RAPIDSCAN AND CROPCIRCLE RADIOMETERS: OPPORTUNITIES AND LIMITATION IN ASSESSING WHEAT BIOMASS AND NITROGEN

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ABSTRACT

Remote sensing is a promising technology that provides information about the crop's physiological and phenological status. This information is based on the spectral absorption and scattering features of the plants. Many different vegetation indices (VI) have been developed, and are in use to estimate quantitatively the relationship between multi and hyper-spectral reflectance and effective crop physiological parameters, i.e. nitrogen (N) content, biomass, leaf area index (LAI). The CropCircle and the RapidScan, the simple radiometers, offer an option retrieving red (R), red edge (RE) and near infrared (NIR) plant reflectance enabling calculate the VI such as NDVI, NDRE, and other based on the important RE region. The objectives of this study were: (i) to test relationships between wheat biophysical characteristics such as biomass and nitrogen and remote sensing data; (ii) to evaluate accuracy of remote sensing biomass and nitrogen estimation; (iii) to explore the potential and limitations of using active remote sensing techniques. The study was carried out during the growing seasons of 2012–2013 on 16 commercial spring wheat fields of kibbutz Saad and 8 experiment fields at the Gilat Research Center, located in the Northern Negev region of Israel. Data have been collected by CropCircle (mounted on a car) in both seasons by passing over fields, while RapidScan data have been collected by hand in 2013. The data set includes fields at different growth stages, from 3 leaves (Zadoks 13) till stem elongation (Zadoks 35), reflecting large differences in canopy height (10 through 50 cm) and vegetation cover. The variation in wheat samples represents biomass of 1 to 880 g m^{-2}, N concentration 9.7 to 54 g kg, and canopy N content 65 to 16500 mg N m^{-2}. High correlations have been found between the different VI, as they were calculated from the same 2 or 3 bands. Very close relationships have been found between many VI and wheat biomass. For CropCircle, indices have been calculated by the closest point and by an average of the area near the sampling point. Most VI had similar correlation with wheat parameters independent of the representing area. Canopy nitrogen concentration estimation was problematic and most indices exhibit very low correlation, the best VI was MSRre that reached r = 0.47 (mREP 0.57 for RapidScan). Despite that low correlation, for most indices the correlation with canopy nitrogen content reached higher or similar correlation as with biomass. The best VI were WDRVI, MSR and WICI2 (r = 0.90) while the correlation with biomass was a little bit lower (r = 0.88). The NDVI and NDRE had lower correlations, of 0.41, 0.40; 0.86, 0.87; 0.84, 0.85 for N concentration, canopy N content and biomass, respectively, with little NDRE advantage. The RE band data can improve correlation, when it is included in newer VI. However, correlation accuracy must be regarded with caution as there was low repeatability in different data bases. The difference between CropCircle and RapidScan relationships as well as variation between fields accounted for the correlation much more than the within field variation. The potential and limitations of using active remote sensing as a tool for growers and/or scientists are discussed.

Keywords: Crop monitoring, On-the-go, Wheat.

INTRODUCTION

Remote sensing is a promising technology that provides information about the crop's physiological and phenological status. Strategies to make use of plant sensors-based diagnostic information for nitrogen recommendations have been reviewed (Samborski et al., 2009). This information is based on the spectral absorption and scattering features of the plants. Many different vegetation indices (VI) have been developed, and are in use to estimate quantitatively the relationship between multi and hyper-spectral reflectance and effective crop physiological parameters, i.e. nitrogen (N) content, biomass, leaf area index (LAI) (Mulla, 2013).

At present, only little has been reported on using active canopy sensors to estimate crop N status. The CropCircle and the RapidScan are simple radiometers offering an option retrieving red (R), red edge (RE) and near infrared (NIR) plant reflectance enabling to calculate many VI such as NDVI, NDRE, and others based on the important RE region (Cao et al., 2013). The objectives of this study were: (i) to test relationships between wheat biophysical characteristics such as biomass and nitrogen and remote sensing data obtained active radiometers; (ii) to evaluate accuracy of active remote sensing of biomass and N estimation; (iii) to explore the potential and limitations of using active remote sensing.

MATERIALS AND METHODS

Wheat Samples

The study was carried out during the growing seasons of 2012–2013 on 16 commercial spring wheat fields of kibbutz Saad and 8 experiment fields at the Gilat Research Center, located in the Northern Negev region of Israel. Data have been collected by CropCircle (mounted on a car) during both seasons by passing over fields, while RapidScan data have been collected by hand in 2013. These samples covered the main development stages of active vegetative growth, spanning from 3 leaves (Zadoks 13) up to stem elongation (Zadoks 35), reflecting large differences in canopy height (10 through 50 cm) and vegetation cover. In the first year, 316 samples were randomly performed on these fields, 197 from Gilat, and 119 from Saad fields. The area surrounding of sampling points have been monitored by CropCircle continuously. Similarly, a total of 242 canopy samples were collected during the second year. In that season, RapidScan measurements included spectral reflectance and sampling of plants contained within the field of view of the RapidScan has been added to the CropCircle, for biomass and N analysis. Samples for the determination of biophysical variables (canopy biomass, and N total concentration based on dry weight) were collected within a 60×50 cm frame (0.3 m^2). The dry biomass was measured after drying for 48 h at 70°C. After drying the samples were weighted and the material from the whole plant was grinded and mixed. N concentration was obtained using NIRS (FOSS 6500) following the micro-Kjeldhal method (Bonfil et al., 2005). Thereafter, N content was calculated by multiplying the biomass by N concentration.

Data Analysis

Vegetation indices

Traditional vegetation indices were evaluated as a potential tool for monitoring the crop's nutritional contents by quantitatively retrieving the nutrient content in the crop. Additionally, based on the outcomes of the 3 specific spectral bands, newly proposed vegetation indices were also evaluated as follow:

Eq. 1: $\boldsymbol{mREP = 670 + 4 * \frac{\rho R + \rho RE + \rho NIR}{3}}$

Eq. 2: $\boldsymbol{\lambda re = 700 + 40 * \left(\frac{\rho R + \rho NIR}{2} - \rho R\right) / (\rho R + \rho RE)}$

Eq. 3: $\boldsymbol{Rre = (\rho R + \rho NIR)/2}$

Eq. 4: $\boldsymbol{NewVI = (\rho NIR - \rho R) * \rho NIR * \frac{\rho NIR - \rho RE}{\rho RE + \rho R}}$

The capability of these VIs to quantitatively retrieve the biomass and N content of the crop was calculated independently in each farm/year dataset, as well as in the combination of both. For each of these three scenarios, a calibration subset of 2/3 of the data was randomly selected for developing linear models that were later applied on the remainder 1/3 of the data (validation subset) predicting the considered biophysical variables. Additionally, the models developed from each dataset were validated on the other dataset. The statistics, correlation coefficient (R), standard error of prediction (SEP), and Root Mean Square Error (RMSE) were calculated to compare the accuracy obtained by each of the VIs.

RESULTS AND DISCUSSION

Biophysical variables

The measurements performed during this research included canopy reflectance and subsequent laboratory analysis of the collected samples (dry biomass and nutritional content of nitrogen). The purpose of collecting data from trial and commercial fields was to simultaneously characterize the real growing conditions in commercial operations and also to increase variability. The statistics of the measured biophysical variables for each dataset (based on laboratory analysis) are presented in Table 1. A total of 662 canopy samples were collected from these experiments, including samples from the very beginning of the season until heading time. The variation in wheat samples represents biomass of 1 to 880 g m^{-2}, N concentration 9.7 to 54 g kg, and canopy N content 65 to 16500 mg N m^{-2}. The data sets differ in their range cover, within GilatCC-2012 all samples did not represent mid-high biomass, and the Saad sets do not include high biomass samples either. Moreover, usually Saad samples represent high N concentration vs. Gilat samples. This is an outcome of the difference between the commercial and the experimental world, Saad and Gilat respectively. Nevertheless, Saad data set samples representing normal reduction in N concentration as biomass increase, while Gilat samples exhibit a chaotic distribution (Fig. 1).

Table 1. Wheat canopy biomass and nitrogen content in samples taken from fields monitored by CropCircle (CC) or RapidScan (RS).

	Data set	Year	n	Mean	Min	Max	SE	CV
DW	Gilat CC	2012	197	13.4	1.0	81.3	0.9	95.3
(g/m^2)	Gilat CC	2013	146	57.1	6.0	538.7	6.8	144.1
	Gilat RS	2013	104	255.0	6.3	876.7	17.8	71.0
	Saad CC	2012	119	75.7	2.7	221.0	5.4	77.5
	Saad CC	2013	96	102.9	2.7	251.3	7.3	69.3
N	Gilat CC	2012	197	38.7	14.2	48.0	0.4	15.2
(g/kg)	Gilat CC	2013	146	35.1	23.7	45.2	0.4	12.6
	Gilat RS	2013	104	20.8	9.7	46.2	0.8	39.1
	Saad CC	2012	119	45.7	30.9	54.1	0.3	7.4
	Saad CC	2013	96	46.4	28.7	54.1	0.5	10.8
N	Gilat CC	2012	197	522	65	3037	36	96.7
(mg/m^2)	Gilat CC	2013	146	1900	178	12772	198	125.7
	Gilat RS	2013	104	5560	215	16472	390	71.5
	Saad CC	2012	119	3368	120	8890	222	71.9
	Saad CC	2013	96	4547	127	11225	305	65.8

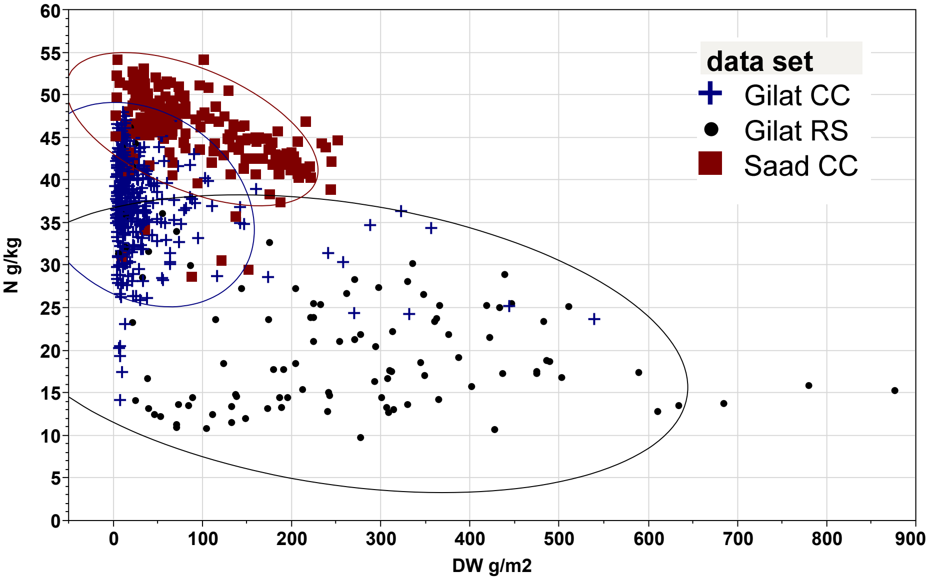

Figure 1. Distribution of wheat canopy biomass and nitrogen content in samples taken from fields monitored by CropCircle (CC) or RapidScan (RS); bivariate normal ellipse P=0.9.

On-The-Go Crop Mapping

The major advantage of active multispectral sensor is their ability to retrieve data on-the-go, under widely various radiation conditions. Both CropCircle and RapidScan systems have the same default, of calculating two VI, the NDVI and NDRE. Since NDVI is the common one, figures 2 and 3 show its value as being collected during passing fields in Gilat and Saad. In Gilat, NDVI values nicely exhibit the long term experiment treatments, and supplemental irrigation is the major factor varying between fields. Within each field nitrogen treatment, and especially N0 (vs. 50/100/150, 21 m each), in the north-south direction and phosphorus (P10 vs. P0) in the east-west direction have significant signature, that is seen nicely from space too (Fig. 2). In Saad data the main variation in NDVI value is related to the field itself as an outcome of variation in the emergence date (Fig. 3). Even within four fields that included a reference area, NDVI values and estimated N yield could not differentiate between areas that received lower or higher base N application (Fig. 4).

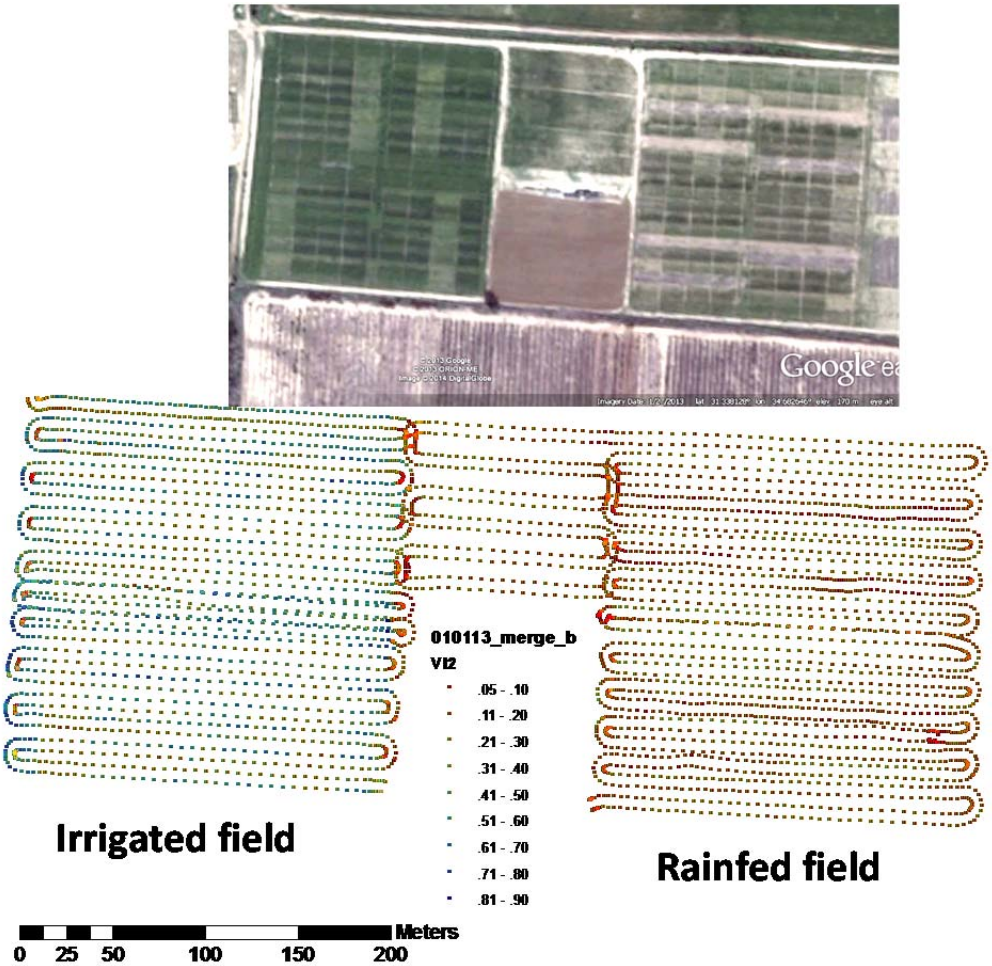

Figure 2. The Gilat long term fix experiment as shown in Google Earth (27/Jan/2013 image) and NDVI estimated by CropCircle (01/Jan/2013).

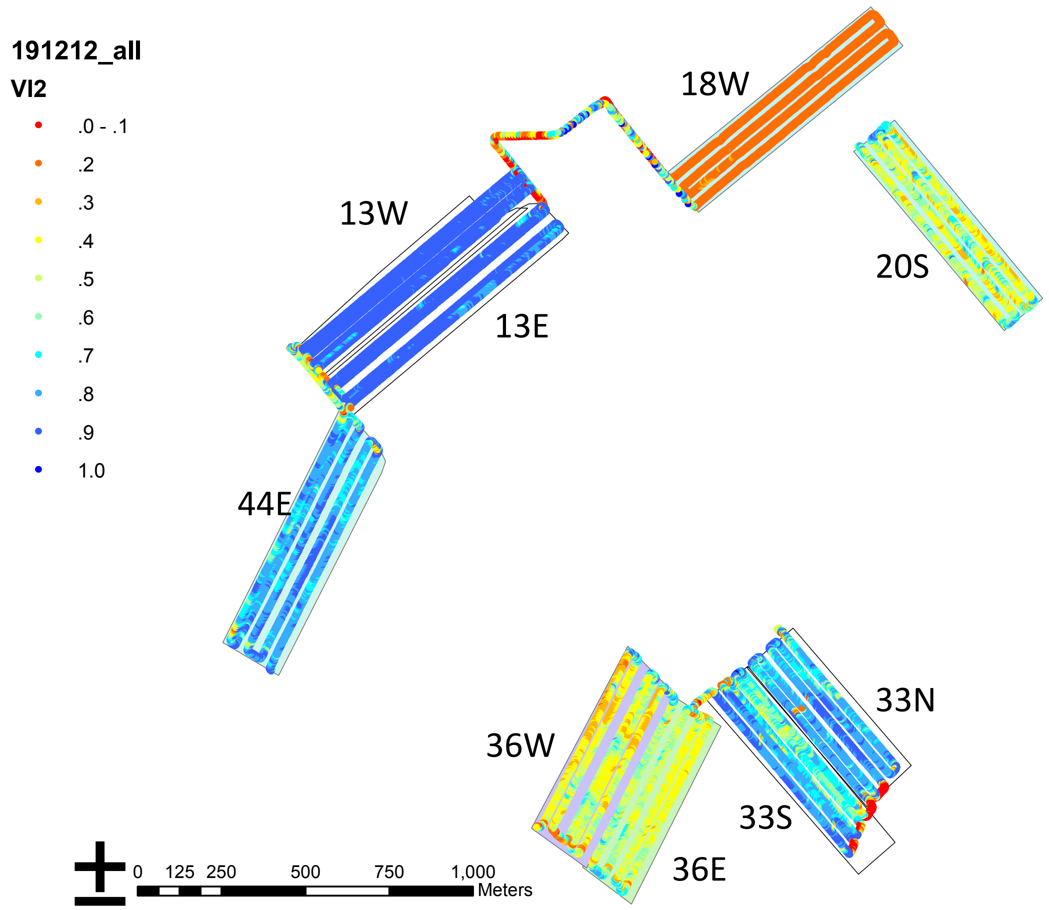

Figure 3. NDVI estimated by CropCircle commercial fields of kibbutz Saad (19/Dec/2012).

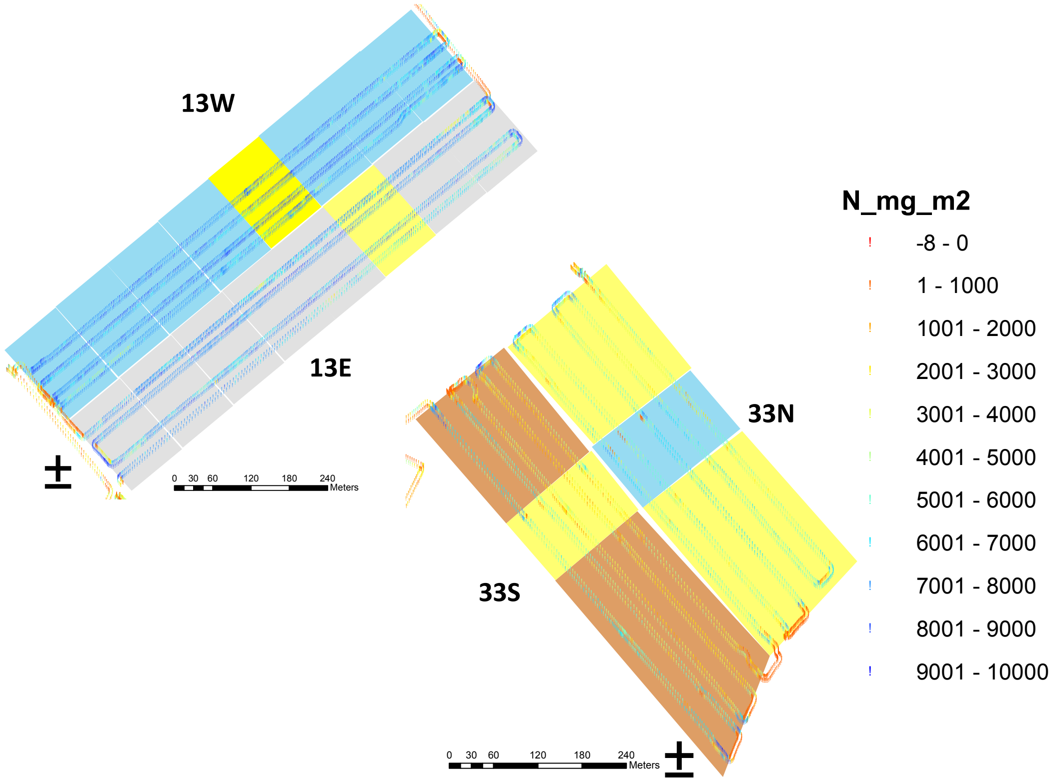

Figure 4. Nitrogen yield estimation by vegetation indices, calculated by CropCircle at 4 commercial fields of kibbutz Saad (19/Dec/2012). Background colors represent the base N application level.

Biophysical variables estimation

High correlations existed between the different VI, as they are calculated from the same 2 or 3 bands (data not shown). Very close relationships have been found between many VI and wheat biomass (Table 2). For CropCircle, VIs have been calculated by the closest point and by an average of the area near the sampling point. Most VIs had similar correlation with wheat parameters independent from the representing area, however it is clear that RapidScan and CropCircle data sets differ (Figure 5) as presented for the default VI's, NDVI and NDRE. Canopy N concentration estimation was problematic, the relation depended highly on the data set (Figure 5), and most indices exhibit very low correlation, the best VI was MSRre that reached r = 0.46, while for the RapisScan dataset mREP reach higher correlation of 0.57. However, for most indices the correlation with canopy N content was much higher or similar to the correlation coefficients as with biomass; it was in accordance with observations over rice (Cao et al., 2013). Moreover, the N content exhibit the lowest data set effect (Figure 5). The best VI were WDRVI, MSR and WICI2 (r = 0.90) while the correlation with biomass was little bit lower (r = 0.85). The NDVI and NDRE reached lower correlations, of 0.41, 0.40; 0.86, 0.87; 0.84, 0.85 for N concentration, canopy N content and biomass, respectively, with little NDRE advantage. The RE band data can improve correlation, when it is included in newer VI.

Table 2. Vegetation indices calculated from RapidScan (RS), CropCircle (CC) of the closet point, and average CropCircle (CC_avg) correlation with wheat biomass and nitrogen.

	DW g m^{-2}			**N g kg^{-1}**			**N mg m^{-2}**		
	RS	CC	CC_avg	RS	CC	CC_avg	RS	CC	CC_avg
NDRE	0.705	0.839	0.851	-0.293	0.382	0.398	0.823	0.857	0.868
NDVI	0.724	0.831	0.838	-0.399	0.388	0.408	0.803	0.851	0.858
RE	-0.706	-0.820	-0.830	0.305	-0.405	-0.415	-0.815	-0.840	-0.849
NIR	0.696	0.863	0.868	-0.269	0.338	0.361	0.827	0.877	0.882
R	-0.721	-0.816	-0.821	0.435	-0.399	-0.422	-0.787	-0.836	-0.841
SRI	0.647	0.887	0.866	-0.271	0.217	0.218	0.766	0.891	0.869
CIre	0.697	0.863	0.869	-0.270	0.338	0.356	0.828	0.877	0.883
WDRVI	0.701	0.887	0.882	-0.334	0.288	0.296	0.803	0.899	0.892
MTCI	0.476	0.698	0.744	0.101	0.347	0.363	0.662	0.713	0.758
EVI2	0.723	0.857	0.861	-0.382	0.357	0.375	0.810	0.874	0.878
SAVI	0.724	0.831	0.838	-0.400	0.388	0.410	0.803	0.851	0.857
NLI	0.706	0.772	0.776	-0.403	0.434	0.459	0.775	0.794	0.798
NDVI*SRI	0.675	0.889	0.880	-0.288	0.248	0.248	0.790	0.897	0.886
SAVI*SR	0.640	0.886	0.863	-0.263	0.210	0.210	0.760	0.889	0.865
RDVI	0.722	0.839	0.844	-0.380	0.382	0.404	0.811	0.858	0.862
MNLI	0.706	0.772	0.777	-0.402	0.434	0.459	0.776	0.795	0.799
MSR	0.693	0.891	0.880	-0.325	0.274	0.284	0.799	0.900	0.889
MSR*mREP	0.692	0.891	0.881	-0.323	0.274	0.283	0.799	0.901	0.889
MSR re	0.704	0.716	0.737	-0.372	0.451	0.474	0.790	0.740	0.761
WICI1	0.712	0.849	0.856	-0.316	0.371	0.389	0.822	0.866	0.873
WICI2	0.692	0.879	0.882	-0.273	0.303	0.317	0.822	0.890	0.893
mREP	-0.560	-0.625	-0.656	0.568	-0.441	-0.464	-0.503	-0.652	-0.682
Rre	-0.180	-0.332	-0.390	0.535	-0.379	-0.427	-0.005	-0.359	-0.417
ג_re	0.476	0.698	0.744	0.101	0.347	0.363	0.662	0.713	0.758
newVI	0.670	0.883	0.883	-0.252	0.253	0.263	0.807	0.891	0.890
TSAVI	0.680	0.891	0.877	-0.306	0.252	0.256	0.789	0.899	0.884
PVI	0.699	0.862	0.867	-0.278	0.343	0.365	0.827	0.876	0.881
WDVI	0.699	0.862	0.867	-0.278	0.343	0.365	0.827	0.876	0.881

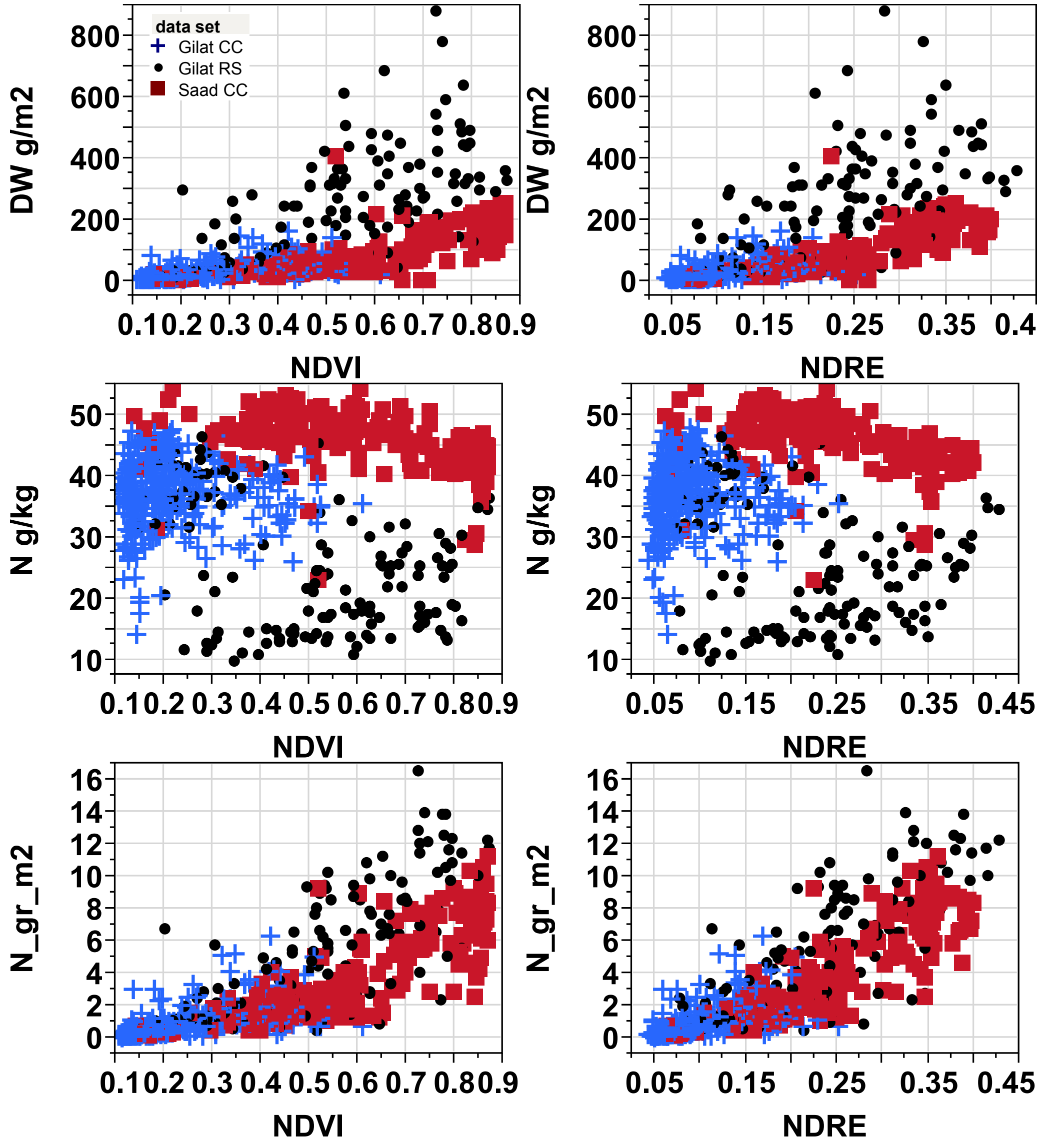

Figure 5. Wheat canopy biomass and nitrogen content in samples taken from fields monitored by CropCircle (CC) or RapidScan (RS) relation to NDVI and NDRE.

Since, N yield is the most important parameter and it exhibits the best uniform response to VI ignoring the data set, a multi regression analysis based on all available VI's have been applied trying improve N yield estimation. A model that combine the ChlI with EVI2 have been found as the best model and reach correlation of 0.843, RMSE=1.67 and SEP=1.4. However, a model that is based on the CropCircle data alone, picks up other indices and reaches higher accuracy. That model is based upon WDRVI and WICI2 with correlation of 0.888, RMSE=1.12 and SEP=1.0. Therefore, correlation accuracy must be taken with caution as there was low repeatability in different data bases, difference between CropCircle and RapidScan correlation, and finally as variation between fields account for the correlation much more than the within field variation. The difference between the data bases can be assign partly to the measurement procedure, as the CropCircle data represent an average of an area while the

RapidScan data represent only the sampling point. Therefore as variation within field increase, the disagreement between the procedures increase too, as shown for NDVI (Fig. 6).

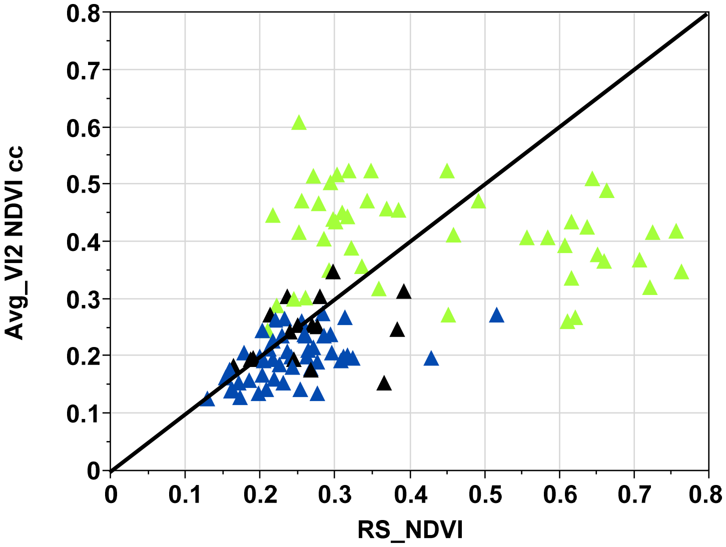

Figure 6. NDVI base on CropCircle (CC) vs. NDVI based on RapidScan (RS) in 3 fields.

Application

Data collected from 4 fields that included reference area (Fig. 4) show that during elongation the N uptake was 78-102% in the deficient reference versus the control, while the superfluous reference increase N uptake by 50% (Table 3). However, usually yield did not vary between the reference area and the whole field, and the largest difference of only 5% has been found as a result of the superfluous treatment. It was consistent with the low difference in the default VI's, NDVI & NDRE, that was restricted usually to below 10%. Hence, more research is required to identify the threshold to be used to make decisions about additional nitrogen application. Since, it seems that the common value of 5% is not the correct value to be used for Israeli wheat and perhaps even for other growing regions as well as for other crops.

Table 3. Correlation coefficient of the relationships between vegetation indices, calculated from RapidScan (RS), CropCircle (CC) of the closet point, and average CropCircle (CC_avg) and wheat biomass and nitrogen.

Field & Cultivar	13E - Ruta		13W - Ruta		33S - Amit		33N - Amit	
Treatment	Control	Reference	Control	Reference	Control	Reference	Control	Reference
Base-N kg/ha	50	10	130	80	50	10	90	130
DM g/m^2	165.7	126.1	190.8	185.1	105.0	89.4	71.1	107.8
N g/kg	43.8	44.1	41.5	43.9	48.1	48.0	37.0	48.3
N uptake g/m^2	7.21	5.60	7.99	8.14	5.03	4.22	3.39	5.20
RS NDRE	0.326	0.331	0.345	0.360	0.270	0.269	0.270	0.285
RS NDVI	0.831	0.838	0.851	0.873	0.745	0.723	0.715	0.728
CC NDRE	0.335	0.336	0.337	0.358	0.220	0.245	0.255	0.277
CC NDVI	0.825	0.839	0.817	0.865	0.587	0.663	0.676	0.722
Yield t/ha	5.77	5.71	6.22	6.24	5.63	5.68	4.78	5.01

DISCUSSION AND CONCLUSIONS

Active multispectral crop canopy sensors are more suitable for practical in-season site-specific N management applications due to their features of weather-independence and relatively low costs compared with passive sensors or hyperspectral sensors (Shaver et al., 2011). Using an active canopy sensor to estimate crop N status has a huge advantage as its enables sensing the crop every day, 24 hour a day, ignoring radiation condition. GreenSeeker sensor exhibits high ability to estimate spring wheat N concentration in addition to biomass and plant N uptake (Osborne, 2007). However it seems that correlation were specific to cultivar X growth stage X N treatment triple interaction. Whereas in reality, within a commercial field (as in our study and especially in Saad fields) absence of N treatments and/or several growth stages should reduce correlations. Moreover, NDVI is exponentially related to winter wheat plant N uptake (Cao et al., 2012), therefore other vegetation indices are preferred. As the new available systems retrieving data from the RE region too, indices based on the RE are added (Li et al., 2014). By four RE based vegetation indices the CropCircle ACS 470 sensor could explain 76% of rice N nutrition index variability across growth stages and site-years (Cao et al., 2013).

Hence, the potential of using active multispectral sensors as a tool for growers and/or scientists is clear. However, these sensors have some limitations. The distance between sensor and target surface is the major factor to be considered (Kipp et al., 2014). During scanning fields, it is too complicated to keep a constant distance between canopy and sensor, and it might affect the results; in our work the CropCircle was mounted at a fix distance from ground and not from canopy. Another question is: what does the sensor sense? Using active crop sensor in sugarcane showed a high correlation between values of biomass and nitrogen uptake (Portz et al., 2012). Our results also showed that the sensor sense mainly biomass, and although sensing N concentration is problematic, sensing N uptake is more accurate than biomass itself. This is very important as N uptake is the parameter of interest. Nevertheless, accurate interpretation of sensor data can be improved by a reference area for nitrogen recommendations (Samborski et al., 2009), but our study emphasized that fine tuning should be done before nitrogen recommendations are taken. Further evaluation of active multispectral crop canopy sensors is needed to fully establish performance of the method in different crops and growth conditions.

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