Spatial Distribution of Ambrosia Weediness in Soybean at Different Rates of Nitrogen Fertilization, based on Digital Imagery Analysis

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Summary

In order to determine distribution of ambrosia within soybean at different fertilization rates on experimental field Potok–Popovača (2005), technique of aerial digital imaging at ground level by digital RGB camera was applied. The digital imaging was carried out within multidiscipline research team: Faculty of Agriculture, Faculty of Geodesy and Croatian Centre for Demining.

Area of cca. 4 ha (300x130m), was under long time research with 10 different rates of nitrogen fertilization. Based on interpretation of aerial digital imagery, the main object of this study was to determine ambrosia weediness in soybean at different rates of nitrogen fertilization, its spatial distribution within soybean, and nitrogen taking by ambrosia and soybean. Ambrosia detection from aerial digital RGB imagery and its spatial distribution have been defined. Bases to continue research by airborne multispectral digital imaging of experimental field within different crops during following years were provided. Digital imaging of field variants at different fertilization rates, and ground samples (4 by experimental variant), including land surveying, was performed by digital RGB camera from 13th - 25th September, 2005. Interpretation of aerial digital imagery was made by field data analysis obtained by sampling plant material, in order to determine biomass, moisture and nitrogen content in both species. Comparison with field data shows that method of aerial digital RGB imagery interpretation is reliable mean of weed detection within immanent crop, and its spatial distribution at different fertilization rates – ambrosia distribution/variant.

Key words

ambrosia, soybean, digital imagery, RGB spectrum, image classification, spatial distribution, biomass, nitrogen fertilization

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Introduction

The main aim of this research was to determine distribution of ambrosia (*Ambrosia artemisiifolia*) weediness in soybean (*Glycine hispida*) at different rates of nitrogen fertilization by digital imagery analysis and interpretation. The method was aerial digital imaging at ground level by digital RGB camera of experimental field with 10 variants of nitrogen fertilization. Digital imagery data have been used to detect and classify two types of vegetation, according to applied nitrogen rates, using unsupervised classification and cluster analysis.

The first step was to calculate efficiency of applied mineral nitrogen, as one of the most important nutrients that determines plant productivity, single, and in different combinations with other material (Phospho-gypsum, Dolomite) in soybean seed, and in ambrosia and soybean spatial distribution by each variant at different rates of nitrogen fertilization. Within soybean (*Glycine hispida*) crop, weediness problem is present from germination till harvest. Ambrosia (*Ambrosia artemisiifolia*) is most common weed in soybean. It competes with soybean for moisture, nutrients and light. Contamination with ambrosia can reduce obtained yield of grown crops. It occurs in patches in soybean field, which can be caused by different rates of nitrogen fertilization, but also by many other reasons. It was important to quantify acquisition of nitrogen in soybean and ambrosia, as frequent weed within this crop. There are various researches reporting that remote sensing of nitrogen content in plant biomass can be valuable tool of evaluation N status in crops and weeds, and, therefore, a valuable tool for detecting weeds in crops by their different canopy reflection (Blackshaw et al., 2003). A number of researchers have explored digital image processing as a way to identify weeds and crops (Gausman, 1985; Bajwa and Tian, 2001; Cardina et al., 1995; Gibson et al., 2004; Pedersen, 2001; Perez et al., 1997; Heisel and Christensen, 1999). El-Faki et al. (2000a and b) have used colour analysis based on RGB colour images for detecting weed and crop. Classification of spectra of crop, weeds and soil, based on limited number of narrow wavelengths bands was researched by Vrindts et al., 1998, and Vrindts et al., 2002. Also, researches of Feyaerts et al. (1998), Vioix et al. (2001) and Pollet et al. (1998) confirmed that spectral measurements of visual and near infrared reflection combined with spatial information can be used to detect weeds within crops.

Material and methods

Investigated test site is located near small village Potok (near 45°33´ N, 16°31´ E), south-west from Moslavačka gora, as a part of farmland between towns Sisak and Kutina (Figure 1). Area has temperate continental climate, with 10.7°C mean temperature. The annual average rainfall is 865 mm. Experimental field of cca. 4 ha (300 x 130m – trial dimensions), was under long term research of mineral nitrogen fertilization, nitrogen use efficiency and nitrogen leaching. Region characteristic are small-holdings which dominate within agricultural land from one side, and hy-

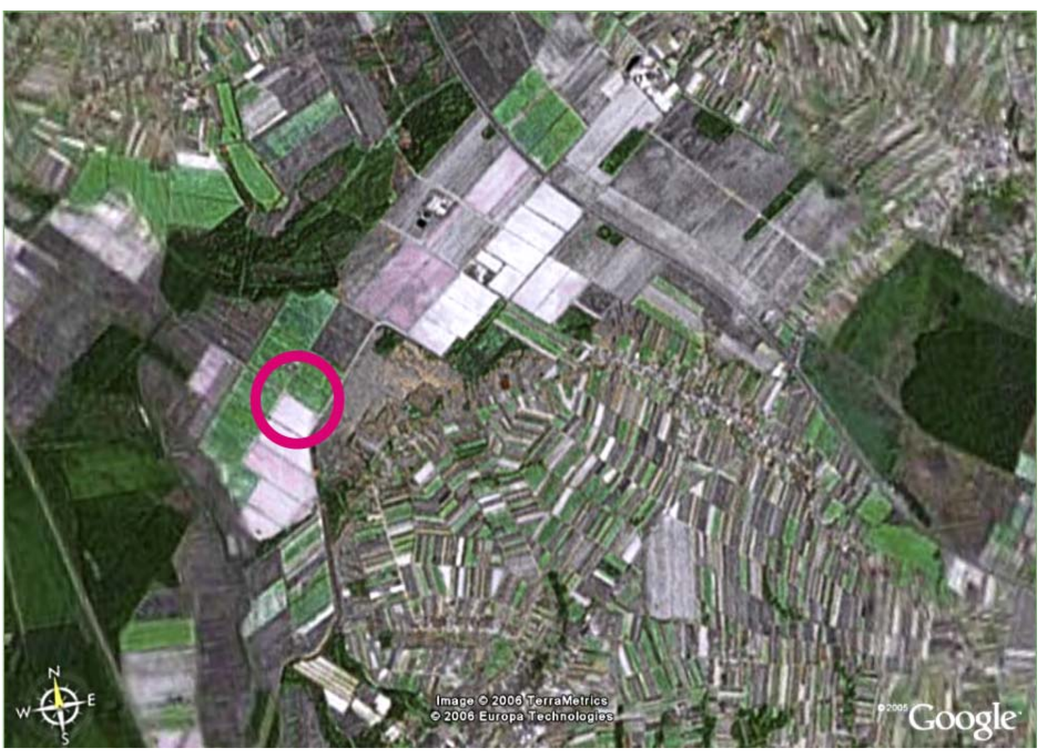

Figure 1. Location of experimental field in Moslavina region. Area of 4 ha is marked within red circle (Google Earth, 2006).

dromeliorated area with organized agricultural production within larger agricultural holdings from the other. Selected parcel is part of large area of arable land with possible economic potential. Terrain is flat with average altitude 102 m, separated by dyke from wetland area on south-east side. Soil type is pseudogley (Stagnosol) – soil with unfavourable water regime and high level of ground water. It is plain, distric, with implemented drainage system of canals and pipes. Investments in this area must be directed to drainage systems. Sufficient moisture is present in upper part of soil profile as result of precipitation and stagnation of water. In soil profile, groundwater occurs under 175 cm below soil surface. Precipitation water periodically stagnates on illuvial horizon.

This research presents results for the year 2005, when soybean was grown in the experimental field. Nitrogen values in plant samples of soybean seed, soybean stem and ambrosia stem, obtained by laboratory analyses, were analyzed by nine trial variants using ANOVA, F-test and t-test. Digital images have been processed using GIS application and interpreted according to field data analysis. Weed distribution within each variant of nitrogen fertilization, obtained by image classification, was compared to the measured data at the samples of 1 m^2 for each replication. Nitrogen content in plant material, soybean seed and stem, and ambrosia stem, was determined, in purpose to examine possible connection among weed growth, it's spreading in soybean, and applied nitrogen rates. Trial variants include different rates of nitrogen fertilization. Area of each variant is divided into four replications (parcels). Parcel dimension is conditioned by distance between drain pipes. Each variant includes two drain pipes. Dimension of each trial variant is 30 x 130 m including blank space. Distance between parcels, as well as between replication is 2 m by each side. Fertilization and seeding practice is implemented on total area of each variant. Total trial area is 39000 m^2.

1. Control – no fertilization
2. N_0 + P + K
3. N_{100} + P + K
4. N_{150} + P + K
5. N_{200} + P + K
6. N_{250} + P + K
7. N_{250} + P + K + Phospho-gypsum
8. N_{250} + P + K + Dolomite
9. N_{300} + P + K
10. Black fallow – no seeding tillage

Plant sampling

Plant samples of soybean seed, soybean stem, and ambrosia stem were taken for analyses one month before the harvest, on 27th September 2005. Plant samples were taken from four ground plots dimensions of 1 m^2 from each experimental variant in order to determine average number of plants by each m^2, fresh and dry biomass, moisture and nitrogen content in both species. Sampled plant material was stem (soybean, ambrosia) and soybean seed. Average value for each variant from 1m^2 sampling area was calculated. Parameters included: percentage of moisture, biomass, and percentage of nitrogen. The aboveground ambrosia and soybean N content were calculated by percentage of N x biomass (soybean seed, soybean stem, ambrosia stem). Ambrosia plant density ranged from 0 to 25 plants m^{-2}, and soybean plant density was 13 to 45 plants m^{-2}.

Imagery acquirement, processing and interpretation

Spatial distribution of soybean and ambrosia is also determined by digital imagery interpretation. Imaging of field variants is acquired by normal digital RGB camera during

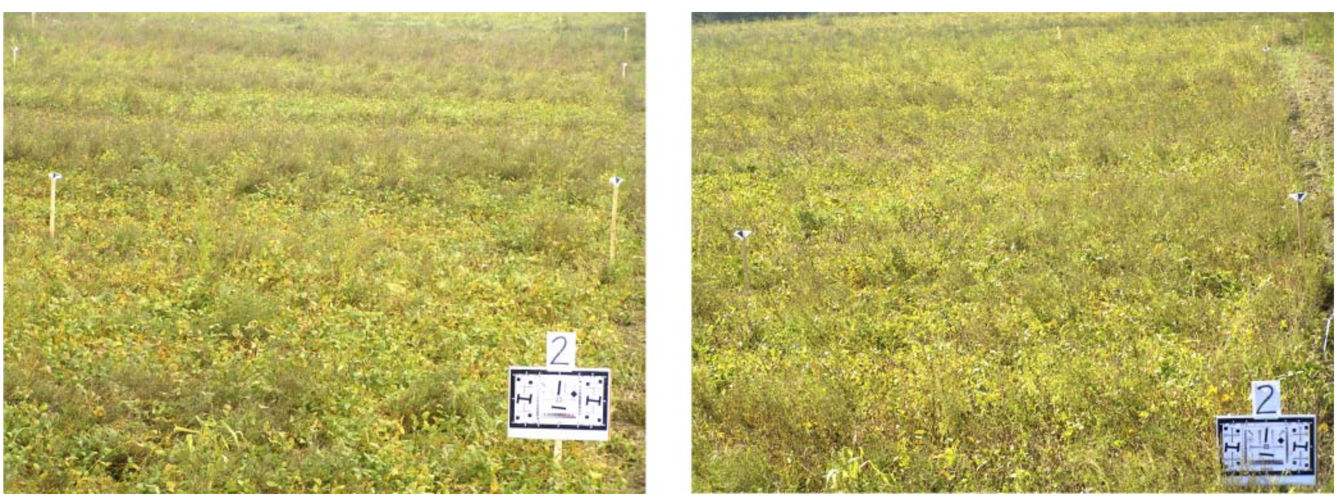

Figure 2. As example, colour digital image of 2nd variant, acquired from two sides of plot (a, b), and used as basis for further image processing in TNT mips software

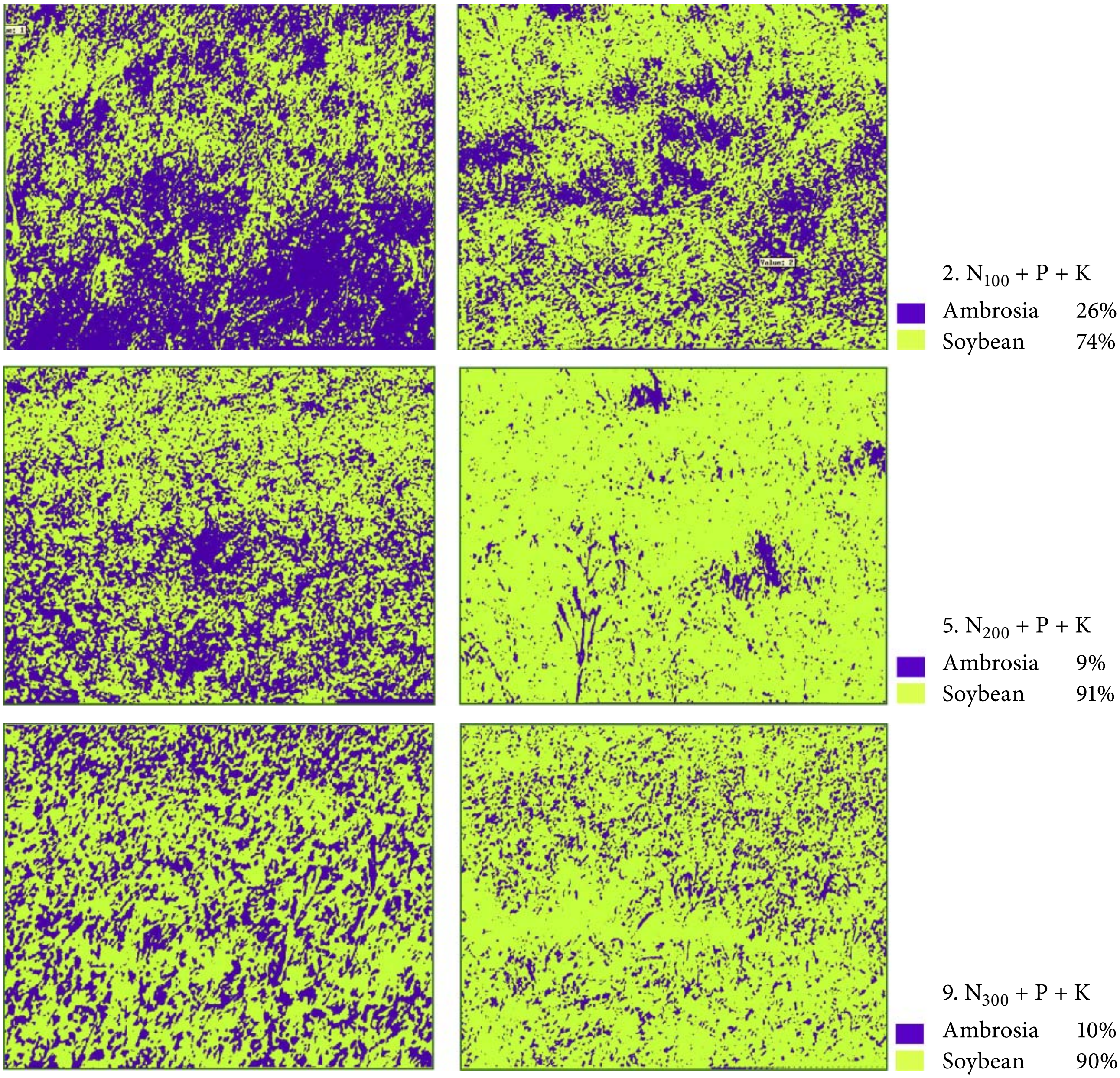

Figure 3. Interpretation of RGB (red, green, blue – visible electromagnetic spectrum) digital images of ambrosia distribution within soybean by GIS software application TNT 6.9. – trial variants 2, 5, 9 as representative samples

the end of summer growing season, on 25th September 2005. Before images recording, it was necessary to perform preparation work which included geodetic surveying of test area. The positions of photographed plots were recorded using a Garmin GPSMap 60C receiver. Two digital images by each shorter side of variant were acquired between 11:00 a.m. and 11:30 a.m. for maximum reflectance and minimal shadowing (Figure 2). Input colour images each cover about 0.27 ha by variant (130 x 30 m). Image dimensions are 614 x 512 pixels, and pixel size is 0.028 m^2. The camera was placed 5m vertically above ground on truck with platform for the instrument. It was covered to avoid direct sunlight, shadows and changing influx of light on digital images. RGB digital camera can sense visible wavelength range, which include red band (0.63-0.69 μm), sensitive to chlorophyll absorption region for plant specifies differentiation and useful for vegetation analysis; green band (0.52– 0.60 μm), useful for measuring green reflectance of vegetation; and blue band (0.45- 0.52 μm), useful for soil/vegetation discrimination. Colour images were downloaded to a computer and saved in JPEG format. Contrast between blocks of pixels of similar colour by each digital image was carried out in Photoshop. Imagery has been analyzed by software application: TNT products 6.9. Image classification applied during processing was unsupervised classification - class raster computed via simple one-pass clustering. The RGB colour image was split into red, green and blue spectral values. Computing red and green values into one raster provided greyscale image. For calculations of area under ambrosia, processed images were classified using TNT mips 6.9. into *Ambrosia artemisiifolia* (magenta) areas and *Glycine hispida* (green) areas within the image (Figure 3). The number of pixels containing weed and crop were counted and the average area of spatial distribution on two processed images by each variant was calculated. Interpretation of digital RGB images was compared with the background data in experimental field, to examine possibility of using digital RGB imagery to detect distribution of ambrosia in soybean, and thus, usefulness of this method in weed mapping situations, compared with nitrogen status in plants.

Image classification

Many remote sensing systems record brightness values at different wavelengths that commonly include portions of the visible light spectrum. The Automatic Classification process in TNT uses the colours, or spectral patterns, of raster cells in a multispectral image to automatically categorize all cells into a specified number of spectral classes. The relationship between spectral classes and different surface materials or land cover types (ambrosia, soybean) were partly known beforehand, and determined after classification by analysis of the spectral properties of each class. The spectral pattern of a cell in a multispectral image is quantified by plotting the raster value from each band on a separate coordinate axis to locate a point in a hypothetical spectral space. This spectral space has one dimension for each band in the image. Classification methods use some measure of the distance between points in this spectral space to asses the similarity of spectral patterns. Cells that are close together in spectral space have similar spectral properties and have a high likelihood of imaging the same surface features. The Automatic Classification process is influenced by the sets of brightness values of a cells in the scene, not just the features that we intend to classify.

Unsupervised classification

Unsupervised classification of the red, green, and blue raster components of digital RGB natural-colour images has been performed. Simple One-Pass Clustering Method establishes initial class centres and assigns cells to classes in one processing pass by determining the spectral distance between each cell and established class centres. Each raster cell is assigned to the nearest class. A cell too far away from existing class centres becomes the centre of a new class.

The main classification results are contained in the categorical class raster. Each numerical value in the raster is an arbitrary class identifier that has been assigned to the cell by the classification process. Each class is displayed by the unique colour.

Input colour images each cover about 0.3 ha area by variant, in experimental field which is part of a farmland south-west from Moslavačka gora. They were acquired during the end of summer growing season, on September 25th, 2005, and include soybean field. The main purpose in classifying the images was to map the distribution of the different plant species, soybean and ambrosia within each variant.

In order to interpret the results of an unsupervised classification, it was useful to compare the class raster to available information about ground cover in the scene. Variations in ambrosia and soybean spectral characteristics may result from differences in plant size, density of the leaf canopy, chlorophyll content, soil conditions, drainage system direction, and in abiotic factors such as sun angle. But this variability is mostly inherent in investigated experimental field. For the same vegetation type, the reflectance spectrum also depends on other factors such as the leaf moisture content and health of the plants. For example, reflectance of leaves and stem generally increases when leaf and stem liquid water content decreases. Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover or between itself by different species. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region which gives rise to the green colour of vegetation.

For better differentiation between soybean and ambrosia, the classification was improved by adjusting the Minimum Cluster Distance parameter, which sets the threshold distance in spectral space used to designate an input cell as a new class centre instead of assigning it to the closest class. By adjusting this parameter downward, we increased the likelihood, so that different soybean and ambrosia covers that are close together in spectral space will be assigned to distinct classes. After that process, class raster shows a much better separation of soybean and ambrosia.

Results and discussion

Resolution and pixel area of digital images are similar with those gained in other projects and researches about digital camera processing (Tonkin et al., 1999). Ambrosia distribution within soybean can be clearly distinguished. Ground imaging did not allow full coverage of each variant area. Only ¾ of each variant area was covered. This

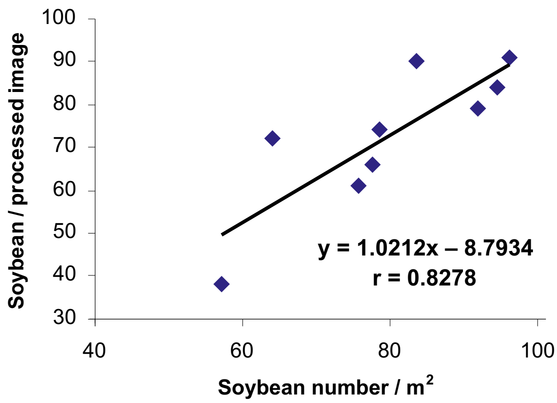

Figure 4. Correlation between percentage of soybean distribution on processed image and percentage of soybean plant number on 1 m^2 of sampled area

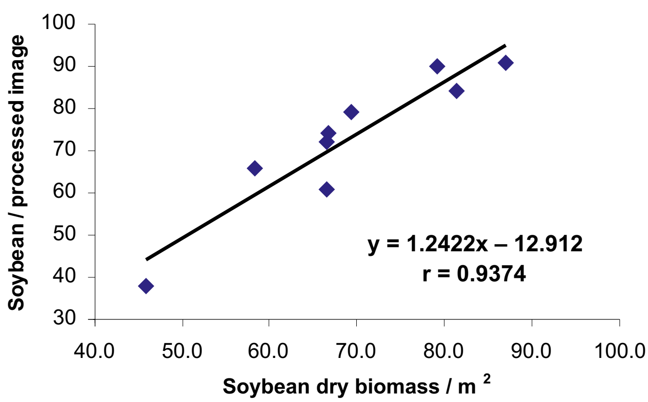

Figure 5. Correlation between percentage of soybean distribution on processed image and percentage of soybean dry biomass on 1m^2 of sampled area

research examined that using digital camera is reliable method for mapping smaller areas with higher resolution requirements. Correlation between percentage of soybean distribution on processed image and percentage of soybean plants number on 1 m^2 of sampled area has very strong positive linear correlation (Figure 4). As seen from Figure 5, correlation between percentage of soybean distribution on processed image and percentage of soybean dry biomass on 1 m^2 has also very strong positive linear correlation. The same correlation exists in relation to ambrosia comparison. Percentage of ambrosia distribution in soybean can be seen on processed digital images (Figure 3). Images recorded with digital RGB camera show object reflections in visible part of electromagnetic spectrum. Ambrosia had a lower absorption of visible light spectra and higher reflectance then soybean, because of low nitrogen content in comparison with soybean. On the combined raster images, ambrosia was detected as lighter colour object.

Spectral variations in canopy reflection make ambrosia plants to differ from soybean. Reason for that are different moisture and chlorophyll content (and thus, nitrogen content). Similar researches were reported on this subject (Guyot et al., 1992, Ma et al., 2001, Zwiggelaar, 1998, Ranson et al., 1984). Chlorophyll has a relative low reflectance in the red part of the electromagnetic spectrum, which means high absorption. Low nitrogen content affects leaf and stem chlorophyll content which visible reflectance is increased.

The addition of nitrogen had effect on ambrosia distribution. Ambrosia responds to higher amounts of N fertilization and in small extent to variants with added lime materials.

According to interpretation of digital RGB images, it has been found that ambrosia weediness in soybean was patchy distributed in the field. Trends of decreasing ambrosia in soybean due to increasing of nitrogen fertilization by variant can be slightly noticed. According to data presented in Table 2, ambrosia is widely distributed in control variant, but the lowest percentage is pointed on variants with applied 200kg N and 300kg N. Ambrosia distribution increases with application of Dolomite and Phospho-gypsum.

Correlation between nitrogen content in soybean seed and soybean distribution by experiment variants indicated its weak positive correlation. Further, there was no correlation between nitrogen content in soybean stem and soybean distribution. Correlation between nitrogen content in ambrosia stem and ambrosia distribution by variants appeared to be weak.

It can be assumed that the difference in the ambrosia population by variants could be due to the increasing N rates application, lime additions, and maybe due to compaction of soil and subsurface drainage network, which means due to soil moisture.

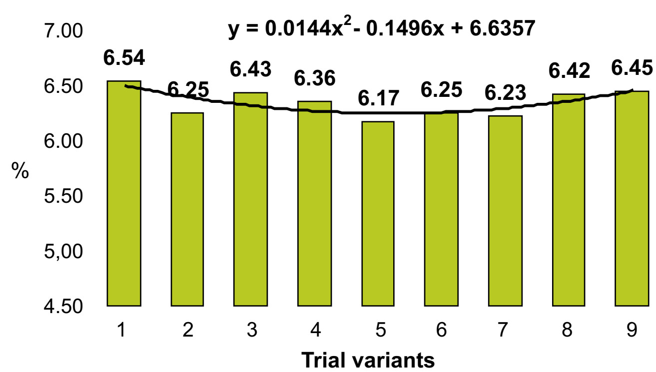

Figure 6. Nitrogen content in soybean seed, % (1-Control – no fertilization, 2-N_0 + P + K, 3-N_{100} + P + K, 4-N_{150} + P + K, 5-N_{200} + P + K, 6-N_{250} + P + K, 7-N_{250} + P + K + Phosphogypsum, 8-N_{250} + P + K + Dolomite, 9-N_{300} + P + K)

Table 1. The amount of nitrogen in soybean seed, soybean stem and ambrosia stem, N (kg ha^{-1})

Trial variants	Soybean seed (kg ha^{-1})	Soybean stem (kg ha^{-1})	Ambrosia stem (kg ha^{-1})
1. Control - no fertilization	147.2	0.78	0.38
2. N_0 + P + K	124.5	1.38	0.17
3. N_{100} + P + K	163.3	1.09	0.13
4. N_{150} + P + K	178.6	1.09	0.06
5. N_{200} + P + K	170.0	1.03	0.09
6. N_{250} + P + K	173.9	1.01	0.43
7. N_{250} + P + K + Phospho-gypsum	171.8	0.81	0.30
8. N_{250} + P + K + Dolomite	189.1	1.39	0.55
9. N_{300} + P + K	188.7	0.98	0.13
G.D. = 5%	40.0	0.56	0.42
G.D. = 1%	54.2	0.76	0.58

Table 2. Spatial distribution and dry biomass of soybean and ambrosia by variants of nitrogen fertilization

Trial variants (0.27 ha)	Ambrosia distribution			Soybean distribution		
	(%)	(ha)	Dry biomass (g m^{-2})	(%)	(ha)	Dry biomass (g m^{-2})
1. Control – no fertilization	62	0.167	11.7	38	0.103	9.9
2. N_0 + P + K	28	0.075	6.8	72	0.194	13.6
3. N_{100} + P + K	26	0.070	6.6	74	0.199	13.2
4. N_{150} + P + K	16	0.043	3.0	84	0.227	13.3
5. N_{200} + P + K	9	0.024	2.1	91	0.246	13.9
6. N_{250} + P + K	21	0.056	5.7	79	0.213	12.8
7. N_{250} + P + K + Phospho-gypsum	34	0.092	7.7	66	0.178	10.8
8. N_{250} + P + K + Dolomite	39	0.105	6.4	61	0.165	12.7
9. N_{300} + P + K	10	0.027	3.4	90	0.243	12.7

Similar results about nitrogen fertilization effect on dry biomass and nitrogen concentration values in soybean stem and seed were reported by Pospišil et al., 2006, Streeter, 1978 and Wood et al., 1993.

Nitrogen content in soybean seed

According to ANOVA results for N content in soybean seed, experiment was significant compared to amounts of applied nitrogen fertilization. Nitrogen content in soybean seed is shown in Figure 6. Increasing fertilization rate to 200 kg N resulted in decrease of N content in soybean seed. In the variants with 250 kg N and lime materials, and in variant with 300 kg N, nitrogen content was increased. The highest amount of N in soybean seed (189 kg N ha^{-1}) was determined in the variant with 250 kg of mineral nitrogen and lime materials (Table 1).

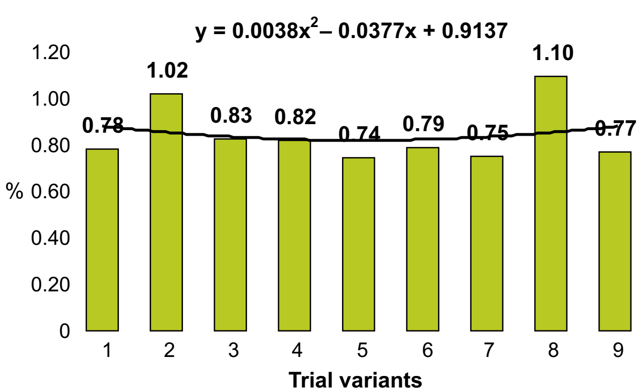

Figure 7. Nitrogen content in soybean stem. % (1-Control – no fertilization, 2-N_0 + P + K, 3-N_{100} + P + K, 4-N_{150} + P + K, 5-N_{200} + P + K, 6-N_{250} + P + K, 7-N_{250} + P + K + Phospho-gypsum, 8-N_{250} + P + K + Dolomite, 9-N_{300} + P + K)

Nitrogen content in soybean stem

According to ANOVA results for N content in soybean stem, experiment was not significant compared to amounts of applied nitrogen fertilization. There was no significant increasing of N content in soybean stem according to higher rates of nitrogen fertilization (Figure 7). Differences between variants were not statistically justified by amounts of applied nitrogen fertilization. The highest nitrogen content in soybean stem was determined in the variant with 250 kg N and lime materials (1.10%).

Nitrogen content in ambrosia stem

For the purpose of determining Ambrosia spatial distribution in soybean and interpretation of digital RGB images of experimental field, Ambrosia was also sampled, and dry stem biomass analysed for N content.

According to ANOVA results for N content in ambrosia stem, experiment was significant, compared to amounts of applied nitrogen fertilization. Significant increasing

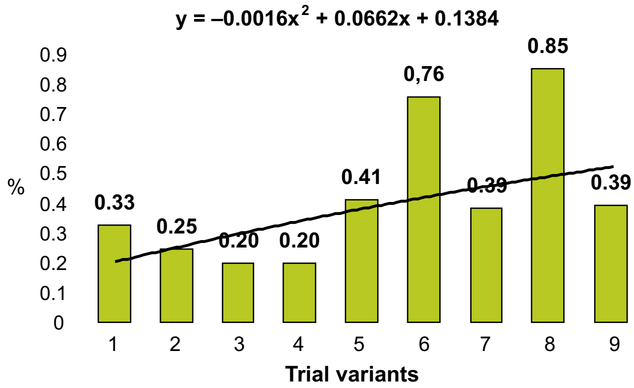

Figure 8. Nitrogen content in ambrosia stem, % (1-Control – no fertilization, 2-N_0 + P + K, 3-N_{100} + P + K, 4-N_{150} + P + K, 5-N_{200} + P + K, 6-N_{250} + P + K, 7-N_{250} + P + K + Phosphogypsum, 8-N_{250} + P + K + Dolomite, 9-N_{300} + P + K)

of nitrogen content in ambrosia stem compared to control variant was determined in the variant with 250 kg N (Figure 8). Differences between variants were not statistically justified by amounts of applied nitrogen fertilization. The highest nitrogen content in ambrosia stem was determined in the variant with 250 kg N and lime materials (0.85 %). The lowest N content was determined on variants with 100/150 kg N (0.20 %). Increasing fertilization to 150 kg N caused decreasing of N content of ambrosia stem up to variants with 200 kg N, 250 kg N, and 250 kg N and Dolomite, where it was increased.

Total amount of nitrogen in soybean and ambrosia biomass

In Table 2, ambrosia and soybean distributions and dry biomass for all nine trial variants are presented. According to results (Table 1), amount of nitrogen carried out by stem biomass of soybean and ambrosia was negligible due to its amount in soybean seed.

Conclusion

Comparison with field data shows that method of digital RGB imagery interpretation is reliable mean of weed detection within immanent crop, and its spatial distribution at different fertilization rates. Soybean distribution on processed image and soybean number on $1m^2$ of sampled area have very strong positive linear correlation. Correlation between soybean distribution on processed image and soybean dry biomass on $1m^2$ is also presented as very strong positive linear correlation. The same correlation exists in relation to ambrosia comparison.

Unsupervised classification, as image classification method, can retain as a reference for further investigations in area of image data processing. Preliminary results have shown that digital RGB imagery has potential for fine resolution, quick and accurate mapping of ambrosia in soybean field. Processed image data can be used to monitor weed distributions.

Understanding of the effects of nitrogen on crop – weed interactions is needed for the development of weed management systems where use of nitrogen fertilizers is very considered. Although correlation between nitrogen content in ambrosia stem and ambrosia distribution by variants appeared to be very weak, it can be assumed that the difference in the distribution of ambrosia population patches by variants could be due to the increasing N rates, lime additions, and maybe due to compaction of soil and subsurface drainage network.

Information on responses of different weed, in this case ambrosia, to various soil nitrogen levels is needed to be more investigated in the future with a view to develop maybe new fertilization strategies. This research has implications as to how soil fertility affects crop and weed competition, and thus their spatial distribution on investigated area.

Results of this experiment indicate that mineral nitrogen application has effect on decreasing/increasing ambrosia distribution depending on rates of fertilization and combination with lime materials. Information on connection of plant N content, weed distribution, and image processing, gained in this research, will contribute to the further incorporation of digital images into a GIS system, and to development of bases to continue research by airborne multispectral digital imaging of experimental field within different crops during following years.

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