ORIGINAL SCIENTIFIC PAPER

Potential of aerial robotics in crop production: high resolution NIR/VIS imagery obtained by automated unmanned aerial vehicle (UAV) in estimation of botanical composition of alfalfa-grass mixture

Hrvoje KUTNJAK[1], Josip LETO[2], Marina VRANIĆ[2], Krešimir BOŠNJAK[2], Goran PERČULIJA[3]

[1]European Commission – JRC, Institute for Environment and Sustainability, Land Resource Management Unit, Via Enrico Fermi 2749, 20127 Ispra (VA), Italy, (e-mail: hkutnjak@gmail.com)
[2]University of Zagreb, Faculty of Agriculture, Department of Field Crops, Forage and Grassland, Svetošimunska cesta 25, 10000 Zagreb, Croatia
[3]Paying Agency for Agriculture, Fisheries and Rural Development, Ulica grada Vukovara 269d, 10000 Zagreb, Croatia

Abstract

Objective of this study is to show possibility of use of aerial imagery acquired by UAV equipped with NIR/VIS cameras and estimation of botanical composition and status on case study legume-grass mixture consisted of alfalfa, orchardgrass and Italian ryegrass. Results showed positive correlations between local NDVI values and relative share of alfalfa and Italian ryegrass and negative correlation between orchardgrass and NDVI. Use of aerial imagery acquired by UAV equipped with NIR/VIS sensors showed potential in estimation of botanical composition and sward status but for interpretation of such remote sensed data it is very important to include into the context additional management data.

Key words: UAV, NDVI, legume-grass mixture, aerial, high resolution

Introduction

Following the human population growth on the Earth and limitations of the land resource, civilization is facing with challenge of sustainable food and energy production (Rockström et al., 2009). In that sense it is expected that field crop production is going to be more intensified, but also with minimum unfavourable effect on environment (FAO, 2011). Some clues and steps related to crop production are already known and present examples of good agriculture practice like an introduction of new crop rotation systems and multiple cropping systems where more different crops grow consociated (Gliessman, 1985). One of the well-known consociations is combination of legumes and grasses in forage production where nutritive and palatable properties, but also ecological amplitudes, mutually complement each other, making such a form of field production relatively cheaper, more balanced, more efficient and environmentally more acceptable than conventional monocultural field production. However, in order to be successful, even this practice requires supervision and interventions in sense of fertilizer availability modifications, pest control or composition corrections, preferably immediately and in real time. Satellite and aerial images are accessible for a long time and they are found to be very useful in monitoring of field production, but except low feasibility, use of such products miss adequate temporal resolution which would provide prompt and accurate action in the field. Answer on this issue are (semi) autonomous or (semi) automated unmanned aerial vehicles (UAV) which are able to provide fast and cheap imagery of the area of interest (WAP, 2013).

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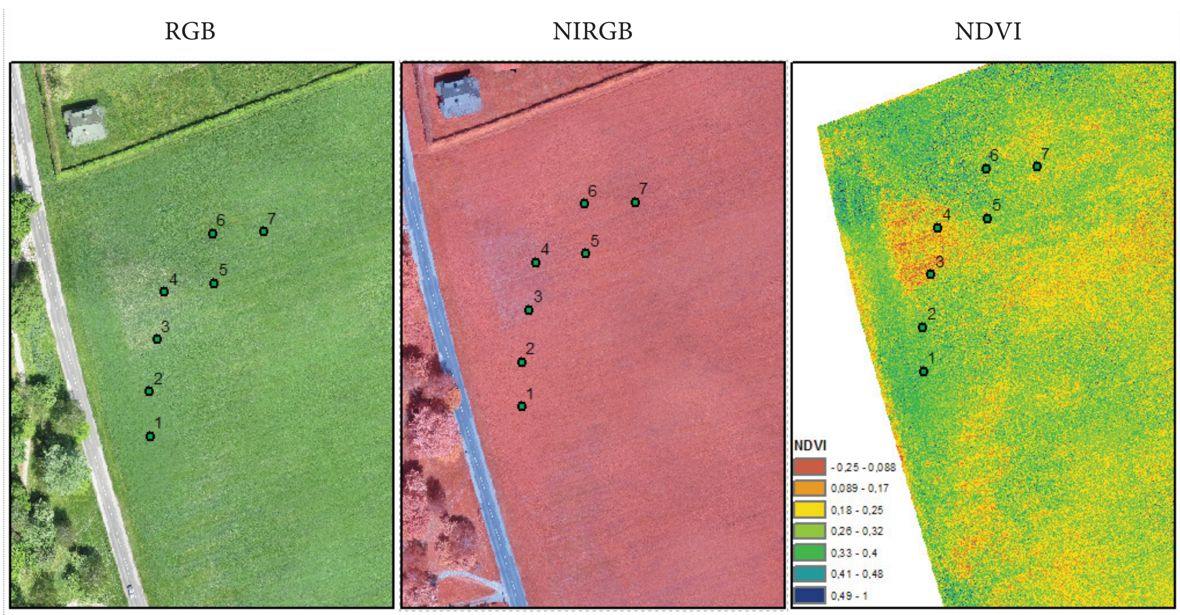
Objective of this study is to show possibility of use of aerial imagery acquired by UAV equipped with visible light (VIS) and near infra-red (NIR) sensors and estimation of botanical composition and status of three component legume-grass mixture.

Materials and methods

Experimental field was located at the Faculty of Agriculture in Zagreb, Croatia with an area of $7.61x10^4$ m^2. The first purpose of the field was fodder production and in autumn 2007 was sown alfalfa (*Medicago sativa*) with seeding rate of 1.9 g m^{-2}. Orchardgrass (*Dactylis glomerata*) and Italian ryegrass (*Lolium multiflorum*) were directly (without ploughing) sowed in alfalfa after 3 years, with seeding rates of 2 g m^{-2} and 0.8 g m^{-2}, respectively.

Images of area were captured in spring (30th April) 2013 before the first harvest using UAV eBee (Sensefly-Parrot company, Switzerland, 2013) and two 16.1 MP cameras Canon IXUS 125 HS VIS (visible spectrum, RGB-red/green/blue) and Canon IXUS 125 HS NIR (near infra-red, NIRGB - near infra-red/green/blue). Pixel size was set to 5 cm with and flight altitude and flight route was set up automatically by the system. The tile overlapping was set to 70% in flight direction and 70% lateral. Post processing (ortho-mosaicking) of acquired images was performed with Postflight Terra 3D software (Run by Pix4D) and final orthomosaic was georefferencet to HTRS96/TM Croatia (EPSG:3765). Normalized difference vegetation index (NDVI) layer was generated in raster calculator ArcInfo (ESRI, California, US) from extracted red (R) and near infra-red (NIR) channels (Picture 1).

$$NDVI = \frac{NIR - R}{NIR + R}$$



Picture 1. Images in RGB and NIRGB with sampling points and generated NDVI layer.

Sampling and determination of the relative share of each component of legume-grass mixture was performed on 7 randomly chosen points through the transect of the part of the field which appeared with the highest visual variability. Fathoms of harvested plants were counted and determinated on the field with marking each with spatial reference using GPS Garmin 60 CSX. Later, collected GPS points were buffered by 2 m which was matched GPS device's maximum accuracy (±2 m) and polygons were overlaid over NDVI layer for zonal statistics.

Results and discussion

Analysis of floristic composition on sampling points showed share of each component in alfalfa-grass mixture, where in average orchardgrass dominated over Italian ryegrass and alfalfa, 41.1%, 30.1% and 28.7%, respectively. The results are shown in Table 1. These results go in favour to the fact that dynamics in such plant communities, their phenological properties and local environmental factors don't allow development of homogenous structure of the sward stand. As it is mentioned before, alfalfa was sown in 2007 and after 3 years of intensive exploitation alfalfa weakened and started to withdraw, leaving gaps of bare soil in sward. In order to improve yield and structure of the sward in 2010 was performed direct sowing of two grass species with different competitiveness and ecological valences. Italian ryegrass is more aggressive in the first year with high nitrogen affinity and lower frost and drought resistance than orchardgrass. These different properties gave polyfunctional properties to the sward segregating mixture components according to the local micro-ecological conditions caused micro relief (frost, rainwater accumulation and of flow) and nutrient availability. Sward structure of alfalfa and Italian ryegrass usually becomes sparsed and weakened after 2-3 years of intensive use and orchardgrass in its second year after sowing showed its full development and took advantage over them.

Table 1. Botanical composition on the sampling points. (MS - alfalfa (*Medicago sativa*), DG - orchardgrass (*Dactylis glomerata*), LM – Italian ryegrass (*Lolium multiflorum*))

Point nr.	MS	DG	LM	total	% MS	% DG	% LM	% grasses	% legume
1	50	28	40	118	42.4	23.7	33.9	66.1	33.9
2	46	32	30	108	42.6	29.6	27.8	72.2	27.8
3	17	102	11	130	13.1	78.5	8.5	91.5	8.5
4	14	67	21	102	13.7	65.7	20.6	79.4	20.6
5	47	19	36	102	46.1	18.6	35.3	64.7	35.3
6	15	41	22	78	19.2	52.6	28.2	71.8	28.2
7	30	24	71	125	24.0	19.2	56.8	43.2	56.8

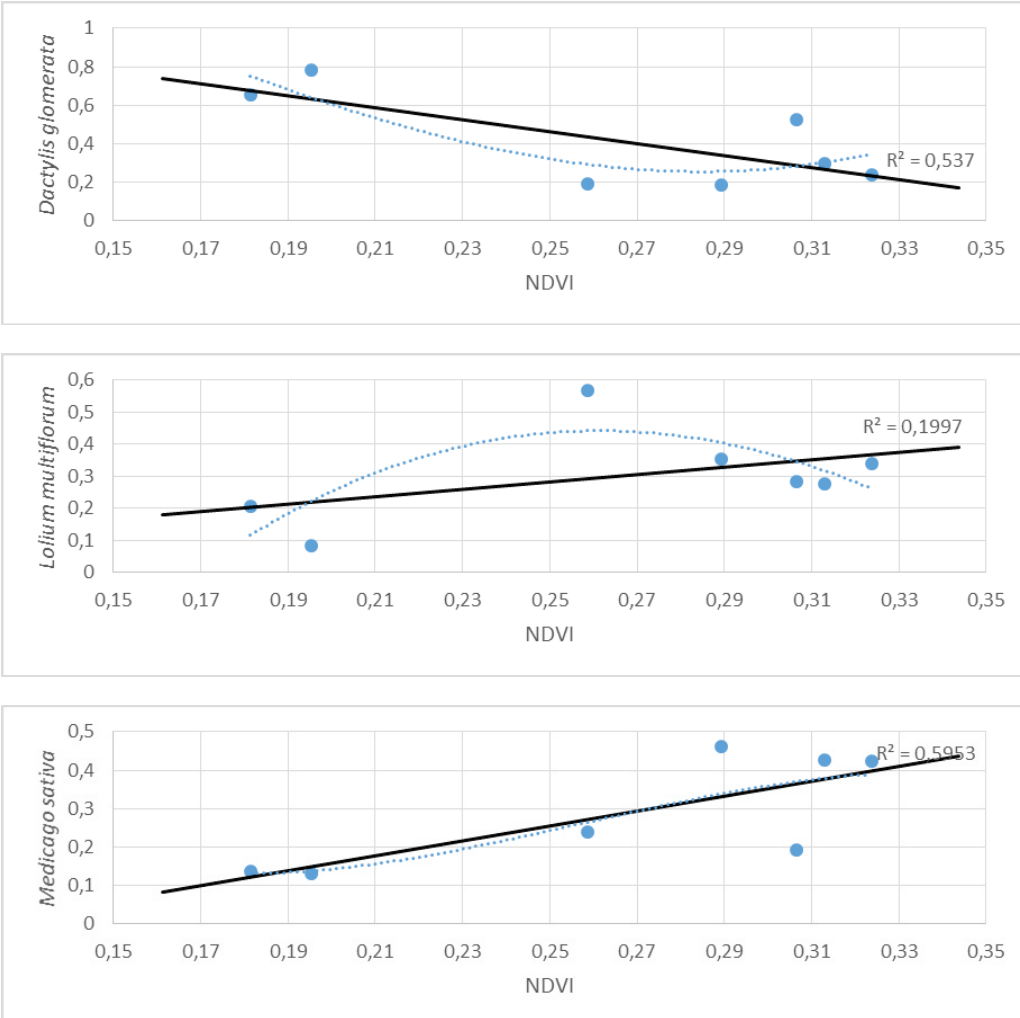
Considering the nature of NDVI values which vary between -1 and +1 and to avoid problems in zonal statistic calculation caused by negative values NDVI values were increased by 1. Zonal statistics of NDVI on sampling points show that average NDVI values ranged between 0.18 and 0.32 which is compared to the literature low for such land cover type, which might be related to the water deficit, shadows or specific reflective and absorptive changes related to development stage of the crops (vegetative, elongation, reproductive - flowering). The results are shown in Table 2.

Table 2. Result of the zonal statistics of the sampled area

Point nr.	n	area [m^2]	MIN	MAX	RANGE	NDVI+1	STDev	SUM
1	7629	12.5	1.15	1.51	0.36	1.32	0.04	10098.70
2	7627	12.5	1.14	1.59	0.45	1.31	0.05	10014.30
3	7632	12.5	0.90	1.54	0.64	1.20	0.08	9122.54
4	7628	12.5	0.96	1.48	0.52	1.18	0.07	9011.54
5	7633	12.5	1.06	1.62	0.56	1.29	0.06	9841.24
6	7632	12.5	1.03	1.68	0.65	1.31	0.08	9971.10
7	7626	12.5	1.01	1.51	0.49	1.26	0.06	9598.87

Positive correlations between NDVI and relative share of components was found with alfalfa (*Medicago sativa*) and Italian ryegrass (*Lolium multiflorum*) and orchardgrass (*Dactylis glomerata*) was negatively correlated (Picture 2.)

This negative correlation of one component and NDVI is a bit unexpected, but could be explained with the assumption that different plant species have different specific NDVI values according to the phenophase. It is



Picture 2. Correlations between relative share of components in alfalfa-grass mixture and NDVI. Dashed polynomial trendlines have orientational nature indicating possible species-phenophase specifffic NDVI maximum values.

well known that NDVI is directly related to many vegetation land cover properties like a green leaf biomass, green leaf area index, chlorophyll content, foliar nitrogen, total and green leaf biomass (Gamon, 1995) and those properties are not expressed in the same way at each component of the sward (in our case on the date of observation orchardgrass has already quite entered the panicle stage). Second possibility is that orchardgrass simply left where alfalfa and Italian ryegrass withdrawed staying with low stand density and yielding with lower NDVI. However, this trailblazing study showed that for more concrete conclusions are needed more sampling points and some additional measurements like measurement of standing biomass, dry mater yield and leaf area index.

Conclusions

Use of aerial imagery acquired by UAV equipped with visible light (VIS) and near infra-red (NIR) sensors showed potential in estimation of botanical composition and dynamics status of the three component legume-grass mixture, but it is very important to include management data and additional land cover measurements for explanation of the remote sensed data.

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References

FAO (2011). Save and grow, A policymaker's guide to the sustainable intensification of smallhoder crop production, Rome. Available at http://www.fao.org/docrep/014/i2215 e/ i2215e.pdf.

Gamon J. A., Field C. B., Goulden M. L., Griffin K. L., Hartley A. E., Geeske J., Peñuelas J., Valentini R. (1995). Relationships Between NDVI, Canopy Structure, and Photosynthesis in Three Californian Vegetation Types, Ecological Applications 5(1): 28-41.

Gliessman S. R. (1985). Multiple cropping systems: A basis for developing an alternative agriculture. Pp 69-83 in Inovative biological technologies for lesser developed countries-workshop proceedings.OTA, Washington, DC.

Rockström J., Steffen W., Noone K., Persson Å., Chapin F. S. III, Lambin E. F., Lenton T. M., Scheffer M., Folke C., Schellnhuber H. J., Nykvist B., de Wit C. A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P. K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V. J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P., Foley J.A. (2009). A safe operating space for humanity. Nature 461: 472-475.

Sensefly-Parrot Company (2013). Switzerland. Available at https://www.sensefly.com/ drones/ebee.html

WAP (2013). Precision agriculture ,13: papers presented at the 9th European conference on precision agriculture, Lleida, Catalonia (Spain), 7-11 July 2013, ed. By John V. Stafford, Wageningen: Wageningen Academic Publishers.

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