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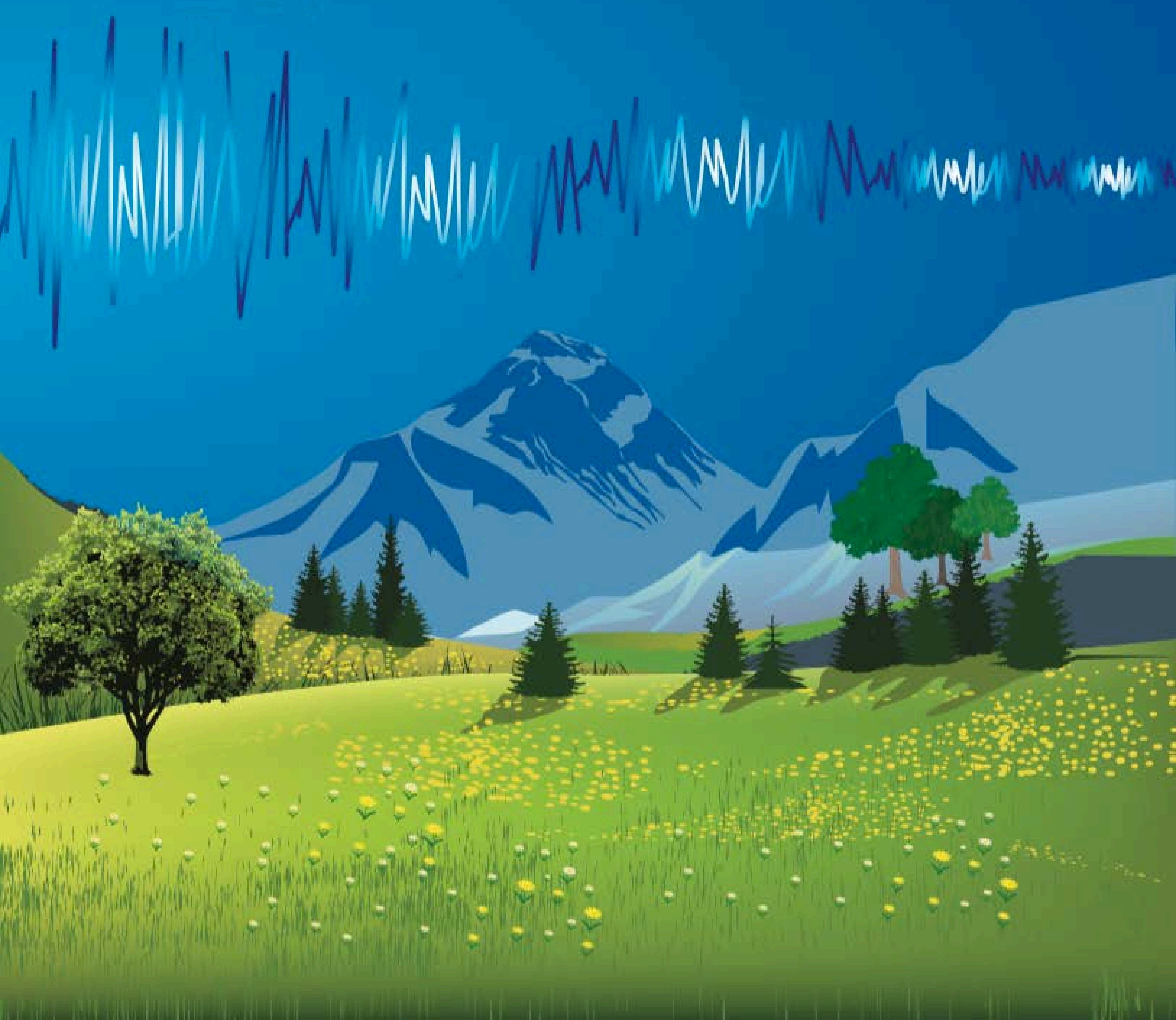

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In-season nitrogen fertilizer management in irrigated wheat based on available decision support tools

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Abstract
Efficient management of nitrogen (N) fertilizer, i.e., minimizing N loses from a rice-wheat cropping system is a major challenge. To identify the efficient and appropriate decision tools to increase N use efficiency (NUE) in wheat crop (cv, Vijaya), a field experiment was conducted at Regional Agricultural Research Station, Khajura, Banke, Nepal during 2017-2019. Eight N fertilizer treatments from combination of application methods and other available decision support tools were tested in a randomized complete block design with three replicates. The treatments consist control (0 kg N ha^{-1}), decision support tools for N management such as use of optical sensor, SPAD meter, leaf color chart (LCC) in combination with basal N fertilization and conventional broadcast application at 100 kg N ha^{-1}. Application of N fertilizer based on decision support tools had significant ($p<0.05$) effects on grain yields. The highest grain yield (3.84 ton ha^{-1}, average across two years) was recorded in the conventional broadcast method, which was at par with optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application. Results suggest that use of optical sensor could reduce N use as much as by 50 kg ha^{-1}.Similarly, use of optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application could save N by 37.5 kg N ha^{-1} and 29.2 kg N ha^{-1}, respectively. The highest agronomic NUE (37.7 kg grain kg^{-1} N) and partial factor productivity of N (PFPN) of 58.7 kg kg^{-1} N was observed in optical sensor guided N management with 25 kg N as basal application. These results indicated that optical sensor and LCC could save N significantly without compromising grain yields. There were significant correlation between NDVI value, SPAD value and LCC value measured at 45 DAS to 75 DAS and grain yield. This indicated that measurement of NDVI, SPAD value and LCC value allow a practical window for in-season N management in wheat.

Key Word: Leaf color chart (LCC), NDVI, Optical sensor, SPAD meter

Introduction

The current recommendations for nitrogen fertilizer typically consist of fixed rate and timing for large tracts to grow wheat (Triticum aestivum L. emend. Fiori & Paol.). Depending on the type of rice and wheat culture and the region, blanket recommendations in different parts of the country vary from 60 to 150 kg N ha^{-1} to be applied in two or three split doses. These blanket recommendations for fertilizer N are developed for large tracts having similar climate and land forms in the quest of achieving high yield levels and fertilizer-use efficiency. These have served the purpose very well but could not help increase the nutrient-use efficiency beyond a limit. Over-application of N fertilizer in cereal crops leads to further lowering of N recovery efficiency. Its application in excess of crop requirements also leads to higher cost of production, increased attack of pests and diseases as well as the possibility of nitrate pollution of ground water and emission of greenhouse gases like nitrous oxide. The nitrogen-use efficiency in rice and wheat is low.

A recent world-wide evaluation shows that the fertilizer N recovery efficiency is around 30% in rice and wheat with current practices (Krupnik et al., 2004). Due to large field to-field variability of soil N supply, efficient use of N fertilizer is not possible when broad-based blanket recommendations for fertilizer N are used (Adhikari et al., 1999). The recommendations based on soil tests remain ignorant about the dynamics of N release from crop residues, organic manures and irrigation water, and are not very successful in rice and wheat. Thus the farmers often apply nitrogenous fertilizers over and above the recommended doses to ensure higher yields by avoiding the risk of N deficiency.

The main reason of low N-use efficiency is inefficient splitting of N applications, including the use of N in excess to the requirements. The need of the time is to synchronize the N application with crop demand. In addition to field-to-field variability, the strategies for fertilizer N management must be responsive to temporal variations in crop N demand and soil N supply to achieve supply-demand synchrony and to minimize N losses. When N application is not synchronized with crop demand, N losses from the soil–plant system are large, leading to low use efficiency of N fertilizer. Peng and Cassman (1998) demonstrated that recovery efficiency of top-dressed urea during panicle initiation stage could be as high as 78%. Thus it seems that improvement in the synchrony between crop-N demand and N supply from soil or the applied N fertilizer is likely to be the most promising strategy to increase N-use efficiency in rice and wheat.

There are various decision support tools introduced into farm production of late aim at precise and need based fertilizer recommendation. In the past, various aspects of fertilizer recommendation techniques were deliberated thoroughly by number of reviewers

(Alam, et al. 2006; Biradar et al. 2012; Bijay-Singh et al. 2012, Costa et al. 2001, Harmandeep et al. 2010). Nevertheless, the comprehensive coverage of different decision support tools is still very meager. The tools and technique needs to be quick, effective and inexpensive, and should allow on-the-spot decision making (Patil 2009). Recently, tools such as Green seeker optical sensor, Chlorophyll meter-SPAD (Soil Plant Analysis Development) have been testing and some of them are available for site-specific and need-based N management in rice and wheat (Varinderpal-Singh et al. 2010).

The Green seeker optical sensor measures Normalized Difference Vegetation Index (NDVI) a unit which is based on the reflectance at red and near infrared (NIR) regions. NDVI is an empirically derived vegetation index related to leaf area index (LAI), biomass and predict yield (Raun et al. 2001; Ma et al. 2001; Inman et al. 2007; Gnyp et al. 2014). Chlorophyll meter is used to estimate crop N status since most N in the plant system is contained in the rubisco enzyme found in chloroplasts and chlorophyll proteins and there is a close relationship between leaf N and leaf chlorophyll content (Peng et al. 1996). Chlorophyll meter can indicate N deficiencies early enough to correct before yield potential is affected. Applying fertilizer based on crop need as determined by chlorophyll meter readings increases fertilizer use efficiency (Peng et al. 1996). Leaf colour chart (LCC), a hand held plastic strip, that can be used as a complementary decision making tool to determine the need for N application in field periodically. Leaf color chart has now been used successfully to guide fertilizer N application in rice, wheat and maize (Yadvinder Singh et al. 2007; Varinderpal-Singh et al. 2010, 2011). It is a comprehensive and decisive apparatus that takes in to account soil supply, crop uptake and plant health on real time basis. It helps achieve need based variable rate of N application to crops based on soil N supply and crop demand. It is a simple, ideal and an eco-friendly tool to optimize N use, irrespective of the source of N; native soil N, applied fertilizer source etc. Effective management of fertilizers, particularly N for wheat remains a major challenge to researchers and producers. Therefore, there is a need to relook in to our traditional method of fertilizer application to enhance N use efficiency. To address this issue a study was carried out with the objective

- To identify the efficient and appropriate decision tools to increase N use efficiency (NUE) in irrigated wheat.

2. Materials and methods

2.1 Study site and weather condition

The field experiments were conducted at Regional Agricultural Research Station, Khajura, Banke district, province no. 5, located at 28⁰11'30"N latitude and 81⁰58'89"E longitude. Majority of area followed rice-wheat cropping system. The climate is wet summer and dry winter subtropical. Average annual rainfall ranges from 1000 mm and more than 80% of annual rainfall distributed from June to September and called monsoon during that period and winter is dry and very low rainfall occurs (Figure 1). In this site soils are generally fertile silty clay with low to medium organic matter content (1.5-2.3%), pH neutral to slightly alkaline (6.5-7.5), high cation exchange capacity (CEC) and K, and low to medium Zn, B, and S.

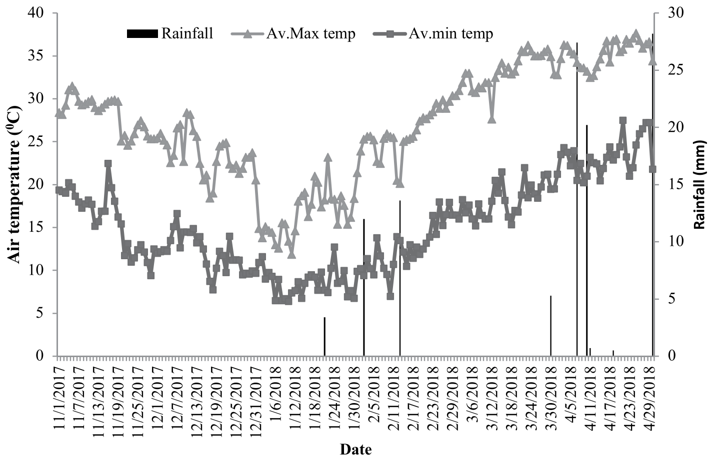

Figure 1: Daily average of rainfall, minimum and maximum temperature of experimental site during crop growing season, Nov 2017 to April 2018 (Source: Department of Hydrology, Government of Nepal, Khajura, Station)

2.2 Experimental set up

The study was carried out by field experiment and consists of eight treatments on decision support tools guidance and with basal N application. The experiment was laid out in randomized complete block design (RCBD) and replicated thrice. The fertilizer treatments were i) control (0 kg N ha^{-1}), ii) Complete optical sensor guided N application iii) Complete SPAD guided N application iv) Complete Leaf Color Chart (LCC) guided N application (v) 25 kg N ha^{-1} basal and rest optical sensor guided N application vi) 25 kg N ha^{-1} basal and rest SPAD guided N application vii) 25 kg basal N ha^{-1} and rest LCC guided N application viii) Conventional recommended 100 kg N ha^{-1} broadcast in three split. Vijaya wheat variety was selected for field trial and it is newly released rust tolerant variety of wheat recommended. Each plot size was 14.4 m^2 (3.6 m x 4 m) and sown in spacing of 25 cm row to row and continuous plant to plant. Seeds were sown in the well tilled plot on 3rd week of November, 2017 and 2018. Phosphorus and Potash were applied in all plots at the time of final land preparation at the rate of 50:25 kg P_2O_5:K_2O ha^{-1} and nitrogen was applied according treatments. Fertilizer sources were Urea, Single Super Phosphate (SSP) and Muriate of Potash. In control treatment no N fertilizer was used. In optical sensor guided, SPAD guided and LCC guided N application treatment amount of N applied were based on response index and critical values. For optical sensor a response index was used in which a reference N rich plot applied with 150 kg N ha^{-1} was established attached with the experiment. When ratio of NDVI measured treatment and reference N rich plot above 1.25 than 25 kg N ha^{-1} applied at one time. Similarly for SPAD critical value

37 was assumed and below 37 value, we applied 25 kg N ha^{-1} applied at one time. In LCC guided treatment critical value of LCC assumed was 4 and when below the critical value 25 kg N ha^{-1} applied at one time. The doses of fertilizer applied with the guidance of decision support tools and conventional practices are presented in table 1. Other cultural operations were same for all the treatments. The crop was harvested on last week of March, 2018 and 2019.

Table 1: Doses of N fertilizer applied in wheat based on decision support tools and conventional recommended practice grown in field experiment at Regional Agricultural Research Station, Khajura, Banke, Nepal, during winter season 2017/2018 and 2018/2019

Treatment	N applied kg/ha										
	2017/2018					2018/2019					
	Basal	30 DAS	45 DAS	60 DAS	Total	Basal	30 DAS	45 DAS	60 DAS	75 DAS	Total
Control	0	0	0	0	0	0	0	0	0	0	0
Complete Optical sensor guided	0	25	25	0	50	0	25	25	0	0	50
Complete SPAD guided	0	25	25	0	50	0	25	16.7	8.3	25	75
Complete LCC guided	0	25	25	16.7	66.7	0	25	25	16.7	16.7	83.4
25 kg N ha^{-1} basal rest Optical sensor	25	25	0	0	50	25	16.7	25	8.3	0	75
25 kg N ha^{-1} basal rest SPAD	25	25	0	0	50	25	0	16.7	16.7	8.3	66.7
25 kg N ha^{-1} basal rest LCC	25	25	0	16.7	66.7	25	8.3	25	8.3	8.3	75
100 kg N ha^{-1} conventional recommended practice	50	25	0	25	100	50	25	0	25	0	100

1.3 Measurement and data collection

The measurement of NDVI, SPAD and LCC was carried out at 30 DAT, 45 DAT, 60 DAT in first year and 30 DAS, 45 DAS, 60 DAS and 75 DAS in second year. Ten plants from each plot have been selected randomly and tagged for recording observations.

The normalized difference vegetation index (NDVI) reading, Chlorophyll count and Leaf Color Chart (LCC) and response index was measured and calculated as following procedures

NDVI measurements

Spectral reflectance expressed as NDVI was measured using a handheld Green Seeker crop sensor (NTech Industries Incorporation, Ukiah, CA, USA). The measurement was carried out by holding the unit at a height of about 1feet above the plant canopy. The optical sensor calculates NDVI as:

NDVI = (NIR _ RED)/(NIR + RED)

Where, NIR and RED are the fractions of near infra red and red radiation reflected back from the sensed area. Chlorophyll count reading was taken by using SPAD and LCC reading was taken by LCC chart designed by IRRI. The measurements were taken at same time and interval as NDVI measurement taken. For NDVI, from each plot ten readings were taken from inside the plot randomly. SPAD and LCC value were measured same time selecting fully matured, disease free upper leaf from 10 plot from each plot.

Recording the Response Index (RI):

Response index with N rich strip to control plot and other treatment plot was calculated for in season N management. Response index of NDVI (RI) was calculated by average NDVI readings from the high N rich strip plots are divided by the average NDVI readings in the check plots. The Response Index (RI) of SPAD and LCC measured reading will be also calculated to see the response of added fertilizer or potential responsiveness to added fertilizer N.

Different nitrogen use efficiencies calculated and their formulas are as follows which are well described by Ladha et al. (2005), Fageria et al. (2010) and Ali et al. (2012) also:

1) **Partial factor productivity (PFPN)**= GY_N/ FN, kg grain yield per kg N applied
2) **Agronomic N use efficiency (AEN)=** GY_N- GY_0/ FN, kg grain yield increase per kg N applied

Where, GY_N= Grain yield when N applied, FN= Fertilizer applied kg, GY_0= Grain yield without N application, without N application treatment

The total dry matter production was measured at harvest. The grains were separated by threshing separately from each net plot and after drying and cleaning grain yield was recorded. Straw from each net plot was dried under sun for 10 days, and weight recorded.

Soil samples were collected before planting and after harvesting from each plots to analyze soil OM, pH, total nitrogen, available P_2O_5 and exchangeable K_2O. Available nitrogen was estimated by following Bremner and Mulvaney (1982). In this method the organic matter in soil is oxidized with hot alkaline $KMnO_4$ solution. The ammonia evolved during oxidation is distilled and trapped in boric acid mixed indicator solution. Available phosphorus is extracted with sodium bicarbonate (0.5 M) at pH 8.5 (Olsen's reagent) and the amount of P in the extract is estimated by chlorostannous reduced phosphomolybdate blue colour method using Spectrophotometer at wave length of 660 nm (Olsen et al. 1954). Available K is extracted with neutral normal ammonium acetate and determined using flame photometer (Jackson 1973).

2.4 Data Analysis

The analysis of variance (ANOVA) was carried out using Genstat 13.2 (VSN International Ltd, Hemel Hempstead, United Kingdom). Homogeneity of variance was tested using Levene's test. The significant differences among the means were tested using least significance difference test (LSD) at 5 % significance level.

2. Results and discussion

3.1. Periodic NDVI, SPAD and LCC Value

Periodic NDVI, SPAD and LCC values measured varied year wise and presented in table 2 and table 3. During both years result of NDVI reading taken at 30 DAS trend showed that the highest NDVI reading was measured in conventional recommended split application and was at par with 25 kg N/ha basal applied in connection with decision support tools. Similar trend also found at 45 DAS and 60 DAS. The NDVI readings reached at maximum at 60 DAS and thereafter remain constant up 75 DAS and decline as getting mature. The lowest reading was recorded in control treatment. Similarly the SPAD value measured was also found highest in conventional recommended split N application. The SPAD value reached peak at 45 DAS and declined then. Similar trend was also seen in LCC value. The LCC value reached maximum at 60 DAS and declined then. Decreasing trend NDVI, SPAD and LCC value after 60 DAS might be due to decreasing greenness or plant start senescence and chlorophyll formation cease which was also supported by SPAD value measured. Our measured NDVI values were similar range 0.55 to 0.85 measured by Raun et al (2002).

Table 2: Effect of fertilizer application techniques on periodic NDVI, SPAD and LCC value of wheat grown in field experiment at Regional Agricultural Research Station, Khajura, Banke, Nepal, during winter season 2018

S.N	Treatment	NDVI			SPAD			LCC		
		30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
1.	Control	0.56	0.51	0.62	28.69	31.73	34.04	2.7	2.9	2.7
2.	Complete Optical sensor guided	0.53	0.67	0.76	29.5	36.61	40.64	2.5	3.4	3.6
3.	Complete SPAD guided	0.53	0.67	0.77	28.95	35.48	39.19	2.9	3.6	3.7
4.	Complete LCC guided	0.59	0.70	0.78	28.83	38.4	41.2	2.7	3.6	3.8
5.	25 kg N ha^{-1} basal rest Optical sensor	0.76	0.80	0.78	30.57	37.02	38.76	3.1	3.9	3.5
6.	25 kg N ha^{-1} basal rest SPAD	0.75	0.75	0.8	34.38	39.81	39.85	3.3	3.9	3.5
7.	25 kg N ha^{-1} basal rest LCC	0.73	0.79	0.81	34.09	37.9	39.78	3.3	4.2	3.9
8.	100 kg N ha^{-1} conventional recommended practice	0.78	0.8	0.80	36.43	36.64	40.04	3.5	3.9	3.5
F-test		**	**	**	**	**	**	**	**	**
LSD(0.05)		0.06	0.05	0.03	3.5	2.7	1.78	0.38	0.43	0.62
CV%		5.1	4.3	3.0	6.4	4.2	2.6	7.2	6.8	9.9

NS=Not significant, * significant at P<0.05, ** Significant at p<0.01, LSD=Least significance difference, DAS=Days after sowing,

Table 3: Effect of fertilizer application techniques on periodic NDVI, SPAD and LCC value of wheat grown in field experiment at Regional Agricultural Research Station, Khajura, Banke, Nepal, during winter season 2019

S. N	Treatment	NDVI				SPAD				LCC			
		30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS	30 DAS	45 DAS	60 DAS	75 DAS
1.	Control	0.40	0.56	0.57	0.59	28.2	27.7	30.6	28.7	2.5	2.2	3.1	2.9
2.	Complete Optical sensor guided	0.40	0.65	0.76	0.76	25.4	33.4	39.0	33.0	2.4	2.7	3.7	3.3
3.	Complete SPAD guided	0.39	0.62	0.76	0.76	26.6	34.6	36.5	34.2	2.4	2.8	3.7	3.5
4.	Complete LCC guided	0.40	0.63	0.76	0.79	27.6	33.3	38.7	36.2	2.5	2.8	3.4	3.5
5.	25 kg N ha^{-1} basal rest Optical sensor	0.49	0.71	0.7	0.80	32.3	33.3	39.5	34.4	2.9	3.2	3.7	3.5
6.	25 kg N ha^{-1} basal rest SPAD	0.53	0.64	0.74	0.75	36.4	32.8	36.5	36.4	3.1	3.1	3.6	3.6
7.	25 kg N ha^{-1} basal rest LCC	0.46	0.64	0.78	0.79	34.5	32.4	40.6	36.5	3.7	3.0	3.7	3.7
8.	100 kg N ha^{-1} conventional recommended practice	0.50	0.73	0.79	0.82	34.9	37.4	37.7	36.1	2.9	3.3	3.7	3.8
F-test		**	**	**	**	**	**	**	**	**	**	**	*
LSD(0.05)		0.06	0.03	0.07	0.03	4.07	3.58	4.41	2.61	0.25	0.46	0.2	0.49
CV%		8.3	3.1	5.5	2.3	7.6	6.2	6.7	4.3	5.3	9.1	3.3	8.0

NS=Not significant, * significant at P<0.05, ** Significant at p<0.01, LSD=Least significance difference, DAS=Days after sowing,

3.2. Grain and straw yield

Application of N fertilizer based on decision support tools had significant ($p<0.05$) effects on grain and straw yields (Table 4). The highest grain yield (3.84 ton ha^{-1}, average across two years) was recorded in the conventional broadcast method, which was at par with optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application. Similarly, the highest mean straw yield (4.99 ton ha^{-1}) was measured with application 25 kg N ha^{-1} basal rest Optical seonsor guided treatment and was at par with 100 kg N ha^{-1} conventional recommended practice and 25 kg N ha^{-1} basal rest LCC guided treatment

Using decision support tools has significantly ($p<0.01$) reduced the amount of N fertilizer applied for the same level of grain yield. Results suggest that use of optical sensor could reduce N use as much as by 50 kg ha^{-1}. Similarly, for the same yield as conventional broadcast, a use of optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application could save N by 37.5 kg N ha^{-1} and 29.2 kg N ha^{-1}, respectively.

Although the approach followed in the present study is not exactly similar, amount N adjustment was based on critical value we had set with respect to N rich reference plot. There was not so much different on grain yield by using different strategies and decision support tools in N management, difference were much on amount of fertilizer used as per strategies used or decision guide used except control treatment. Using complete optical sensor based fertilizer application strategy only 50 kg N ha^{-1} used but the grain yield was lower as compared to 25 kg N ha-1 rest optical sensor guided treatment.

The nitrogen use efficiency was significantly ($p<0.051$) differed with N applied based on decision support tools (Table 5). The highest agronomic NUE (37.7 kg grain kg^{-1} N) and partial factor productivity of N (PFPN) of 58.7 kg kg^{-1} N was observed in optical sensor guided N management with 25 kg N as basal application and was at par with complete optical sensor guided, 25 kg N/ha basal rest LCC guided , 25 kg N h^{-1} basal rest SPAD guided, complete SPAD guided. In contrast, conventional recommended split application has very low NUE. At lower fertilizer level efficiency was higher that might be due to less external loess through leaching, volatization, runoff and plant crop utilization more.

Therefore considering both yield level and fertilizer amount of N fertilizer saving as produced applying 100 kg N ha^{-1} from conventional blanket recommendation.

In compared 100 kg N ha^{-1} conventional recommended practice using Optical sensor or SPAD, 50 kg N ha^{-1} was saved using for the same yield level so it could be a good implication for fertilizer management strategy for in season N management in wheat but to confirm it further research is required.

Table 4: Effects of fertilizer application techniques on wheat grain and straw yield at Regional Agricultural Research Station, Khajura, Banke, Nepal, during winter season 2018

S. N.	Treatment	N applied kg/ha	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})
1.	Control	0	*1.30*	*2.03*
2.	Complete Optical sensor guided	50	*2.90*	*5.23*
3.	Complete SPAD guided	62.5	*3.18*	*5.09*
4.	Complete LCC guided	75	*3.35*	*5.31*
5.	25 kg N ha^{-1} basal rest Optical sensor	62.5	*3.60*	*6.25*
6.	25 kg N ha^{-1} basal rest SPAD	58.3	*2.95*	*5.16*
7.	25 kg N ha^{-1} basal rest LCC	70.8	*3.66*	*5.67*
8.	100 kg N ha^{-1} conventional recommended practice	100	*3.84*	*5.45*
F-test		*	**	**
LSD(0.05)		16.4	0.38	0.8
CV%		14.4	10.6	13.5

NS=Not significant, * significant at P<0.05, ** Significant at p<0.01, LSD=Least significance difference, DAT=Days after transplanting, DAS=Days after sowing,

Table 5: Effects of fertilizer application techniques on wheat grain and straw yield at Regional Agricultural Research Station, Khajura, Banke, Nepal, during winter season 2018

S.N.	Treatment	N Saving kg ha^{-1}	AUEN(kg kg^{-1} N)	PFPN (kg kg^{-1} N)
1.	Control	100.0		
2.	Complete Optical sensor guided	50.0	*33.4*	*58.0*
3.	Complete SPAD guided	37.5	*31.2*	*52.2*
4.	Complete LCC guided	25.0	*28.9*	*45.8*
5.	25 kg N ha^{-1} basal rest Optical sensor	37.5	*37.7*	*58.7*
6.	25 kg N ha^{-1} basal rest SPAD	41.7	*29.9*	*52.1*
7.	25 kg N ha^{-1} basal rest LCC	29.2	*36.1*	*54.2*
8.	100 kg N ha^{-1} conventional recommended practice	0.0	*26.1*	*38.4*
F-test		*	*	*
LSD(0.05)		16.4	7.32	10.0
CV%		21.5	19.3	16.3

NS=Not significant, * significant at P<0.05, ** Significant at p<0.01, LSD=Least significance difference,

DAS=Days after sowing

There was good correlation between NDVI value, SPAD value and LCC value measured at 60 DAS and grain yield (Figure 2a, 2b,2c). This indicated that increased NDVI value, SPAD value and LCC value can be predict increased grain and straw yield. This is indicated that 60 DAS was the most critical stage determining the yield potentiality of wheat. We can also predict the yield potentiality with the NDVI, SPAD and LCC value measured at 60 DAS. Early measured value i.e 30 DAS gives an indication or windows of an opportunity to apply N in-season top dressing to overcome N limitation along with N losses reduction from blanket application of recommended practice. Among the three tools Optical sensor shown strongest correlation with yield as compared to SPAD and LCC but rest two can be also use.

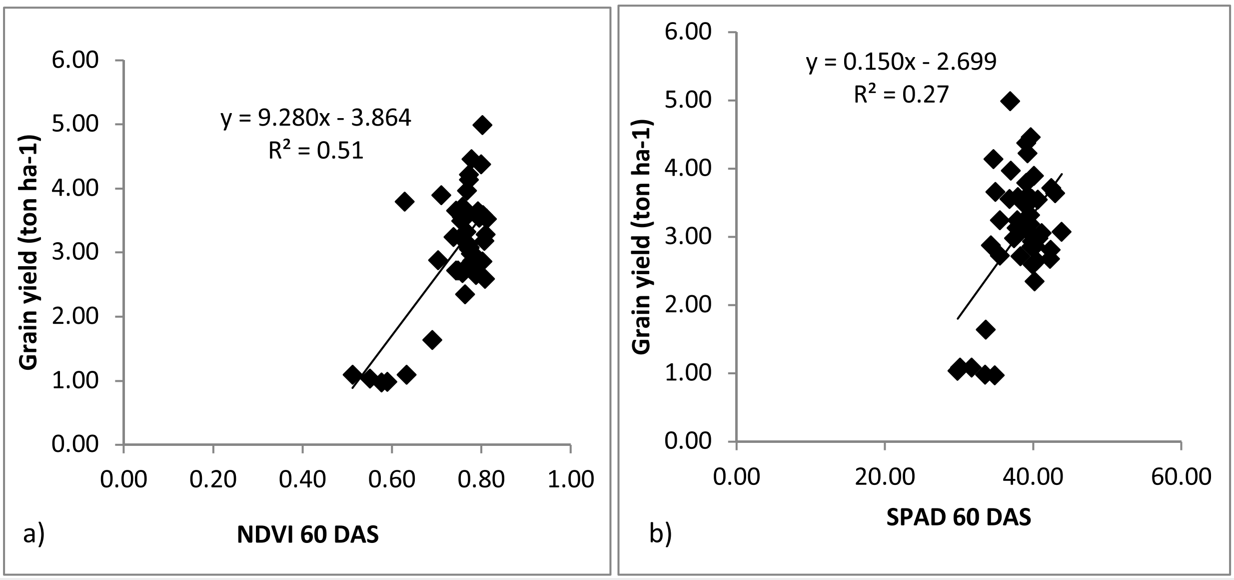

Figure 2: Relationship between wheat grain yield and (a) NDVI value at 45 DAS (b) SPAD value at 45 DAS and (c) LCC value measured at 45 DAS (d) N applied

3. Conclusion

Application of N fertilizer based on decision support tools had significant ($p<0.05$) effects on grain yields. The highest grain yield (3.84 ton ha^{-1}, average across two years) was recorded in the conventional broadcast method, which was at par with optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application. Results suggest that use of optical sensor could reduce N use as much as by 50 kg ha^{-1}.Similarly, use of optical sensor and LCC in combination with 25 kg N ha^{-1} as basal application could save N by 37.5 kg N ha^{-1} and 29.2 kg N ha^{-1}, respectively. The highest agronomic NUE (37.7 kg grain kg^{-1} N) and partial factor productivity of N (PFPN) of 58.7 kg kg^{-1} N was observed in optical sensor guided N management with 25 kg N as basal application. These results indicated that optical sensor and LCC could save N significantly without compromising grain yields. There were significant correlation between NDVI value, SPAD value and LCC value measured at 45 DAS to 75 DAS and grain yield. This indicated that measurement of NDVI, SPAD value and LCC value allow a practical window for in-season N management in wheat.

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