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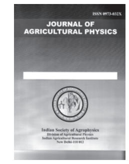

Research Article

Growth Assessment of Wheat using Remote Sensing Techniques under Various Mulch and Nitrogen Levels in a Semi-arid Delhi Region

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ABSTRACT

Optical and thermal remote sensing were used to characterize the growth and yield in wheat (*Triticum aestivum* L.) under black polyethylene and paddy husk mulching and three nitrogen application rates (60, 120 and 180 kg N ha^{-1}) in the semi-arid region of Delhi. Mulch significantly improved biomass and yield at harvest, and so the higher N dose and significant cooler canopy was recorded with 120 kg N ha^{-1}. Vegetation indices could successfully identify N limitations to crop. However, neither the crop growth nor remote sensing parameters showed significant mulch and N interaction effect. Peak vegetation indices were recorded at booting stage (70-75 DAS); and the values at this stage might be used to predict the harvestable biomass and yield in wheat.

Key words: Remote sensing, Mulch, Nitrogen, Wheat

Introduction

Spectral reflectance of crop canopies at various wavelengths has become useful in monitoring the vegetation at large, and especially the stress effects, if any, in crops. This information allows the evaluation of growth of crops at specific phenological stage before final harvest. The yield of wheat (*Triticum aestivum* L.) is showing stagnation in many parts of India, and is a matter of concern for food security of an ever-increasing population. Yield increase is mostly due to increased biomass and little contribution comes from the improvement in harvest index (Waddington *et al*., 1987; Richards 1987, 2000), suggesting a rapid and non-destructive mode of estimation of crop growth parameters and assessment of stress, if any. Thus, the present study aims to characterize the growth of wheat at various stages, and the final biomass and yield based on remote sensing indices at visible and near infrared wavelengths, as affected by mulches and N application rates in the semi-arid region of Delhi.

Materials and Methods

Field experiments were conducted at the Research Farm, Indian Agricultural Research Institute, New Delhi (28°372 N, 77°92 E, 228.7 m amsl) during 3 crop seasons involving factorial combinations of synthetic (black polyethylene, BP), organic (paddy husk, PH) and no mulching (NM) (main plots) and 60, 120 and 180 kg N ha^{-1} levels (sub-plots) in split-plot design with three replications. The soil is Typic Haplustept and sandy loam in texture (sand, silt and clay content

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as 74, 10 and 16%, respectively), neutral in pH, and with 0.4-0.5 g kg^{-1} organic carbon content, 1.5 Mg m^{-3} bulk density and 14-16% available water holding capacity in the 0-15 cm plough layer. The average temperature during crop growth period ranges between 15 and 25°C with occasional light showers. Wheat crop (cv. PBW-343) was sown between 15-25 November, and all recommended agronomic practices were followed. Mulch was applied just after sowing between the rows. A hand-held infrared thermometer (AG-42, Telatemp Corporation, USA with 4° FOV) was used to monitor the canopy-air-temperature difference (CATD) between 11:00 and 12:00 hrs at regular intervals and was summed over the entire growth period to obtain the stress degree day (SDD) (Idso *et al*., 1977). Spectral data of crops were obtained using spectroradiometer (Model 102, Delphi Ind. Ltd. New Zealand) during the same period and reflectance values of different bands were averaged to obtain the vegetation index [VI; [IR/R] and normalized difference vegetation index [NDVI; (IR-Red)/(IR+Red)], in which Red and IR stand for spectral reflectance measurements acquired in the red and near infrared bands. Leaf area index (LAI) using leaf area meter (LICOR-3100), and aboveground dry biomass of the crop (BM) by cutting the plants near soil surface from running 1-m row length, were obtained at tillering, booting, flowering and dough stages. Grain yield was recorded at harvest. All the data were analyzed using MS Excel and SAS programmes.

Results and Discussion

Thermal and spectral indices

The prevailing negative values of stress-degree-days (SDD) in all the treatments indicated no water stress evidenced by the crop in all the years (Table 1). Increase in N dose has lowered the SDD, indicating a better canopy thermal environment under higher N application. Canopy was significantly cooler with 180 kg N ha^{-1} application (SDD -348.6 °C-day) than 60 N ha^{-1} (-257.2 °C-day), while 120 kg N ha^{-1} made no significant impact (-314.1 °C-day). Mulch application did not show significant difference in SDD, and the interaction between mulches and N levels was also non-significant. It appears that under mo-moisture stress, N does not essentially correlate with SDD, except when it is applied in very low quantity. Spectral indices (VI and NDVI) at booting stage (70-75 DAS) were not significantly different between BP and PH. However, it was significantly lower on no mulch as compared to PH (Table 1). As expected, vegetation indices value at booting stage was higher for higher dose of N but there was no significant difference between 120 and 180 kg N ha^{-1}.

Peak leaf area index, dry biomass at maturity and grain yield

The leaf area index of wheat at flowering stage (75-90 DAS) was significantly affected by N application rates, but the effect of mulch was not significant. Maximum LAI was attained with 180 kg N ha^{-1} under PH (4.08), followed by NM (3.72) and BP (3.68). Difference among mulches were non-significant, although crop dry biomass showed significantly higher values under both the mulches (7.33 and 7.67 t ha^{-1} under BP and PH, respectively), compared to no mulch (6.70 t ha^{-1}), possibly due to greater moisture availability under mulches (Chakraborty *et al*., 2010). Application of 120 and 180 kg N ha^{-1} significantly increased LAI and BM over 60 kg N ha^{-1}, while the difference between these N-doses was non-significant. Grain yield followed similar trend as the biomass, and recorded 4.29 and 4.06 t ha^{-1} with PH and BP, respectively which were significantly higher than no mulch (3.57 t ha^{-1}) treatment. Application of 120 kg N ha^{-1} increased grain yield by 1.72 t ha^{-1} over 60 kg N ha^{-1} (2.70 t ha^{-1}) and was marginally less than that with 180 kg N ha^{-1} (4.79 t ha^{-1}). Interaction effect of mulch and N dose was not significant either for LAI or BM or grain yield.

Crop growth monitoring and assessment

The spectral discrimination of wheat among various treatments was observed mostly between 45-90 DAS (Table 2), as also reported by Das *et al*. (1985) and Kamat *et al*. (1983) under similar

Table 1. Stress degree days (SDD) at maturity (90-100 DAS); vegetation index (VI) and normalized difference vegetation index (NDVI) at booting stage (70-75 DAS); leaf area index at flowering (75-90 DAS), grain yield and biomass at harvest in wheat (average of three years)

Mulch	N doses	SDD (°C-day)	VI	NDVI	LAI	BM (t ha^{-1})	GY (t ha^{-1})
BP	N60	-267.0	13.05	0.81	2.85	5.79	2.77
	N120	-314.5	15.53	0.87	3.70	7.95	4.56
	N180	-349.1	16.44	0.88	3.68	8.24	4.84
PH	N60	-248.7	13.09	0.80	3.04	5.65	3.10
	N120	-318.5	15.51	0.88	3.74	8.48	4.71
	N180	-367.1	17.89	0.89	4.08	8.89	5.05
NM	N60	-256.0	12.64	0.80	3.06	4.06	2.23
	N120	-309.3	13.87	0.86	3.43	7.78	4.00
	N180	-329.5	15.18	0.87	3.72	8.25	4.48
Mean							
BP		-310.2	15.01	0.85	3.41	7.33	4.06
PH		-311.4	15.50	0.86	3.62	7.67	4.29
NM		-298.3	13.90	0.84	3.40	6.70	3.57
	N60	-257.2	12.93	0.80	2.98	5.17	2.70
	N120	-314.1	14.97	0.87	3.62	8.07	4.42
	N180	-348.6	16.50	0.88	3.83	8.46	4.79
CD (P<=0.05)							
Mulch		NS	1.36	0.02	NS	0.54	0.39
N		51	1.62	0.04	0.58	1.42	0.94
Mulch × N		NS	NS	NS	NS	NS	NS

Table 2. Means ± SE of leaf area index (LAI), aboveground biomass (BM), vegetation index (VI) and normalized difference vegetation index (NDVI) and canopy-air-temperature-difference (CATD) at various growth stages of wheat across various mulches and N application

Growth stages	Days after sowing	LAI	BM (t ha^{-1})	VI	NDVI	CATD (°C)
Tillering	45	1.12±0.17	3.41±0.81	5.42±0.51	0.69±0.02	-2.4±0.1
Booting	70	3.51±0.35	6.04±0.98	15.63±2.06	0.86±0.04	-3.2±0.2
Flowering	90	2.70±0.24	8.12±1.44	13.73±1.36	0.85±0.02	-1.7±0.2
Dough	115	2.05±0.09	9.15±2.20	7.97±0.73	0.77±0.01	-1.1±0.2

agro-climatic condition. The maximum values of vegetation indices and more negative CATD were observed at booting (70 DAS). Greater VI and NDVI under mulches as well as their minimal fluctuations suggested a better canopy development and higher biomass. This might possibly be due to higher water availability under mulches for maximum time period during crop growth (Sharma and Acharya, 2000; Rahman *et al*., 2005; Chakraborty *et al*., 2008), facilitating higher N uptake (Chakraborty *et al*., 2010). Results suggest that spectral behaviour of crop was in harmony with general crop growth and yield. Crop growth variation due to differential treatments imposed through mulches and N applications could clearly be spectrally differentiated, though their interaction effects were non-significant. The peak value of LAI, coinciding well with either peak VI or NDVI values evidently indicated that crop growth can well be retrieved from the spectral data between booting (70 DAS) or flowering (90 DAS) stage.

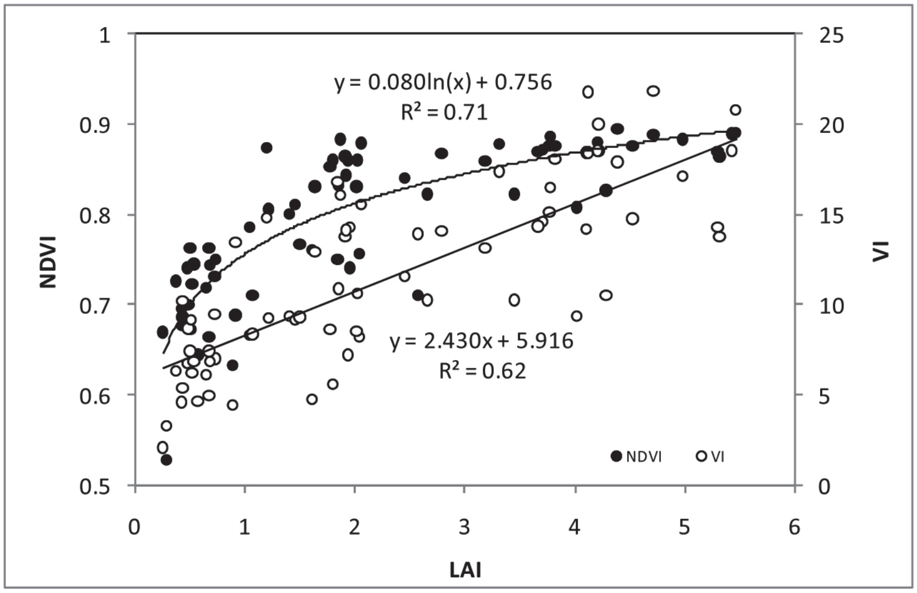

Fig. 1. Relationship of leaf area index (LAI) with vegetation index (VI) and normalized difference vegetation index (NDVI) across mulches, N application rates and growth stages (each point is mean of 3 replicates)

Restricted growth under 60 kg N ha^{-1} resulted in reduced LAI in wheat and also less VI and NDVI values, indicating the potential of remote sensing in detecting N stress in plants.

A logarithmic relationship was observed between NDVI and LAI, whereas VI was linearly related to LAI (Fig. 1); both the relations were significant at $P \leq 0.05$. However, in another study across experiments, growth stages and genotypes of wheat, the relation between LAI and band ratio was reported non-linear (Aparicio *et al*., 2002). This difference might be due to variability associated with pooled data across locations and genotypes. As indicated by the mean values of LAI, BM, VI, NDVI and CATD during tillering, booting, flowering and dough stages (Table 2), LAI reached its peak values (3.51±0.65) at booting stage, but not coinciding with the maximum DM (9.15±2.20 kg ha^{-1}), recorded at dough stage. Both VI and NDVI were maxima at booting stage, though NDVI values at this stage were close to that at flowering stage. This suggested that booting period (at 70 DAS) might be the ideal time in collecting the crop signature to predict the harvestable biomass and yield. The CATD was also recorded minimum at the booting stage.

The correlation between the yield and growth parameters, thermal and vegetation indices as well as water use by the crop is presented as a matrix (Table 3). Grain yield and biomass was highly correlated (r=0.91) and so with LAI (r=0.87). Correlation between LAI and NDVI was better than BM and NDVI, as observed by Aparicio *et al*. (2002). Stress degree days are strongly correlated with all the growth parameters including yield. NDVI was also (negatively) correlated with SDD, suggesting the usability of either of these indices in predicting the crop growth and yield in wheat. Similar results had been reported in wheat and barley by several workers in past few years (Tucker, 1979; Asrar *et*

Table 3. Correlation matrix between grain yield (GY), leaf area index, LAI; and vegetation indices (VI and NDVI) (pooled data across years and treatments) * and ** indicate significance at 5 and 1% levels

Parameters	GY	LAI	VI	NDVI
LAI	0.87**	-		
VI	0.73*	0.68*	-	
NDVI	0.88**	0.88**	0.63*	-
SDD	-0.85**	-0.89**	-0.67*	-0.88**

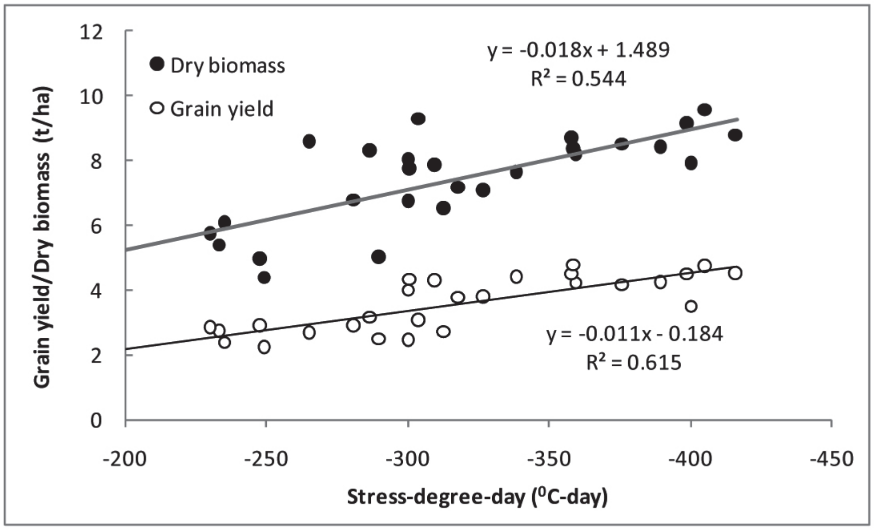

Fig. 2. Relationships between grain yield and biomass with stress degree days

al., 1984; Elliott and Regan, 1993; Aparicio *et al*., 2000; 2002).

A strong negative relationship was observed between grain yield and SDD where an increase of one unit in SDD might result in reduction in grain yield to the tune of 20.8 kg (Fig. 2). Our finding supports a previous report from same region (Chakraborty *et al*., 2008) and also corroborates the findings elsewhere (Diaz *et al*., 1983; Akderfasi and Nielsen, 2001; Limon-Ortega *et al*., 2000).

Conclusions

The SDD could be identified as sensitive indicator for yield. However for N, this may not be sensitive under no-moisture stress condition. Synthetic and organic mulches failed to show any differential effect, and the mulch-N interaction was found non-significant. Spectral signatures at booting stage could be useful in predicting grain yield of wheat at harvest. This should be evaluated further by incorporating more variations in terms of genotypes and agronomic treatments.

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