Use of optical sensor for in-season nitrogen management and grain yield prediction in maize

Bandhu Raj Baral[1]* and Parbati Adhikari[1]

ABSTRACT

Precision agriculture technologies have developed optical sensors which can determine plant's normalized difference vegetation index (NDVI).To evaluate the relationship between maize grain yield and early season NDVI readings, an experiment was conducted at farm land of National Maize Research Program, Rampur, Chitwan during winter season of 2012. Eight different levels of N 0, 30, 60, 90, 120, 150, 180 and 210 kg N/ha were applied for hybrid maize RML 32 × RML 17 to study grain yield response and NDVI measurement. Periodic NDVI was measured at 10 days interval from 55 days after sowing (DAS) to 115 DAS by using Green seeker hand held crop sensor. Periodic NDVI measurement taken at a range of growing degree days (GDD) was critical for predicting grain yield potential. Poor exponential relationship existed between NDVI from early reading measured before 208 GDD (55 DAS) and grain yield. At the 261GDD (65DAS) a strong relationship (R^2 = 0.70) was achieved between NDVI and grain yield. Later sensor measurements after 571 GDD (95DAS) failed to distinguish variation in green biomass as a result of canopy closure. N level had significantly influenced on NDVI reading, measured grain yield, calculated in season estimated yield (INSEY), predicted yield with added N (YPN), response index (RI) and grain N demand. Measuring NDVI reading by GDD (261−571 GDD) allow a practical window of opportunity for side dress N applications. This study showed that yield potential in maize could be accurately predicted in season with NDVI measured with the Green Seeker crop sensor.

INTRODUCTION

Nitrogen is the most limiting nutrient for crop production and has the greatest effect on grain yield. Crop response to applied N is an important criterion for evaluating crop N requirement for maximum economic yield (Fageria and Baligar 2005). The management of N plays a key role in improving crop quality (Campbell *et al.*, 1995) and optimal N management will be influenced by crop type and crop rotation (Grant *et al.*, 2002). Previous research has shown that nitrogen (N) availability depends on seasonal changes in soil water content, temperature, soil structure, and organic matter distribution (Ranells and Wagger, 1992). Fageria and Baligar (2005) stated that improving nitrogen use efficiency is desirable to improve crop yields, reduce cost of production, and maintain environmental quality. Determination of the extent to which the crop will respond to additional N can help the farmers to apply only what

Corresponding author Info: [1]*National Maize Research Program Rampur, Chitwan, Nepal *E-mail-bandhubaral@gmail.com*

is needed. There have been numerous studies that showed high correlations between

certain vegetation indices developed from spectral observations and plant stand parameters such as plant height, percent ground cover by vegetation, and plant population (Raun *et al.*, 2005 and Stone *et al.*, 1996). NDVI (Normalized Difference Vegetation Index) is used widely for mapping plant growth. NDVI is defined as (NIR - Red) / (NIR + Red). The Red and NIR values represent the reflectance in the Red and NIR bands, respectively. Researchers at Oklahoma State University have developed an algorithm for maize nitrogen fertilization based on optical sensors. The N fertilizer rates depends on making an in-season estimate of the potential or predicted yield, determining the yield response to additional nitrogen fertilizer, and finally calculating N required obtaining that additional yield (Raun *et al.*, 2005).

MATERIALS AND METHODS

The experiment was conducted at the farm land of National Maize Research Program (NMRP), Rampur, Chitwan. NMRP is located in between 27°40' N latitude and 84°19' E longitude and an altitude of 228 m above mean sea level in the inner terai (Siwalik Dun Valley). The experiment was carried out during the September to February of 2013. The experiment was laid out in randomized complete block design (RCBD) with three replications. Eight different levels of N (0, 30, 60, 90, 120, 150, 180 and 210 kg N/ha) were applied for grain yield and NDVI measurement. Hybrid maize RML-32/RML-17 was planted in 12 sq. m plot with the row to row spacing 60 cm and 25 cm plant to plant spacing. Soil sampling was done before sowing and analyzed for total N, available P, available K, Soil Organic matter and pH. The soil type was *Ustic Psamments* (USDA classification) and was alluvial sandy loam in texture. The initial total N content was low (0.052%), available P was high (254 kg/ha), available K was medium (155 kg ha^{-1}), soil organic matter was low (1.57%) and very strongly acidic in pH (5.2). Plant Normalized Difference Vegetation Index (NDVI) was measured in each plot using a Green Seeker hand held Crop Sensor (NTech Industries, USA). Previous research showed that NDVI is an excellent measure of plant growth and N requirements (Raun *et al.*, 2005). In order to generate the algorithm, planting and emergence dates were recorded and used to compute the number of days from planting to sensing in each zone. For this method, we eliminated those days where Growing Degree Days (GDD) were equal or less than zero. The GDD values were calculated as: GDD = [(Tmin + Tmax)/2] – 10°C; where, Tmin and Tmax are the minimum and maximum temperatures, respectively. In Season Estimated Yield (INSEY), which is the yield with no added N, was calculated by dividing the plant NDVI by the number of days from planting to sensing (where GDD > 0). The Response Index (RI) was calculated by dividing the average NDVI readings from the high N plots by the average NDVI readings in the plots without N application. The predicted yield with added nitrogen (YPN) and grain N demand was calculated as described by Raun *et al.* (2002). Linear and nonlinear regression models were used to determine the relationships between grain yield and NDVI using Genstat.

RESULTS AND DISCUSSION

N level, NDVI and grain yield

Grain yield was significantly increased with applied N fertilizer (Table 2). Maximum grain yield was produced with 180 kg N/ha which indicated that increased in more than 180 kg N/ha had no yield benefit. The grain yield and NDVI measured in periodic interval showed a good correlation with grain yield and NDVI reading measured (Table 1 and Fig.1a). The NDVI reading was higher with increased N applied treatment (Fig.1b). The sensor reading taken at different date from planting to sensing date were calculated and described here as GDD. The NDVI measured at 261 GDD (65 DAS) showed a better fit among different GDD with r^2 =0.78 (Fig. 2). Measured higher NDVI reading to a limit had increased grain yield in RML-32 × RML-17 hybrid variety of maize at Chitwan condition. High correlations of early season NDVI readings with the plant biomass were also shown in the research conducted by Stone et al. (1996). Growth stage was a major factor in predicting yield potential. Regression analysis showed that weak exponential relationships occurred between NDVI and grain yield when sensor measurements were taken too early or too late (Table 1). This was probably a result of the failure in distinguishing the NDVI reading. However, a strong relationship between yield and NDVI was achieved at 261 GDD (Fig.1a) with an r^2 value of 0.70. Later sensor measurement (at 571 GDD and later) relationships with grain yield were similar to earlier (before 208 GDD) comparisons, where yield potential was not accurately determined (Table 2). Due to canopy closure influence on the sensor field of view, the later NDVI readings were unable to distinguish variation, similar to research findings for other remote sensing techniques measuring NDVI (Vin˜a et al. 2004).
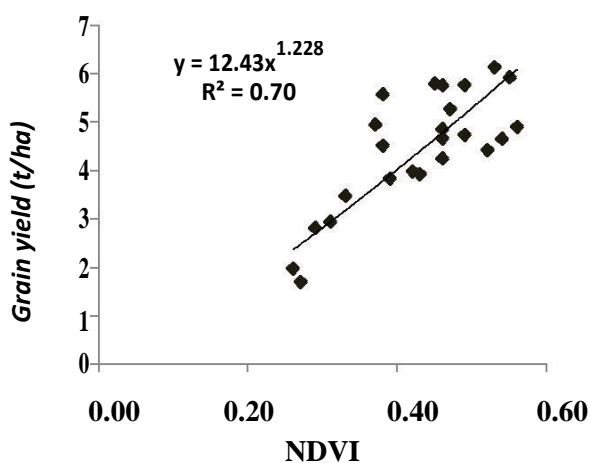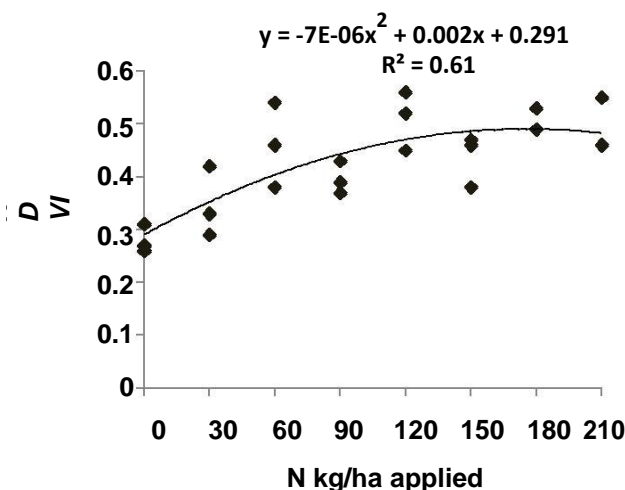

Fig. 1 (a)   **Fig. 1 (b)**

Figure: 1(a). Relationship between NDVI and grain yield and 1(b) nitrogen doses applied and NDVI

Table 1: Correlation between NDVI measured at different days after sowing and other parameters

	GY	NDVI-115	NDVI-105	NDVI-95	NDVI-85	NDVI-75	NDVI-65	NDVI-55	DM-105	DM-75
GY										
NDVI-115	0.39									
NDVI-105	0.71	0.12								
NDVI-95	0.60	-0.10	0.65							
NDVI-85	0.78	0.07	0.52	0.43						
NDVI-75	0.74	-0.08	0.78	0.75	0.63					
NDVI-65	0.78	0.05	0.56	0.60	0.54	0.70				
NDVI-55	0.42	-0.09	0.41	0.60	0.27	0.62	0.56			
DM-105	0.73	0.40	0.51	0.42	0.14	0.60	0.57	0.31		
DM-75	0.10	-0.12	0.15	0.31	-0.15	0.07	0.17	0.17	-0.17	
SY	0.74	0.26	0.30	0.43	0.51	0.37	0.59	0.38	0.48	0.03

Predicted grain yield, response index and grain N demand

The predicted grain yields, INSEY, response index and grain N demand were significantly varied with N levels. The established relationship between the harvested grain yields and calculated INSEY showed a high correlation between yields and INSEY in this study (Fig. 2).The INSEY index estimates the plant biomass produced per day when growth was possible. Furthermore, Raun *et al.* (2002) showed that the plant NDVI readings and calculated INSEY can be used to predict grain yields. The INSEY was increased with increased N doses upto 120 kg N/ha after that not much varied (Table 3). The highest INSEY was recorded at 447 GDD which revealed that maximum greenness was obtained during that growth period. At early stage and later stage (before 261 GDD and after 571 GDD) the INSEYs were low and not much varied with N levels. This might be due to poor canopy cover and low chlorophyll content in leaves. The response index is the ratio of NDVI to without N and N rich plot. The RI indicates the fertilizer response to added N fertilizer and was explained by Johnson and Raun (2003). The RI was significantly affected with the N level and maximum RI was recorded at 120 kg N/ha applied and followed by 180 kg N/ha applied treatment. The maximum RI value of 1.84 indicated that 84% more grain yield can be obtained in comparison to without N fertilizer treatment with 120 kg N/ha with NDVI reading prediction (Table 2). The predicted grain yield was calculated with the RI. The Predicted grain yield was consistent only up to 120 kg N/ha after that inconsistent with applied N to the soil which indicates that the N applied was not used efficiently or poor N use efficiency which indicated that major applied N lost to the environment and we should improve N application in time or methods or rate. The grain production N demand was significantly affected with N level; however, it was based on predicted grain yield production. Our results showed that for the maximum grain yield of 4.75ton/ha production requires 59.8 kg N/ha available during in season. That amount was only for grain N demand but not for stover.

Table 2: Nitrogen level, measured grain yield, predicted grain yield, response index and grain N demand

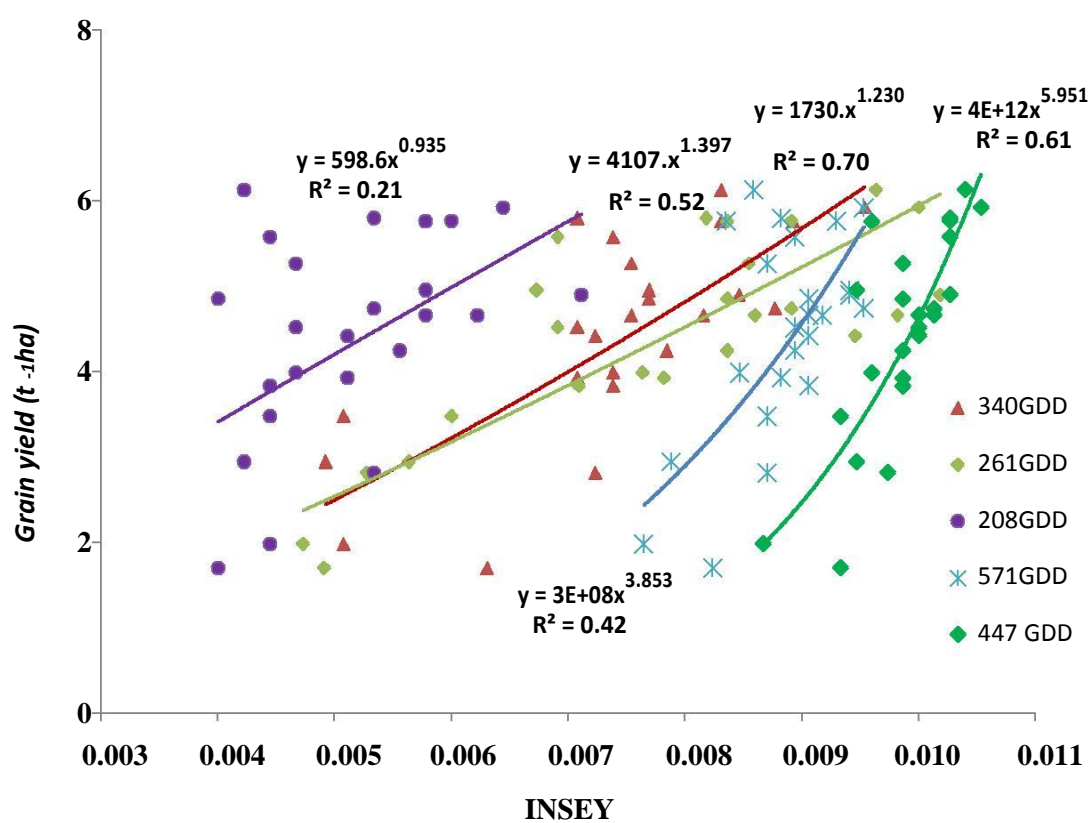| S.N	N level (kg/ha)	Measured grain yield (t/ha)	Predicted grain yield (YPN)	Response index (RI)	Grain N demand (kg/ha)
1	0	2.21	2.61		0.00
2	30	3.43	3.23	1.25	17.32
3	60	4.47	4.29	1.65	47.00
4	90	4.24	3.70	1.42	30.51
5	120	5.04	4.75	1.84	59.80
6	150	5.24	4.07	1.58	40.66
7	180	5.55	4.70	1.80	58.35
8	210	5.45	4.57	1.77	54.65
F-test		**	*	*	**
LSD		1.00	0.85	0.37	23.9
CV%		12.8	12.2	12.1	35.5

Figure: 2 Relationship between in season estimated yield (INSEY) calculated at different GDD and grain yield

Table 3: Effect of nitrogen level on in-season estimated yield (INSEY) measured at different GDD.

S.N.	N level (kg/ha)	INSEY						
		208 GDD	261 GDD	340 GDD	447 GDD	571 GDD	696 GDD	840 GDD
1	0	0.0042	0.005	0.0054	0.0092	0.0079	0.0076	0.0068
2	30	0.0048	0.0063	0.0066	0.0096	0.0086	0.0079	0.0066
3	60	0.0055	0.0083	0.0075	0.01	0.009	0.0081	0.0068
4	90	0.0051	0.0071	0.0074	0.0097	0.0091	0.0081	0.0068
5	120	0.0059	0.0092	0.0076	0.0102	0.0091	0.0081	0.0068
6	150	0.0044	0.0079	0.0075	0.01	0.0089	0.0082	0.0071
7	180	0.0052	0.0091	0.0087	0.0103	0.0091	0.0083	0.0068
8	210	0.006	0.0094	0.0087	0.0101	0.009	0.0081	0.0068
F-test		**	*	*	*	*	*	NS
LSD		0.0012	0.0016	0.001	0.0005	0.0005	0.0002	
CV%		12.4	12.3	8.4	2.9	5.3	1.7	3.3

CONCLUSION

Measuring NDVI reading by GDD (261–571 GDD) allow a practical window of opportunity for side dress N applications. This study showed that yield potential in maize could be predicted in season with NDVI measured with the Green Seeker crop sensor.

REFERENCES

Campbell, C.A., Myers, R.J.K., & Curtin. D. (1995). Managing nitrogen for sustainable crop production. *Fert. Res*. 42, 277–296.

Fageria, N.K., Baligar, V.C., & Bailey, B.A. (2005). Role of cover crops in improving soil and row crop productivity. *Comm. Soil Sci. Plant Anal.* 36, 2733-2757.

Grant, C.A., Peterson, G.A., & Campbell, C.A. (2002). Nutrient considerations for diversified cropping systems in the Northern Great Plains. *Agron. J.* 94, 186-198.

Johnson, G.V. & Raun, W.R. (2003). Nitrogen response index as a guide to fertilizer management. *Journal of Plant Nutrition,* 26, 249–262.

Ranells, N.N., & Wagger, M.G. (1992). Nitrogen release from crimson clover in relation to plant growth stage and composition. *Agron. J.* 84, 424-430.

Raun, W.R., Solie, J.B., Johnson,G.V. Stone, M. L., Mullen, R.W., Freeman, K.W., Thomason,W.E. & Lukina, E.V.(2002). Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. *Agron. J.,* 94(4), 815-820. http://dx.doi.org/10.2134/agronj2002.8150.

Raun, W.R., Solie,J.B., Stone, M.L., Martin, K.L., Freeman, K.W., Mullen, R.W., Zhang, H., Schepers, J.S.,& Johnson, G.V. (2005). Optical sensor based algorithm for crop nitrogen fertilization. *Commun. Soil Sci. Plant Anal*. 36, 2759-2781.

Stone, M.L., Solie, J.B., Raun, W.R., Whitney, R.W., Taylor, S.L.,& Ringer, J.D. (1996). Use of spectral radiance for correcting in-season fertilizer nitrogen deficiencies in winter wheat. Trans. *ASAE* 39(5), 1623–1631.

Vin˜a, A., Gitelson, A. A., Rundquist, D. C., Keydan, G., Leavitt, B., & Schepers, J. (2004). Monitoring maize (*Zea mays* L.) phenology with remote sensing, *Agric. J.,* 96, 1139–114