Canopy temperature depression and normalized difference vegetation index as indicators of drought resistance and nitrogen recommendation in hybrid maize genotypes

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ABSTRACT

Improving maize production is one of the most effective strategies for solving a food insecurity issue. Differences in the normalized difference vegetation index (NDVI), canopy temperature depression (CTD), and grain yield were evaluated for 14 hybrid maize genotypes at Sundarbazar, Lamjung, Nepal. During a growing season (May to September, 2019), the NDVI was measured using a Greenseeker™ handheld sensor to predict in-season yield and nitrogen (N) recommendations. The CTD was measured using a Fluke infrared thermometer to estimate yield and determine heat resistant genotypes. Both NDVI and CTD showed significant positive relationships with grain yield. For the NDVI, the coefficient of determination (R^2) were 0.66, 0.52, 0.76, and 0.49 at 15, 30, 45, and 60 days after sowing (DAS), respectively. For the CTD, R^2 values were 0.41, 0.45, 0.59, and 0.58 at 15, 30, 45, and 60 DAS, respectively. Nitrogen (N) requirement from the NDVI-based N calculator for the yield potential under the farmers' nutrient management levels, regardless of genotypes, was nearly half of the recommended N dosages. The genotypes with negative CTD values (RML-11-2/ RML-18, RL-35-1/RL-105, and RL-24-0/RL-111) were particularly prone to heat stress, while all other genotypes were heat stress-resistant. The results indicated that top dressing of ~54kg N ha⁻¹ is required at 45 DAS. Nitrogen requirements decreased as crop growth progressed towards the reproductive stage. Results indicated that 45 DAS was an appropriate time for the top dressing of N, and the application of N at a later stage of crop growth had a smaller advantage.

INTRODUCTION

Maize (*Zea mays* L.), a major cereal crop worldwide, is known as queen of cereals for its highest genetic yield potential among the cereal crops (Singh 2002). The world leaders in maize production are the United States (34%), China (24%), the European Union (5%), Brazil (8%), Mexico (2%), and others (10%) (Statista, 2020). In Nepal, maize is the second most important cereal crop after paddy rice (*Oryza sativa* L.) (MoALD 2018/19). It is the most important crop for farmers in the hilly regions of Nepal. Nepal's per capita maize consumption (98 g person⁻¹ day⁻¹) is the highest in South Asia (Ranum et al. 2014). In the last decades in Nepal, demand for maize has been growing by ~5% each year (Sapkota and Pokhrel 2010). It is grown in an area

of 956,447 ha with a total production of 2,713,635 metric ton (mt), with productivity of 2.84 mt ha⁻¹ in Nepal (MoALD 2018/19).

The canopy temperature depression (CTD), difference between air temperature (T_a) and canopy temperature (T_c), is used to assess plant response to environmental stress, to compare genotypes for water use and heat stress, and to estimate the drought tolerance (Balota et al. 2007). However, its suitability should be evaluated for the specific environments. The normalized difference vegetation index (NDVI) is a surface-reflectance indicator that provides a quantitative estimate of vegetation growth and biomass. The NDVI ranges from - 1.0 to + 1.0. The positive NDVI values indicate the increase in green vegetation, while the values close to zero or negative indicate no vegetation. The NDVI provides an effective assistance for management decisions for several purposes, including irrigation (Sultana et al. 2014), N status (Rambo et al. 2010) and, grain or forage yield (Inman et al. 2008).

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Cultivation of maize genotypes with good yield under drought conditions is of major importance for food security. Drought-related yield losses limit maize production for the areas under dryland productions. Drought-resistant maize genotypes are difficult to choose based on their potential grain yield. Thus, CTD can be used to estimate yield and determine heat tolerance crop genotypes (Guendouz et al. 2012).

Inefficient nitrogen (N) fertilization is one of the key constraints leading to low maize productivity in Nepal (Karki 2013). Traditionally, farmers used to apply all N fertilizers in one dose either as a basal application prior to planting or as a top-dressing later during the growing season without synchronizing the crop N demand (Karki 2013). Thus, it is important to establish effective N management strategies to enhance productivity and N use efficiency. The NDVI and CTD might be used to enhance productivity and N use efficiency of maize. Thus, the objective of this study was to examine CTD and NDVI as indicators of drought resistance and N recommendation in hybrid maize genotypes.

MATERIALS AND METHODS

Experimental site:

The study was conducted for a growing season (May to September, 2019) at Sundarbazar (latitude: 28.14° N, longitude: 84.41° E, and altitude: 610 m), Lamjung, Nepal. Total rainfall of 1040 mm was recorded for the study period (i.e., growing season). The P^H was slightly acidic (6.4) and soil type was silt loam.

Experiment materials:

The experiment comprised 14 maize hybrids namely Rampur Hybrid-4, Rampur Hybrid-6, Rampur Hybrid-10, Pariposa 4525, Ganga Kaberi, Pioneer, Rashi 3022, RL-24-8/RML-25, RL-213/RML-17, RL-24-0/RL-111, RML-95/RML-96, RML-86/RML-96, RML-11-2/RML-18 and RL-35-1/RL-105. Four multinational varieties (Pariposa 4525, Ganga Kaberi, Pioneer, and Rashi 3022) were obtained from local market. We received other 10 genotypes from National Maize Research Program, Rampur, Chitwan, Nepal.

Experimental design and crop management:

The experimental design was randomized complete block design (RCBD) and replicated three times. Each plot of 5 × 2 m² with 75 cm spacing and 25 cm between rows and plants were maintained (one seed/hill). We applied fertilizers at 120:60:40 NPK kg ha⁻¹. The first half N was applied at pre-sowing and the second half was side dressed at knee height. Other crop management practices such as irrigation, earthing up and

weeding were performed following the recommendation for the region.

Data Collection

We used NTech's GreenSeeker™, an active hand-held sensor, to determine NDVI (equation 1). Measurements were performed at 15, 30, 45, and 60 days after sowing (DAS). A sensor-based N rate calculator developed by Oklahoma State University (OSU, www.soiltesting.okstate.edu) was employed to estimate yield potentials and required amount of N for top-dressing. Measurement of Tc was done by a hand held infrared thermometer-based equipment (Fluke-Model 62 MAX+) by targeting the canopy tissues at an angle of 45° in bright sunny days between 12:00 and 14:00 hours (local time) at 15, 30, 45, and 60 DAS. The CTD was determined by using the equation (2). Grain yield was estimated using the equation (3) as in Carangal et al. (1971) and Shrestha et al. (2018). We adjusted grain moisture at 15% and converted to the grain yield per hectare basis.

$$NDVI = \frac{(\text{Near Infrared Band Reflectance} - \text{Red})}{(\text{Near Infrared Band Reflectance} + \text{Red})} \quad (1)$$

$$CTD = \text{Air temperature (Ta)} - \text{Canopy temperature (Tc)} \quad (2)$$

$$\text{Grain yield } \left(\frac{\text{kg}}{\text{ha}}\right) = \frac{\text{FWT} \left(\frac{\text{kg}}{\text{plot}}\right) \times (100 - \text{HMP}) \times \text{SCF} \times 10000}{(100 - \text{DMP}) \times \text{NPA}} \quad (3)$$

Where, FWT = Fresh weight of ear in kg per plot at harvest, HMP = Grain moisture percentage at harvest, DMP = Desired moisture percentage, NPA = Net harvest plot area (m²), SCF = Shelling coefficient (0.8)

Statistical analysis:

The R Studio was used for the statistical analyses. We performed the analysis of variance (ANOVA) considering fixed effects for genotypes and rand effects for replications. The correlation coefficient (r) between two characters was calculated by using components of variance and covariance as in Weber & Moorthy (1952). Linear regression analysis was performed to analyze the relationship of grain yields with NDVI and CTD.

RESULTS AND DISCUSSION

Differences in grain yield among genotypes

Grain yield was significantly different ($P < 0.001$) among maize genotypes (Table 1). It ranged from 5.6 mt ha⁻¹ to 12 mt ha⁻¹. Pioneer had the highest grain yield (~12 mt ha⁻¹) followed by Rampur Hybrid-6 (~11.2 mt ha⁻¹), Ganga Kaberi (~10.7 mt ha⁻¹), and Pariposa 4525 (~9.8 mt ha⁻¹), while the lowest grain yield was observed for genotype RL-24-0/RL-111 (~5.6 mt ha⁻¹) (Figure

Table 1. Analysis of variance for canopy temperature depression (CTD) and normalized difference vegetation index (NDVI) with grain yield in hybrid maize.

SN	Traits	Mean sum of squares		
		Replications (D.F. =2)	Treatments (D.F. =13)	Error (D.F. =26)
1.	CTD (15 DAS)	2.21	6.91***	0.48
2.	CTD (30 DAS)	2.61	3.74*	1.57
3.	CTD (45 DAS)	2.23	3.98**	1.02
4.	CTD (60 DAS)	0.68	3.76***	0.54
5.	NDVI (15 DAS)	0.00	0.00***	0.00
6.	NDVI (30 DAS)	0.00	0.00**	0.00
7.	NDVI (45 DAS)	0.00	0.00***	0.00
8.	NDVI (60 DAS)	0.00	0.00***	0.00
9.	Grain Yield (mt ha ⁻¹)	6.14	9.01***	0.42

*Significant at 5 percent level, ** significant at 1 percent level and *** significant at 0.1 percent level.

1). The results indicated a large range of yield potential for the maize genotypes tested in this study, which can be attributed to differences in their genetic yield potentials and adaptation to the climate.

Differences in NDVI and CTD among genotypes

Difference in NDVI was significant among genotypes at different DAS (Table 1). At 15 DAS, the NDVI ranged from 0.15 (RL-24-0/RL-111) to 0.19 (Pioneer), with an average NDVI of 0.16 for all genotypes. At 30 DAS, the NDVI ranged from 0.31 (RL-24-0/RL-111) to 0.46 (Pioneer), with an average NDVI of 0.40 for all genotypes. At 45 DAS, the NDVI ranged from 0.71 (RL-24-0/RL-111) to 0.81 (Pioneer), with an average NDVI of 0.77 for all genotypes. At 60 DAS, the NDVI ranged from 0.77 (RL-24-0/RL-111) to 0.89 (Pioneer), with an average NDVI of 0.85 for all genotypes (Figure 2). Our timings of N stress sensing was concentrated around the V2-VT growth stages as these timings can provide the best balance for accurately estimating maize N stress, providing enough supply of N fertilizer to growing maize plants at much needed time, and reducing the extent of lost yield potential due to N stress.

Differences in the CTD was significant among

genotypes at different DAS (Table 1). At 15 DAS, the CTD ranged from -0.08 (RL-24-0/RL-111) to 4.98 (Pioneer), with an average CTD of 1.28 for all genotypes. At 30 DAS, the CTD ranged from -0.17 (RL-24-0/RL-111) to 4.43 (Pioneer), with an average CTD of 1.76 for all genotypes. At 45 DAS, the CTD ranged from -0.50 (RL-24-0/RL-111) to 4.05 (Pioneer), with an average CTD of 1.29 for all genotypes. At 60 DAS, the CTD ranged from -1.13 (RL-24-0/RL-111) to 3.67 (Pioneer), with an average CTD of 0.70 for all genotypes (Figure 3). The genotypes with negative CTD values indicate these genotypes are particularly prone to heat stress (Guendouz et al. 2012). High temperature and relative humidity induce closure of stomata to avoid an excess loss of water as transpiration, resulting in an increase in leaf temperature. It hampers the ability of the plant to retain a relatively cooler canopy for the physiological adaptation to heat stress.

Relationships of NDVI and CTD with grain yields

The NDVI and grain yields showed strong relationships, with R² values of 0.66, 0.52, 0.76, and 0.49 at 15, 30, 45, and 60 DAS, respectively (Figure 4). A similar result was reported at 15 and

Table 2. Sensor based inputs and outputs at 45 days of sowing (DAS).

Treatment	Input				Output						
	DAS	GDD	NDV I-FP	NDVI- RDF	Y- max (kg ha ⁻¹)	RI	YO-FP (kg ha ⁻¹)	YO- RDF (kg ha ⁻¹)	N (Kg ha ⁻¹)	Retur n-FP (\$/ha)	Return- FDP(\$/ ha)
Ganga Kaberi	45	627.5	0.231	0.790	6000	2	3424.4	6000	53.7	993.1	1727.7
Pariposa 4525	45	627.5	0.231	0.790	6000	2	3424.4	6000	53.7	993.1	1727.7
Pioneer	45	627.5	0.231	0.810	6000	2	3424.4	6000	53.7	993.1	1727.7
Rampur Hybrid- 10	45	627.5	0.231	0.770	6000	2	3424.4	6000	53.7	993.1	1727.7
Rampur Hybrid-4	45	627.5	0.231	0.772	6000	2	3424.4	6000	53.7	993.1	1727.7
Rampur Hybrid-6	45	627.5	0.231	0.795	6000	2	3424.4	6000	53.7	993.1	1727.7
Rashi 3022	45	627.5	0.231	0.758	6000	2	3424.4	6000	53.7	993.1	1727.7
RL-213/RML-17	45	627.5	0.231	0.776	6000	2	3424.4	6000	53.7	993.1	1727.7
RL-24-0/ RL-111	45	627.5	0.231	0.718	6000	2	3424.4	6000	53.7	993.1	1727.7
RL-24-8/RML-25	45	627.5	0.231	0.764	6000	2	3424.4	6000	53.7	993.1	1727.7
RL-35-1/RL-105	45	627.5	0.231	0.740	6000	2	3424.4	6000	53.7	993.1	1727.7
RML-11-2/ RML-18	45	627.5	0.231	0.742	6000	2	3424.4	6000	53.7	993.1	1727.7
RML-86/ RML-96	45	627.5	0.231	0.777	6000	2	3424.4	6000	53.7	993.1	1727.7
RML-95/ RML-96	45	627.5	0.231	0.778	6000	2	3424.4	6000	53.7	993.1	1727.7

Figure 1. Grain yield of the 14 hybrid maize genotypes.

Figure 2. Normalized difference vegetation index (NDVI) at different days after sowing (15, 30, 45, and 60) for hybrid maize genotypes.

Figure 3. Canopy temperature depression (CTD) at different days after sowing (15, 30, 45, and 60) for hybrid maize genotypes.

45 DAS for maize in Chitwan, Nepal (Karki 2013). Similarly, the CTD and grain yields of maize showed strong relationships, with R^2 values of 0.41, 0.45, 0.59, and 0.58 at 15, 30, 45, and 60 DAS, respectively (Figure 5). A similar result was reported by Guendouz et al. (2012) for wheat in Algeria. Strong positive relationships of grain yields with NDVI and CTD indicate the potential of NDVI and CTD for the physiological basis of maize grain yield. Our results also revealed that high yielding genotypes had higher NDVI and CTD values. As a result, NDVI and CTD have been used in breeding programs for selection criteria (Ararus et al. 2002; Shrestha et al. 2014).

Grain yield and N status predictions

The grain yield of maize was predicted from the inputs entered in the sensor-based N rate calculator by using formula in equation (4) to obtain both farmers' practice (FP) yield production as well as recommended fertilizer (RDF) dosages (Table 2). The grain yield was predicted for different time series (15, 30, 45 and, 60 DAS). The NDVI-based N calculator showed that hybrid maize genotypes had a yield potential of 3.42 mt ha⁻¹ under FP and 6 mt ha⁻¹ under RDF if an estimated 53.7 kg N ha⁻¹ ha was applied (top-dressing) at 45 DAS (Table 2). A previous study in maize (Shaktiman variety) in Nepal reported a yield potential of 3.21 mt ha⁻¹ under FP and 6.4mt ha⁻¹ under RDF if an estimated 67 kg N ha⁻¹ was applied at 45 DAS (Karki 2013). Conversely, not applying N until 60 DAS would decrease the

capacity for hybrid yields substantially. The result revealed that the prediction of grain yields was the most accurate by using NDVI at 45 DAS in maize.

$$Y P_0 = 2592 * (\text{EXP} (\text{NDVI} / \text{Sum of GDD} * 1775.6)) \text{ Kg ha}^{-1} \quad (4)$$

where, EXP = Exponential, GDD= Growing degree days

Nitrogen recommendation

The output data showed that the crop needs to be top-dressed with 53.7 kg N ha⁻¹ at 45 DAS to get 6 mt ha⁻¹ of grain yield in maize (Table 2). If the crop was not top-dressed at this stage, the grain yield would be reduced to 3.42 mt ha⁻¹. Gross FP return was \$993 ha⁻¹, while gross returns from RDF nearly doubled to \$1728 ha⁻¹ (Table 2). A previous study in maize in Chitwan, Nepal has recorded that gross FP return was \$755 ha⁻¹, while gross returns from RDF nearly doubled \$1322 ha⁻¹ (Shrestha et al. 2014). The FP and RDF trend in grain yield production showed that topdressing in earlier stages of crop growth produced higher yields and profits than in later stages. As the crop progressed towards maturity N requirements decreased, and subsequent application of N did not contribute to higher grain yield. Likewise, N is subject to loss through leaching in early stage, as less established crop stands cannot utilize it properly.

Figure 4. Grain yield vs. normalized difference vegetation index (NDVI) at different days after sowing (15, 30, 45, and 60).

Figure 5. Grain yield vs. canopy temperature depression (CTD) at different days after sowing (15, 30, 45, and 60).

CONCLUSIONS

This study showed that there was a significant correlation of grain yield with the CTD and NDVI.

Positive strong relationships of grain yield with the NDVI and CTD indicated that both NDVI and CTD could be used as selection criteria in breeding programs. Positive CTD value indicates heat stress

tolerant genotypes, while negative CTD value indicates heat stress sensitive genotypes. Genotypes RML-11-2/ RML-18, RL-35-1/RL-105, and RL-24-0/RL-111 were prone to heat stress, while all other genotypes were heat stress resistant. Likewise, by using the NDVI, in-season yield was predicted along with N recommendations. The results showed that hybrid maize would need to be top-dressed at 45 DAS with 53.7 kg N ha⁻¹ to get the maximum yield. Both CTD and NDVI are new decision supporting tools for the applied breeding research to improve crop grain yields. Further research is needed to evaluate their performances across wider climatic conditions and crop types.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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