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Detection and Management of Abiotic Stresses in Wheat Using Remote Sensing Techniques

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A B S T R A C T

Different aspects of climate change, such as higher atmospheric CO_2 concentration, increased temperature and changed rainfall patterns have different effects on crop yields. In combination, these effects can either increase or decrease crop production as the net effect of climate change on crop yield depends on the interactions between these factors. Among all changes, temperature plays a dominant role for wheat production in India. The high temperature stress at reproductive phase of crop results in poor yield due to reduced number of grains per spike and shriveled grains with poor quality. Along with thermal stress, the continuous availability of nutrients to wheat during various phases of its growth and development is important factor which influences the grain yield. So suitable production strategies for obtaining higher yield under stress conditions need to be developed for detection of these stresses at early stages of crop growth. Among these strategies, remote sensing techniques provide a platform for which plant stress and growth response can be evaluated. Variation in spectral reflectance under different type of stresses in the form of spectral vegetation indices allows us to develop suitable strategies for reducing these stresses and helps in maximizing the wheat yield. The impact of these stresses on wheat productivity can be minimized by adoption of various agronomic management practices as time of sowing, alternative method of planting, nutrient management, mulching, seed priming, foliar spray of salts and foliar spray of micronutrients to mitigate the high temperature effect on the productivity of wheat.

Introduction

Wheat is a photo-insensitive and thermo-sensitive long day plant. It requires cool climate during the early part of its growth. Temperature plays a dominant role for wheat production in India. Both the start and end of wheat crop season are limited by temperature regimes. Within the growing season itself, warmer temperature shortens the vegetative crop duration. Wheat grain yield and quality are also influenced by temperature regimes during different phases of crop growth. High temperature during early vegetative phase results in sparse tillering, poor vegetative growth and early heading; and during grain filling phase it leads to forced maturity (Reddy 2006). The IPCC (2014) has reported the globally averaged combined land and ocean surface temperature of 0.85°C over the period 1880 to 2012. The warming is more pronounced over land areas with a maximum increase over northern India. Increased concentrations of greenhouse gases and warming will have serious consequences like increased evaporation, uncertainty of monsoon rainfall, increased frequency of extreme events like floods, droughts, heat waves etc. All these events have profound impact on crop yields due to increased abiotic and biotic stresses (Reddy and Hodges, 2000).

Growth and development of wheat is adversely affected by environmental stresses like high temperature, soil moisture deficit, nutrient stress, low light intensity, etc. Temperature and nutrient play important role in growth, development and yield of wheat. Extremely high and low temperature as well as higher or lower dose of nutrients has a detrimental effect on crop growth, development and yield. Estimates indicate that in India alone around 13.5 million hectares of wheat is under heat stress (Joshi *et al.,* 2007). The high temperature stress at reproductive phase of crop results in poor yield due to reduced number of grains per spike and shriveled grains with poor quality (Sharma *et al.,* 2007). Along with thermal stress, the continuous availability of nutrients to wheat during various phases of its growth and development is important factor which influence the grain quality and yield (Kumari *et al.,* 2000). Among the several nutrients, nitrogen is the most important responsible to a great extent for the higher yields under intensive agriculture. Application of nitrogen enhances not only biomass production but also yield and yield components (Latiri-Souki *et al.,* 1998).

Therefore, it becomes imperative to develop suitable production practices for obtaining higher yield under thermal and nutrient stress conditions. In the effort of developing sustainable production strategies, remote sensing has been commonly considered as an effective technique for non-destructive monitoring of plant growth viz. for the detection of many environmental stresses which limit plant growth like temperature stress, nutrient deficiencies, diseases, water stress, wind damage etc and allow us to develop suitable strategies for reducing the effect of different stresses in wheat for maximizing the yield. Since reflectance of crops and soils differs in the visual and near infrared wavelengths under both stressed as well as unstressed conditions, there is potential for using reflection measurements at different wavelengths to distinguish yield as well as quality differences in wheat crop when observed under thermal and nutrient stresses. Keeping this in view, the relevant literature depicting the effect of heat and nutrient stresses in wheat, the significance of remote sensing for detecting these stresses and suitable strategies for their management has been consulted and presented in the manuscript.

Effect of thermal stress on growth and yield of wheat

The temperature rise is likely to be much higher during the winter (*Rabi*) rather than in the rainy (*Kharif*) season. It is projected that by the end of the 21st century, rainfall over India will increase by 10-12 per cent and the mean annual temperature by 3-5°C. The warming is more pronounced over land areas with a maximum increase over northern India. Perry and Swaminathan (1992) reported that an increase of 0.5°C temperature resulted in decrease in the duration of wheat crop by seven days, which reduced the yield by 0.5 tonnes per hectare in North India. High temperature enhanced the plant growth, flowering and maturation, thus the number of days to booting, heading, anthesis and maturity of wheat were significantly decreased (Rahman *et al.,* 2009). The stress was experienced either throughout crop growth period or at one of the three growth phase's viz., seedling to ear initiation, ear initiation to flowering and flowering to maturity. The warmer temperature hasten crop development, shortens the growth period

(Zacharias *et al.,* 2010 and Hossain *et al.,* 2012). A significant inverse correlation was observed between mean seasonal ambient temperatures with culm length, spike length, duration from heading to maturation and thousand-grain weights (Nishio *et al.,* 2013). Heat stress modified the early dough stage and maturity, shortened the kernel desiccation period and caused grain yield loss. Plants subjected to stress at the early growth stages had higher grain yields than the non-early-stressed plants when stress reoccurred at anthesis (Zhang *et al.,* 2013).

Heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts, with concomitant reductions in dry matter accumulation and grain yield (Farooq *et al.,* 2011). The rate of decrease in grain yield was more for higher temperatures rise in contrast to lower temperatures and the rate of increase in grain and biomass yield was more for higher CO_2 concentration with lower levels. On an average, there was 8% decrease in wheat grain and biomass yield per 1°C increase in temperature (Mohanty *et al.,* 2015). The grain yield decreased from 0.7 to 3.3 percent when temperature increased by 1°Cduring second fortnight of February, 2.1 to 3.2 percent during first fortnight of March, 1.24 to 3.4 percent during second fortnight of March and 0.38 percent during first week of April (Prabhjyot-Kaur and Hundal, 2010). With the increase in temperature (maximum and minimum) during grain filling period, all the yield components of wheat were reduced in mean values ranging from 4.77 to 10.05% (Singh *et al.,* 2006).

Because of exposure to high temperature during grain filling and maturity under late sown conditions, the development of plant organs and transfer from source to sink were remarkably affected with delayed planting, which was reflected by overall shortening of plant height, reduction in number of internodes, days to heading, days to maturity and grain filling period and ultimately in the reduction of yield and yield components. Refay (2011) also reported that delayed sowing was associated with substantial loss in grain yield estimated as 7.98 per cent as compared to early sowing. The highest values of spike weight, grain yield and dry biological yield were obtained when the crop was sown in November. Similar results were also reported by Mukherjee (2012), Andarzian *et al.,* (2015), Fayed *et al.,* (2015) and Meena *et al.,* (2015). The protein content of the genotypes was higher in late condition, possibly due to low grain weight (Sial *et al.,* 2005). Sowing dates severely influenced protein and carbohydrate contents in subsequent grains of wheat crop (Table 1). Wheat crop sown from the seeds obtained from the crop previously sown at November 10 and 25 showed better grain protein and carbohydrate content as compared to December 10 and 25 (Hussain *et al.,* 2015). The protein content and bread quality are improved by delayed sowing due to synthesis of heat shock proteins under such conditions (Abdullah *et al.,* 2007 and Munsif *et al.,* 2015). Best chapati quality was obtained in mid and late sowings because protein content was higher in delayed sown crop (Abdullah *et al.,* 2007 and Eslami *et al.,* (2014).

Effect of nutrient stress on growth and yield of wheat

The continuous availability of nutrients to wheat during various phases of its growth and development is important factor which influence the grain quality and yield of wheat (Kumari *et al.,* 2000). Increased crop growth due to nitrogen fertilization is attributed to increased leaf-area index (LAI) and radiation interception (Caviglia and Sadras, 2001).The nutrient content in grain and straw increased with delay in sowing of wheat whereas, uptake of these nutrients decreased as the sowing of wheat gets delayed (Kumar *et al.,* 1998). The N use efficiency was also greater in optimum and early sown crop compared to late sown crop.

Nutrient stress has a significant impact on growth and yield of wheat. It's yield and quality are adversely affected due to wheat stress but significantly improved under increase in dose of fertilizers. The number of productive tillers per m^2, 1000–grain weight and grain yield of wheat increased with the application of 150 kg N ha^{-1} (Ali *et al.,* 2003).Maximum plant height, total number of plants/m^2, number of spikes/m^2, spike weight, biological yield and grain protein content were observed at 200 kg N/ha (Hussain *et al.,* 2006 and Iqbal *et al.,* 2012). Grain yield increase was mainly due to increase in the number of effective tillers (Abad *et al.,* 2005). The rate and time of N application had significant effect on grain yield (Haile *et al.,* 2012). There was 4.14% increase in grain yield when N was applied as 45% of recommended N (150 kg) at sowing followed by 50% at first irrigation and 5% as foliar application at the rate of 3% concentration over recommended schedule (Kaur *et al.,* 2010). The combined application of plant growth regulator (PGR) treatments and higher nitrogen rates reduced the plant height and this reduction played an important role in the increase of the grain yield in wheat, via the alteration of dry matter partitioning into the spikes (Shekoofai and Emami, 2008) (Table 2). The grain yield, nitrogen absorption, and nitrogen harvest index were increased with increasing nitrogen fertilization level when the nitrogen application rate was 0-150 kg N x hm^{-2}, but not further increased significantly (Li *et al.,* 2013). Similar findings were also observed by Akram *et al.,* (2014) and Mandic *et al.,* (2015). Nitrogen application improved grain protein and reduced phosphorous percentage (Warraich *et al.,* 2002) (Table 3).

Nitrogen rate increased hectoliter weight and grain protein, but decreased NUE (Campillo *et al.,* 2010). The dose of 200 kg N/ha, compared to dose of 150 Kg N/ha, significantly increased the protein content (Maqsood *et al.,* 2000; Cui *et al.,* 2005 and Hussain *et al.,* 2006). The reduction of N reduced grain yield, agronomic NUE, grain protein content, grain N content and bread volume but caused increasing of thousand kernel weight (Khalilzadeh *et al.,* 2011). Split application of N resulted in superior quality attributes than when the entire N was applied at once. The sensitivity of rate and time of N application was found to be greater in the wheat quality attributes than the grain yield and yield components (Ooro *et al.,* 2011 and Moraes *et al.,* 2013). The simultaneous increase was observed in the quality and yield with the increase of nitrogen fertilizer in winter wheat when the amount of nitrogen fertilizer was in the range of 0 and 225 kg/hm^2; but once the amount of nitrogen fertilizer reached 300 kg/hm^2, the winter wheat showed the best quality and decline both in the percentage of weight gain in grain filling stage to kernels and the kernels yield (Liu and Shahi 2013) (Table 4).

Diagnosis of thermal stress using vegetation indices

The use of thermal remote sensing, especially when combined with spectral reflectance or even fluorescence measurement, is becoming a powerful and increasingly-used tool to diagnose and monitor the effects of heat and moisture stress on plants (Jones 2009).The remotely-sensed infrared crop water stress index (CWSI) provided a useful tool for the evaluation of crop water status especially that of winter wheat and could be useful for irrigation scheduling. The relationship was developed between canopy–air temperature difference and vapour pressure deficit for no stress condition of wheat crop (baseline equations), which was used to quantify crop water stress index (CWSI) to schedule irrigation in winter wheat (*Triticum aestivum* L.) (Gonita and Tiwari 2008). Chlorophyll fluorescence and chlorophyll content were reduced and chloroplast ultra-structure was disrupted by heat stress and the effect was exacerbated by low supplies of Zn (Peck and McDonald 2010). Camp *et al.*, (1982) evaluated the changes in photosynthetic enzymes and photochemical activities in vegetative wheat (*Triticum aestivum* L.) leaves during senescence. Identification of appropriate wavelengths for monitoring changes in chlorophyll content has focused on studying the absorption coefficient. The absorption coefficient describes the incident light in the green (~550 nm) and red edge (~700 nm) spectra has been found to have a very low absorption coefficient as compared to light in the blue (~450 nm) and red (~650 nm) spectra. Gitelson *et al.*, (2003) also demonstrated the relationship between leaf chlorophyll content and spectral reflectance. A simple and integrated way to measure stay-green in large sets of germplasm is using a Green-Seeker to measure NDVI during the grain-filling stage in wheat plots. NDVI has been related to temperature stress, nitrogen status; chlorophyll content, green leaf biomass, and grain yield (Shanahan *et al.*, 2003). The cumulative effects to improve stress adaptation may be achieved by introgressing low canopy temperature and stay-green expression traits into new wheat lines (Lopes *et al.*, 2012). High temperature during anthesis and grain development stages coupled with sharp irradiance, low humidity and moisture deficit, resulting in adverse effect on different vital activities and finally the yield and yield attributes of the crop (Srivastava *et al.*, 2012).

Table.1 Sowing date effect for the quality characters

Quality charactersitcs	**25th Oct.**	**10th Nov.**	**25th Nov.**	**10th Dec.**	**25th Dec.**	**10th Jan.**
Protein content	11.94	12.27	12.49	12.62	12.57	12.92
Flour yield	71.31	70.21	68.67	67.24	67.24	64.40
Bread quality	69.75	70.61	70.95	71.65	71.71	72.56
Chapatti quality	Fair to fairly good	Fairly good to good	Good	Good	Good	Fairly good to good

(Source: Abdullah *et al.*, 2007)

Table.2 Effect of N rates on grain yield of wheat

N levels (kg ha^{-1})	**Grain yield (kg ha^{-1})**	
	2000-01	**2001-02**
84	2940	3600
128	4090	4770
150	4330	5160
175	3890	4920
200	3250	4730
LSD (<0.05)	38.81	6.85

(Source: Ali *et al.*, 2003)

Table.3 Effect of nutrient management on growth parameters of wheat varieties

Treatment	**LAI (90 DAS)**	**Crop Growth rate at (60-90 DAS) (g/m^2/day)**	**Relative Growth rate at (60-90 DAS) (mg/g/day)**	**Crop Growth rate at (60-90 DAS) (g/dm^2 leaf area/day)**
100% RDF	5.39	10.72	41.57	3.17
50% RDF + 50% RDN	5.95	12.00	42.81	3.27
SEm	0.05	0.14	0.43	0.03
CD (P= 0.05)	0.15	0.46	1.36	0.11

(Source: Kumar *et al.*, 2015)

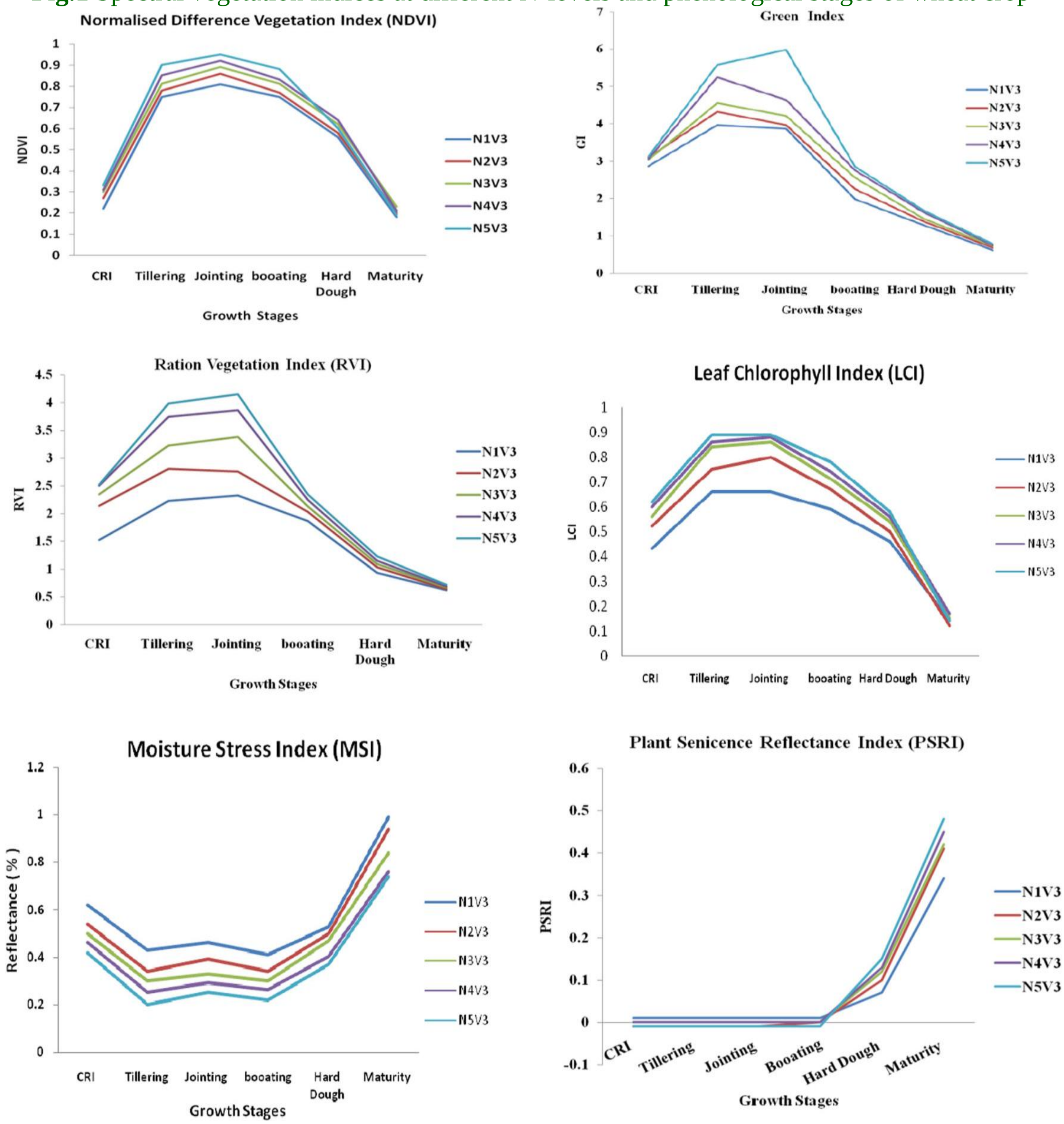
RDF = Recommended dose of fertilizer; RDN = Recommended dose of nitrogen.

Table.4 Interaction effects of nitrogen and compost on wheat grain yield (kg ha^{-1})

Nitrogen (Kg/ha)	Compost (Mg/ha)			
	0	**30**	**60**	**Mean**
0	1274.19	3600.90	3312.65	2720.20
80	2893.58	4206.67	5274.42	4124.80
160	3439.00	7546.19	6548.55	5844.59
240	4507.00	6089.94	5307.09	5301.00
Mean	3021.70	5110.60	5360.90	

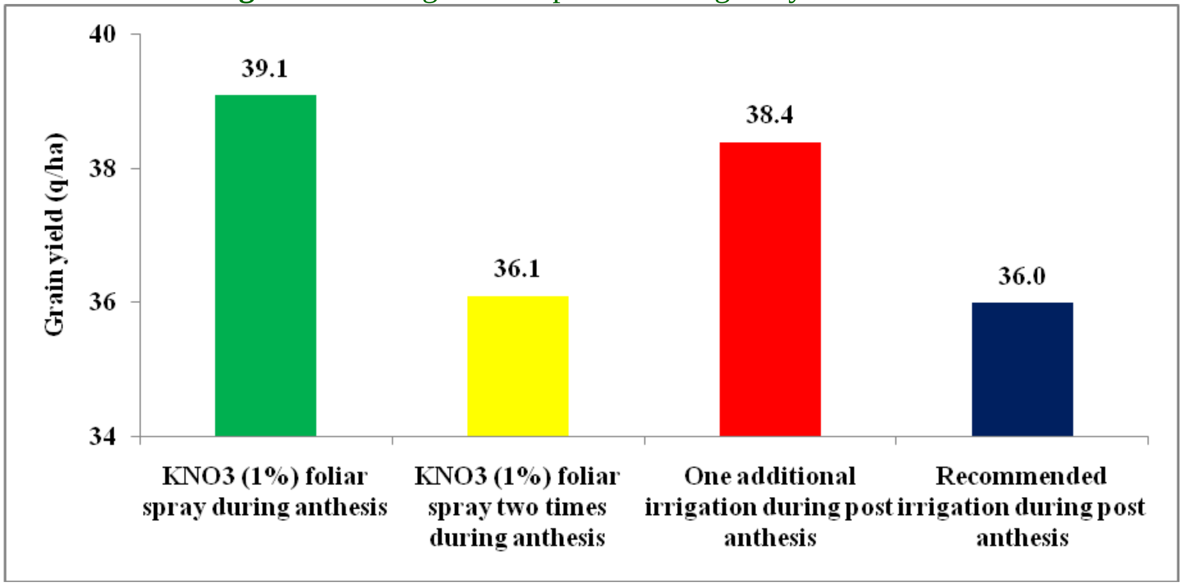
(Source: Abedi *et al.*, 2010)

Fig.1 Spectral vegetation indices at different N-levels and phenological stages of wheat crop



(Source: Kaur *et al.*, 2015)

Fig.2 Effect of agronomic practices on grain yield of wheat



(Source: Singh, 2010)

Diagnosis of nutrient stress using vegetation indices

Aerial photography can be used to detect several factors including diseases, insect damage and N deficiency (Blackmer *et al.,* 1996). Remote sensing imagery can be a better and quicker method compared to traditional method for managing nitrogen efficiently (Daughtry *et al.,* 2000). The remote sensing technology has vital potential for the assessment of crop growth monitoring and stress detection. Infrared Red reflectance ratio and NDVI were found highly correlated with LAI and final yield, establishing the role of remote sensing for predicting grain yield. The different temporal spectral response under fertilized and nutrient deficient plots confirmed that spectral parameters can be used for detecting nutrient stress in wheat, maize, sunflower and possibly in other crops (Mahey *et al.,* 1991). These relationships provided a method to optimize N rates at most critical time for achieving higher NUE (Scharf *et al.*, 1993; Serrano *et al.*, 2000 and Broge and Mortensen 2002). Blackmer and Schepers (1995) proposed a system for N application to corn based on photometric sensors mounted on the applicator machine. They showed that corn canopy reflectance changed with N rate within hybrids, and the yield was correlated with the reflected light. Aerial photographs were used to show areas across the field that did not have sufficient N. The machine read canopy colors directly and applied the appropriate N rate based on the canopy color of the control (well fertilized) plots. Greenness normalized difference vegetation index (GNDVI) was significantly correlated with nitrogen content of plants. Vegetation index (VI) used in the study, whether from satellite or aircraft correlated well with preseason N and plant tissue analysis, but had lower correlation with protein (Wright 2003).

Remote sensing in the form of aerial color infrared (CIR) photography can be a useful tool for in-season N management in winter wheat (Sripada *et al.*, 2007). The absorption band depth (ABD) normalized to the area of absorption feature (NBD) at 670 nm (NBD670) was the most reliable indicator for winter wheat canopy N status assessment (Chunjiangzhao *et al.*, 2012). Leaf color index (LCI) was the only index which was correlated better, with all the plant growth parameters and yield at booting stage of the wheat crop (Kaur *et al.*, 2015).

Management of thermal stress

The management practices to mitigate the impact of high temperature on wheat involved different techniques (Singh *et al.,* 2011). The effect of increasing temperature during grain filling stage of wheat causes substantial reduction in grain yield. Timely sowing of wheat crop generally gives higher yield as compared to late sown crop. Late sown wheat crop faces high temperature stress during ripening phase. Adjustment in sowing time is one of the most important agronomic strategies to counteract the adverse effect of temperature stress (Kajla *et al.,* 2015). Planting of wheat with zero tillage, bed planting and conventional tillage with mulching produced higher grain yield than conventional tillage. Organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield, which subsequently resulted in higher water and nitrogen uptake and their use efficiencies. The foliar spray of KNO_3 (0.5%) at 50 percent flowering stage, 1.0 per cent KNO_3 during anthesis stage, 2.5 mM of arginine, spray of zinc, extra irrigation water during grain filling stage, use of potassium fertilizers with municipal waste water increased the productivity of wheat under high temperature conditions. The higher grain and straw yield of wheat was obtained by spraying 0.5 per cent KNO_3 at 50 per cent flowering stage of the crop (Das and Sarkar 1981) (Fig. 2).

Both K+ and Ca^{2+} gave beneficial effect on grain filling and yield of wheat when applied as foliar spray at 50 per cent flowering stage of the crop (Sarkar and Tripathy, 1994). One of the reasons of reduction of crop yield is insufficient supply of micronutrients. Zinc is one of those micronutrients which have an important role in metabolic activities of the most plants (Shahramlack *et al.,* 2011). On the other hand, its mobility is low under drought stress conditions, so this element can be sprayed to increase its intake in the plant. Inorganic (ZnO, $ZnSO^4$) and chelated sources of Zn (ZnEDTA, glycine-chelated Biomin Zn) applied foliarly provided sufficient Zn for vigorous growth (Haslett *et al.,* 2001). Foliar application of arginine with 2.5 and 5.0 mM on normal or delayed sowing wheat exhibited significant increment in yield and its components in comparison to untreated plants. The magnitude of increments was much more pronounced in response to 2.5 mM of arginine which induced 19.2, 20.5 and 25.5 per cent increases in economic yield per feddan at normally, 30 and 60 days delay, respectively (Hozayan and Monem, 2011).

Management of nutrient stress

The appropriate management of soil water, oxygen fertilization, and well-balanced nutrients supply significantly enhance N uptake and utilization efficiencies of corn and wheat, and minimize N loss (Guodongliu *et al.*, 2012). Application of 50% RDF (recommended dose of fertilizer) + 50% RDN (recommended dose of nitrogen) through FYM gave significantly higher number of tillers/m^2, spike length, number of spikelets/spike, grains/spike, 1,000-grain weight and grain yield. Application of 100% recommended dose of fertilizer (RDF) in wheat, vegetable cowpea, mungbean, maize and potato gave significantly highest yield, followed by 50% RDF + 50% RDN through FYM and 50% RDF + 25% RDN through FYM + biofertilizers (Singh *et al.,* 2015). To elucidate the most effective and economical method of Zn application for wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] Yield improvement in partially reclaimed sodic soils, all the Zn application methods, increased the plant height, tillers/plant, grains/spike, spike length, test weight, grain yield, straw yield and nutrient uptake over the control (no Zn). Foliar spray of Zn sulphate (5 kg/ha hepta hydrate) resulted in 26% higher grain yield than the control. Foliar spray of 5 kg/ha ZnSHH with 2% urea in 1,000 litres water at 25 and 50 days after sowing was most economical (Mauriya *et al.*, 2015). Application of 6 Kg Zn/ha resulted in 8.8% higher grain yield (5.22 t/ha) than yield obtained in the control (4.80 t/ha) (Singh *et al.*, 2015) (Fig. 1).

In conclusion, Wheat growth, yield and quality are adversely effected under thermal and nutrient stresses, which can lead to severe impacts under changing climatic scenarios. Remote sensing technology can be used successfully for selection of different types of stresses in wheat. Various vegetation indices viz. RI, NDVI, GNDVI, and CWSI etc. can be used efficiently for detection of thermal and nutrient stresses based on variations in spectral reflectance characteristics used for enhancing input use efficiency. Different management options like appropriate sowing time, bed planting, zero tillage, irrigation management, appropriate rate and time of fertilizer application, foliar application of KNO_3, $ZnSO_4$ etc. can be used for management of thermal and nutrient stresses in wheat.

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