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Need Based Nitrogen Management Using SPAD Meter in Wheat of Eastern India

Mainak Ghosh, Neh Kiran, R. P. Sharma and S. K. Gupta*

Abstract: *Spectral properties of leaves are become effective in SPAD (Soil Plant Analysis Development) meter based on light transmittance for guiding real-time N top dressings in wheat. A field study was conducted to analyze the effect of SPAD based N management on wheat productivity and N use efficiency for sustainability during the dry season of 2013-14 on alluvial belt of eastern India, with twelve combinations of four SPAD threshold (38, 40, 42, and 44) and three N levels (15, 20 and 25 kg N ha^{-1}) at each topdressing as real time N management (RTNM), one fixed time N management (FTNM), and control (Zero N) in three replications. Moderate rate (20 kg N ha^{-1}) of N top dressing at high SPAD (S44) produced more grain yield (7.7%) over FTNM. It reduced N requirement by 17.7% from the existing N fertilizer recommendation in FTNM without reducing the grain yield. At moderate rate of N top dressing both medium and high SPAD (S42 and S44) are at par in grain yield production. Moderate rate of N top dressing at medium SPAD increased the Agronomic N use efficiency (AE_N) by 29% over FTNM. The SPAD based N top dressing was found a better option for N management in wheat for increasing yield and N use efficiency. Moderate rate of N topdressing at high SPAD in RTNM recorded the highest gross (79339 Rs. ha^{-1}) and net (51334 Rs. ha^{-1}) returns comparable to those of high N rate at higher SPAD; but markedly greater than those with high N rate at lower and medium SPAD, and control treatment. FTNM though fetched good economic return but incurred higher fertilizer N consumption than required to produce the expected yield. Moderate rate of N topdressing at medium SPAD was found best for precision N management in wheat crop aiming at greater profit with higher N use efficiency.*

Keywords: *Agronomic N use efficiency; Wheat; SPAD Meter; Partial factor productivity*

INTRODUCTION

Nitrogen is a key nutrient element for vegetative and reproductive growth of all the crops, hence N fertilizer application has become one of the most yield-enhancing elements as well as limiting factor in modern crop production (Hucklesby *et al*., 1971; Bouman, 1992; Scheromm *et al*., 1992; Woodard and Bly, 1998; Ma and Dwyer 1998; Tremblay 2004).The farmers are acquainted with blanket N recommendation in wheat to obtain higher production in eastern part of India. It is very important to identify nitrogen management practices that will allow high yields per unit area while minimizing environmental impact and being economically attractive to farmers. Therefore, timing and quantity of N fertilizer application is a big challenge. To increase fertilizer N use efficiency in irrigated wheat, fertilizer N should be applied at growth stages when N needs of the crop are high so that applied N is least prone to losses from the soil to plant system. Crop N requirement depends on combination of soil and weather always changes with time and region (Mamo *et al*. 2003). Current N fertilizer management strategies for wheat production systems in India and around the world are characterized by low N use efficiency (NUE) and it is due to poor synchrony between soil N supply and crop demand (Fageria and Baligar, 2005). Site-

* Department of Agronomy, Bihar Agricultural University, Sabour, Bihar, India
Corresponding author: E-mail address: mainakghosh999@gmail.com

specific N management (SSNM) such as real-time N management (RTNM) and fixed-time N management (FTNM) was developed to increase the fertilizer-N use efficiency of irrigated wheat. Variable Rate Technology (VRT) such as SPAD (Soil Plant Analysis Development) Meter, Leaf Color Chart, Green Seeker, Remote Sensing, Global Positioning System (GPS), Geographical Information System (GIS) and several Sensors are the tools of RTNM.

Improving N use efficiency is a challenging issue of current research for sustainable food grain production. Extensive use of agro-chemicals in conventional farming has led to negative environmental impacts such as soil erosion, ground water pollution and atmosphere contamination. Farming systems should be more sustainable to reach economical and social profitability as well as environmental preservation. SPAD meter is a non-destructive hand-held instrument which measures leaf transmittance at two wavelengths absorbed by single leaves. The SPAD meter readings have been found to be significantly correlated with leaf N concentration and dry matter yield in wheat (Follett and Follett 1992; Peltonen *et al*. 1995; Shukla *et al*. 2004 and Spaner *et al*. 2005). Kyaw (2003) observed that SPAD threshold 44 guided application of 20 kg N ha^{-1} at maximum tillering stage improved wheat yield in the lower Gangetic plains in Bangladesh. Peng *et al*. (2006) reported that SPAD meter have been used successfully to increase N-use efficiency while maintaining high yields in rice production. Over application of N by the farmers to get ensure good crop production reflects in leaf colour subjective indicator of the need for N fertilizer resulting in low recovery efficiencies. The excessive use of N may cause weed problems & could result in an increased risk of lodging, delayed maturity and greater wheat susceptibility to diseases (Skjodt, 2003).

In Eastern part of India, wheat is grown with a recommended dose of 120-150 kg N/ha applied in two equal splits basal N at land preparation or planting and N topdressing at crown root initiation (CRI) stage along with first irrigation. As N applications to irrigated wheat are linked to irrigation events, farmers often apply an extra dose of N with the irrigation events at maximum tillering stage to avoid the risk of N deficiency. Suitable criteria to determine the timing and amount of N in split are not adequate. Hence, the challenge for farmers is to convert the applied N in soil to grain yield with maximum efficiency because N is one of the most critical inputs to cereals. The study emphasizes the development and evaluation of need based fertilizer N management in improving N use efficiency in wheat using SPAD meter in alluvial belt of Indian sub-tropic for higher yields and sustainable environment.

MATERIALS AND METHODS

Experimental site

Field experiment was conducted in the research farm of Bihar Agricultural University, Sabour, Bhagalpur (25°152 402 2 N latitude, 87°22 422 2 E longitude and an elevation of 37.0 m a.s.l.), India for developing need based N management strategies in wheat through SPAD meter. The soil of the location is silty clay loam in texture and low in fertility status. The climate of Bhagalpur is characterized by hot and humid summer (April and May), rainy during June to September, moderately hot and dry autumn (October and November), cool and dry winter (December and January) and moderate spring (February and March). The site receives annual average rainfall of 1200 mm of which 70-75% occurred in the monsoon months (June to October). The average temperature varies from 19°C in December/January to 29.6°C in May/June.

Experimental details and treatments

The experiment was carried out during the dry season (November to April) of 2013-14 in Completely Randomized Block Design (RCBD) with three replications. The experiment included twelve treatment combinations of four SPAD values (38, 40, 42, and 44) and three N levels defined as low (15 kg ha^{-1}), medium (20 kg ha^{-1}) and high (25 kg ha^{-1}) respectively at each topdressing under real time N management (RTNM), one fixed time N management (FTNM) with 120-60-40 kg N-P_2O_5-K_2O ha^{-1}, and control (zero-N). The plot size for each treatment was 6m × 3m. All treatment combinations except control received 60-60-40 kg N-P_2O_5-K_2O ha^{-1} as basal. In the RTNM treatments, N was topdressed in the form of urea when the SPAD value went below the threshold level up to the first flowering. In FTNM, N was topdressed at 30 kg ha^{-1} each at CRI and jointing stages of wheat crop. The SPAD meter (SPAD 502) was used for SPAD measurement started from CRI (22 days after sowing - DAS) and was continued up to the soft dough stage (85 DAS) at 10 days interval for all treatments and replications. The fully youngest expanded leaf was used for the SPAD measurement. Readings were taken on one side of the midrib of the leaf blade, midway between the leaf base and tip. A mean of 15 readings per plot was taken as the measured SPAD value. The sources of chemical fertilizers were urea, single super phosphate and muriate of potash.

The details of treatment combinations are as follows:

$T_1 = S_{38}N_{15}$	$T_4 = S_{40}N_{15}$	$T_7 = S_{42}N_{15}$	$T_{10} = S_{44}N_{15}$	T_{13} = FTNM (120-60-40 kg N-P_2O_5-K_2O ha^{-1})
$T_2 = S_{38}N_{20}$	$T_5 = S_{40}N_{20}$	$T_8 = S_{42}N_{20}$	$T_{11} = S_{44}N_{20}$	T_{14} = Control (No fertilizer)
$T_3 = S_{38}N_{25}$	$T_6 = S_{40}N_{25}$	$T_9 = S_{42}N_{25}$	$T_{12} = S_{44}N_{25}$	

FTNM = Fixed time N management

Crop management

Wheat variety 'HD 2733' was used for this investigation. It is most popular variety of wheat grown in India for several decades and provides good yield. It takes about 130-135 days to mature at Bhagalpur condition in India. Basal dose of fertilizer as per the treatments was applied and incorporated in each plot at one day before sowing of wheat. Wheat crop was sown on 25th November in 2013 at a spacing of 20 cm between rows.

Observations recorded

An area 5 m^2 from each plot was ear–marked for destructive sampling and the rest of the plot was used for yield estimation. Various biometric data were recorded at different growth stages of the crop from the ear–marked area of each plot and economic yield was estimated at final harvest. The number of earhead m^{-2}, number of spikelets $earhead^{-1}$, number of grains $earhead^{-1}$ and test weight of grain were recorded from each plot at maturity. The crop was harvested from 10 m^2 area for yield estimation in each plot. After threshing the grain and straw were dried in the sun for 3-4 days and their weights were recorded. The grain and straw yields were converted into kg ha^{-1} and corrected to 12% moisture content. Harvest index was estimated dividing the grain yield by biological yield and expressed in percentage.

Efficiency estimation

The nitrogen use efficiency (NUE) in terms of agronomic N use efficiency (AE_N), nitrogen recovery efficiency (RE_N), internal N use efficiency (IE_N), and partial factor productivity of applied N (PFP_N) as described by Huang *et al*. (2008), and Singh *et al*. (2012) were computed as follows:

$$AE_N\,(kg\,kg^{-1}) = \frac{Grain\ yield\ in\ N\ fertilized\ plot, kg\,ha^{-1} - Grain\ yield\ in\ control\ plot, kg\,ha^{-1}}{Quantity\ of\ N\ fertilizer\ applied\ in\ fertilized\ plot, kg\,ha^{-1}}$$

$$RE_N\,(kg\,kg^{-1}) = \frac{Total\ N\ uptake\ in\ fertilized\ plot, kg\,ha^{-1} - Total\ N\ uptake\ in\ control\ plot, kg\,ha^{-1}}{Quantity\ of\ N\ fertilizer\ applied\ in\ fertilized\ plot, kg\,ha^{-1}}$$

$$IE_N\,(kg\,kg^{-1}) = \frac{Grain\ yield, kg\,ha^{-1}}{Total\ N\ uptake, kg\,ha^{-1}}$$

$$PEP_N\,(kg\,kg^{-1}) = \frac{Grain\ yield, kg\,ha^{-1}}{Quantity\ of\ N\ fertilizer\ applied, kg\,ha^{-1}}$$

Statistical analysis

The data were analyzed statistically by applying "Analysis of Variance" (ANOVA) technique of RCBD (Cochran and Cox 1985). The significance of different sources of variations was tested by Error mean square of Fisher Snedecor's 'F' test at probability level 0.05. Standard error of mean (SEm±) and least significant difference (LSD) at 5% level of significance were worked out for each character and provided in the summary tables of the results to compare the difference between the treatment means. The relationship between the

SPAD value and grain yield was evaluated through regression analysis.

RESULTS

Wheat yield components

The yield components of wheat such as earheads m^{-2}, grains $earhead^{-1}$, and test weight responded well to N management practices (Table 1).

Table 1
Earhead number, grain number, earhead length and test weight of wheat grown under different nitrogen management practices

Treatments	*N rate (kg ha^{-1})*	*Earhead m^{-2}*	*Grains earhead^{-1}*	*Test Weight (g)*
$S_{38}N_{15}$	55	227	48	40.0
$S_{38}N_{20}$	60	213	53	39.4
$S_{38}N_{25}$	65	223	56	39.8
$S_{40}N_{15}$	70	237	55	41.6
$S_{40}N_{20}$	60	223	54	40.3
$S_{40}N_{25}$	65	227	56	40.8
$S_{42}N_{15}$	85	287	56	39.4
$S_{42}N_{20}$	93	303	56	41.0
$S_{42}N_{25}$	82	277	50	41.1
$S_{44}N_{15}$	85	277	55	39.6
$S_{44}N_{20}$	100	310	57	41.4
$S_{44}N_{25}$	98	280	55	39.5
FTNM	120	283	51	39.0
Control	0	163	35	36.5
SEm(±)		12	2	1.0
LSD (0.05)		34	6	2.9

*S = SPAD threshold value; N = Nitrogen top dressing in kg N ha^{-1} in each application; FTNM = Fixed time nitrogen management; SEm(±) = Standard error of mean; LSD = Least significant difference

The highest number of ear heads m^{-2} (310) was recorded in $S_{44}N_{20}$ followed by (303) in $S_{42}N_{20}$. However it was at par with the FTNM. The lower SPAD levels obtained (S_{38} and S_{40}) significantly lower ear head number than that of S_{42} and S_{44}, whereas they are at par with each other. It was noticed from the results that medium rate (20 kg ha^{-1}) of N top dressing at S_{42} and S_{44} were most suitable for producing large number of ear heads m^{-2}. The N management practices did not exerted marked effect on number of grains $earhead^{-1}$ and test weight of wheat. The highest number of grains $earhead^{-1}$ (57 and 56) and greater test weight of grain (41.4g and 41.0g) were recorded at medium rate of N management with S_{42} and S_{44} respectively, which were comparable with FTNM.

Wheat productivity

Grain yield responded well to N management practices. Among the RTNM, N application at S_{38} and S_{40} recorded significantly lower grain yield than that of SPAD index 42 and 44 at all N management practices (Table 2). At higher SPAD level (S_{42} and S_{44}), changing the N application rate from low (15 kg ha^{-1}) to medium (20 kg ha^{-1}) level resulted in a increase in grain yield. Further increasing the N application to 25 kg ha^{-1} reduced the grain yield, though they were at par. The highest grain yield (4903 kg ha^{-1}) was recorded with medium rate of N top dressing at highest SPAD ($S_{44}N_{20}$) followed by $S_{42}N_{20}$ (4800 kg ha^{-1}) and both were significantly greater than low SPAD; but statistically at par with each other and FTNM treatment. The medium rate (20 kg ha^{-1}) of N top dressing at S_{42} and S_{44} value were not only produced high grain yield as compared to that of high rate of N top dressing in RTNM and FTNM, but also saved considerable amount of N fertilizer.

The highest straw yield (6036 kg ha^{-1}) was produced with FTNM (Table 2), which was significantly higher than all other treatments except medium and high rate (20 and 25 kg ha^{-1}) of N top dressing at highest SPAD (S_{44}). The straw yield (5689 kg ha^{-1}) also recorded highest at medium rate of N top dressing (20 kg ha^{-1}) at S_{44} which was superior over S_{38} and S_{40}, but statistically at par with S_{42} with medium rate (20 kg ha^{-1}) of N top dressing. Use of medium N rate (20 kg ha^{-1}) at highest SPAD (S_{44}) in RTNM produced the highest straw yield among RTNM with 16.7% saving of chemical fertilizer as compared to FTNM. This indicates that judicious (timely and adequate) use of N fertilizer through RTNM can considerably reduce the N rate without reducing straw yield. The harvest index did not vary significantly among the different N management practices under RTNM and FTNM during the study.

Table 2
Productivity of wheat recorded under different nitrogen management practices

Treatments	*N rate (kg ha^{-1})*	*No. of split of applied N*	*Grain yield (kg ha^{-1})*	*Straw yield (kg ha^{-1})*	*Harvest Index (%)*
$S_{38}N_{15}$	55	2	3050	3746	44.9
$S_{38}N_{20}$	60	2	3317	3941	45.8
$S_{38}N_{25}$	65	2	3400	4121	45.2
$S_{40}N_{15}$	70	3	3833	4093	48.4
$S_{40}N_{20}$	60	2	3133	3830	45.0
$S_{40}N_{25}$	65	2	3350	3863	46.5
$S_{42}N_{15}$	85	4	4683	4940	48.7
$S_{42}N_{20}$	93	4	4800	5203	48.0
$S_{42}N_{25}$	82	3	4350	4767	47.9
$S_{44}N_{15}$	85	4	4553	4967	47.9
$S_{44}N_{20}$	100	4	4903	5689	46.4
$S_{44}N_{25}$	98	4	4718	5633	45.6
FTNM	120	3	4550	6036	43.0
Control	0	-	1733	2516	40.9
SEm(±)			126	240	1.4
LSD (0.05)			366	697	4.0

*S = SPAD threshold value; N = Nitrogen top dressing in kg N ha^{-1} in each application; FTNM = Fixed time nitrogen management; SEm(±) = Standard error of mean; LSD = Least significant difference

However, relatively higher value of harvest index was recorded with low (15 kg ha^{-1}) and medium rate of N top dressing (20 kg ha^{-1}) at S_{44} than those of other N management practices. Better grain filling of wheat under this treatment might be responsible for improving the harvest index of the crop.

Nitrogen use efficiency

The N use efficiency in terms of agronomic N use efficiency (AE_N), nitrogen recovery efficiency (RE_N), internal N use efficiency (IE_N) and partial factor productivity of applied N (PFP_N) were studied (Table 3). The higher SPAD (S_{42} and S_{44}) recoded markedly higher AE_N than that of lower SPAD (S_{38} and S_{40}) at all rate of N top dressing. However the SPAD index 42 and 44 were at par with each other. The FTNM treatment recorded significantly lower AE_N than all the N top dressing of S_{42} and S_{44} with achieving higher dose of N rate. Overall, the AE_N increased by 19.3% in RTNM over that of FTNM and the medium rate of N top dressing at SPAD 42 ($S_{42}N_{20}$) increased AE_N by 29.0% over that of FTNM. The highest RE_N (1.09%) was recorded in $S_{42}N_{25}$ followed by $S_{42}N_{20}$ (1.00%) which were statistically at par with FTNM (0.86%). However, the former treatments and FTNM were recorded significantly higher RE_N over lower SPAD (S_{38}) with lowest rate (15 kg ha^{-1}) of N top dressing. The results showed need based N top dressing as per SPAD value was better option of N management in wheat for increasing yield and N use efficiency. The IE_N varied significantly among the different N management practices under RTNM. It decreased steadily and significantly by changing the rate of N top dressing from 15 to 25 kg N ha^{-1} irrespective of SPAD levels. Increasing SPAD levels also decreased IE_N during the study. The N management practices under RTNM did not show much significant effect on PFP_N of wheat. The PFP_N decreased gradually due to

Table 3
Nitrogen use efficiencies of wheat at maturity under different nitrogen management practices

Treatments	*N rate (kg ha^{-1})*	*A_{EN} (kg kg^{-1})*	*REN (%)*	*IEN (kg kg^{-1})*	*PFP_N (kg kg^{-1})*
$S_{38}N_{15}$	55	23.9	0.62	43.14	55.5
$S_{38}N_{20}$	60	26.4	0.91	36.29	55.3
$S_{38}N_{25}$	65	25.6	0.94	35.14	52.3
$S_{40}N_{15}$	70	30.0	0.72	44.25	54.8
$S_{40}N_{20}$	60	23.3	0.79	37.58	52.2
$S_{40}N_{25}$	65	24.9	0.93	34.71	51.5
$S_{42}N_{15}$	85	34.7	0.77	45.98	55.1
$S_{42}N_{20}$	93	33.1	1.00	37.41	51.8
$S_{42}N_{25}$	82	32.0	1.09	35.05	53.5
$S_{44}N_{15}$	85	33.2	0.80	43.83	53.6
$S_{44}N_{20}$	100	31.7	0.86	40.38	49.0
$S_{44}N_{25}$	98	30.7	0.80	41.55	48.7
FTNM	120	23.5	0.86	32.81	37.9
Control	0			47.43	
SEm(±)		1.6	0.08	1.61	1.9
LSD (0.05)		4.6	0.24	4.68	5.6

*S = SPAD threshold value; N = Nitrogen top dressing in kg N ha^{-1} in each application; FTNM = Fixed time nitrogen management; SEm(±) = Standard error of mean; LSD = Least significant difference increasing the rate of N top dressing and it decreased further at increasing SPAD levels 42. Among the N management treatments, the highest PFPN (55.1 kg kg^{-1}) value was recorded with low rate (15 kg N ha^{-1}) of N top dressing at SPAD 42. The FTNM provided significantly lower values of PFPN as compared to those all other treatments. Overall, RTNM recorded 28.2% higher value of PFPN than that of FTNM.

Table 4
Effect of nitrogen management practices on economics of wheat production

Treatments	*N rate (kg ha^{-1})*	*Cost of cultivation (Rs. ha^{-1})*	*Gross return (Rs. ha^{-1})*	*Net return (Rs. ha^{-1})*
$S_{38}N_{15}$	55	24055	49496	25442
$S_{38}N_{20}$	60	24535	53691	29156
$S_{38}N_{25}$	65	24740	55121	30381
$S_{40}N_{15}$	70	25645	61593	35949
$S_{40}N_{20}$	60	24260	50830	26570
$S_{40}N_{25}$	65	24665	54113	29448
$S_{42}N_{15}$	85	27335	75190	47855
$S_{42}N_{20}$	93	27585	77203	49619
$S_{42}N_{25}$	82	26548	70017	43470
$S_{44}N_{15}$	85	27140	73267	46128
$S_{44}N_{20}$	100	27905	79239	51334
$S_{44}N_{25}$	98	27484	76408	48924
FTNM	120	27520	74286	46766
Control	0	19400	28516	9116
SEm(±)		246	1976	1740
LSD (0.05)		715	5744	5057

*S = SPAD threshold value; N = Nitrogen top dressing in kg N ha^{-1} in each application; FTNM = Fixed time nitrogen management; SEm(±) = Standard error of mean; LSD = Least significant difference

Economics

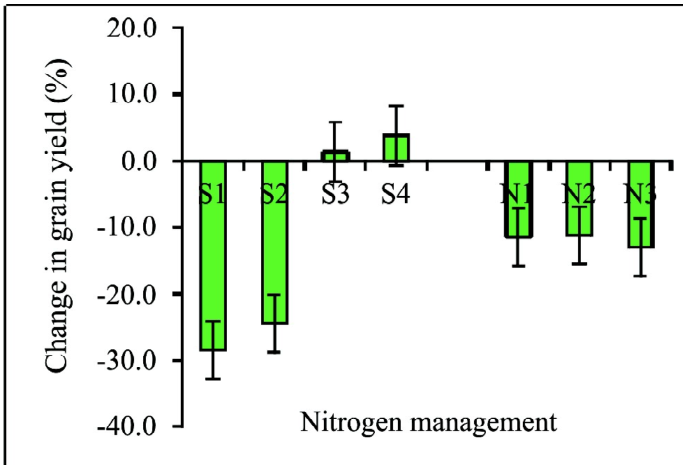
The highest cost of wheat cultivation (Rs. 27,905 ha^{-1}) was noted with medium rate (20 kg ha^{-1}) of N top dressing at high SPAD (S_{44}). The gross and net returns increased steadily by increasing N application up to high rate (25 kg ha^{-1}). The medium rate of N top dressing at S_{44} reported the highest gross and net return which was comparable with all N rates at S_{42} (Table 4). The gross and net return of FTNM was comparable with the S_{42} and S_{44}, but was significantly higher over S_{38} and S_{40}. The highest gross (Rs. 79239 ha^{-1}) and net (Rs. 51334 ha^{-1}) returns were obtained with medium rate of N top dressing (20 kg ha^{-1}) at SPAD 44, which was comparable to those with high N rate (35 kg ha^{-1}) at same SPAD, and medium rate of N top dressing (20 kg ha^{-1}) at S_{42}.

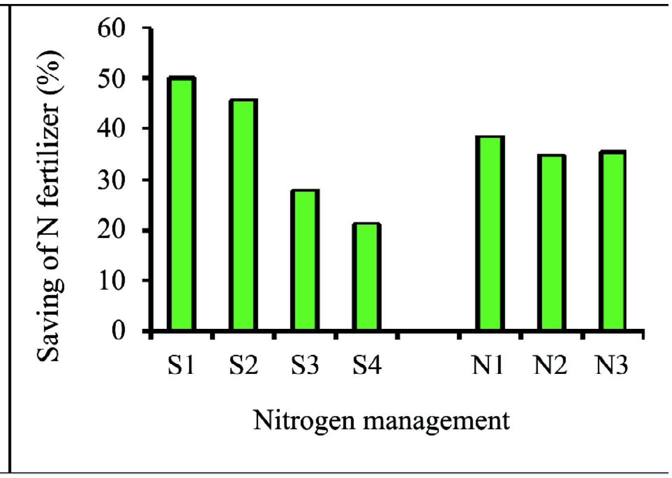
DISCUSSION

Yield components and productivity of wheat

Ear-bearing tillers played important role in grain formation and productivity of wheat. Medium and high rate of N (20 and 25 kg ha^{-1}) topdressing at medium and high SPAD (S_{42} and S_{44}) in RTNM produced greater number of ear-head m^{-2}, grains ear-$head^{-1}$, ear head length and test weight of wheat than those with low rate of N (15 kg ha^{-1}) top dressing at all SPAD values; but comparable to those obtained in FTNM. The increased dry matter during jointing and grain filling promoted ear-head production, grain filling percentage and test weight and finally increased grain yield in the real-time N management treatments (Ling 2000; Pirjo *et al.*, 2009). The highest grain yield (4903 kg ha^{-1}) produced with medium rate of N (20 kg ha^{-1}) top dressing at high SPAD (S_{44}) was comparable to those with high rate of N (25 kg ha^{-1}) top dressing at medium and high SPAD ($S_{42}$and S_{44}). The lower in grain yield, despite receiving highest N rate in FTNM was due to relatively lower number of ear bearing tillers, grains per ear-head and low test weight as compared to those of SPAD based N management in RTNM (Singh *et al.*, 2010; Peng *et al.*, 2012; Walsh *et al.*, 2013). Optimization of SPAD value at critical stages of wheat is most important in regulating growth and maximizing grain productivity. In our study, SPAD 42 and 44 had comparable grain yield, but SPAD 42 had lower N requirement than SPAD 44. Hence, for precision N management aiming at increasing grain yield with improving N use efficiency, the optimal SPAD threshold was evaluated as 42 (Hussain *et al.*, 2003; Kyaw 2003). Maiti and Das (2006) found that SPAD based N management can save 40-72.5 kg N ha^{-1} over the blanket N application without reduction in grain yield. Application of 150 kg N ha^{-1}

following threshold SPAD value of 38 produced wheat grain yield equivalent to that obtained with blanket application of 180 kg N ha^{-1} in two split doses in the middle IGP of Pantnagar in India (Singh *et al*., 2010). Our data suggest that use of excessive N input might have reduced the yield advantage of FTNM over RTNM (Figure 1). Total amount of N application varied from 55 to 100 kg N ha^{-1} on the basis of SPAD and it covered well the range of wheat grain yield of this region. In our study, SPAD based N application in RTNM could considerably reduce the N application rate by 17 to 29% of the existing N fertilizer recommendation in FTNM without reducing the wheat grain yield (Figure 2). Similar beneficial effect of SPAD based N management in wheat also observed by Shukla *et al*. (2004), Khurana *et al*. (2008) and Singh *et al*. (2010).





S_1, S_2, S_3 and S_4 represent SPAD threshold levels of 38, 40, 42 and 44 respectively; N_1, N_2 and N_3 represent N top dressing at 15, 20 and 25 kg ha^{-1} respectively.

Figure 1: Change in grain yield of wheat under SPAD based real time N management over fixed time dose of N management.

Figure 2: Saving of N fertilizer use under SPAD based real time N management over fixed time dose of N management in wheat crop.

Nitrogen use efficiency in wheat

Significant increases in AE_N and RE_N were achieved through SPAD based N management by many workers over farmers' fertilizer practices (Dobermann *et al*., 2004; Singh *et al*., 2012; Diacono *et al*., 2013). The increase in AE_N with medium rate of N top dressing at medium SPAD was associated with increase in grain yield with less fertilizer N use over that of high rate of N top dressing at high SPAD and FTNM (Singh *et al*., 2002; Tubana *et al*., 2008; Peng *et al*., 2012). Overall, RTNM increased AE_N by 19.3% over that of FTNM. But the crop at FTNM recorded RE_N comparable to that of other N management practices under RTNM. The SPAD based N top dressing appears to be a better option of N management in wheat for increasing yield and N use efficiency. FTNM recorded considerably lower value of IEN than that of RTNM and it decreased by 17.2% in comparison to those of RTNM under the study. N application in middle and late growth periods will enhance the photosynthetic productivity and encourage the N uptake after heading stage. Low rate N application in low/ medium SPAD under RTNM promoted larger ear heads, increased test weight, harvest index, and overall improved yield efficiency indices (Pathak *et al*., 2003; Peng *et al*., 2012). Our result showed that low rate of N (15 kg ha^{-1}) top dressing at low to medium SPAD was conducive for improving IE_N in wheat. The results corroborate the findings of Raun *et al*. (2001), Shukla *et al*. (2004) and Singh *et al*. (2010). The high PFPN in wheat was recorded with low rate of N (15 kg ha^{-1}) top dressing at SPAD 42, which were greater than those of moderate to high (20-25 kg N ha^{-1}) rate of N top dressing at SPAD 44 under RTNM. Khurana *et al*. (2008) also noticed increased PFPN by 7.72 kg kg^{-1} (26%) indicating greater saving of N fertilizer with positive increment of fertilizer N use efficiency. RTNM increased PFPN by 28.2% over those of FTNM. The results showed low and medium rate (15 and 20 kg ha^{-1}) of N top dressing at medium SPAD (S_{40}) was conducive for improving PFPN wheat under mild and short winter condition of the Indian subtropics. Similar positive effect of low rate of N top dressing at low SPAD in RTNM on wheat productivity and N use efficiency was also reported by Takebe *et al*. (2006), Zebarth *et al*. (2007) and Tubana *et al*. (2008).

Economics of wheat

High yield and maintaining sustainability of wheat crop required relatively high rate of nutrient supply that regulate largely the economics of the cereal crop. Fixed rate of N application at specific growth stages of wheat under FTNM resulted in more N application incurring more cost without much economic gain (Koch *et al*., 2004; Berntsen *et al*., 2006; Roberts, 2009). The medium rate of N topdressing (20 kg ha^{-1}) at S_{44} gave the highest gross (Rs. 79239 ha^{-1}) and net (Rs. 51334 ha^{-1}) returns under the study. It recorded comparable gross and net return to those with low and medium N rate (15 and 25 kg ha^{-1}) at S_{42}. The results suggested that judicious and timely nutrient management was necessary in improving the economics of intensive cropping system (Biswas *et al*., 2006; Mondal *et al*., 2013). Pre-determined rate of N application at specific growth stages in FTNM though fetched good economic return but incurred higher fertilizer N consumption than required to reach the expected yield (Roberts, 2009; Yao *et al*., 2012). It appeared from our results that moderate rate of N (20 kg N ha^{-1}) topdressing at high SPAD could yield high gross and net returns. Similar beneficial effect of SPAD based N management in cereal based cropping systems was also obtained by Cui *et al*. (2008), Kitchen *et al*. (2010) and Scharf *et al*. (2011). Thus, moderate N rate (20 kg N ha^{-1}) at high SPAD was recommended for precision N management aiming at greater profit with higher N use efficiency.

CONCLUSIONS

Blanket recommendations of N fertilizer may serve well for achieving the good wheat yield, but lead to poor N use efficiency and unable to maintain the sustainability. The bridge between the demand and supply of N can reduce the loss by matching crop N demand with supply. The SPAD meter can be used to measure the leaf N status nondestructively for guiding need based N application. In our results, a marginal increase in wheat grain yield at medium SPAD (S_{42}) was noticed as compared to that of fixed time N management with a saving up to 30% N fertilizer. The study suggests that SPAD meter based N management saved about 30% of the existing N fertilizer recommendation in FTNM. Maintaining SPAD threshold value of 42 with topdressing 20 kg N ha^{-1} at each time had significant positive effect on grain yield with a saving of N fertilizer as compared to FTNM. The SPAD value of 42 was found to be critical for wheat in eastern India. The findings strongly suggest the revision of current recommendations in the rate and timing of N fertilizer application to maintain SPAD value e"42 up to heading stage to improve growth and productivity of wheat in the subtropics of eastern India.

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