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Soil Electrical Conductivity as One Possible Tool for Predicting of Cirsium Arvense Infestation Occurence

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1. Introduction

From a practical point of view it is necessary to use an exact low cost and time consuming approximation to obtain information about an actual weed infestation. In this study the intensity of *Cirsium arvense* (L.) SCOP infestation was monitored in a 12 ha experimental field, where malting barley (2002) and winter wheat (2003) were grown.

The sampling points for *C. arvense* infestation were established in a square raster with one 18 m long side of one raster unit.. *Cirsium arvense* occurrence was manually counted. During the data collection at the sampling points, the number of *C. arvense* plants which were situated outside of sampling points was counted as well. Each *C. arvense* patch was localized by GPS and saved as digital coordinates as well. On the basis of the field survey and the *C. arvense* infestation monitoring, two data sets were collected. The first data set contains the *C. arvense* densities in the raster, and the second data set offers information about *C. arvense* occurrence in patches. The soil variability was described by means of soil electrical conductivity (EC_a) measurement in the year 2003. The number of *C. arvense* plants from the raster and values of EC_a were included into the evaluation.

Acquired data were evaluated in GIS using a geostatistical procedure. Correlation analysis brought the following results: relatively high correlation R = 0.64 in the year 2002 and R = 0.91 in the year 2003 were found between EC_a and *C. arvense* infestation. The results indicated a statistically significant correlation at a 99% confidence level, it means a close dependence between *C. arvense* infestation and EC_a was observed. This fact proved our presumption about *C. arvense* response to soil properties. According to our results it can be stated that higher values of EC_a are be observed at places where higher density of *C. arvense* is present.

The aim of this research is: (1) the evaluation of the *C. arvense* infestation and spatial distribution, (2) the herbicide effect, (3) the field heterogeneity by means of the soil electrical conductivity (EC_a) measurement and (4) the comparison of relations between EC_a and *C. arvense* infestation.

Several studies proved that many weeds, including grass weeds, are spread non-uniformly within a field. Furthermore, the weed patches are relatively stable within a season and

among seasons (Hamouz et al. 2002, 2004; Godwin & Miller 2003; Krohmann et al. 2002; Werner & Garbe 1998). On the other hand, Soukup et al. (2003) noticed biological differences of crops in crop rotation and specific characteristics of general year-to-year crop rotation which may have an important influence on annual changes in weed infestation. Moreover, weed distribution proved to be heterogeneous during several years and with different crops (Gerhards et al. 2000). Targeted protection could be done only on the basis of every year and more than once repeated diagnostics. Further, weed seeds in soil seed bank are dispersed during soil cultivation and harvest (Godwin & Miller 2003). Weed patches are often extended in the direction of machinery movement (Hamouz et al. 2004). These facts have to be taken into account for the site-specific weed management.

A considerable sum of money was spent on monitoring weed infestation. In general, the number of weeds is hold down on a sustainable threshold value of plants per square meter. The economical threshold varies within fields as well as within different weed species (Scotford & Miller 2005). For example, it is reported (SAC 2001) that low populations (10 plants m^{-2}) of volunteer barley in oilseed rape can reduce yield by 5 %, whereas populations of broad leaved weeds (excluding cleavers) can be up to 200 plants m^{-2} without any significant effect on crop yield. In accordance with the level of malignancy it is generally possible to find areas in a field, where the chemical weed management could be omitted or reduced (Hamouz et al. 2000). As a matter of routine the same dose of herbicide is applied to hold the weeds under the economic thresholds, despite the fact that the weeds infestation varies (Hamouz et al. 2000). Of course, there is a chance for herbicide savings by using site specific herbicide application. The results of Gerhards et al. (1997) demonstrated that the site specific weed management was technically feasible but further investigations are needed to verify and evaluate site specific weed control methods.

The site-specific herbicide application presumes, that the herbicide spray can be omitted at certain areas within the field with no or low weed infestation. The area with higher infestation necessary to be treated should be sprayed with the dose adjusted precisely according to the weed infestation level (Sökefeld et al. 2000; Gerhards & Oebel 2006). Soukup (2000) noticed possible savings of herbicides in the range of 30 to 50 %, which would have significant economical and ecological benefits. But there are some difficulties linked with this idea. First of all, the weed detection in the required time interval for the treatment is very difficult as well as the setting of a precise dose for the optimal treatment. Furthermore, it is inexpedient to carry herbicides which are not needed in the field. The type of weed detection and the proper detection time is the crucial factor for the whole weed detection system (on-line or off-line), especially for the acceptable delay time of the direct injection system (Sökefeld et al. 2004).

As far as the information of weed infestation is concerned, from a practical point of view, it is important to use an exact real approximation with low time and low cost consumption. One way of mapping is manual weed detection connected with GPS. However, walking over the whole field on foot is very time consuming and expensive and not possible for larger fields. According to Soukup (2000), manual classification of weed infestation with the raster 50 x 36 m in a big field takes time from 0.5 to 2.5 hours per one hectare. Manual classification is impractical in this regard. Utilization of tractors, harvesters or off-road cars is preferable to do good weed mapping.

An alternative method is checking just the areas of interest. These areas could be chosen according to vegetations indexes obtained by remote sensing or by radiometers mounted onto the machines (Godwin & Miller 2003). Hamouz (2008) describes an algorithm for

detection of *Cirsium arvense* in cereals using an aircraft with high resolution multispectral camera. He calculated and tested the classification accuracy of various vegetation indices including NDVI. The best correlation coefficient and also the highest classification accuracy was reached using DVI index.

Spectral vegetations indexes, calculated as a ratio of particular wave lengths, were described and used in many studies. These indexes are further compared with other characteristics of investigated environment like coverage or weed infestation (Scotford & Miller, 2005). Remote investigation, alternatively for sampling plots establishment, is also used for example to determine plant nutritious conditions, yield, soil characteristics, organic matter, and weed infestation, (Cox 2002; Zhang 2002; Selige 2003). The advantage of satellite pictures, as opposed to sensors and sampling points, is in providing information about the whole area and detailed overview of spatial variability. Sampling points taking considerably limits quality of spatial variability description, because of its difficulty and high labour consumption (Basso et al. 2003).

Oebel and Gerhards (2005, 2006) tested variable herbicide application in cereals and also in sugar beet, maize and winter rape. They used a manual and automatic real time mapping system, application maps and economic thresholds.

During the automatic weed classification 69 % of weed plants were recognized in sugar beet and 72 % in maize. These systems require costly and sophisticated technical and software equipments.

2. Materials and methods

An intensity of *Cirsium arvense* (L.) SCOP populations was monitored in a 12 ha experimental field at Prague-Ruzyně district, Czech Republic (50°05´N, 14 °18´E), where malting barley (2002) and winter wheat (2003) were grown. The field was tilled by conventional ploughing technology. The soil type at the study site is *Orthic Luvisol*, according to the FAO classification, with different share of skeleton. The soil texture is non-homogenous with different textures of loam and sandy loam. The altitude of the field is about 340 m above sea level, the average rainfall is 450 mm per year and the average temperature 7.8°C. The experimental field slopes from north to south and it merges to a plane in lower part. In the same direction on the left hand side from the axial fall line a shallow ground wave is present.

The sampling points were established in the 18 x 18 m raster (Figure 1). *Cirsium arvense* occurrence was manually counted at 0.25 m^2 squares along the raster in April. The number of plants per 0.25 m^2 was converted to the number of plants per 1 m^2. During the data collection at the sampling points, the number of *C. arvense* plants which were situated outside of sampling points was counted as well. Each *C. arvense* patch was localized by GPS and registered as well.

The soil variability was described by means of soil electrical conductivity measurement (Figure 2).

Soil conductivity was measured by using the contact method. Output signal from the sensor was simultaneously recorded with the GPS position signal. The records were written into the data set in 5 second intervals. Data were processed using geostatistical methods. In order to process data accurately and to eliminate measuring errors, several modifications on the initial EC_a values were performed prior to statistical processing and evaluation. The majority of errors, when measuring EC_a, occurred when the machine started a new line.
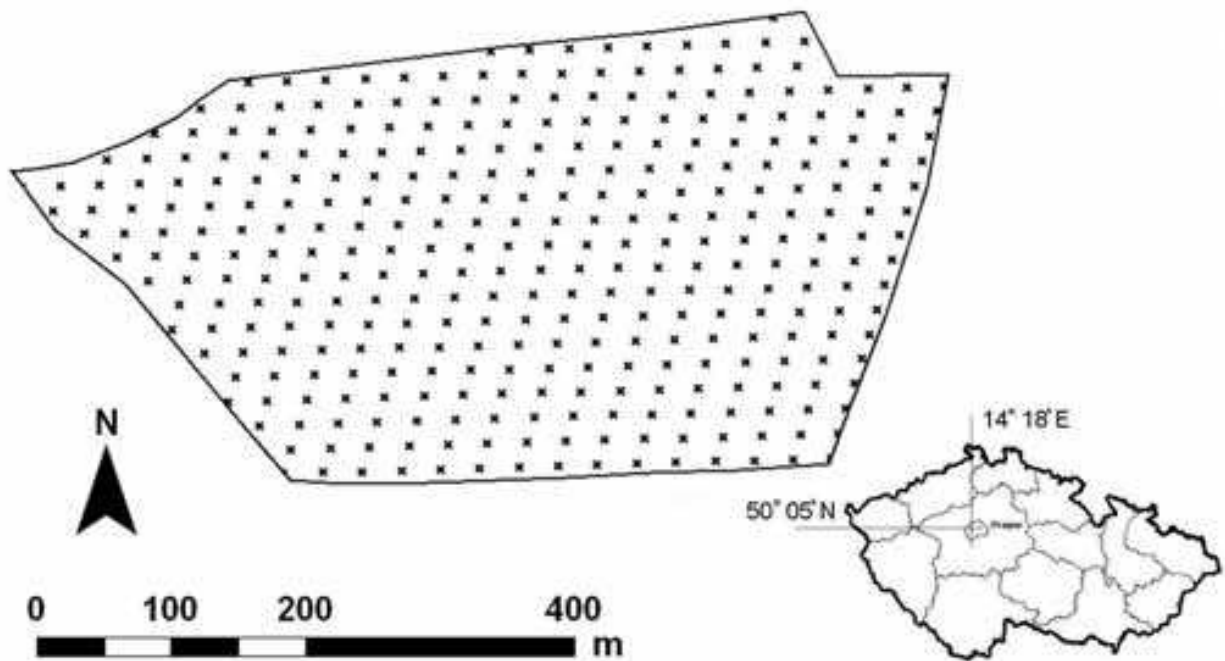
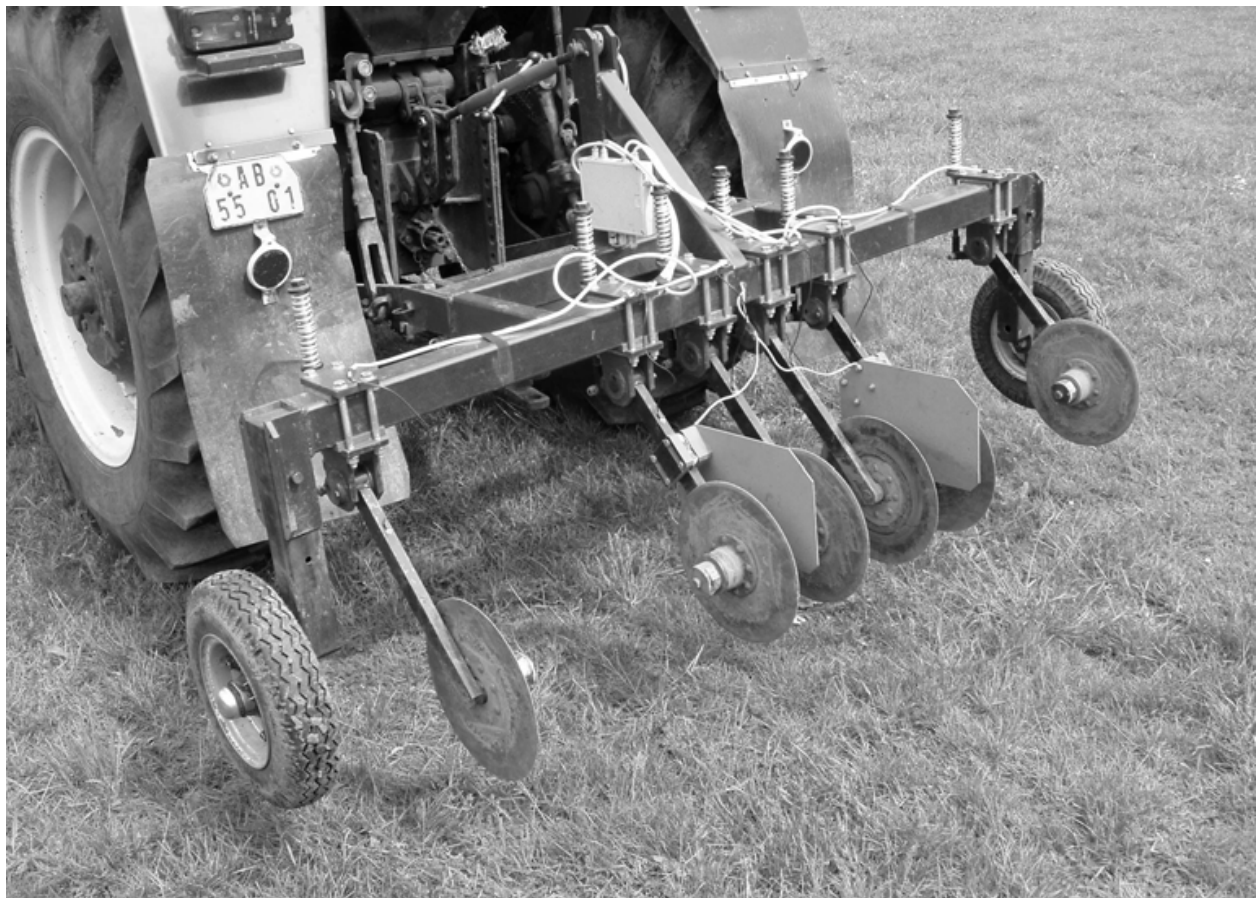Fig. 1. Map of sampling points in the experimental field.

Fig. 2. Tractor drawn device for soil conductivity measurement

Thus, values that did not describe precisely the factor measured were removed from the initial data set (for example errors occurring during measurement interruptions on headlands and turning points of a vehicle). These values were eliminated by trimming the marginal points recorded. Values larger then the double value of the average were also excluded from the initial data set. The time series were smoothened during the subsequent modification. The values of EC_a usually show oscillations from the curve. A simple running average method was applied to smooth the time series of all measurements. The following formula was used:

$$\hat{Y}_t = \frac{1}{3}(Y_{t-1} + Y_t + Y_{t+1})$$ (1)

where *Y* are original values at time t.

The number of *C. arvense* plants from the raster and values of EC_a were included into the evaluation. Spatial dependence of sampled values was described by variogram parameters. Experimental variograms were calculated and fitted by models. Variogram parameters such as Nugget (C_0), Sill (C_0+C) and Range (A_0) were calculated. The spatial relation itself is expressed as a portion of the nugget (C_0) in the sill value (C_0+C). The infestation map was completed with patches of *C. arvense* consequently without geostatistical analysis. Spatial interpolation of values was carried out by *Ordinary Kriging* interpolation method. Validity of interpolation method was confirmed by Cross-Validation method. Estimated values were collected after this process. The errors between the measured data and the estimates were analysed. The goodness-of-prediction statistic was used as the criterion for checking and comparing the map accuracies (*G*) (Kravchenko 2003).

The obtained EC_a map and the *C. arvense* infestation map were transferred to the raster after the interpolation process. These two rasters showed a relatively close interval of values (similar values) which is clear from the map as different types of colors. These raster maps were merged into a final file in the next step. EC_a values from the localized patches were recorded as well. All these procedures were made in ArcGIS 9.2. This procedure was necessary to apply because the data of particular measurements were not possible to record at the same measurement point of the field. It means that the comparison of that two measured data sets is not possible to achieve without this procedure. Thus, it was possible to apply statistical evaluation procedure for the data prepared in this way in the next step. The procedure in data evaluation was the calculation of a correlation coefficient which showed Pearson product moment correlation between a pair of values.

According to the field survey a herbicide application map was created in the year 2002. A uniform dose of herbicides was applied in the sprayer mode on – off. The sprayer was operated manually. The real points of beginning and end of spraying were registered during the spray job. The herbicides Dicopur M750 (active ingredient *MCPA*) and Banvel 480S (active ingredient *dicamba*) were applied. Four weeks after herbicide application the observation of herbicide effect was carried out by a field survey. The number of *C. arvese* plants in the raster and on patches was counted again Herbicide treatment was done uniformly throughout the whole field also in the year 2003.

Satellite pictures were taken by QuickBird satellite in August in the year 2002 with a graphics resolution of 2.8 m. The satellite pictures were taken after main crop harvest. A normalized difference vegetation index (NDVI) map was created. The following software was used for data processing: MS Office XP, ArcGIS 9.1 and GS + 5.1.1. The picture was distributed by QuickBird©Digital GlobeTM, Distribution Eurimage/ ARCDATA PRAHA, s.r.o.

3. Results

On the basis of the field survey and the *C. arvense* infestation monitoring, two data sets were collected. The first data set contains the *C. arvense* densities in the raster, and the second data set offers information about the occurrence of *C. arvense* in patches. Descriptive statistics of data shows Table 1 for the year 2002 a Table 2 for the year 2003.

Variable / Property	Raster	Patches centers
Mean value	5.65	20.42
Median	0.00	16.00
Standard deviation	11.80	19.34
Skew	3.53	2.29
Minimum	0.00	4.00
Maximum	84.00	124.00

Table 1. Descriptive statistics of data set (number of Cirsium arvense per m²) (2002).

Variable / Property	Raster	Patches centers
Mean value	14.86	11.13
Median	8.00	12.00
Standard deviation	20.91	6.49
Skew	1.941	3.38
Minimum	0.00	4.00
Maximum	116.00	80.00

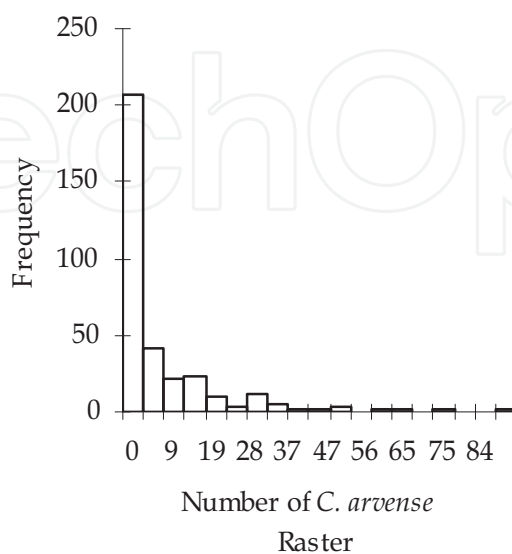Table 2. Descriptive statistics of data set (number of Cirsium arvense per m²) (2003).

Fig. 3. Histogram of values from sampling raster (number of Cirsium arvense per m²) (2002).
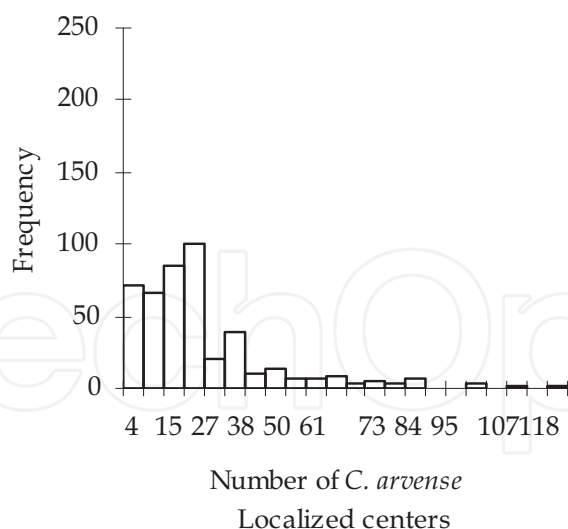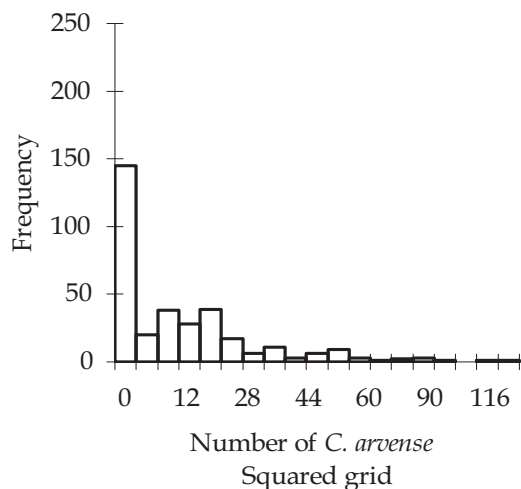
Fig. 4. Histogram of values from random localized patches (number of Cirsium arvense per m²) (2002).

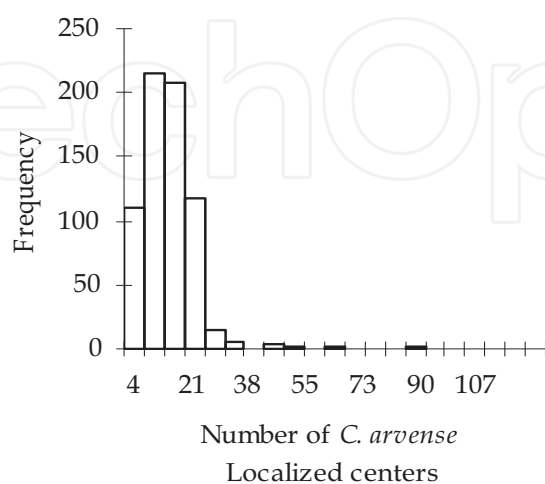Fig. 5. Histogram of values from sampling raster (number of Cirsium arvense per m²) (2003).

Fig. 6. Histogram of values from random localized patches (number of Cirsium arvense per m²) (2003).

Each data sets display left side asymmetry according to values of the skew. High skew value of basic data set from the raster is caused by a considerable high number of points, where no weed plants were present. Less skew value of second data set shows normal distribution approximation. Figures 3 and 4 show histograms of values from the raster and the random localized patches for the year 2002. Figures 5 and 6 show histograms of values from the raster and the random localized patches for the year 2003.

During the modeling of variogram for number of *C. arvense* plants, it was not possible to define exactly the variogram structure. It is evident that the value of sill is equal to nugget (Table 3).

Variable / Property	Number of *C. arvense* Raster (2002)	Number of *C. arvense* Raster (2003)
Nugget C_0	140	429
Sill C_0+C	140	429
Range A_0 (m)	-	-
R^2	0.38	0.12
RSS	3061	17323
C_0/C_0+C (%)	100.00	100.00
Model	Pure nugget	Pure nugget

Table 3. Parameters of model variogram, (number of Cirsium arvense per m2).

The measurement errors as well as the variability character can influence the values of the nugget (Heisel et al. 1999; Ilsemann et al. 2001; Lopez-Granados et al. 2002). The higher value of ratio calculated from the formula where nugget is divided by sill, the lower spatial dependencies are observed. Pure nugget was observed in this case. According to Lopez-Granados et al. (2002) and Cambardella & Karlen (1999), the ratio C_0/C_0+C higher than 75 % represents spatial independent data. According to the nugget value it was proved that the spatial dependence of *C. arvense* infestation was under the value of the distance between two adjacent sampling points and it could be concluded that the distance between points was too big.
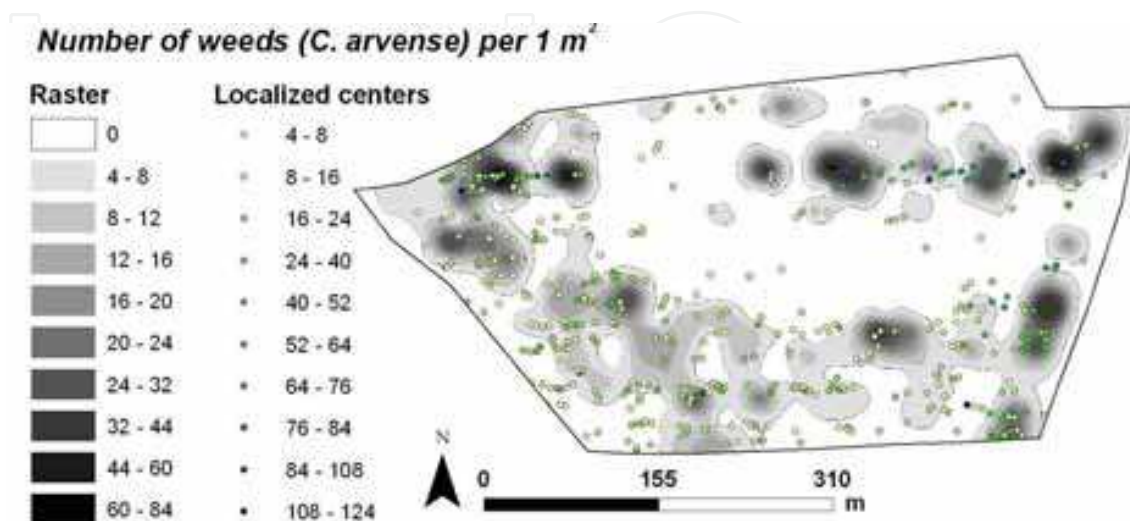

Fig. 7. Cirsium arvense infestation map (2002).

Despite the fact that the variograms structure was not suitable for the interpolation, the Kriging method was used. An exponential models without nugget was used to describe the spatial distribution of *C. arvense*. The variability of the *C. arvense* distribution is evident (Figure 7 and 10). The *C. arvense* infestation showed significant variability and spatial distribution was found at two areas in the field. The infestation is characterized by cumulating the weeds (south, west and northeast). The middle part of the field except of a few patches was not infested with *C. arvense*.

On the basis of the mentioned results, the variable herbicide application against *C. arvense* was carried out. According to the measured data the actual consumption of herbicide was: 1 l ha-1 of Dicopur M750, 0.2 l ha-1 of Banvel 480S and 210 l ha- 1 of water. The spray was applied approximately onto 73.8 % of the total field area, which represents 8.86 ha.

Descriptive statistics of the *C. arvense* infestation recorded about four weeks after herbicides application is shown in Table 4. The results of application efficiency are shown in Figure 8. Repeated occurrence of *C. arvense* was observed at the places with the highest *C. arvense* concentration before the herbicides were applied.

Variable / Property	Raster	Patches centers
Mean value	2.21	12.32
Median	0.00	8.00
Standard deviation	4.76	9.61
Skew	3.25	2.73
Minimum	0.00	4.00
Maximum	40.00	60.00

Table 4. Descriptive statistics of data set (four weeks after herbicide application) (number of Cirsium arvense per m^2) (2002).

The NDVI index evaluation was taken as additional information in order to complete and precise the research (Figure 9). In this case lighter colour represents higher NDVI index and vice versa. Results of this map showed an exact demarcation of the areas where herbicides were applied and the area without herbicide treatment. Weeds undergrowth was visible at the places without herbicide treatment.

We can also derive from Figures 7 and 10 that the spatial distribution of *C. arvense* plants was presumably partly dependent on soil properties and generally on site specific conditions.

The descriptive statistics of EC_a data set is shown in Table 5.

Variable / Property	EC_a
Mean value	24.63
Median	24.30
Standard deviation	6.57
Skew	0.27
Minimum	7.49
Maximum	45.18

Table 5. Descriptive statistics of soil electric conductivity [ECa (mS m^{-1})] data set.
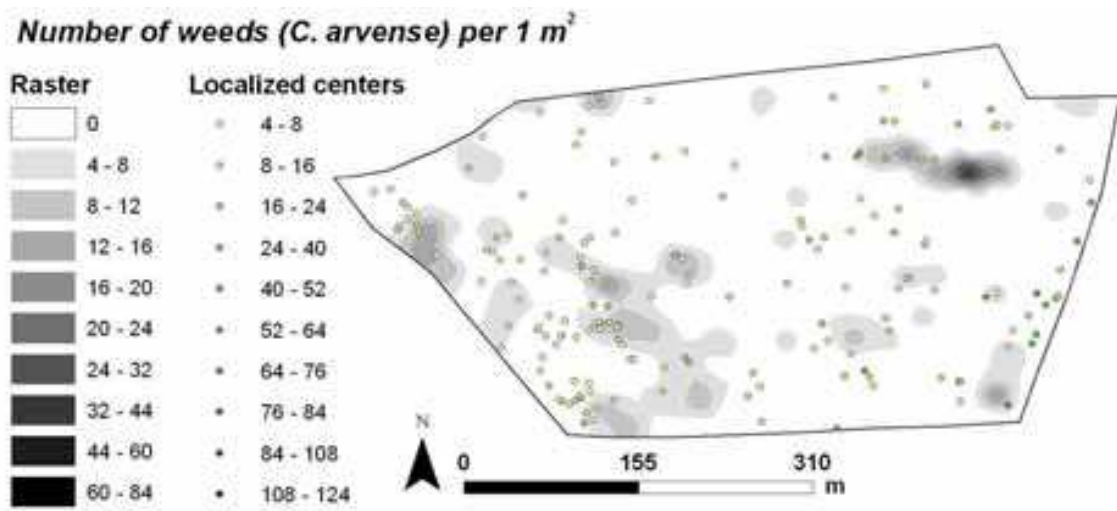
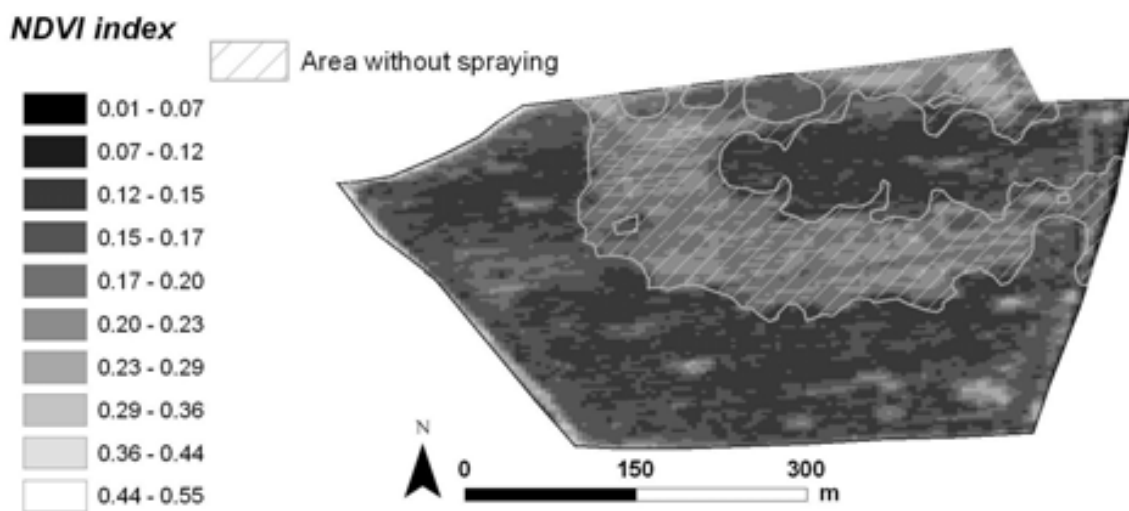Fig. 8. Application efficiency map about four weeks after herbicide application.

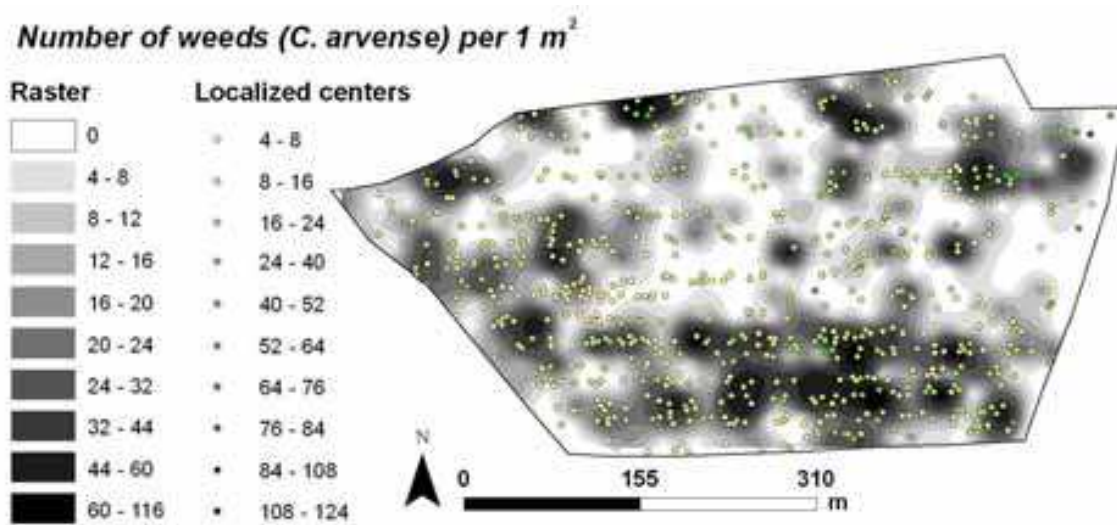Fig. 9. Normalized difference vegetation index (NDVI) map.

Fig. 10. Cirsium arvense infestation map (2003).

The range of values expressed as the maximum and minimum as well as variation coefficient illustrates the variability of the individual data sets. Asymmetry from the normal distribution is expressed as a coefficient of asymmetry. According to Lopez-Granados (2002), the normality condition is met, if the interval of inclination lies between -2 and 1. Low inclination values prove that data show a normal distribution.

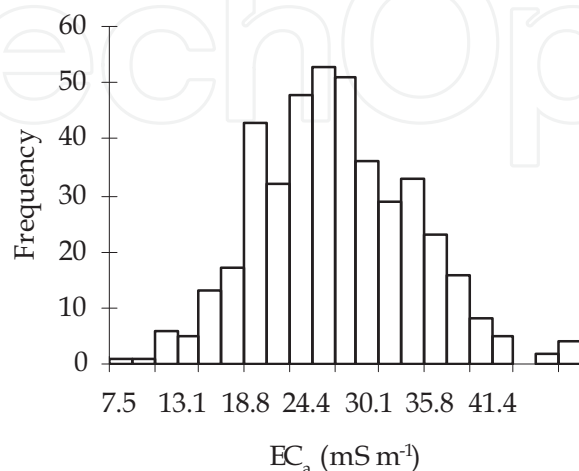Figure 11 shows the histograms of EC_a values. The picture proves normal distribution of EC_a values.

Fig. 11. Histogram of soil electric conductivity [ECa (mS m^{-1})] values.

The exponential model of the variogram of EC_a values with nugget was chosen. Parameters of model variogram were taken off (Table 6).

Variable / Property	EC_a
Nugget C_0	3.91
Sill C_0+C	34.22
Range A_0 (m)	39.50
R^2	0.96
RSS	14.70
C_0/C_0+C (%)	11.42
Model	Exponential

Table 6. Parameters of model variogram, [soil electric conductivity ECa (mS m^{-1}) values].

Spatial relation of 11.42 % according to ratio C_0/C_0+C was observed in this case. According to variogram parameters, a spatial interpolation of the EC_a was done. The EC_a map is shown in Figure 12. *G*-value of 82.9 % was observed. It is evident from Figure 12 that the variability of tested data set is relatively high. Higher values of measured factors were indicated in the south and south-eastern part of the tested field. In relation to slope of the field, the colour scheme of the picture matches the segmentation of the terrain.

Correlation analysis brought the following results: relatively high correlation R = 0.64 in the year 2002 and R = 0.91 in the year 2003 were found between EC_a and *C. arvense* infestation level. The results indicated a statistically significant correlation at a 99% confidence level. According to the correlation coefficient value a close dependence between *C. arvense* infestation and EC_a was observed.
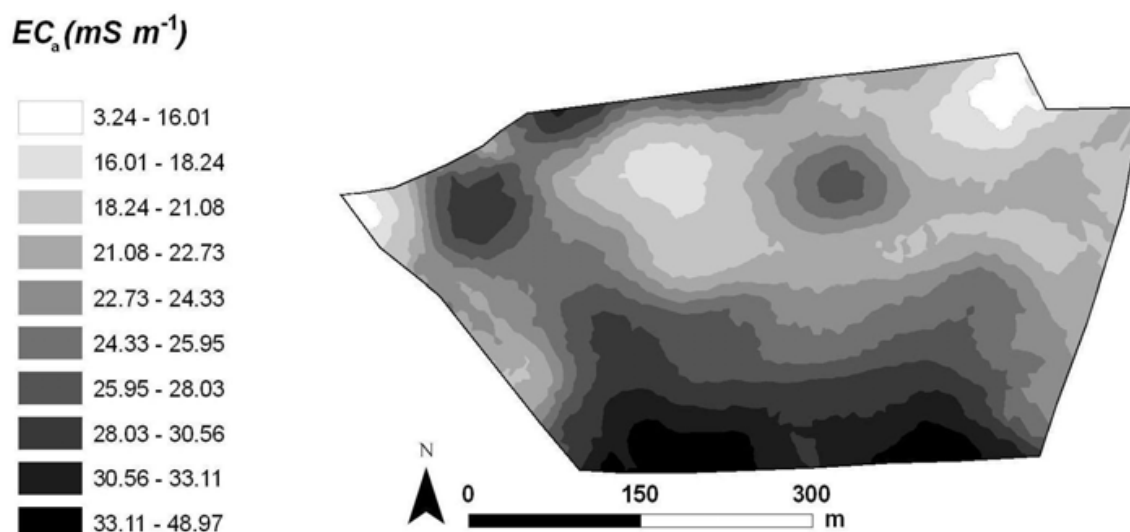
$EC_a (mS\ m^{-1})$

□	3.24 - 16.01
	16.01 - 18.24
	18.24 - 21.08
	21.08 - 22.73
	22.73 - 24.33
	24.33 - 25.95
	25.95 - 28.03
	28.03 - 30.56
	30.56 - 33.11
	33.11 - 48.97

Fig. 12. Soil electric conductivity (ECa) map.

4. Discusion

Generally, indirect measuring methods will play an important role in precision farming system development. High density of the data measured, time accessibility, low cost and undemanding measurements are the crucial points for the possible application of precision farming tools into a common practice. Data from the soil sensors could be widely used in precision agriculture system. Especially soil conductivity measurement is very advantageous tool for soil properties description (Zhang et al. 2002; Godwin & Miller 2003). Soil electrical conductivity is especially affected by soil humidity and soil grain contents (Godwin & Miller 2003). Despite the amount of various sensors used in precision agriculture system, soil EC_a measurement represents a simple and cheap instrument for soil variability determination in the field.

When excluding climatic conditions influence, the formation of plants cover (arable crops, weeds, wild plants) is influenced mainly by soil conditions (Soukup et al. 2003). The agronomical practices have an important role as well. Further discussed results of many research projects do not explain unambiguously the dependence of the weed infestation on the soil properties. Dunker & Nordmeyer (2000) reported certain correlations between weed occurrence and soil properties in their results. Kurstjens & Perdok (2000) show in their study, that relationships between weed control and good crop growth may not only depend on weed and crop characteristics but also on soil conditions and tractor-implement settings.

On the other hand Medlin et al. (2001) pointed out that prediction of weed infestations with environmental properties was specific for each field, year, and species. However, it was evident from the weed infestation maps that the distribution of *C. arvense* infestation was not only random. It was proved that the *C. arvense* plants distribution could be also affected by different soil properties. It was also noticeable from the same map that the patches which underlie beyond the raster are concentrated at the places with previously noticed *C. arvense* appearance. *C. arvense* infestation was not extended in the direction of movement by a soil cultivator. Similar results reported Hamouz et al. (2004). Donald (1994) on the basis of literature review describes, that Canada thistle (*C. arvense)* shoots density varies across

patches and often decreases near patch borders, but not as a uniform trend. Canada thistle shoot biomass exhibited a bell-shape distribution across a 35-m-wide path in Colorado. Also in our case we recognised circular shape of infestation patches.

In our research, the variability of *C. arvense* plants distribution was observed, but the evaluation according to the raster did not bring the exact result. This fact was proved by *G* parameter derived from the evaluation of prediction quality. The goodness-of-prediction fit was observed in this case (*G* = 0.06 % (2002) and *G* = - 8.13 % (2003)), monitoring in a raster was not sufficient for the description of real weed infestation conditions and its intensity. Negative and close to zero *G* values indicate that the field average predicts the values at unsampled locations as accurately (or even better) than the raster sampling estimates (Kravchenko 2003). Donald (1994) in his work described spatial dependencies for weeds spreading. However he used a raster with 1.8 m long side which would not be possible for our experiments. Donald (1994) also used a so called weed infestation average value in the experimental method which thus tended to use a uniform herbicides application. But this was in contravention of field observation.

The map of EC_a represents reliable output data which can relatively exactly describe the spatial variability. Division of spatial relations into classes can be found e.g. in Lopez-Granados et al. (2002) and Cambardella & Karlen (1999) work. Magnitude of the spatial relation is expressed as a ratio of the nugget divided by the total sill of the variogram. If this ratio is ≤ 25 % the observed relation is strong spatial relation. Positive *G* values indicate that the map obtained by interpolating data from the raster samples is more accurate than the field average. Jaynes et al. (1994) stated that it is possible to control variable herbicide application on the basis of soil conductivity measurement. According to the correlation coefficient value a close dependence between *C. arvense* infestation and EC_a was observed (significant dependence on the 99% confidence level was observed). This fact proved our presumption about *C. arvense* response to soil properties.

On the other hand it is necessary to say that lots of other factors may significantly influence the final EC_a measurement results. Concerning *C. arvense* infestation in the field in relation to EC_a data measured, it could not be assumed precisely, that higher values of EC_a will be observed explicitly where higher density of *C. arvense* is present. EC_a measurement does not totally substitute further soil survey. However, it may provide important data for the decision making processes, when applying the precision agriculture principle. The results indicate sufficient density of sampling points and suitably chosen evaluation methods. Map of EC_a represents a valuable outcome.

5. Acknowledgements

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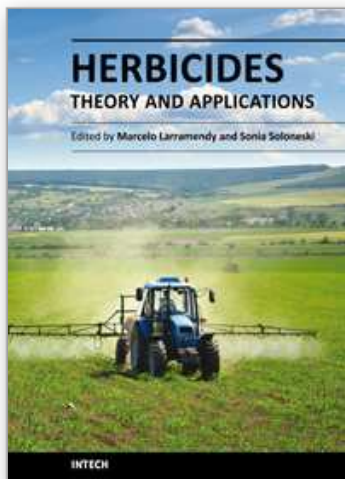
Herbicides, Theory and Applications

Edited by Prof. Marcelo Larramendy

The content selected in Herbicides, Theory and Applications is intended to provide researchers, producers and consumers of herbicides an overview of the latest scientific achievements. Although we are dealing with many diverse and different topics, we have tried to compile this "raw material" into three major sections in search of clarity and order - Weed Control and Crop Management, Analytical Techniques of Herbicide Detection and Herbicide Toxicity and Further Applications. The editors hope that this book will continue to meet the expectations and needs of all interested in the methodology of use of herbicides, weed control as well as problems related to its use, abuse and misuse.

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