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ORIGINAL PAPER

A non-destructive approach for assessment of nitrogen status of wheat crop using unmanned aerial vehicle equipped with RGB camera

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Abstract
Unmanned aerial vehicle (UAV) equipped with RGB (colored image), multispectral and thermal camera, has excellent potential for making a revolution in the field of agriculture for determining water stress, nitrogen status, and fertilizer application for different crops in different climatic conditions. The main objective of this study is to develop relationships between vegetation indices obtained from RGB camera mounted on drone and ground truth data for assessment of nitrogen status in wheat crop. For this purpose, field experiments for wheat crop are conducted at Agricultural Research Farm, IIT Kharagpur, West Bengal, India. Two cultivars of wheat crop, namely Sonalika and PBWB-343, are used for the experiment. To determine the ground truth data, soil plant analysis development (SPAD) meter and Greenseeker are used to measure chlorophyll content and normalized difference vegetation index (NDVI), respectively. An RGB (red, green, blue) camera mounted on an UAV is flown over the Agricultural Research Farm at 20-m altitude to capture images of wheat field in Rabi season. The fuzzy c mean clustering method of image analysis is employed to determine 13 spectral indices (R, G, B, R/(R+G+B) (normalized R), G/(R+G+B) (normalized G), B/(R+G+B) (normalized B), normalized green-red difference index (NGRDI), ExG, ExR, ExGR,) from RGB image of wheat crop. This method consists of segmentation and successive analysis of the foreground color, i.e., only green plant parts. Relationships are developed using linear regression method between SPAD and NDVI, spectral indices and SPAD, and spectral indices and NDVI for wheat crop. Results show that NGRDI is highly correlated with NDVI and SPAD values. Coefficients of determination (R^2) for NDVI and SPAD value, NGRDI and NDVI, and NGRDI and SPAD value are estimated as 0.55, 0.68, and 0.31 for PBWB-343 variety and 0.51, 0.49, and 0.43 for Sonalika variety of wheat.

Keywords Digital image analysis · UAV · SPAD · NDVI · Spectral indices

Introduction

Agriculture is a key activity of human being since it provides basic needs such as food, clothing, and shelter. It has been demonstrated that every 1% increase in agricultural yield translates into a 0.6–1.2% decrease in the numbers of absolute poor households in the world (Ngoune Tandzi and Mutengwa 2020). Meanwhile, population growth was predicted to be 9.7 billion by 2050, and this will require an increase of about 70% in food production to meet the demand (Ngoune Tandzi and Mutengwa 2020). Rainfed agriculture is projected to produce one-third or more of the food increase in global food output for the coming decades. Unfortunately, agricultural productivity depends on various factors such as climate, water, nutrition, and soil conditions. Plant nutrition refers to a plant's need and use of basic chemical elements. Plants need 17 elements for normal growth. Three of them—carbon, hydrogen, and oxygen—are found in air and water. The rest are found in the soil. Six soil elements are called macronutrients because they are used in relatively large amounts by plants. They are nitrogen, potassium, magnesium, calcium, phosphorus, and sulfur. Nitrogen is one of the important major plant nutrient. Nitrogen is the most important and essential element for crop

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growth and development, and its accurate assessment in plants is a key to nutrient management. Plants normally contain between 1 and 5% nitrogen by weight (Arregui and Quemada 2006). Nitrogen is a major component of the chlorophyll molecule that enhances photosynthesis (Tumbo et al. 2002).

Application of optimum amount of nitrogen at right time has substantial importance in the crop life for maintaining its condition in every stage (Novoa and Loomis 1981). The crop/plant consumes nutrients up to a certain limit; consequently over or under application of nitrogen (N) is worthless, reckless, and unfavorable for environmental, ecological balance, and human health (Ju et al. 2009; Tremblay et al. 2011; Parks et al. 2012). Therefore, optimum application of nitrogen for different crops and real-time assessment of crop N status in the field are an effective way to enhance the quality and quantity of crop yield (Raun et al. 2002).

There have been several commonly used methods for estimating the nitrogen contents such as the traditional destructive sampling method (DS), simulation models (SM), and remotely sensed vegetation index (VI) (Guo et al. 2020). Destructive methods for estimating leaf nitrogen content like Kjeldahl digestion and Dumas combustion are required at regular time interval to inspect the plant health condition in the field that is time-consuming (Muñoz-Huerta et al. 2013). In this method, it is required to collect the leaf samples from multiple plots which are challenging. Optical properties such as canopy reflectance and leaf transmittance (Hansen and Schjoerring 2003; Zhu et al. 2007; Yao et al. 2009) are highly correlated with N content of the plant and used as one of the N indicators. However, instruments, which are used to measure the abovementioned optical properties, have some limiting factors such as calibration, maintenance, and cost (Yoder and Pettigrew 1995; Kokaly 2001).

It is also becoming a challenging task to quantify the N status accurately and quickly at different growth conditions of different crops in different soil and climate conditions. So, more applications of remote sensing were explored and used for determining the N status and are found to be an alternative to non-destructive method and behave better for real-time monitoring of crop N status (Zhu et al. 2008). Indirect sensing of the plant reflectance can be classified as the ground-based remote sensing, airborne remote sensing, and satellite-based remote sensing techniques (Gitelson et al. 1997; El-Shikha et al. 2007). Borhan et al. (2004) developed

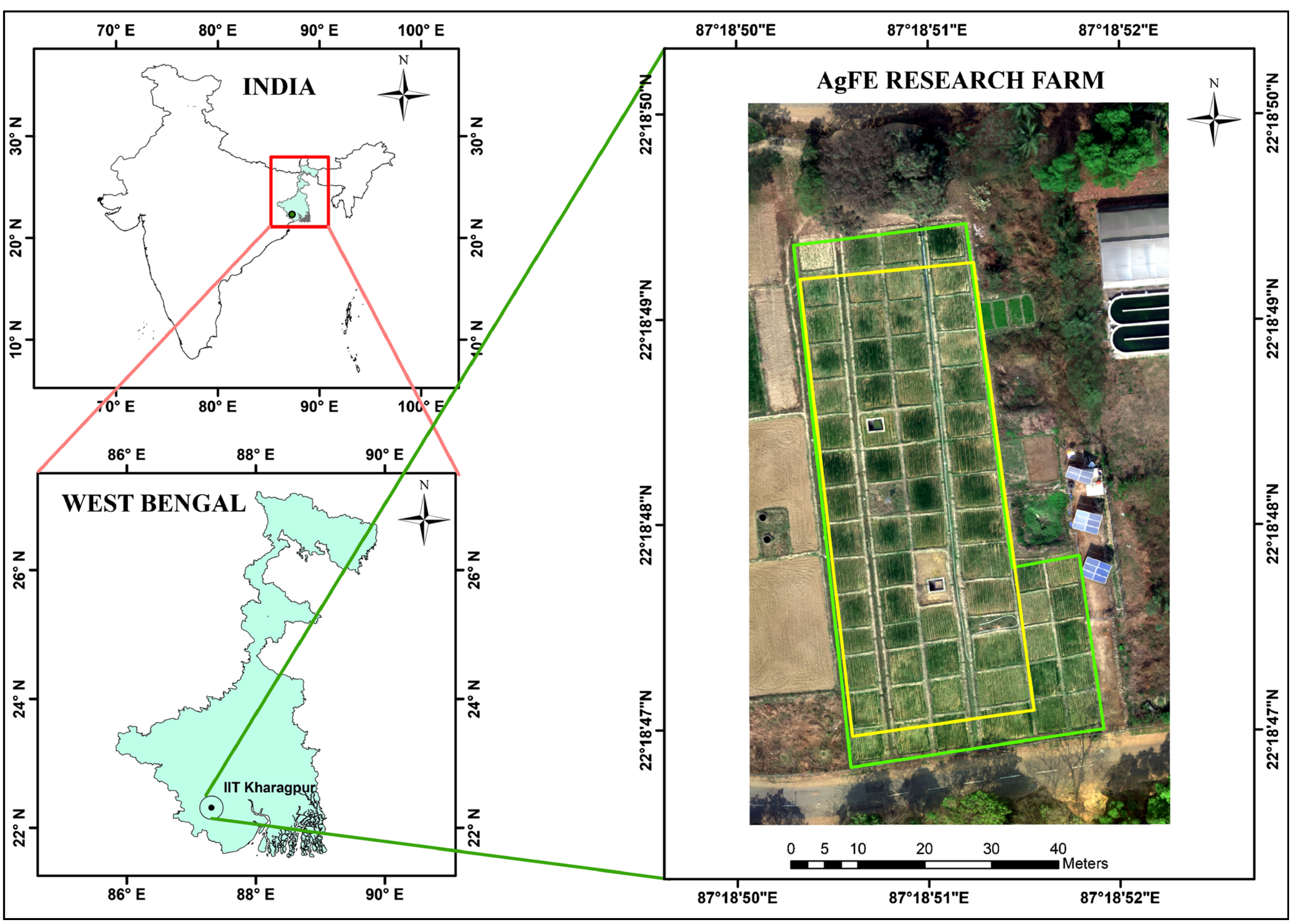


Fig. 1. Agricultural Research Farm at Indian Institute of Technology Kharagpur, West Bengal, India. Here green boundary shows the actual field area, and yellow boundary shows the area which use for image accusation.

two laboratory-based multispectral imaging systems; the image features from color (red, green, and blue) and multispectral bands (550, 710, and 810 nm) were evaluated in predicting chlorophyll and nitrate contents of potato leaves grown in the greenhouse. An exponential gap fraction model and an ellipsoidal leaf angle distribution are used to determine leaf area index (LAI) from red-green-blue (RGB) images of the canopy for analyzing plant density and growth conditions (Kirk et al. 2009). Unmanned aerial vehicle (UAV) mounted with RGB camera is used to acquire the images, and different spectral indices like red (R), green (G), blue (B), (R-G)/(R+G), and green channel minus red channel (GMR) are derived from these images. Then these indices are compared with chlorophyll content measured by soil plant analysis development (SPAD) meter and chemical analysis of plant leaves, and regression models are developed between spectral indices and plant nitrogen status which show that RGB-based spectral indices have the potential to assess the plant N status (Wang et al. 2013; Tewari et al. 2013; Wang et al. 2014). The use of drones for crop condition monitoring in India is still in a nascent stage. This is primarily because very few studies have been conducted to develop image-based analytics for different crop conditions for different Indian crops and their varieties.

The main objective of this study is to develop relationships between remotely sensed vegetation indices obtained from RGB camera mounted on a drone and ground truth data normalized difference vegetation indices (NDVI) and SPAD value taken by Greenseeker and SPAD-502 meter, respectively, for the assessment of nitrogen status at different growth stages of wheat crop. In this, we use fuzzy c means clustering approach for analyzing the image. The main benefit of this is we can use RGB camera instead of destructive method which required more time and multispectral camera which have high cost for nitrogen management of crop.

Materials and methods

Study area

Experiments are conducted in the Rabi season (2017–2018) at the Research Farm of Agricultural and Food Engineering Department, which is situated at the Indian Institute of Technology Kharagpur, West Bengal, India (22° 31′ N, 87° 31′ E) at an altitude of 48 m above mean sea level (Fig. 1). The climate of site is subhumid and subtropical, and it receives mean annual rainfall of about 1600 mm with occurrence of 70–75% of total rainfall in Kharif season (June–November). The daily average minimum and maximum temperatures range between 13.3 to 25.9°C and 25.8 to 45°C, respectively. The soil of the study area is sandy loam texture with low organic content, having high infiltration rate with low water holding capacity.

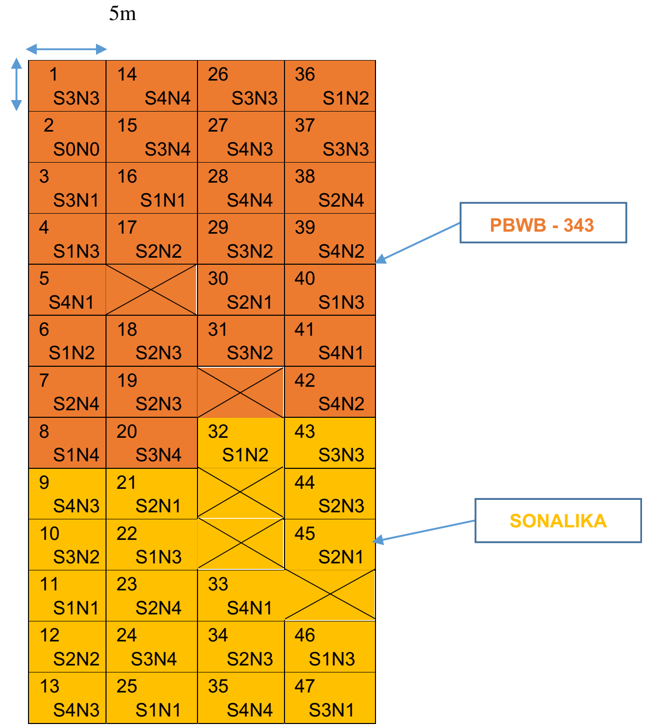


Fig. 2. Experimental field layout with application treatment for wheat crop. Note: X shows that these plots are not considered in image analysis part

Table 1 Nitrogen treatment according to growth stage of wheat crop

Treatments	N application (kg/ha)	N application at different crop growth stages (kg/ha)			
		Sowing	CRI	Booting	Flowering
S1N1	80	40.0	40.0	0	0
S1N2	100	50.0	50.0	0	0
S1N3	120	60.0	60.0	0	0
S1N4	150	75.0	75.0	0	0
S2N1	80	26.6	26.6	26.6	0
S2N2	100	33.3	33.3	33.3	0
S2N3	120	40.0	40.0	40.0	0
S2N4	150	50.0	50.0	50.0	0
S3N1	80	26.6	26.6	0	26.6
S3N2	100	33.3	33.3	0	33.3
S3N3	120	40.0	40.0	0	40.0
S3N4	150	50.0	50.0	0	50.0
S4N1	80	20.0	20.0	20.0	20.0
S4N2	100	25.0	25.0	25.0	25.0
S4N3	120	30.0	30.0	30.0	30.0
S4N4	150	37.5	37.5	37.5	37.5

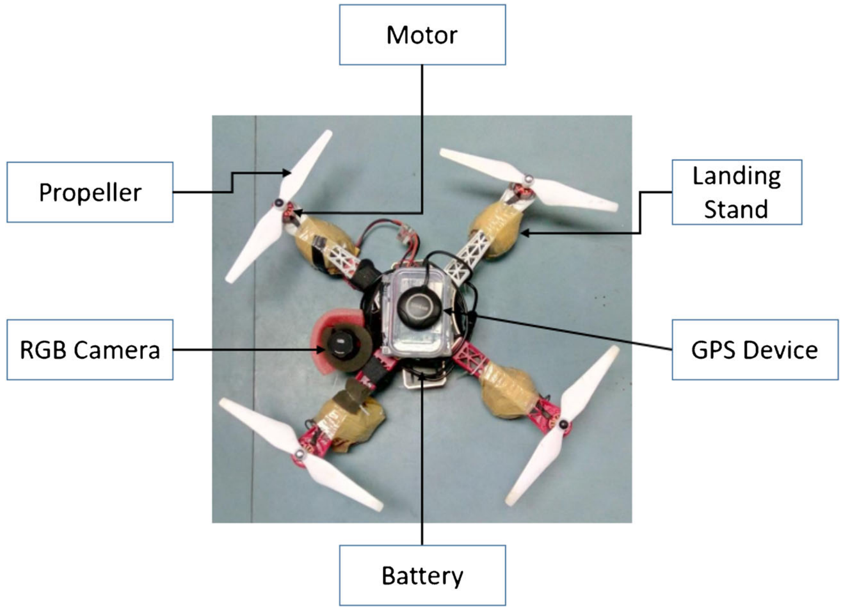


Fig. 3. Quadcopter UAV

Experimental layout

Field plot experiments are conducted for determination of nitrogen status of wheat crop (Sonalika and PBWB-343 varieties normally grown in this region) grown in Rabi season of 2017–2018 (Fig 2). The sowing of wheat crop is done on 8 Dec. 2017, and it is harvested on 28 March 2018. Row-to-row spacing is 20cm. The sowing of wheat is done by simple raking method. The field experimental area consists of 68 plots (Fig. 1, green boundary) of 5m × 5m size. The randomized block design is used to design the experimental layout. Different nitrogen doses such as N1-80 kg/ha, N2-100 kg/ha, N3-120 kg/ha, and N4-150 kg/ha are applied at different growth stages of the crop as shown in Table 1. S1, S2, S3, and S4 refer to how the N doses are equally split for the different growth stages of the crop. Here, S1N1, S2N1, S3N1, and S4N1 represent that 80 kg/ha (N1) is applied at sowing and crown toot initiation (CRI) stage (41 days after sowing (DAS)) (S1); sowing, CRI, and booting stage (56 DAS) (S2); sowing, CRI, and flowering stage (76 DAS) (S3); and sowing, CRI, booting, and flowering stage (S4), respectively. Similar pattern of nitrogen application is followed for other nitrogen doses, i.e., 100 kg/ha (N2), 120 kg/ha (N3), and 150 kg/ha (N4). However, due to waypoint constraint, drone could not cover the entire field; therefore only 47 plots (Fig. 1, yellow boundary) are used for this study. Out of 47 plots, 28 and 19 plots were used for PBWB-343 and Sonalika varieties, respectively. Consequently two treatments such as S1N4 and S3N3 of Sonalika variety could not be covered by drone. In this study, the CRI stage comes after 41 DAS because of poor germination of seed and climatic condition of Kharagpur region. Irrigation is applied when the maximum allowable deficit (MAD) of soil reaches 40%.

Table 2 UAV specifications

UAV specification	Performance
Wingspan	9 inches
Nominal air speed	5–10 m/s
Max flight duration	10–12 min
Max battery capacity	8000mAh or 14.8v
Payload capacity	Up to 1 kg

Field data collection

Ground truth data collection

SPAD meter (SPAD-502, Minolta Camera Co., Osaka, Japan) and Greenseeker are used for measuring chlorophyll content and NDVI, respectively. SPAD value and NDVI are measured for wheat crop on 29, 36, 43, 54, 61, 68, 75, 83, and 90 DAS. SPAD values (chlorophyll content of leaf) of fifteen leaves per plot (3 at each corner at 3 at center) were measured randomly exempt the 2 rows from boundary to make it free from boundary effect. Third and fourth fully expanded leaves from the top of the plant were taken for measuring the SPAD value (Yuan et al. 2016). The Greenseeker handheld crop sensor is an active light source optical sensor that is used to measure plant biomass and display as NDVI (normalized difference vegetation index). When the Greenseeker held at 20–30 cm above the crop surface, the trigger is press, and the measured NDVI reading appears on the LCD display immediately (Păcurar et al. 2019).

Table 3 List of different color indices used in this study

Color space	Color indices	Formula	References
	R	Mean of R channel	Wang et al. (2014)
	G	Mean of G channel	Wang et al. (2014)
	B	Mean of B channel	Wang et al. (2014)
	R/(R+G+B)	-----	Wang et al. (2014)
RGB	G/(R+G+B)	-----	Wang et al. (2014)
	B/(R+G+B)	-----	Wang et al. (2014)
	NGRDI	(G-R)/(G+R)	Wang et al. (2014)
	ExG	2*G-R-B	Woebbecke et al. (1995)
	ExR	1.4*R-G	Meyer and Neto (2008)
	ExGR	3*G-2.4R-B	Meyer and Neto (2008)
	MRBVI	$(R^2 - B^2) / (R^2 + B^2)$	Guo et al. (2020)
	Normalized R	[(R/3)/I]*255	Tewari et al. (2013)
RGB & HIS	Normalized G	[(G/3)/I]*255	Tewari et al. (2013)
	Normalized B	[(B/3)/I]*255	Tewari et al. (2013)

The data collected from SPAD meter and Greenseeker are used as ground truth data for this study. An average value of 15 and 5 readings per plot is considered measured SPAD value and NDVI value, respectively.

Aerial data collection

The quadcopter UAV (Fig. 3), developed by SWAN (Smart Wireless Application & Networking) lab, CSE Department, Indian Institute of Technology, Kharagpur (details of UAV are shown in Table 2), is used to collect the aerial data. It has a maximum payload capacity of 2 kg and maximum flight range of 100 m along with flying potential up to 8 to 25 min duration depending on battery charge and payload. Quadcopter UAV also has the features of GPS-based geo-fencing which ensure avoidance of potential security risks in no-fly zones. A high-resolution RGB camera (SOOCOO S20WS RGB camera with 170-degree FOV, 12 Mega Pixel resolution) mounted on quadcopter UAV is used to capture the images. The UAV flight operation is performed at 20-m altitude under clear sky between 11:00 and 14:00 local time on the same day when ground truth data are collected. Mission Planner, an open source software, is used to configure, control, and calibrate the quadcopter system.

Image processing

The raw images acquired by RGB camera are first undistorted by removing the fish eye distortion property. The lens distortion correction is performed by GML (Graphics and Media Lab) Undistorter software by setting the focal length at 1.5 mm. The image pixels are segmented as vegetation and non-vegetation pixels using fuzzy c means clustering approach (Choy et al. 2017). Pixels are clustered based on pixel values or intensity. This clustering process is performed by developing a program in MATLAB2017a. The result of the

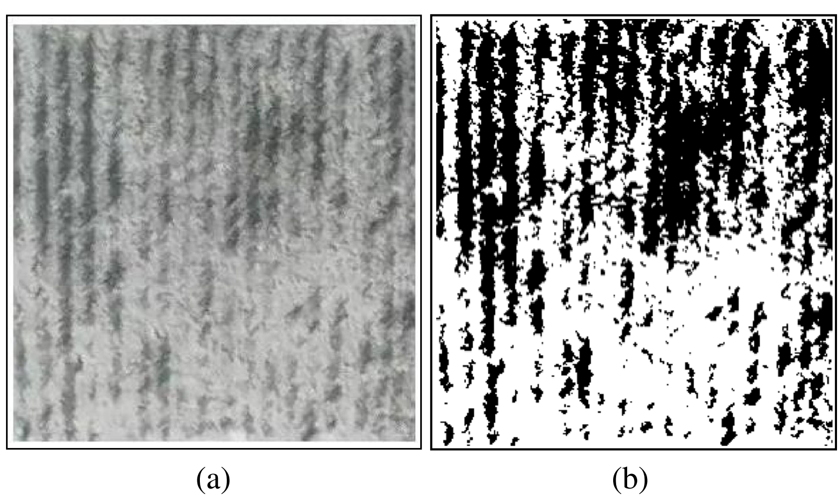
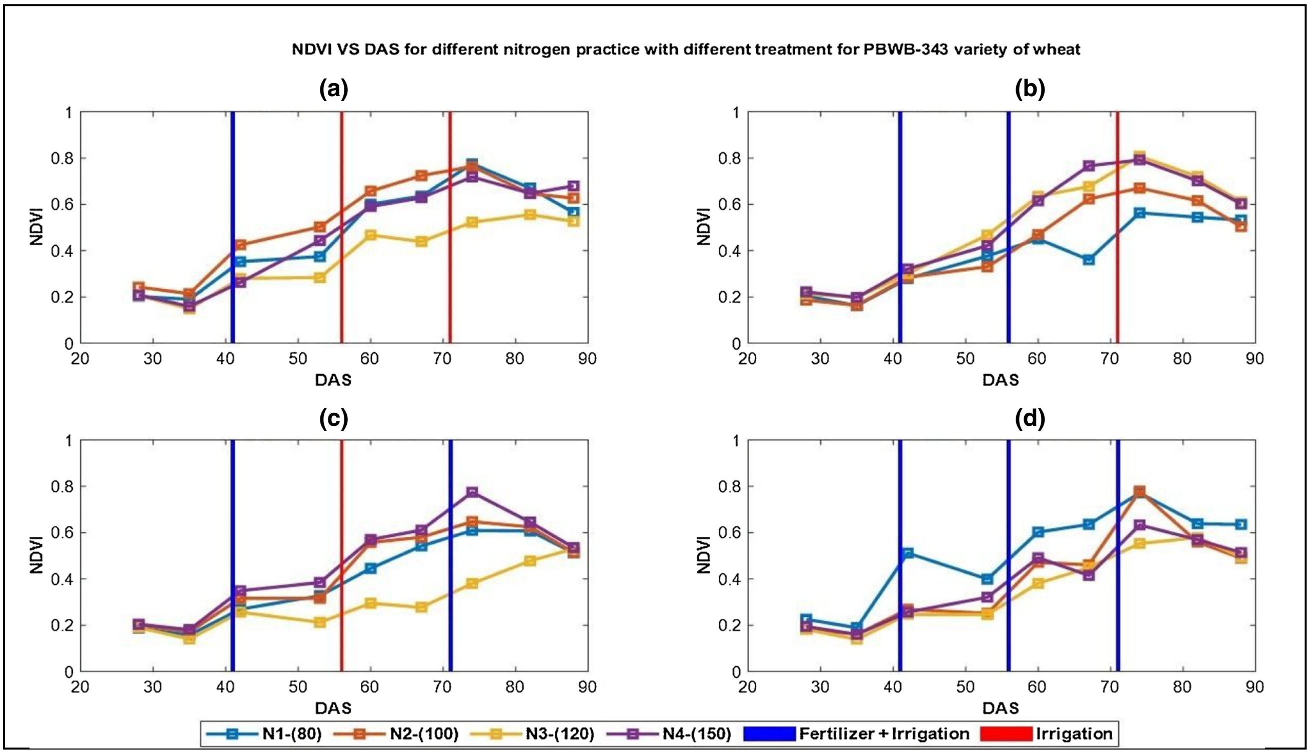
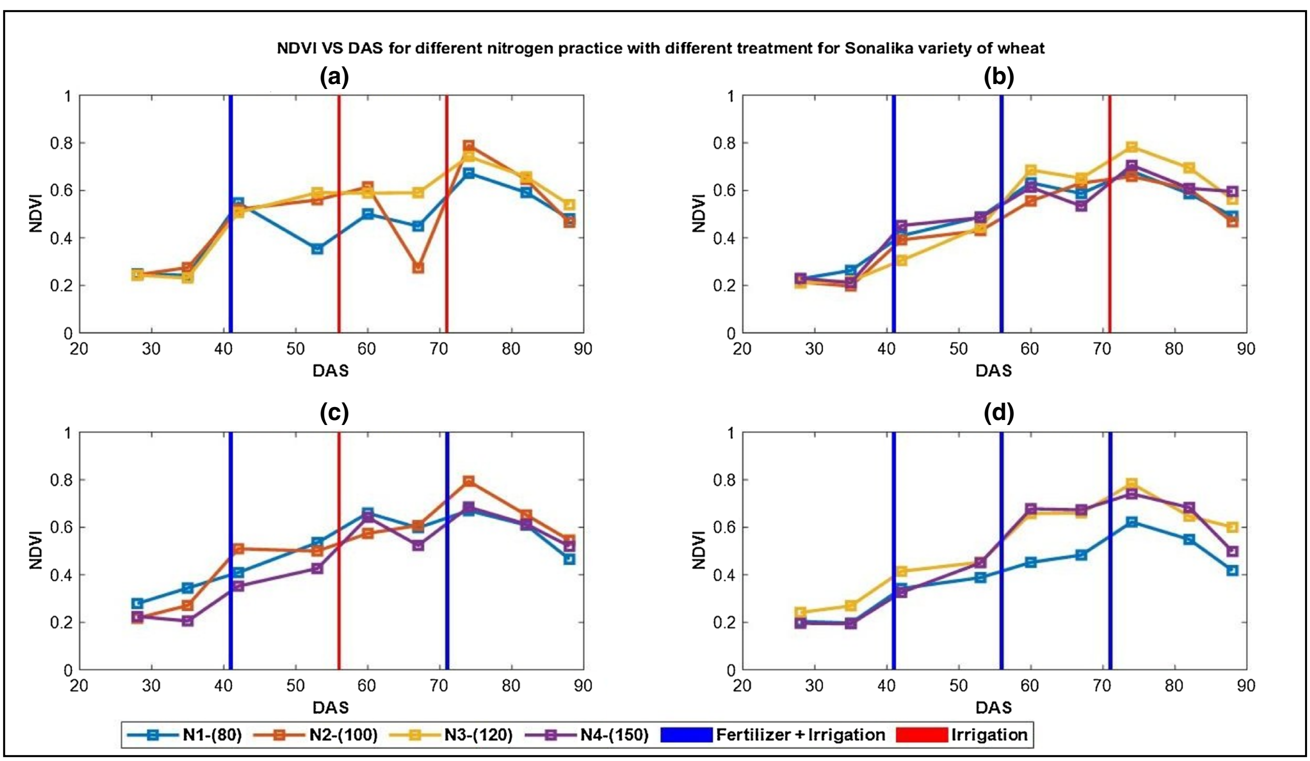


Fig. 4. **a** RGB image of wheat plot. **b** Segmented binary image of wheat plot after 36 DAS

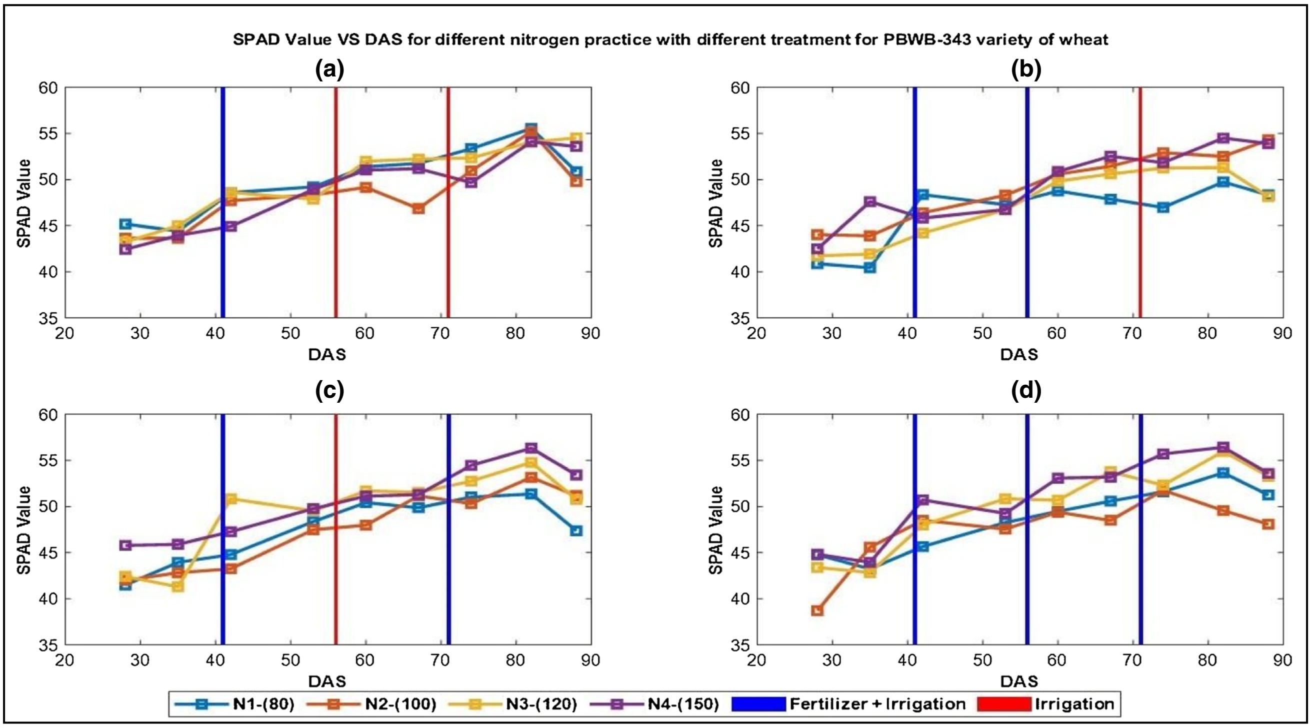


(A)

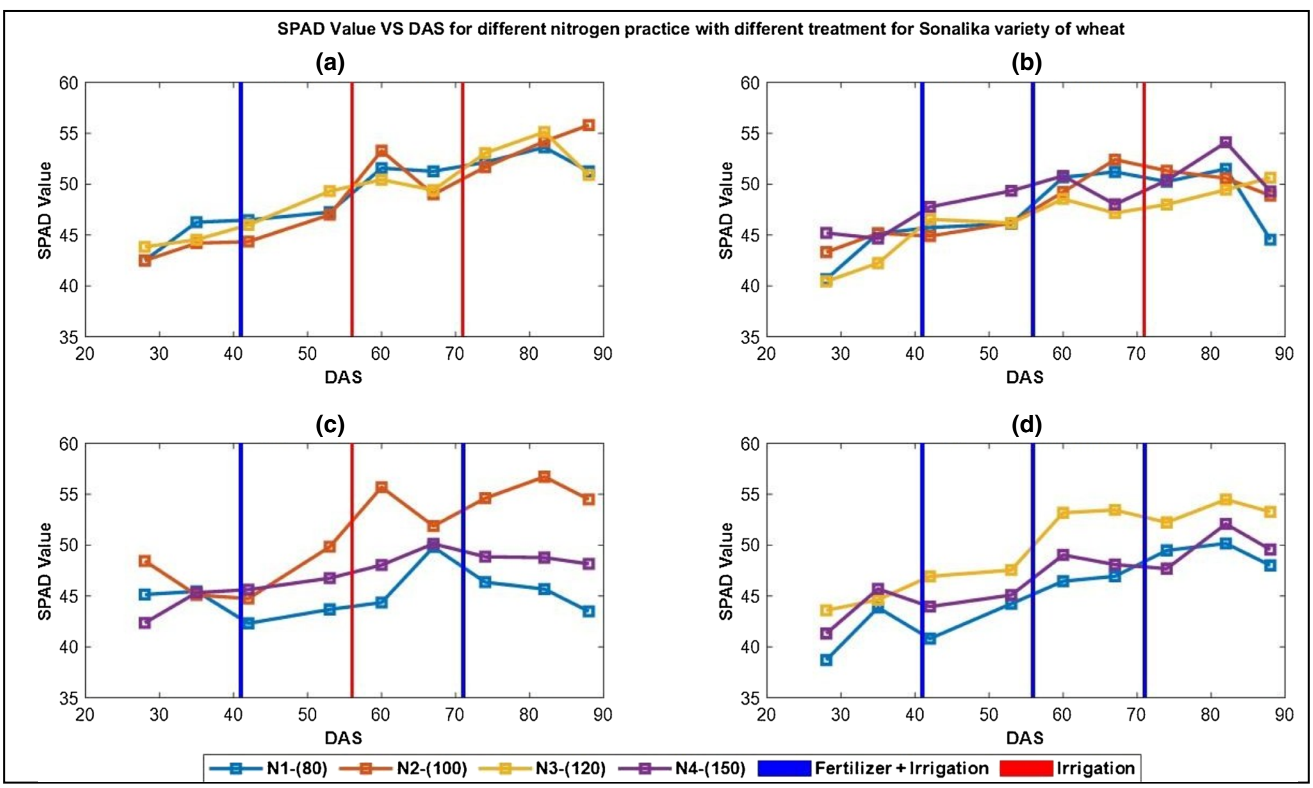


(B)

Fig. 6. Variation of NDVI for different nitrogen fertilizer applications with DAS for **A** PBWB-343 and **B** Sonalika varieties of wheat with (a) S1 treatment, (b) S2 treatment, (c) S3 treatment, and (d) S4 treatment



(A)



(B)

Fig. 5. Variation of SPAD values for different nitrogen fertilizer applications with DAS for **A** PBWB-343 and **B** Sonalika varieties of wheat with (a) S1 treatment, (b) S2 treatment, (c) S3 treatment, and (d) S4 treatment

segmentation is shown in Fig. 4. Subsequently, the segmented images are used to calculate 13 different types of color indices (R, G, B, R/(R+G+B), G/(R+G+B), B/(R+G+B), normalized green-red difference index (NGRDI), ExG, ExR, ExGR, normalized R, normalized G, and normalized B) (Table 3) based on RGB color space for each plot.

Results and discussion

Relationship between NDVI and SPAD value

Seasonal variation of SPAD values with DAS for PBWB-343 and Sonalika varieties for different stage treatments (S1, S2, S3, and S4) is shown in Fig. 5 A and B. Results show that there is an increase in SPAD value with increase in DAS up to 75 DAS and subsequently it decreases. This reduction in SPAD value after 75 DAS is due to the ripening stage of the crop. At this stage, plant leaves are subjected to a stress condition which results in photosynthetically active radiation (PAR) reduction. The SPAD values of N3 (120 kg/ha) and N4 (150 kg/ha) application are higher compared to N1 (80 kg/ha) and N2 (100 kg/ha) because of higher dose of N fertilizer, wherein plant uptakes more N and it increases the ability of absorption of radiation in the red region. Variation in NDVI with respect to DAS is given in Fig. 6 A and B for both the varieties for different stage treatments. It also shows an increase in NDVI with increase in DAS up to 75 DAS and

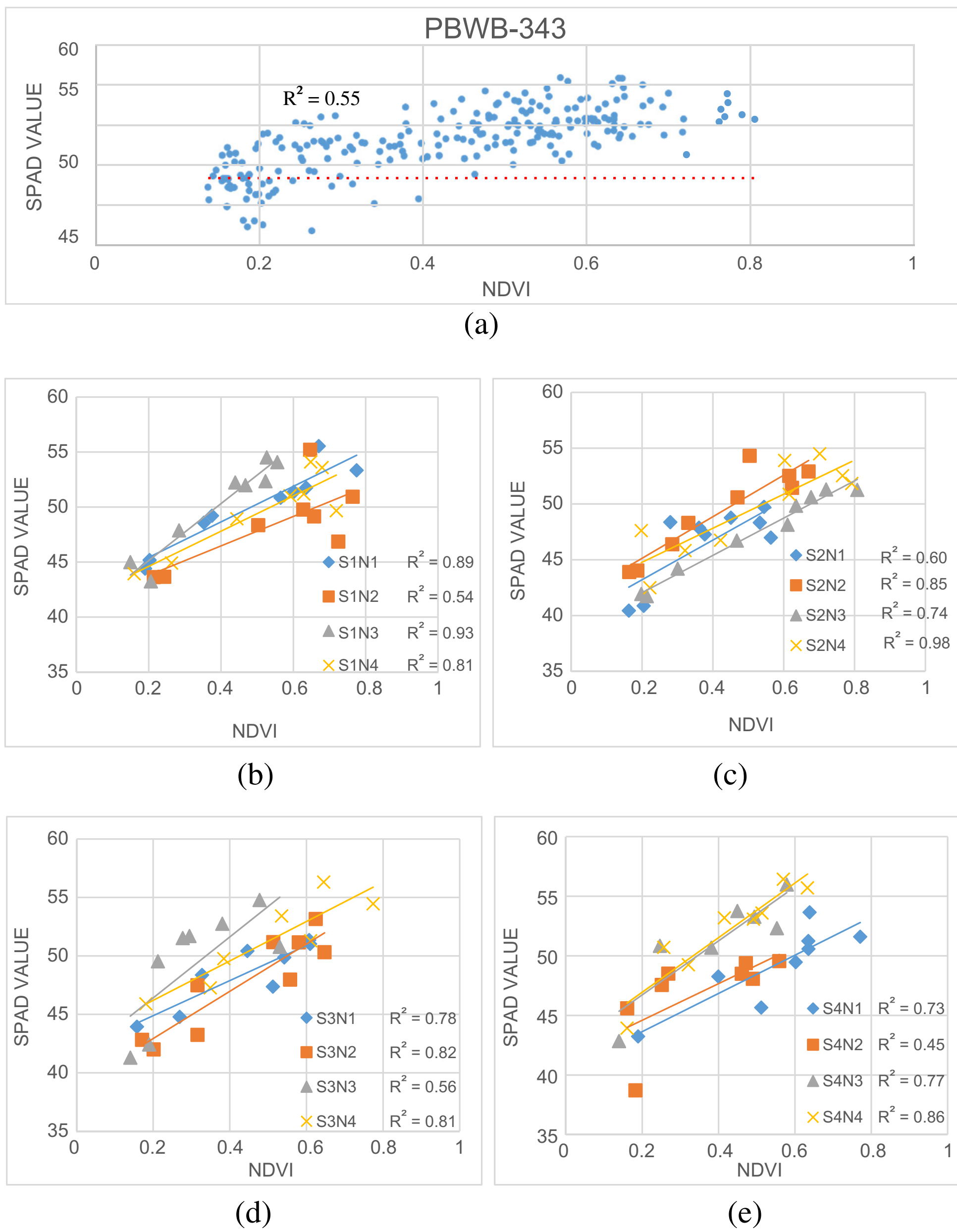


Fig. 7. SPAD value vs. NDVI for different nitrogen applications for PBWB-343 variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, and **e** S4 treatment

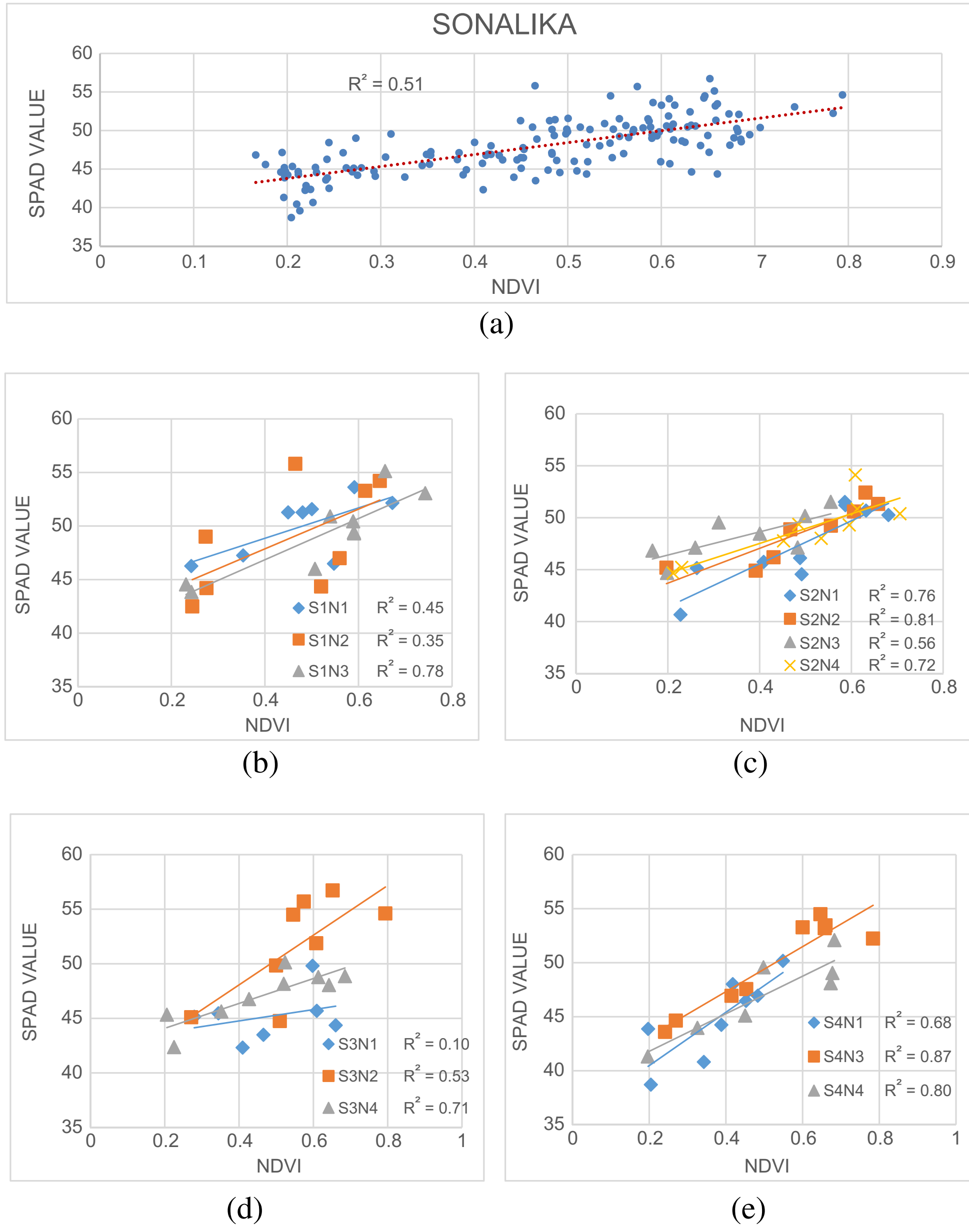


Fig. 8. SPAD value vs. NDVI for different nitrogen applications for Sonalika variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, and **e** S4 treatment

Table 4 Correlation coefficients of relationships between the RGB indices and NDVI measured at ground for PBWB-343 variety of wheat crop

Indices/DAS	34	41	53	60	67	74	82	88
R	−0.37	**−0.66**	−0.4	**−0.72**	**−0.74**	**−0.91**	**−0.84**	**−0.7**
G	−0.39	**−0.65**	−0.38	**−0.65**	**−0.68**	**−0.87**	**−0.77**	**−0.6**
B	−0.45	**−0.74**	−0.4	**−0.68**	**−0.7**	**−0.84**	**−0.73**	**−0.56**
R/(R+G+B)	0.24	**0.72**	**0.54**	0.31	**0.61**	−0.42	0.37	0.23
G/(R+G+B)	0.24	**0.74**	**0.55**	**0.62**	**0.74**	**0.55**	**0.61**	0.39
Nor_R	0.31	**0.75**	0.34	0.04	0.48	**−0.54**	0.23	0.17
Nor_G	0.31	**0.76**	0.37	0.26	**0.65**	−0.06	0.43	0.26
Nor_B	0.3	**0.75**	0.37	0.21	**0.65**	0.02	0.43	0.27
NGRDI	0.35	**0.55**	0.37	**0.74**	**0.76**	**0.91**	**0.79**	**0.73**
ExG	0.28	0.44	0.17	**0.79**	**0.66**	**0.72**	0.44	0.38
ExR	0.17	**0.67**	0.05	−0.49	−0.14	**−0.87**	−0.33	−0.13
ExGR	−0.15	**−0.63**	0.01	**0.72**	0.46	**0.91**	0.42	0.28

Table 5 Correlation coefficients of relationships between the RGB indices and NDVI measured at ground for Sonalika variety of wheat crop

Indices/DAS	34	41	53	60	67	74	82	88
R	**−0.72**	−0.49	**−0.6**	**−0.6**	**−0.66**	**−0.85**	**−0.54**	−0.3
G	**−0.71**	**−0.51**	**−0.56**	**−0.55**	**−0.64**	**-0.81**	**−0.57**	−0.17
B	**−0.76**	−0.45	**−0.54**	**−0.52**	**−0.61**	**−0.81**	−0.34	−0.08
R/(R+G+B)	**0.75**	**0.52**	**0.67**	0.22	**0.71**	**−0.78**	**0.52**	0.06
G/(R+G+B)	**0.74**	**0.51**	**0.69**	0.47	**0.69**	0.06	**0.62**	0.24
Nor_R	0.38	0.38	**0.5**	−0.08	−0.09	**−0.84**	0.19	0.1
Nor_G	0.39	0.4	**0.54**	0.02	0.02	**−0.76**	0.27	0.19
Nor_B	0.37	0.43	**0.54**	−0.01	−0.01	**−0.7**	0.31	0.2
NGRDI	0.42	0.35	**0.7**	0.45	**0.56**	**0.85**	**0.55**	**0.53**
ExG	**0.64**	0.18	**0.52**	0.47	0.47	0.1	−0.07	0.22
ExR	**0.69**	0.41	0.45	−0.25	−0.48	**−0.88**	0.04	-0.36
ExGR	**−0.6**	−0.29	−0.24	0.36	**0.53**	**0.9**	−0.06	0.37

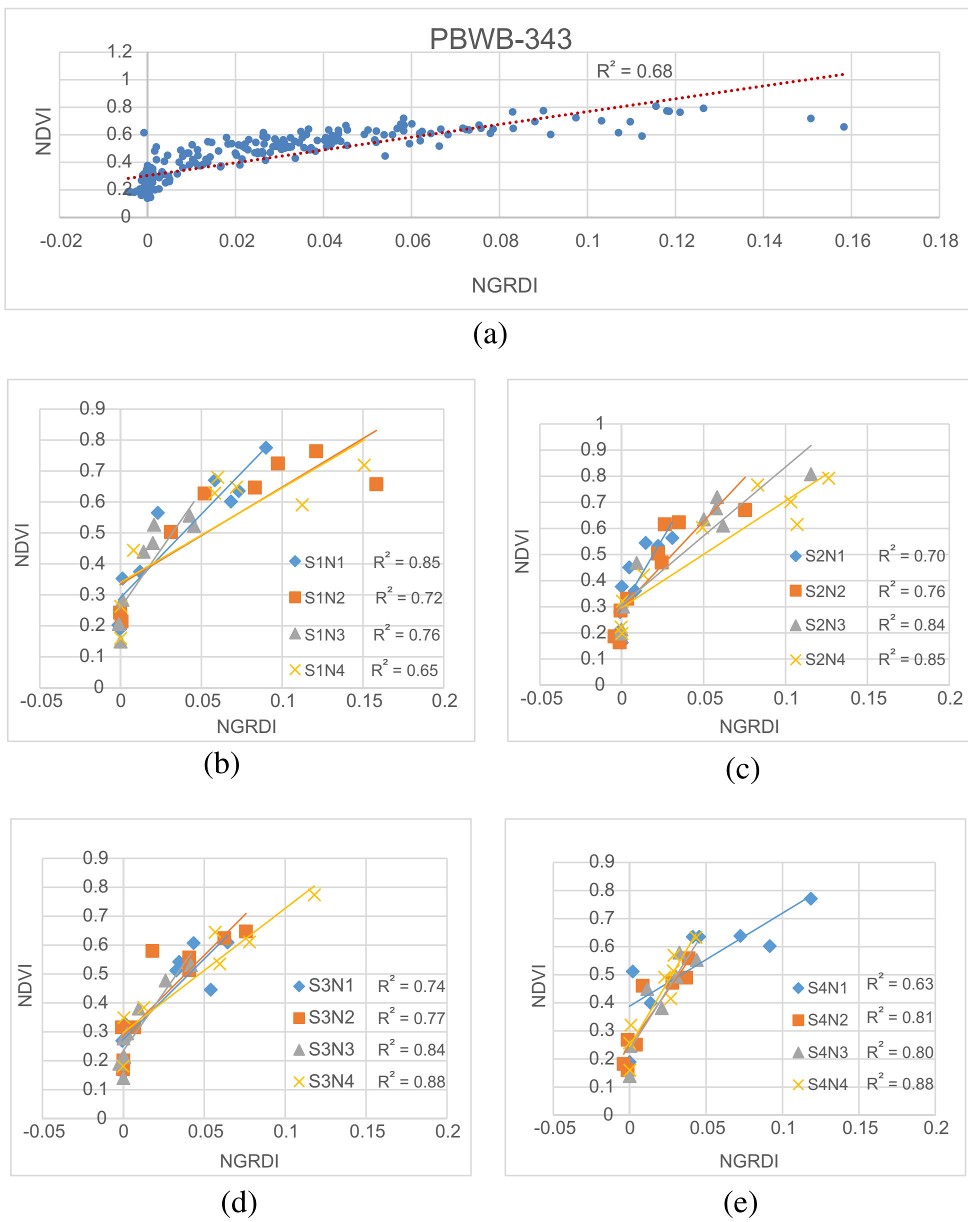


Fig. 9. NDVI vs. NGRDI for different nitrogen applications for PBWB-343 variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, and **e** S4 treatment

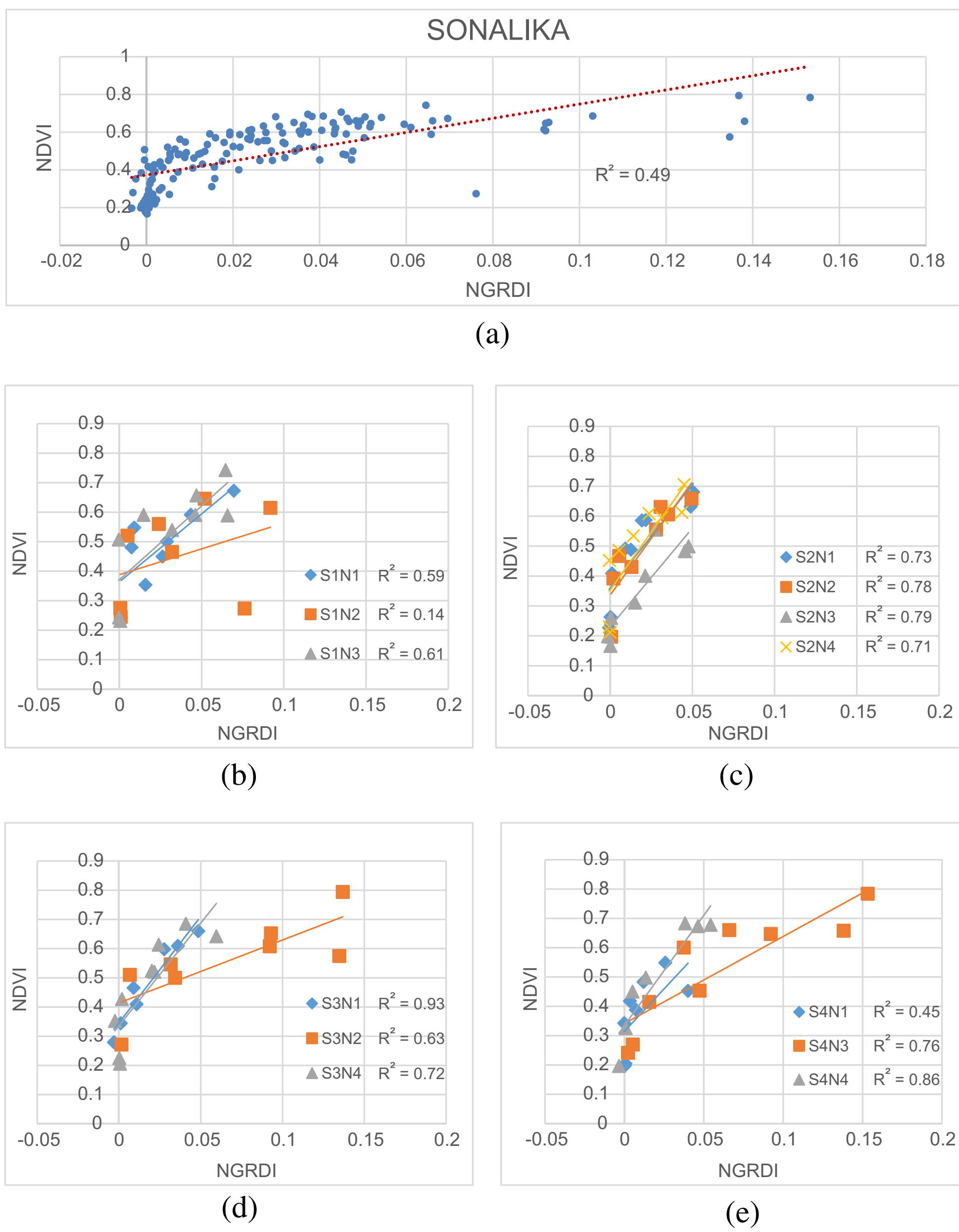
subsequently it decreases. The SPAD value and NDVI both depend on reflectance and health of plant. This is also in agreement with the studies performed by Dreccer et al. (2000)and Bertheloot et al. (2008),who showed that N concentration in wheat plants follows the luminic gradient within the canopy, thus reinforcing the idea that a decrease in chlorophyll concentration and, therefore, in N reduces the ability of the canopy to absorb radiation in the red region, and this reduces the NDVI.

The coefficient of determination (R^2) between NDVI and SPAD value is found to be 0.55 and 0.51 for PBWB-343 and Sonalika varieties, respectively (Fig. 7a and Fig. 8a). For individual treatments with different nitrogen dose applications (Fig. 7b, c, d, e and Fig. 8b, c, d, e), the R^2 values are reasonably good for both the varieties. The N3 (120 kg/ha) shows good R^2 for both varieties.

General relationship between NDVI and spectral indices

A general relationship is developed between NDVI and 13 RGB spectral indices for both PBWB-343 and Sonalika varieties, and correlation coefficients (r) between NDVI and spectral indices are shown in Tables 4 and 5. From the tables, it is clear that there is high correlation between the normalized green-red difference index (NGRDI) and NDVI for both the varieties of wheat crop. R and G indices also show good

Fig. 10. NDVI vs. NGRDI for different nitrogen applications for Sonalika variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, **e** S4 treatment



correlation with NDVI. The remaining RGB indices weakly correlate with NDVI.

Relationship between NGRDI and NDVI

The R^2 between NGRDI and NDVI for PBW-343 and Sonalika is found to be 0.68 and 0.49, respectively (Fig. 9a and Fig. 10a). For individual treatment with different nitrogen dose applications (Fig. 9b, c, d, e and Fig. 10b, c, d, e), N3 and N4 show good correlation compared to N1 and N2 treatments. It is due to less development of canopy cover for low levels of nitrogen treatment. Both NGRDI and NDVI indices depend on green cover and biomass, and both of them consider red reflectance.

Relationship between NGRDI and SPAD value

The SPAD meter measures the chlorophyll concentration on the basis of the red light absorbed by the leaf. The chlorophyll concentration in the leaf depends on the amount of absorbed red light by leaf. NGRDI is the ratio of (G –R)/(G+R), where the difference between the green (G) and the red (R) band reveals the canopy-soil fraction, and the sum of the green and the red band normalizes the index. Therefore, both NGRDI and SPAD value increases as a result of increment in nitrogen content of leaf. NGRDI is one of the indices to show the green vegetation (Hunt at el. 2011), and nitrogen is one of the nutrients which affect greenness. The R^2 between NGRDI and SPAD meter readings is found as 0.31 and 0.43

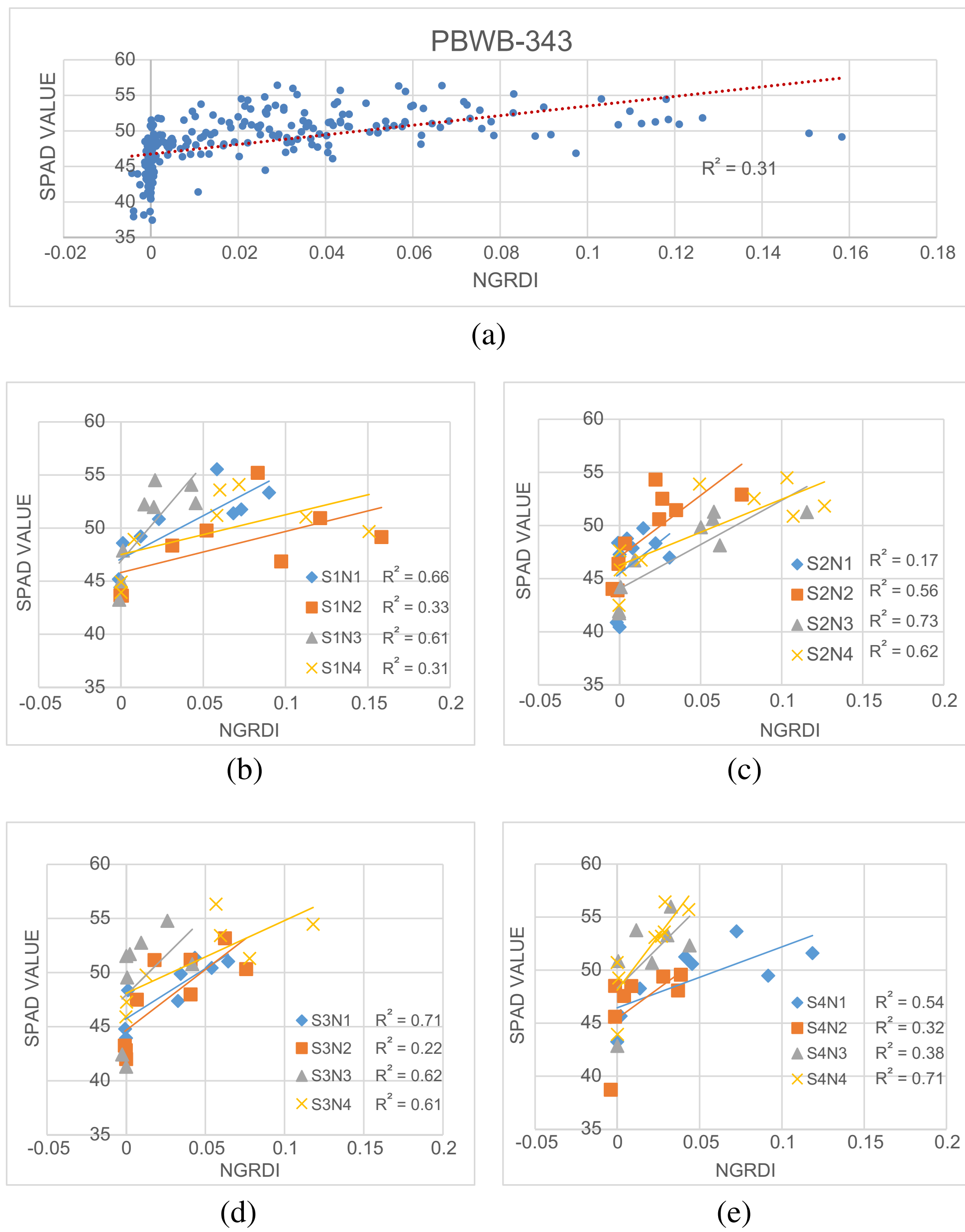


Fig. 11. SPAD value vs. NGRDI for different nitrogen applications for PBWB-343 variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, **e** S4 treatment

for PBWB-343 and Sonalika varieties (Fig. 11a and Fig. 12a). For individual treatment with different nitrogen dose applications (shown in Fig. 11b, c, d, e and Fig. 12b, c, d, e), N3 and N4 show good correlation compared to N1 and N2 treatments. It may be due to less canopy cover development for the N1 and N2 treatments.

Conclusions

Different methods (Kjeldahl digestion, Dumas combustion, etc.) of measuring nitrogen status are laborious and time-consuming, for assessing N distribution in the field. Therefore, in this study, aerial data (NGRDI) are correlated with ground data (SPAD value and NDVI) for capturing the current N status of wheat crop. For this purpose, RGB camera mounted on UAV is used for estimating current N status of wheat crop.

From this study, it can be concluded that SPAD value and NDVI increases till ripening stage, and after that, it reduces. The correlations of linear relationship (R^2) between SPAD value and NDVI are 0.55 and 0.51 for PBWB-343 variety and Sonalika variety of wheat, respectively. N3 (120kg/ha) shows good correlation between SPAD value and NDVI compared to other nitrogen applications. Out of 13 spectral indices, NGRDI shows the best correlation with NDVI for both varieties of wheat as compared to other spectral indices. The correlations of linear relationship (R^2) between NGRDI and NDVI are 0.68 and 0.49, and between NGRDI and SPAD

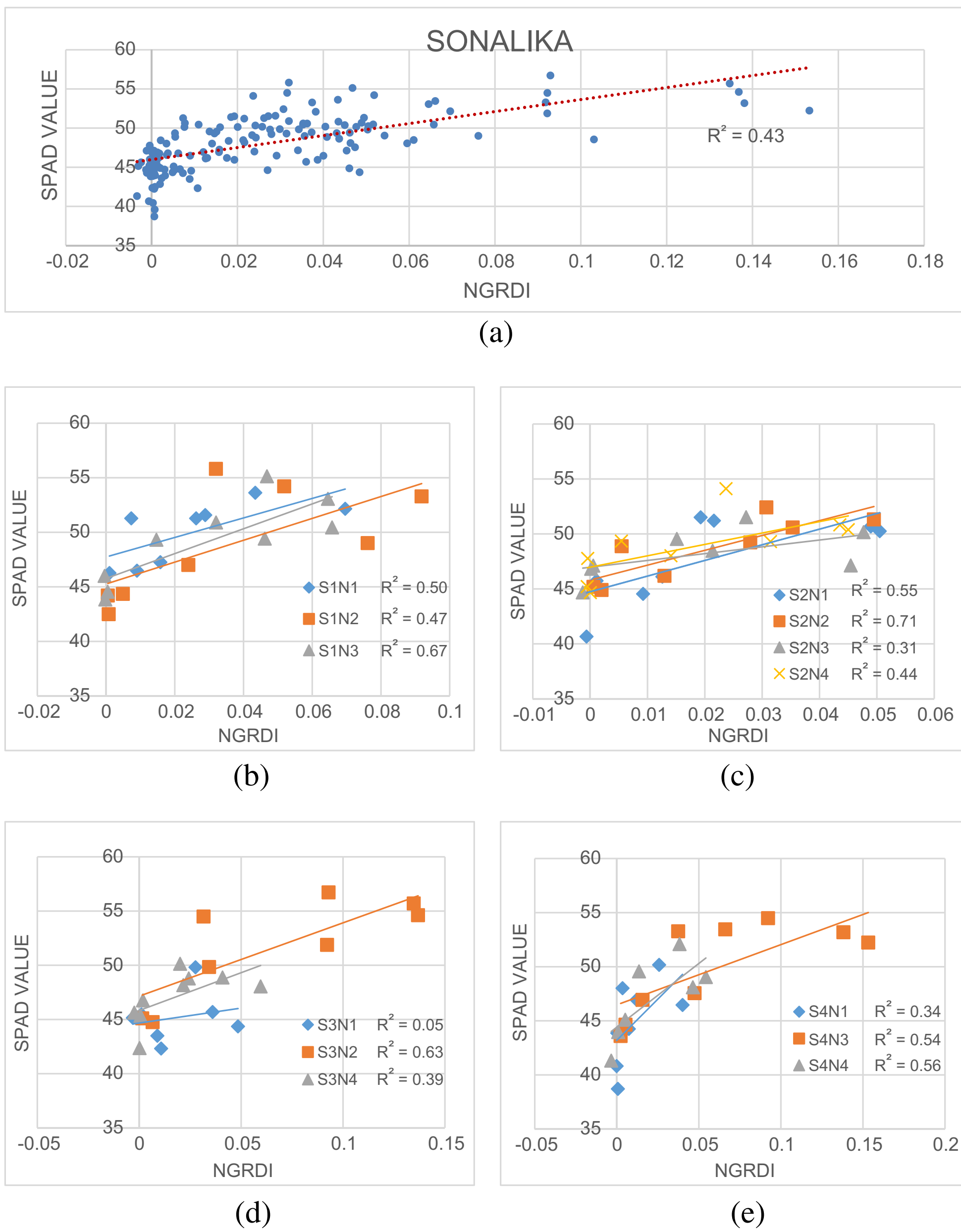


Fig. 12. SPAD value vs. NGRDI for different nitrogen applications for Sonalika variety of wheat for **a** all plots, **b** S1 treatment, **c** S2 treatment, **d** S3 treatment, and **e** S4 treatment

value are 0.31 and 0.43 for PBWB-343 variety and Sonalika variety of wheat, respectively. This study concludes that the proposed RGB index (NGRDI) obtained from RGB camera is a reliable and efficient one for assessing nitrogen status of wheat crop. More studies are needed to be carried out with different varieties of crops under different climatic conditions and with additional cameras (multispectral and thermal) mounted on UAVs for development of accurate and robust generic relationships for assessment of nitrogen status.

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Declarations

Conflict of interest There authors declare no competing interests.

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