BOOK OF
PROCEDINGS

IX International Scientific Agriculture Symposium
"Agrosym 2018"
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PREFACE

A Word from the Editor-in-Chief

Dear colleagues,

In your hands are the Proceedings of the 9th International Scientific Agricultural Symposium "AGROSYM 2018" held on 4-7 October 2018 in Jahorina, Bosnia and Herzegovina. The Symposium gathers about 1200 participants from 85 different countries and organizers received over 1200 abstracts/full papers. Symposium themes covered all branches of agriculture and were divided into seven sessions: 1) Plant production, 2) Plant protection and food safety, 3) Organic agriculture, 4) Environmental protection and natural resources management, 5) Animal husbandry 6) Forestry and Agro-forestry, and 7) Rural Development and Agro-economy.

In the plenary lectures was presented the importance of new information and communication technologies for agriculture in the 21st century and biological protection in plant production. Furthermore, a particular attention was devoted to avoiding knowledge waste through networking and partnership.

Agriculture has a complex relationship with natural resources and the environment, thus attributing specific environmental effects to agriculture is difficult and not fully understood. Today, it is obvious that conventional methods of agricultural production, in addition to providing sufficient food and other products, have led to a number of negative impacts, including direct or indirect effects on human health. Excessive use of agrochemicals can cause various disorders in the biological equilibrium of agroecosystems and beyond. These negative impacts raise serious questions about long-term sustainability of high-input agriculture. Measures to protect soil and water in agriculture include comprehensive and complex undertakings and pre-planned measures. These problems are a constant reason for 'popularisation' of all ecological trends in agriculture (e.g. organic agriculture, permaculture, biodynamic agriculture, conservation agriculture, regenerative agriculture, integrated farming, agroecology, etc.). Meanwhile, there are also calls for a genuine, deep transformation of agro-food systems that goes beyond 'ecologisation' of agricultural production. All these developments in agricultural research field, as well their implications on farmers' fields, were discussed during the 4 days of AGROSYM 2018.

All papers included in the Proceedings were peer-reviewed. Full texts of the accepted contributions are available in electronic form on AGROSYM website (http://agrosym.unssa.rs.ba).

I hope that the Proceedings will be useful to many agriculturalists and to those engaged in related fields and enable better collaboration of scientists, researchers and producers.

Many thanks to all the authors, reviewers, session moderators and colleagues for their help in editing the Proceedings "AGROSYM 2018". Special thanks go to all co-organizers for their unselfish collaboration and comprehensive support.

East Sarajevo, 07th October 2018

Dušan Kovačević

Prof. Dušan Kovačević, Editor-in-Chief

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Abstract

Aboveground biomass of wheat is considered as one of the most important crop parameters and correct estimation of aboveground biomass can help improve crop monitoring and grain yield prediction. Remotely sensed vegetation indices such as NDVI (Normalized Difference Vegetation Index) represent one of the most promising tools for application in field phenotyping with potential to provide complex information on different traits of wheat. The objective of this study was to evaluate the potential of different NDVIs derived from field reflectance measurements in identification of a specific growth stage in which proximally or remotely sensed data showed the highest correlation with aboveground biomass and grain yield of 24 winter wheat genotypes. The NDVI was determined using an integrated proximal sensor GreenSeeker (NTech Industries Inc., Ukiah, California, USA) and hyperspectral camera (Ximea Corp., Lakewood, CO USA) at four growth stages of wheat: full flowering, medium milk, early dough and fully ripe. The hyperspectral NDVI indices were calculated from two-band combinations between red (600-700 nm) or far-red (700-750 nm) and near-infrared (756-955 nm) regions. Highly significant correlations were found between different NDVIs and both examined traits at medium milk growth stage, with r values of up to 0.69. The strong positive relationship implies that medium milk stage is optimal for wheat traits assessment in semiarid or similar growing conditions. The overall results indicated that hyperspectral camera provided alternative spectral combinations for different NDVIs which could be successfully used in assessing aboveground biomass and grain yield of a large number of wheat genotypes.

Keywords: *GreenSeeker, hyperspectral, NDVI, wheat, yield*

Introduction

Being adapted to a broad range of latitudes, temperatures, water regimes and nutritional levels, wheat is one of the most widely grown crops and the future productivity of wheat will arguably have more influence on global food security than any other crop (Reynolds et al., 2012a). Beside of high potential for yield of current wheat cultivars, weather conditions are becoming increasingly unstable due to climate change and grain yields of wheat fluctuate more widely from year to year (Hristov et al., 2012). Since that the pressure put on modern crop production to maximize the yield and minimize the inputs, timely monitoring of crop growth status early in the growing season could be of vital importance for in-season site-specific crop management, especially in regions characterized by climatic uncertainties (Henik, 2012). Large agricultural lands are usually monitored using proximal and remote sensing technology, which allows for instantaneous data acquisition over vast areas (Kostić et al., 2016). Recent studies suggest that remote sensing technology possesses a great potential for estimation of yield and yield related traits, both in precision farming, as well as in large breeding programs (Duan et al., 2017). Agricultural remote sensing is based on canopy light reflectance indices, which rely on the fact that plants absorb the light at specific wavelengths associated with specific plant traits. These indices could provide large-scale evaluation of germplasm in a rapid and nondestructive manner (Reynolds et al., 2012b; Araus and Cairns, 2014; Morgunov, 2014). Among various vegetative indices, Normalized Difference Vegetation Index (NDVI) is one of the most widely used for crop monitoring, since it is related to leaf development, amount of chlorophyll, amount of photosynthesis, stay-green traits, grain yield and aboveground biomass of wheat (Lopes and Reynolds, 2012). Based on the principle that green vegetation strongly absorbs solar radiation in the red (R) part of the visible electromagnetic spectrum, while strongly reflecting radiation in the near-infrared (NIR) region, NDVI is defined as the difference between the red and near-infrared reflectance divided by their sum (Tucker, 1980). GreenSeeker is the one of the most widely used active hand-held sensors for measuring NDVI due to its invariance to light conditions and the time of day, but limited by its use of only two central wavelengths (Yao et al., 2013). Reflectance in visible and near-infrared regions is strongly dependent on both structural and biochemical properties of the canopy, varies with the growth stage and environmental conditions (Kumar et al., 2001). Hence, it is a challenge to develop a unique and optimal two-waveband combination for NDVI exclusively sensitive to targeted grain yield traits. Hyperspectral data could provide extensive information about plants and can serve as a basis for finding the most indicative wavebands for assessment of targeted crop parameters (Kaur et al., 2015). Therefore, the present study was carried out with two main objectives. The first objective was to find the optimal combination of hyperspectral wavebands in R and NIR regions, for aboveground biomass and early grain yield assessment of 24 winter wheat genotypes. The second objective was to determine the specific growth stage where the correlation between the yield traits and NDVI acquired by GreenSeeker sensor and hyperspectral camera is highest and therefore the most suitable for use in both proximal and remote sensing.

Material and Methods

The present study was carried out at the experimental field of the Institute of Field and Vegetable Crops (45°19′51′ N, 19°50′59′ E) in Novi Sad, Serbia, in typical semiarid conditions, during the 2015–2016 growing season. The experimental material was comprised of 24 winter wheat (*Triticum aestivum* L.) genotypes, namely, Ubavka (G1), Matuška (G2), Javorka (G3), Brazda (G4), Efrosinija (G5), Doroteja (G6), Obala (G7), Vlajna (G8), Kala (G9), Mila (G10), Azra (G11), Nafora (G12), Pudarka (G13), Ljubica (G14), Petrija (G15), Futura (G16), Ilina (G17), NS 40S (G18), Zvezdana (G19), Simonida (G20), Rapsodija (G21), Renesansa (G22), Evropa (G23) and Pobeda (G24). The cultivars were sown in 2 m long rows with 20 cm of inter-row spacing and 10 cm spacing between plants in the row. The trial was sown in a randomized block design, with three replications. Examined cultivars were grown using common agronomic practice. Meteorological data, values of temperature and precipitation throughout the season were obtained from Rimski Šančevi Meteorological Station, located near the experimental field (Table 1). At the stage of full maturity, grain yield (t ha^{-1}) of 24 winter wheat genotypes was estimated, while plants in one square meter of each genotype were harvested from the experimental plots individually to record aboveground biomass (g m^{-2}). For each of the 24 winter wheat genotypes NDVI was measured at four different growth stages: full flowering (BBCH 65), medium milk (BBCH 75), early dough (BBCH 83) and fully ripe (BBCH 89). For NDVI measurements, the GreenSeeker handheld (NTech Industries Inc., USA) proximal sensor and Ximea hyperspectral camera xiSpec MQ022HG-IM-SM5X5-NIR (Ximea Corp., USA) were used.

Table 1. Temperature and precipitation values for the growing seasons 2015–2016 and multi-year averages (1981-2010) for field trial region

	2015–2016		Multi-year average	
Month	Temperature °C	Precipitation mm	Temperature °C	Precipitation mm
October	11.3	74.6	11.7	47.6
November	7.8	56.1	5.9	51.2
December	3.2	3.6	1.5	46.2
January	1.2	51.6	-0.5	37.3
February	7.3	49.0	1.8	31.8
March	7.9	65.3	6.4	37.1
April	14.3	74.2	11.4	48.8
May	16.7	84.6	16.8	59.6
June	22.6	143	19.9	85.7
Average	10.14	67.32	8.3	49.5
Total	91.3	669.32	74.9	615.5

GreenSeeker, as an active hand-held sensor, emits light and measures the reflectance at 660 nm (R) and 770 nm (NIR) (Tremblay et al., 2009). In-field reflectance measurements were taken by holding GreenSeeker sensor about 60 cm horizontally above the crop canopy and scanning the central part of each wheat plot. For each plot, 10 NDVI readings were collected and averaged to obtain a single value per plot. Hyperspectral camera was mounted at a height of 1 m above canopy on a mobile tripod, which corresponded to an image area of 2 m^2 while the spatial resolution was 0.5 × 0.5 mm per image pixel. Its output was consisted of 66 images, each corresponded to one channel between 600 and 955 nm. As the pixel values are proportional to the existing amount of sunlight, each image was calibrated using Sphere Optics Zenith reflectance sheet. For calibration and calculation of NDVI was used MATLAB (MathWorks Inc., US). As NDVI requires measurements in RED and NIR domains, candidates for the red domain were hyperspectral channels in visible red (600–700 nm) and far-red (700–750 nm) part of the spectrum, while candidates for NIR channel were hyperspectral channels between 756 nm and 955 nm. This gave the aggregate of 3 (red), 22 (far-red and near-infra red) and produced 66 different NDVI indices. The NDVI measurements from both instruments were made close to noon, between 10:00 am and 2:00 pm on sunny, cloud-free days when the plant canopy and soil surface were dry. Pearson correlation coefficient (r) was used as a measure of correlation of NDVI with aboveground biomass and grain yield. Besides observing the correlation based on absolute NDVI values, the relationship between the yield traits and the decline in NDVI between BBCH 65 and BBCH 75, BBCH 83 and BBCH 89 was analysed. The relative decline (Dj) in NDVI served as a measure of magnitude of reduction in NDVI from BBCH 65 to BBCH 75, BBCH 83 and BBCH 89, calculated as follows:

$$\mathrm{Dj} = \frac{\mathrm{NDVI_i} - \mathrm{NDVI_j}}{\mathrm{NDVI_i}} \times 100\%$$

where *i* present NDVI measured at BBCH 65 growth stage of wheat, while *j* presents NDVI measured at BBCH 75, BBCH 83 and BBCH 89 growth stage of wheat. In this way we introduced three relative decline measures: D1, D2 and D3, respectively. All statistical analyses were carried out using software STATISTICA, version 13 (StatSoft Inc., USA).

Results and Discussion

The presented results revealed wide range between the minimum and maximum values for observed traits of wheat and the greatest values varied on overall basis. The overall mean values of aboveground biomass of the 24 winter wheat genotypes varied from 300 g m^{-2} for genotype G8 to 700 g m^{-2} for genotype G10. The mean grain yield values varied from 9.2 t ha^{-}

^{1} for genotypes G8, G15 and G21 to 11.2 t ha^{-1} for genotype G9. In respect of NDVI values, the results showed that maximum values of NDVI were observed during BBCH 65, when photosynthesis was at the highest point and the leaf area was largest. Through the later growth stages, NDVI values gradually declined reaching the minimum values at BBCH 89. In chronological order, the sensor GreenSeeker based NDVI score ranged from 0.61 to 0.72, 0.40 to 0.61, 0.24 to 0.36 and 0.15 to 0.20 at BBCH 65, BBCH 75, BBCH 83 and BBCH 89 stage of wheat, respectively (Table 2). These results indicated that through the process of senescence toward the end of the season, reflectance of visible wavelengths increases and reflectance of NIR decreases as a consequence of less absorption of visible light in the leaves (Reynolds et al., 2012b; Sultana et al., 2014). The variability of NDVI throughout the genotypes was lowest at the BBCH 65, because the NDVI was mainly affected by saturation effects, which is well known at high crop densities (Erdle and Schmidhalter, 2013). Since that all observed wheat genotypes showed similar and the largest NDVI values at BBCH 65, it becomes clear that this growth stage could not prove to be indicative for aboveground biomass and grain yield assessment. With respect to NDVI values derived from hyperspectral imagery, the results show that two-band combinations respond in different manner to variations in yield traits, but the mean values displayed the same tendency as the GreenSeeker based NDVI values (Table 2). With respect to the association between grain yield and aboveground biomass of wheat it was observed the strong positive relationship (r = 0.88**). Positive relationship between grain yield and aboveground biomass of wheat is mandatory for a system intended to predict yield traits early in the season by assessing the canopy growth (Marti et al., 2007). The strong positive relationship between the grain yield and aboveground biomass of wheat (r = 0.88**) suggested that higher biomass production during the green up stage, particularly during the grain filling period have an advantage for the yield increase in wheat because translocation of assimilates from the vegetative to generative parts of a plant contribute significantly to yield. Significant positive association between aboveground biomass and grain yield of wheat has been confirmed by several researchers (Bogale and Tesfaye, 2016). In present study a high and significant positive correlation between grain yield and aboveground biomass of wheat was observed, which justified approach of predicting the yield by measuring NDVI of the canopy. With respect to the association between measured traits and NDVI from both devices and all hyperspectral two-waveband combinations, the result revealed that the significant and positive association was observed at the medium milk stage of wheat. The GreenSeeker based NDVI showed the correlation of 63%** with aboveground biomass and 58 %** with grain yield. Positive, but not significant correlations were observed at BBCH 83, while the correlations in the stages BBCH 65 and BBCH 89 were lower or even negative with none of them being significant. It can be noted that in aboveground biomass assessment, the NIR wavelength used by GreenSeeker (770 nm) was the optimal one for hyperspectral NDVI, as well, while the R wavelength was slightly longer (674 nm instead of 660 nm). The optimal R wavelength for grain yield prediction remained the same, while the optimal NIR wavelength changed to 909 nm (Fig. 1). Beside of significant positive correlation between NDVI and both traits found at BBCH 75, it was also observed that wheat genotypes which displayed high NDVI values at BBCH 75 tended to have high yield, as well as aboveground biomass. This indicates that the delay in senescence extends the grain-filling period and increase grain yield (Hawkesford et al., 2015). This result agrees with the previous findings of several researchers (Morgounov et al., 2014; Gonzalez-Dugo et al., 2015). Since that optimal stage for measuring NDVI depending on the germplasm and environmental conditions, contradictory findings have been reported.

Table 2. The mean values of aboveground biomass, grain yield, best selected NDVI and magnitude of reduction in NDVI from BBCH 65 to BBCH 75 of 24 winter wheat genotypes

			GreenSeeker NDVI					NDVI (R770-R674)/(R770+R674)				
G[a]	GY[b]	AB[c]	BBCH 65	BBCH 75	BBCH 83	BBCH 89	D_1	BBCH 65	BBCH 75	BBCH 83	BBCH 89	D_1
G1	10.8	660	0.71	0.54	0.26	0.18	23.9	0.68	0.50	0.22	0.16	27.0
G2	10.6	580	0.69	0.57	0.25	0.15	17.4	0.67	0.53	0.21	0.13	21.3
G3	9.8	560	0.68	0.58	0.25	0.16	14.7	0.66	0.54	0.21	0.14	19.0
G4	11.1	680	0.67	0.58	0.28	0.21	13.4	0.64	0.54	0.23	0.22	15.7
G5	10.7	570	0.71	0.54	0.36	0.20	23.9	0.69	0.50	0.32	0.20	28.5
G6	11.1	670	0.62	0.55	0.34	0.16	11.3	0.58	0.53	0.30	0.14	8.8
G7	11.0	650	0.67	0.57	0.31	0.20	14.9	0.68	0.50	0.28	0.27	26.3
G8	9.2	300	0.72	0.40	0.28	0.16	44.4	0.68	0.34	0.24	0.14	50.3
G9	11.2	620	0.65	0.58	0.28	0.18	10.8	0.62	0.54	0.24	0.18	11.8
G10	11.0	700	0.71	0.61	0.29	0.15	14.1	0.67	0.57	0.25	0.01	15.3
G11	9.9	460	0.72	0.58	0.24	0.18	19.4	0.67	0.54	0.20	0.20	19.7
G12	10.2	500	0.70	0.61	0.25	0.17	12.9	0.68	0.55	0.21	0.15	18.2
G13	10.9	480	0.71	0.52	0.31	0.18	26.8	0.69	0.49	0.27	0.20	30.0
G14	9.8	370	0.61	0.50	0.26	0.19	18.0	0.64	0.46	0.20	0.18	28.8
G15	9.2	310	0.71	0.48	0.27	0.16	32.4	0.67	0.40	0.23	0.09	40.7
G16	9.3	340	0.72	0.51	0.29	0.19	29.2	0.69	0.47	0.25	0.19	31.8
G17	10.9	550	0.69	0.51	0.30	0.19	26.1	0.67	0.48	0.26	0.18	27.9
G18	10.5	660	0.72	0.55	0.35	0.17	23.6	0.70	0.53	0.31	0.14	24.6
G19	10.5	580	0.69	0.54	0.31	0.18	21.7	0.67	0.51	0.29	0.17	23.8
G20	9.4	450	0.66	0.53	0.26	0.20	19.7	0.65	0.52	0.22	0.20	20.4
G21	9.2	310	0.71	0.49	0.32	0.19	31.0	0.69	0.44	0.28	0.17	36.4
G22	10.0	360	0.70	0.56	0.23	0.16	20.0	0.68	0.52	0.21	0.14	23.7
G23	9.3	320	0.68	0.51	0.30	0.16	25.0	0.65	0.48	0.26	0.18	26.9
G24	9.7	350	0.69	0.54	0.31	0.16	21.7	0.67	0.50	0.27	0.16	25.9
G	GY	AB	NDVI(R900-R674)/(R900+R674)				D1	NDVI(R909-R674)/(R909+R674)				D1
G1	10.8	660	0.78	0.65	0.43	0.36	16.2	0.80	0.63	0.46	0.38	21.2
G2	10.6	580	0.77	0.64	0.31	0.34	16.7	0.77	0.56	0.39	0.35	27.5
G3	9.8	560	0.76	0.63	0.42	0.34	17.3	0.77	0.70	0.43	0.40	9.5
G4	11.1	680	0.77	0.67	0.40	0.41	13.4	0.78	0.71	0.44	0.42	8.6
G5	10.7	570	0.79	0.65	0.45	0.40	18.1	0.81	0.62	0.48	0.43	23.1
G6	11.1	670	0.72	0.64	0.44	0.29	11.9	0.72	0.65	0.45	0.36	9.5
G7	11.0	650	0.77	0.66	0.43	0.43	14.4	0.77	0.68	0.47	0.44	11.1
G8	9.2	300	0.79	0.46	0.36	0.35	41.6	0.78	0.47	0.40	0.39	40.4
G9	11.2	620	0.75	0.67	0.42	0.39	10.5	0.77	0.68	0.46	0.41	11.2
G10	11.0	700	0.77	0.65	0.43	0.28	16.2	0.79	0.69	0.44	0.33	12.1
G11	9.9	460	0.76	0.64	0.38	0.37	15.1	0.77	0.66	0.44	0.41	15.0
G12	10.2	500	0.78	0.62	0.32	0.35	20.5	0.79	0.68	0.38	0.34	14.4
G13	10.9	480	0.79	0.63	0.41	0.35	19.8	0.81	0.70	0.41	0.31	13.5
G14	9.8	370	0.74	0.58	0.38	0.40	22.6	0.79	0.59	0.43	0.39	25.1
G15	9.2	310	0.77	0.50	0.36	0.27	35.6	0.78	0.51	0.40	0.29	34.5
G16	9.3	340	0.77	0.61	0.43	0.39	21.4	0.79	0.64	0.45	0.42	19.2
G17	10.9	550	0.77	0.55	0.44	0.36	28.4	0.79	0.65	0.47	0.40	17.6
G18	10.5	660	0.79	0.64	0.49	0.37	18.3	0.81	0.68	0.48	0.38	15.6
G19	10.5	580	0.76	0.55	0.46	0.35	26.6	0.78	0.66	0.49	0.39	15.4
G20	9.4	450	0.76	0.58	0.37	0.41	23.9	0.77	0.62	0.43	0.36	19.4
G21	9.2	310	0.79	0.61	0.40	0.35	23.3	0.79	0.57	0.44	0.40	27.6
G22	10.0	360	0.77	0.59	0.39	0.30	23.7	0.80	0.66	0.39	0.37	17.2
G23	9.3	320	0.75	0.55	0.43	0.41	27.0	0.77	0.58	0.46	0.45	24.6
G24	9.7	350	0.78	0.65	0.40	0.34	17.2	0.79	0.60	0.46	0.41	24.1

[a]G: Wheat genotypes, [b]GY: Grain yield t ha^{-1}, [c]AB: Aboveground biomass g m^{-2}, [c]D1: Relative decline, reduction in NDVI from BBCH 65 to BBCH 75 for GreenSeeker based and hyperspectral NDVI measured at (R770-R674)/(R770+R674), (R900-R674)/(R900+R674) and (R909-R674)/(R909+R674), respectively (%).

Contrary to these results, previous studies demonstrated that grain yield can be estimated at earlier stages, such as stem elongation and booting stage (Marti et al., 2007; Kaur et al., 2015). The contrasted and variable climate could explain the inability to estimate yield before grain filling, as this period is critical for yield formation, as well as under most conditions 90–95% of the carbohydrate in grain is derived from carbon dioxide fixation after flowering stage (Gonzales-Dugo, 2015). With better growing conditions the grain-filling period extended and the amount of available nutrients increased, the grain achieves a higher yield. Although, the average temperatures during grain filling in early June was 22.6°C, frequently short periods (3–5 days) of hot and dry weather were reflected in NDVI, as well as in grain yield losses. In the stage of full maturity, significant correlation between both traits and NDVI was not observed since in this stage canopy dries out and NDVI drops to minimum.

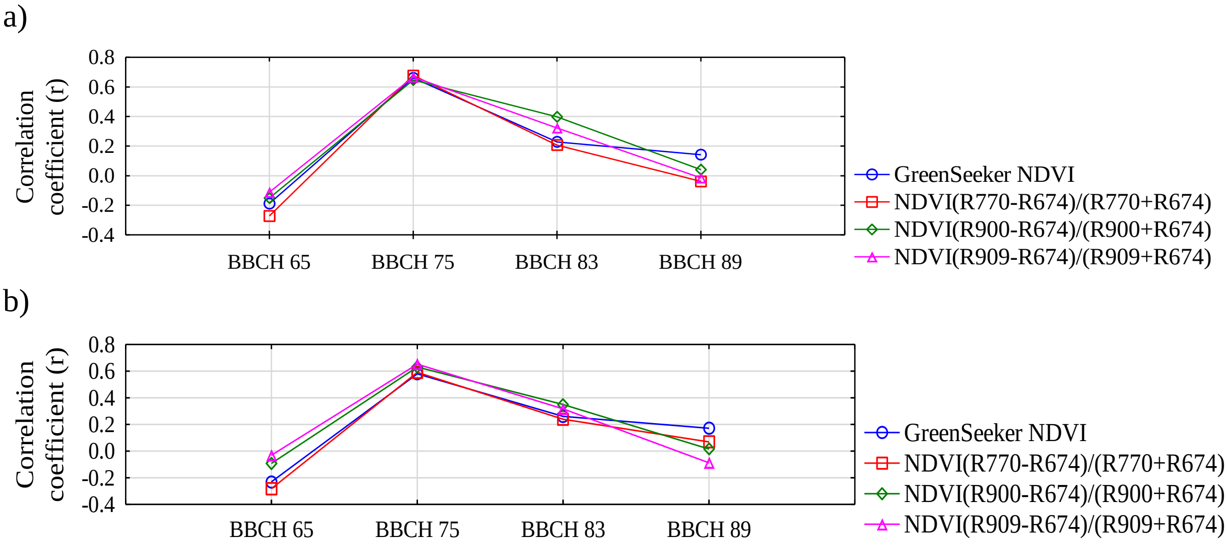

Figure 1. Pearson's correlations coefficients (r) obtained between the best selected NDVI and aboveground biomass (a) and grain yield (b) of wheat at 4 growth stages: BBCH 65, BBCH 75, BBCH 83 and BBCH 89

Besides the positive and significant correlation between the absolute NDVI and examined traits at BBCH 75, the significant negative correlation between reduction in NDVI from BBCH 65 to BBCH 75 and both traits was observed (Fig. 2). NDVI values acquired by both devices displayed similar tendency as they both showed the sharpest decline between BBCH 65 and BBCH 75 and expressed the greatest negative correlation with the examined traits. The relative decline displayed the largest, significant negative correlation with the trait aboveground biomass (*r* = -0.66**) for GreenSeeker based and hyperspectral NDVI (r = -0.71**). The largest significant negative correlation for GreenSeeker based (*r* = -0.60**) as for hyperspectral NDVI (*r* = -0.66**) with grain yield was also observed (Fig. 2). Considering this correlation, hyperspectral camera generally outperformed GreenSeeker sensor, by 5% in aboveground biomass prediction for wavelengths (674 nm – 770 nm) and by 7% in grain yield prediction, for wavelengths (674 nm – 909 nm). The magnitude of reduction in NDVI from BBCH 65 to BBCH 75 proved to be different for genotypes and showed a strong negative correlation with measured traits. Based on the magnitude of reduction in NDVI from BBCH 65 to BBCH 75, wheat genotypes G9, G6 and G10, which displayed the lowest reduction (10.8, 11.3 and 14.1 %), could be considered as genotypes with the highest potential for aboveground biomass and grain yield. Corresponding reduction from 44.4, 32.4 and 31.0 % indicated that wheat genotypes G8, G15 and G21 could be considered as genotypes with lower aboveground biomass and grain yield, as seen in Table 2. These results revealed that with progressing senescence, when the temperatures were higher, the quality of differentiating cultivars increased and with certain exceptions, high grain-yielding wheat cultivars maintained higher NDVI during the BBCH 75 than in other stages. A slow decline in NDVI during the BBCH 75 of certain genotypes as a consequence of delayed senescence increased the wheat grain yield.

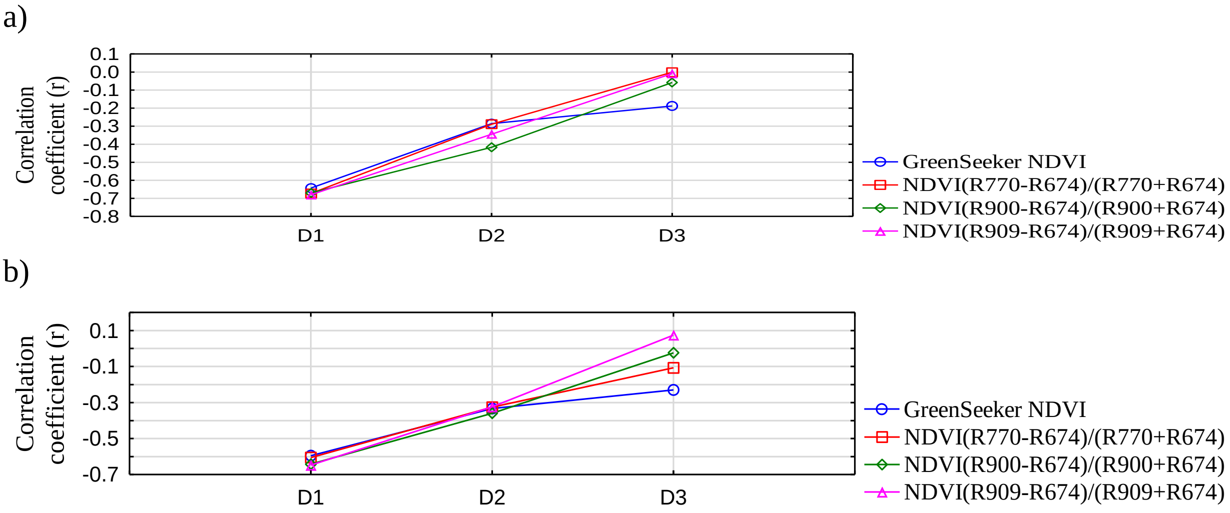

Figure 2. Pearson’s correlations coefficients between the values of relative decline of best selected NDVI and aboveground biomass (a) and grain yield (b), where D1 present relative decline in NDVI from BBCH 65 to BBCH 75, D2 relative decline in NDVI from BBCH 65 to BBCH 83, D3 relative decline in NDVI from BBCH 65 to BBCH 89

Conclusions

Reliable estimation of aboveground biomass and grain yield of winter wheat based on NDVI is attained measuring during the medium milk stage. Besides observing absolute values of NDVI in different growth stages, observing the change in NDVI throughout the stages may be very indicative. With certain exceptions, high yielding wheat cultivars maintained higher NDVI during the BBCH 75 than in other growth stages. Furthermore, NDVI acquired with hyperspectral camera was found to be more indicative than NDVI acquired with GreenSeeker sensor since it provides additional waveband combinations for NDVI more sensitive to examined traits. The findings of this study give promising results which can be used as a basis for development and improvement sensing devices with alternative spectral combinations which could be successfully used in assessing important traits of winter wheat.

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