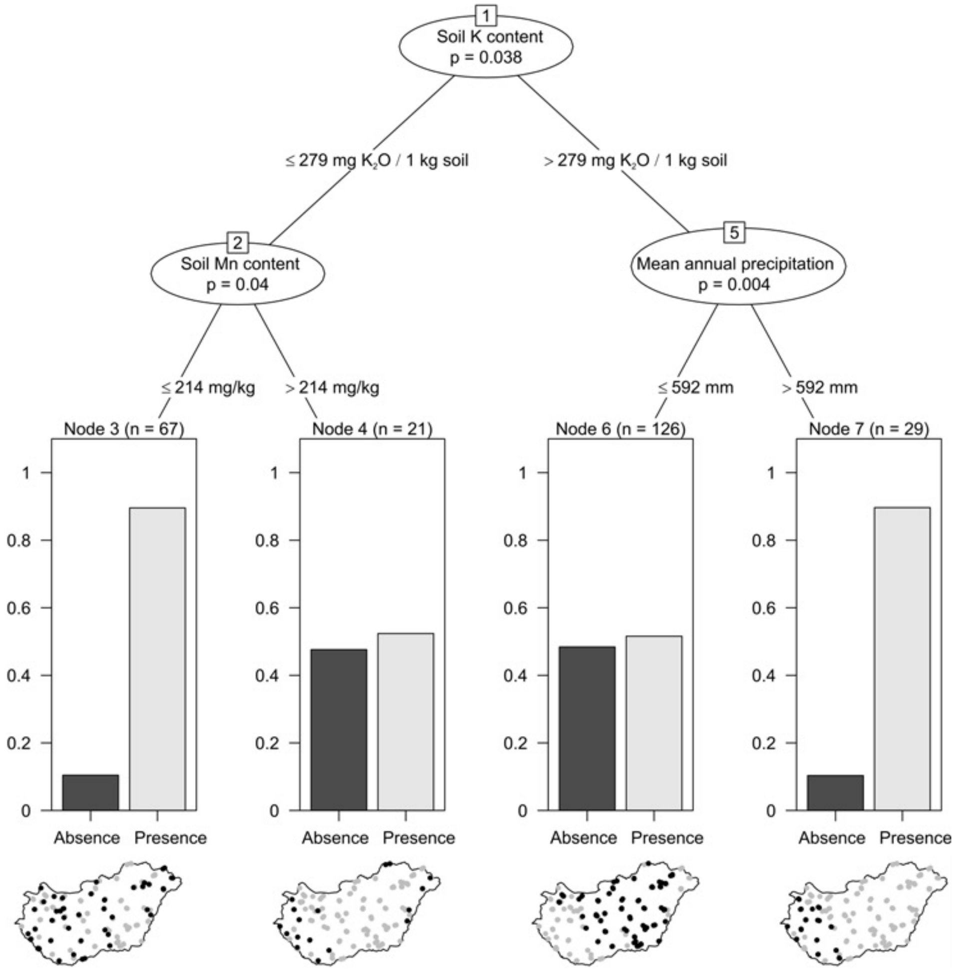

Fig. 7. – Classification tree model for the presence/absence data of *Ambrosia artemisiifolia* at the centres of fields (see Fig. 3 for details).

effect. In addition it indicated that the highest infestations were found at the edges of sunflower fields. Sunflower is the third most prevalent crop in Hungary and keeping *A. artemisiifolia* under control in this crop is a 'great challenge' for farmers. The low efficiency of chemical control is not only due to the botanical similarity between the weed and crop, but also because of the ineffectiveness of pre-emergent herbicides when it is dry in spring (Kazinczi et al. 2008b). In the centres of fields, irrespective of the crop, crop cover was one of the most important explanatory variables, suggesting that at low levels of crop cover (under ~30%) the conditions are very favourable for the light-demanding *A. artemisiifolia*. In addition, this can also account for why in dense crop stands *A. artemisiifolia* is usually restricted to the outermost few meters of fields. Field size was important only for the small fields in the eastern regions of Hungary, indicating that at the edges of large fields (above 7 ha) the rate of infestation is generally lower. Small fields are usually considered to be weedier than large fields and smallholder farmers are generally regarded to be more responsible for the spread of *A. artemisiifolia*. However, this assumption is not supported the results for the whole of Hungary. After the political transitions in the 1990's many large fields were subdivided and due to poor crop management were quickly colonized by *A. artemisiifolia* (Kiss & Béres 2006). In small fields some agro-technical operations (e.g. chemical weed control) are less efficient and the farmers tended to use less intense farming methods (Pinke et al. 2009). This is also supported by the investigations of Gaba et al. (2010), who observed that the lower weed diversity in large fields is partly attributed to weed control being more efficient in large fields, as they can be managed more intensively as it is easier to use agricultural machinery in such fields.

Soil properties

At the centres of fields, soil texture is one of the most important factors, with higher infestation where the soil was coarse sand or sandy. In France the majority of *A. artemisiifolia* populations are recorded growing on sandy soils (Fumanal et al. 2008b). Soil pH was also significant at the edges of sunflower fields with the highest weed cover when the soil pH was < 5. This is consistent with the edaphic preferences of *A. artemisiifolia* reported in Hungarian literature, namely that it thrives best on acidic sandy soils (Ujvárosi 1973, Szigetvári & Benkő 2008). Furthermore, a high soil Na content was significantly associated with a lower presence of *A. artemisiifolia* at the edges of fields. High sodium concentration usually leads to salinization, which can negatively affect soil structure and fertility, a major abiotic constraint for plants and agricultural populations of *A. artemisiifolia*, which is intolerant of saline conditions (DiTommaso 2004, Szigetvári & Benkő 2008).

The results indicate that soil K content is also a very important variable, both at the edges and centres of fields. High potassium contents are associated with slightly smaller infestations at the edges of fields. This finding is consistent with the general observation that negative potassium indicator weed species usually prefer acidic soils (Holzner 1971). Andreasen et al. (1991) also record that high potassium contents have a negative effect on *Anagallis arvensis* and *Solanum nigrum*. In a recent study Tarmi et al. (2009) did not find a significant relationship between soil K content and the composition of weed communities, however, Andreasen & Skovgaard (2009) show that this soil property influences the occurrence of some species. The associations of *A. artemisiifolia* with soil K are, therefore, likely to be driven by complex soil chemical interactions with plant functions, which require further study. The association with soil Mn content was also significant, with less frequent occurrences of *A. artemisiifolia* where the concentration was high. The investigations of Andreasen et al. (1991) reveal that this element is rather important for certain weed species. The background of this dependency is unclear. Even though the amount of manganese is usually higher in acidic and waterlogged soils (Bohn et al. 1979), earlier surveys suggest that *A. artemisiifolia* thrives well in fields that are temporarily waterlogged or flooded (Pál et al. 2006).

Climatic conditions and geographical position

In the centres of fields with soils with high clay content, mean April precipitation was a significant predictor, indicating higher infestations in wetter areas (April precipitation > 39 mm).

This is associated with the high requirement for water of the seeds and seedlings of *A. artemisiifolia*, which germinate mainly in April and May in Hungary (Kazinczi et al. 2008a). Mean annual precipitation was also important, with a more frequent occurrence of this weed where it was over 600 mm. In addition, May temperature was also significant at the edges of sunflower fields, with higher infestations in cooler regions (< 15.5 °C). These results agree with those of Ujvárosi (1973), who states that *A. artemisiifolia* grows best in the cooler and more humid regions of western-Hungary. Notwithstanding its relatively high temperature requirements, ragweed is not competitive in areas where the summers are hot and dry (Chauvel et al. 2006). In Austria, however, where large areas of agricultural land are only slightly too cool for *A. artemisiifolia*, its distribution is not associated with precipitation, but with temperature, namely that of the hottest month, July (Essl et al. 2009).

The results presented indicate that on certain soils the infestations of *A. artemisiifolia* are less severe in eastern Hungary (east of longitude 20°13'). This is a consequence of regional variation in climate and soil type, with the regions with a very dry climate and heavy soils, which are unfavourable for *A. artemisiifolia*, mainly located in the east (Ujvárosi 1973). Under certain conditions at higher altitudes (> 220 m) high infestations are reported. This is probably because of the higher rainfall recorded at these altitudes, although only altitudes up to 415 m were included in this study. This relationship does not hold at higher altitudes due to the limitations imposed by decreasing temperature (Essl et al. 2009).

Implications for management

The results indicate that the most important land-use variables associated with the variation in abundance of *Ambrosia artemisiifolia* were crop type and crop cover, while the most relevant environmental variables were soil texture, soil pH, soil Na, K and Mn content, May temperature, annual and April rainfall. Inappropriate crop management is often identified as the most important reason for the high infestations of *A. artemisiifolia* in Hungary, but the results indicate that soil and climatic factors are also important and that the ecological conditions in the Carpathian Basin are very favourable for this weed. If presence/absence data are more relevant and informative than plant cover values, the results indicate that certain soil variables might be more important than any of the land-use factors. The effect of environmental variables should not be overlooked when formulating effective ragweed control policies. In addition to recognizing ragweed as a problem, farmers should be aware of the conditions and practices favouring or limiting ragweed infestations.

Of the land-use variables studied only two were important. Furthermore, as herbicides were not included in the analysis and the effect of mechanical weed control was insignificant, it is not possible to strongly recommend a management policy for reducing the incidence of ragweed. As a drastic mitigation measure avoiding growing sunflowers in fields with sandy soils may be considered. Growers also expect that herbicide-tolerant sunflower varieties may be the solution in the future (Nagy et al. 2006, Schröder & Meinlschmidt 2009). The mechanical mowing of the edges of sunflower and maize fields and increasing the density of the crop stands in these fields could reduce the incidence of high *A. artemisiifolia* infestations. In some cases the mowing of adjacent road margins should also be recommended, because roadsides can be sources of spread into fields (Simard & Benoit 2010). *Ambrosia artemisiifolia* can often form dense carpets in stubble fields, but thanks to the growing awareness that ragweed poses serious problems the mass pollen emission that is so hazardous has increasingly been prevented by the timely ploughing of stubble-fields over the last few years.

The large expansion of *Ambrosia artemisiifolia* is currently making it difficult to conserve arable habitats in Hungary, not only because it is invading the habitats of rare weed species (Pál 2004, Pinke & Pál 2009), but also because its allergenic effects have resulted in eradication campaigns (Kazinczi et al. 2008c). As a consequence of these campaigns and the threat of penalties, farmers have recently more actively controlled *A. artemisiifolia*. The increasing frequency of allergic cases, the eradication campaigns and high media attention have shifted public opinion towards the necessity for total ragweed control. However, this inevitably means the eradication of a wide spectrum of species, because the chemicals and mechanical operations used are not species-specific. Nevertheless, arable habitats not treated with herbicides provide refugia for several rare and threatened weed species that are susceptible to intensive agricultural management. In addition, common species of weeds provide valuable sources of food and habitats for several insect and bird species (Marshall et al. 2003, Storkey 2006, Pinke & Pál 2009, Barberi et al. 2010). Therefore, even though there is a need to eradicate ragweed, authorities inspecting infestations of *A. artemisiifolia* and imposing penalties on farmers and landowners should also consider the conservation value of other weed species. The control of ragweed in arable habitats with a high diversity of weeds should be done by applying more selective methods and receive more attention from conservationists.

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Souhrn

Ambrosia artemisiifolia je nejobtížnějším invazním plevelným druhem v Maďarsku. Cílem této studie bylo kvantifikovat vliv faktorů prostředí na abundanci tohoto druhu na zemědělské půdě v Maďarsku. Celkem byl zaznamenán výskyt druhu na 243 polích a analyzován vliv 19 proměnných prostředí a 12 typů využití krajiny. Data byla zpracována klasifikačními a regresními stromy. Abundance *A. artemisiifolia* byla statisticky průkazně vyšší na okrajích polí, v slunečnicových kulturách a na polích s nízkou pokryvností plodiny. Písčité nebo kyselé půdy, dubnové srážky převyšující 39 mm, průměrné roční srážky vyšší než 592 mm a průměrná květnová teplota pod 15,5 °C byly dalšími faktory přispívajícími k vysoké abundanci *A. artemisiifolia*. Druh se naopak vyskytoval s nižší abundancí na polích s vysokým obsahem Na, K a Mn.

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