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THE POSSIBILITY OF USING DIGITAL IMAGES IN ASSESSMENT OF PLANT CANOPY DEVELOPMENT AND WEED SPREAD

Elena KONDRLOVÁ*, Ján HORÁK, Dušan IGAZ, Dagmar DOBIAŠOVÁ

Slovak University of Agriculture in Nitra, Slovak Republic

Nowadays, there are various methods of plant biomass assessment available for the purposes of plant growth analysis. Visual plant coverage assessment is often subjective; the other methods are destructive or require purchasing some special devices. This paper presents the assessment of the possibilities and limitations of using digital images made by conventional digital cameras for the purposes of monitoring of the plant canopy development and weed distribution during a vegetation period using the example from the field experiment established on agricultural land in Malanta at the experimental site of the Slovak University of Agriculture. The study is focused on assessment of the effect of biochar application on gas emission, hydrophysical soil properties as well as plant response and yields and it was established in the spring of 2014. Downward images of corn (*Zea mays* L.) were taken during four sampling campaigns in the vegetation season 2015. Images were analysed by the BreedPix software that could estimate the portion of green fraction (count of green pixels) and thus the image-derived vegetation index (IDVI). According to the image analysis of photos taken during different sampling dates, it could be concluded that biochar addition had a positive effect on the plant growth (above ground biomass) since all treatments resulted in higher IDVIs at the end of the vegetative growth in comparison to control. Further, we assume that the increasing trend in the crop canopy growth was partially limited by competitive presence of weeds at the beginning of the study. According to our experience, we can recommend the software for temporal and spatial monitoring of agricultural crops development. The usage is limited to early growth stages. Moreover, it can be also used for assessment of the weed coverage.

Keywords: plant growth; vegetation index; digital imagery; weed distribution; corn

Plant biomass is an important factor in the study of functional plant biology and growth analysis, and it is the basis for the calculation of net primary production and growth rate (Golzarian et al., 2011). Spatial and temporal variation of plant biomass density is inherent to cropland and pastures. Variations may be attributed to many factors arising from environmental or natural cases and management decisions. Temporal variability is the change within the field expressed over a specific time period, while spatial variability refers to changes that occur across the field often due to environmental and landscape variability and management practices. Understanding temporal and spatial crop biomass variability requires effective assessment and quantification of biomass levels (Trotter et al., 2008).

Depending on the available budget, accuracy required and vegetation structure, there are several techniques to measure plant biomass (Golzarian et al., 2011). Visual plant coverage assessments are often subjective, and require a degree of expert knowledge and/or experience (Casadesús and Villegas, 2014). Traditional quadrat-based plant harvesting determinations of biomass is labour intensive and costly when accurate quantification of crop variability over large areas is required (Trotter et al., 2008). Moreover, this method is destructive and it is not possible to take several measurements of the same plant/group of plants at different development steps (Golzarian et al., 2011). This is not an issue with using non-destructive passive or active optical methods. Passive instruments depend on sunlight and often consist of a general-purpose spectroradiometer measuring a number of wavelengths in visible and near-infrared, whereas active sensors are equipped with light-emitting components providing radiation in specific waveband region (Erdle et al., 2011). The requirement of such specific equipment might be limiting for organisations and farmers with low budget.

Currently, readily available digital scanners and cameras, in conjunction with digital image processing software, have largely replaced older methods using light obstruction to estimate vegetation parameters such as leaf area (Easlon and Bloom, 2014). The application of spectral reflectance indices has been gaining popularity as a physiological and breeding tool (Morgounov et al., 2014). The use of conventional digital cameras can assist to meet at least some fraction of the goals in plant biomass assessment, since they are affordable, portable, and easy to use (Casadesús and Villegas, 2014).

In this paper, we present the assessment of the possibilities and limitations of using digital images made by conventional digital cameras for the purposes of monitoring the plant canopy development and weed distribution during vegetation periods. The example is based on the

Contact address: Ing. Elena Kondrlová, PhD., Slovak University of Agriculture in Nitra, Faculty of Horticulture and Landscape Engineering, Department of Biometeorology and Hydrology, Hospodárska 7, 949 76 Nitra, Slovakia, ☎ +421 37 641 52 52, e-mail: elena.kondrlova@uniag.sk

field experiment established on agricultural land in Central Europe.

Material and methods

The data presented in this paper are partial results of the field experiment studying the effect of biochar application on gas emission, hydrophysical soil properties as well as plant response and yields established in the spring of 2014 at the experimental site in Malanta (48° 19´ N, 18° 09´ E), in the Nitra region of western Slovakia. The study plots (4 × 6 m) were organised in a full random block design (3 replicates per treatment) on loamy Orthic Luvisol. Biochar was applied at 0, 10 and 20 t ha^{-1} (B0, B10 and B20) together with N-fertilizer at amounts of 0, 40 and 80 kg ha^{-1} in 2014. In 2015, nitrogen was applied at 0, 160 and 240 kg ha^{-1} (N0, N160 and N240). Spring barley (*Hordeum vulgare* L.) was sown in 2014 followed by corn (*Zea mays* L.) that was sown on April 27, 2015. Further information on the experimental setup, biochar characteristics as well as partial results from the study can be found in Šimanský et al. (2016) and Kondrlová et al. (2016).

Images were taken by the digital camera Canon EOS 60D, 28–105 mm f/3.5–4.5 A according to the methodology described by Casadesus and Villegas (2012). Photo sampling was performed by walking across the field following a pre-defined path and taking three downward images of canopy from the 1.7 m height on every plot. The borders of the plot were excluded from the photo sessions to avoid edge effects. From the beginning of May up to the end of June 2015, four photo sessions were performed of each plot around solar noon to avoid shadows on the images. After downloading and sorting, the images were processed by the BreedPix software. Image-derived vegetation indices (IDVI) were calculated by representation of green fraction (GF), which is calculated according to the sum of frequencies of the histogram classes included in the image hue range from 60° up to 120° (Casadesús and Villegas, 2014).

Results and discussion

Regarding the remote sensing technique, the methods of plant variability assessment are limited by sizes of experimental areas. Satellite and aerial images are suitable methods to be used for monitoring of fields of more than a few hectares (Kumhálová et al., 2014), but their use on a plot scale is very limited. For plots of few m^2, as well as for pot studies (Tackenberg, 2007), digital images are a cheap and easy method to use with higher resolution.

The BreedPix software is an easy-to-use application for image analysis. The images located in the same folder are loaded into the software as a content of an image list.

Figure 1 Input images (top row) including and excluding corn plants from the green fraction analysis and the equivalent output images (bottom row) from the Breedpix software. Example shown for plot 14 (image 14_3), sampling date May 18, 2015

Table 1 Calculation of image-derived vegetation index (%) for images with mixed vegetation cover. Example for plot 14.

Date	IDVI – original image			IDVI – modified image		
	C + W	W	C	C + W	W	C
18. 5. 2015	7.1	3.5	3.6	6.2	2.9	3.3
	6.9	3.6	3.4	6.1	3.0	3.1
	6.7	3.7	3.0	5.9	3.1	2.8
	mean	**3.6**	**3.3**	**mean**	**3.0**	**3.1**
	SD	0.1	0.2	SD	0.1	0.2
	error	0.	0.01	error	0.0	0.1
28. 5. 2015	7.8	0.2	7.6	7.5	0.1	7.4
	7.4	0.5	6.9	6.9	0.3	6.7
	5.0	0.3	4.7	4.6	0.1	4.5
	mean	**0.3**	**6.4**	**mean**	**0.2**	**6.2**
	SD	0.1	1.2	SD	0.1	1.2
	error	0.1	0.7	error	0.1	0.7

Note: C + W (corn + weed), W (weed), C (corn)

Depending on the amount of images being processed, the analysis takes few seconds up to few minutes. One of the advantages of the software is that it also produces output images that indicate the quality of input image processing by the software (Figure 1). The GF is kept with its original colour while the grey colour indicates background that is excluded from counting.

One of the problems that might arise when processing the imagery and being dependent on specific colour is that the software cannot exclude different plant species from analyses. In situations where there were weeds and corn plants growing in the field (as it was during May 18 and May 28), the calculated GF of the images included corn (C) as well as weeds (W) (Figure 1 and Table 1). To deal with this problem, images showing corn and weeds were modified in the Microsoft Office Picture Manager (used because of its wide availability) in such a way that the corn plants were manually recoloured to dark red. After that the calculation of IDVI was performed again giving the result of GF only for weeds. To calculate the real GF for corn, the values of GF for weed were subtracted from GF for corn and weed (Table 1). The decrease in weed IDVI as observed for May 28 was caused by herbicide application on May 15 (Figure 2). During the next photo session performed on June 4, there were no weeds present and thus the images could be analysed considerably faster. Easlon and Bloom (2014) developed a tool that uses a combination of thresholding, colour ratios, and connected component analysis to rapidly measure leaf areas in individual images made by conventional cameras even by an iPhone camera. Application of the minimum component size criterion might be useful for image analysis of crop canopies with infestation by weeds of considerably smaller size. On the other hand, using this tool requires presence of a red calibration area on every image while shades and different types of crops might require additional manual adjustments.

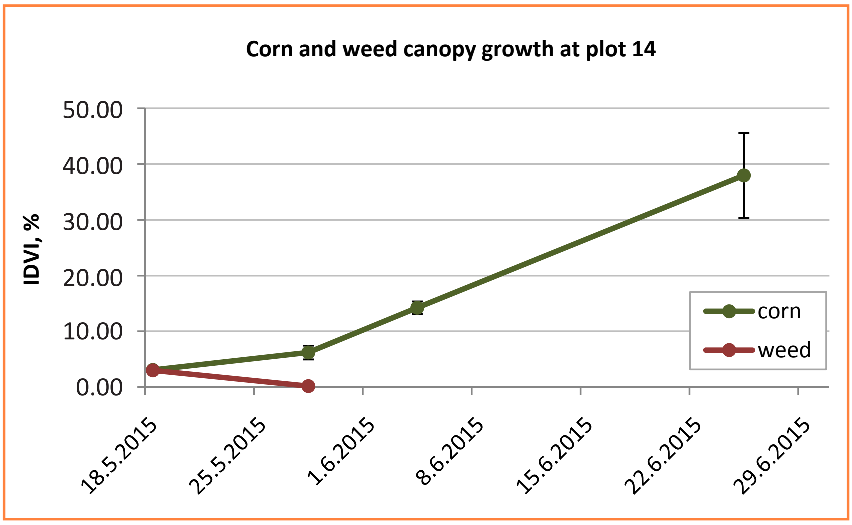

Figure 2 Canopy cover growth of corn and weed according to IDVI (n = 3). Error bars show standard deviation of the mean. Example for the plot 14

Checking the output images of the analysis, we have realised that in some cases the amount of GF was overestimated because of inclusion of some post-harvest residues (present in the soil from the previous year and being wrongly included into calculation of IDVI by the software). This problem can be easily solved by increasing of the image saturation in any image processing software (in our case, increasing the saturation to 100 in the Microsoft Office Picture Manager). After the modification, GF calculation was performed again and the output images checked again (Table 1). Although the differences

Table 2 Changes of image-derived vegetation indices (%) for corn estimated by the Breedpix software according to the photographic sampling at different sampling dates

Sampling date		Treatment					
		N0 B0	N0 B10	N0 B20	N160 B0	N160 B10	N160 B20
18. 5. 2015	mean	**2.1**	**2.1**	**2.2**	**1.7**	**2.3**	**2.3**
	st. dev.	0.3	0.7	0.5	0.2	0.5	0.7
	st. error	0.2	0.4	0.3	0.1	0.3	0.4
28. 5. 2015	mean	**5.2**	**3.6**	**4.4**	**5.1**	**4.6**	**5.7**
	st. dev.	1.3	0.9	1.5	1.1	1.5	1.1
	st. error	0.8	0.5	0.8	0.6	0.9	0.6
4. 6. 2015	mean	**10.0**	**9.6**	**12.1**	**11.8**	**15.0**	**13.9**
	st. dev.	2.0	0.2	5.5	1.2	2.1	2.0
	st. error	1.1	0.1	3.2	0.7	1.2	1.1
25. 6. 2015	mean	**33.1**	**39.9**	**38.8**	**32.1**	**42.9**	**40.3**
	st. dev.	8.1	1.3	7.8	7.6	9.2	12.0
	st. error	4.7	0.7	4.5	4.4	5.3	6.9

Source: Kondrlová et al., 2016

between the resulting IDVIs calculated from original and modified images were negligible in our case, this example shows the importance of the image post processing check since situations in field conditions can be very variable.

Comparing the results obtained from various sampling dates, the state of plant biomass development could be easily assessed according to the rising GF and thus increasing IDVI. Table 2 present some of the experimental results already published (Kondrlová et al., 2016). It was estimated that during the monitoring season the IDVI increased from 2% up to 31% on non-fertilised control plot (N0B0). It can be concluded that the biochar addition had a positive effect on the plant growth (above ground biomass) since all treatments resulted in higher IDVIs at the end of the vegetative growth. This increase could be observed in the order N0 B20 < N0 B10 < N160 B20 < N160 B10. Further, we assume that the increasing trend in the crop development was partially limited by competitive presence of weeds at the beginning of the study.

Although IDVI itself is only a dimensionless relative value, it can be used to indirectly evaluate the effect of various growing practices (e.g. fertilization) on plant development. Up to date, there are not many studies using the Breedpix software. Morguounov et al. (2014) used the software for evaluation of Lab colour parameters as potential selection criteria in 23 winter wheat yield trials grown over 4 years at 2 sites in Turkey. These parameters predicted the grain yield as accurately as NDVI. These parameters were similar to NDVI in their response to the stage of measurement, as well as the diversity of the germplasms tested. According to the results obtained by these authors they suggest the importance of early measurements of spectral indices from stem elongation to anthesis, since they have observed substantial differences in NDVI as well as photo parameters that might catch attention of breeding programs. Moreover, they point out the availability and practicality of digital cameras to suit for additional source of information in countries where modern phenotyping tools are not readily available.

Casadesús and Villegas (2014) verified the IDVI estimates with the leaf area index (LAI) and other variables determined by destructive sampling of triticale, bread wheat and tritordeum. The relationship was not the same for growing canopies before anthesis as for senescing canopies after anthesis. If analysed separately, R^2 ranged from 0.8 up to 0.9 before anthesis while after anthesis, R^2 was approximately 0.65. The difference might be attributed to the impact of spikes in the zenithal view of the canopy.

Considering this fact, we can conclude that this approach is a suitable tool for fast interpretation of plant development according to changes in the GF content during the early growth stages. As the plants grow towards maturity, the amount of GF decreases, the grains change colour from green towards yellow and light brown and thus the plant biomass stops to be detectable with the BreedPix software. Due to the same reason the performance of the software might be limited if plants are very dusted or covered by soil (e.g. after splash erosion event).

Conclusion

This contribution aims to show the possible applications of image analysis in the BreedPix software for estimation of agricultural crop coverage development. According to our experience we can recommend it for the development monitoring of agricultural crops especially in the early growth stages. Attention has to be paid to the presence of other plants (weeds) or other green objects since without additional image modification and analysis they would be included in the green fraction calculation and thus would cause overestimation of the estimated image-derived vegetation index. On the other hand, after additional treatment, the images can be used also for other purposes (e.g. weed coverage development, herbicide efficiency evaluation, breeding programs). The advantage is that this method is not disturbing the plant cover and the imagery of the same plants can be done in different time steps. Moreover, the method requires conventional digital cameras, thus no special and expensive equipment and training are needed to obtain IDVI values.

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