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Normalized difference vegetation index as screening trait to complement visual selections of durum wheat drought tolerant genotypes

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Normalized difference vegetation index (NDVI) is considered as a potential screening tool detecting stay green traits for drought tolerance. The present study aimed to evaluate durum wheat genotypes using NDVI under drought condition and investigate its association to grain yield. NDVI scores taken at different growth stages for 64 durum wheat genotypes were replicated twice in both sandy clay and clay textured soils situated at the same geographic location of Debre-Zeit Experimental Station, Ethiopia during 2016 rainy season; also, Green Seeker (Hand held) was used to measure the quantity of photosynthetically active pigments in leaves. Measurements of NDVI were made four to five times on sunny days between booting to physiological maturity. Analysis of variance showed significant variation among genotypes at 0.01% on NDVI values across all growth stages except at physiological maturity in both sandy clay and clay soils. The NDVI scores were highly significantly associated with yield at grain filling and anthesis stages in both soil environments. Overall, it is possible to suggest that use of NDVI would help complement identification of drought tolerant genotypes on durum wheat.

Key words: Grain yield, Normalized difference vegetation index (NDVI), *Triticum durum.*

INTRODUCTION

Wheat is the fourth most important cereal crop after maize, tef and sorghum in terms of area coverage and production in Ethiopia. Both bread and durum are grown extensively in the country, although separate area coverage and production is not known. They are cultivated over an area of 1.69 million hectares with annual production of about 4.5 million tons (CSA, 2018). However, average productivity in the country is low (2704 kg/ha). Drought stress globally, under rain-fed based crop production system of Ethiopia is one of the largest causes of wheat yield reduction. Drought has particularly become a common problem in both lowland environment

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associated with early termination of rainfall and highland vertisols environment which is waterlogged and does not follow optimum planting time which usually results in late planting. Breeding and selection of genotypes for drought tolerance using grain yield alone has a number of constraints. Low heritability and genetic variance are among the major challenges while using grain yield for identification of genotypes under drought stress (Manal, 2009). High genotype × environment is also another challenge for selection of the right genotypes under drought stress (Sangam et al., 2020).

The use of NDVI to measure spectral traits associated with stay green for crop variety evaluation complementing visual selection is suggested to be the simplest and efficient tool for speeding up the selection cycle by reducing the time spent to evaluate germplasm under water stress condition and select genotypes earlier in the season or evaluate large number of genotypes during each round of selection and grain yield prediction before harvesting (Sanchez et al., 2013; Sruthi and Mohammed, 2015). Furthermore, estimating agronomic traits such as yield or drought indirectly using spectral traits measured proximally with handheld devices provides alternative solution to managing the constraints of phenotyping (Araus and Cairns, 2014).

Normalized difference vegetation index (NDVI) has been studied widely on a range of applications on drought (Seyoum et al., 2016), heat stress (Shanahan et al., 2001; Cao et al., 2019) yield prediction and nitrogen management (William et al., 2001; Syeda et al., 2014; Son et al., 2014; Quemada et al., 2019; Hassan et al., 2019), non-destructive biomass estimation (Semeraro et.al., 2019); disease management, (Sheedy and Thompson, 2009) on root lesion nematode and Mahlein et al., (2019) on fusarium head blight. According to Tardieu (2012), genotypes which maintain consistent and high NDVI values across different stages performed better under drought than those with low values, which ultimately resulted in higher biomass and yield under severe to moderate stress. Based on the existing knowledge, the question related to NDVI in breeding to drought could be to what extent the genotypes vary and traits can be associated with the final yield while using this selection tools for early variety selection.

The present study aimed to evaluate and identify durum wheat genotypes using normalized difference vegetation index under drought condition in two soil types of Debre-Zeit Experimental Station and determine its association to grain yield at different growth stages.

MATERIALS AND METHODS

Sixty-four durum wheat genotypes of different origin were used in the study. Twenty-one of the genotypes were released cultivars, 21 of the materials were introduced breeding lines obtained from Centro Internacional de mejoramiento de maiz y Trigo (CIMMYT) and the remaining 14 materials ones were landraces (Table 1).

Site description

The genotypes were grown in the field during the main rainy season in 2016 at Debre-Zeit experimental station which is located in 8° 41' 36" latitude and 39° 03' 17' longitude with altitude 1880 m.a.s.l. Soil data analysis were carried out at Agricultural and Nutritional Research Laboratory of Debre-Zeit Agricultural Research Center (MOALR, 2018) and the physical and chemical properties of the soils are presented in Table 2

Experimental design and field management

The genotypes were planted in 8 x 8 simple lattice design field experiments with two replications on plots consisting of two rows 2 m in length and 20 cm between rows spacing. The genotypes were grown late in the season in sandy clay on August 1, 2016 and in clay soil on July 31, and were exposed to terminal moisture stresses uniformly from the date of anthesis which represent lowland wheat growing environment of Ethiopia. The planting date was selected based on the consistency of the incidence of drought and targeted timing to coincide at anthesis stage for the majority of the genotypes included in the study.

In the experiment, 100 kg of Di-ammonium Phosphate was applied at planting and split application of 100 kg of urea where one-third was applied at planting and two-third at time of tillering. The plots were hand weeded and a fungicide, tilt-250 with rate of 150 ml/ac was applied twice in the season to protect the genotypes from stem rust infection.

Data collection

Five measurements of NDVI were recorded at different growth stages of the plants. The measurement were carried out on a fine sunny, wind free days on plant surface, holding the sensor of the handheld green seeker 50 cm above the stand (Govaerts and Verhulst, 2010). The measurements were taken during booting, heading, anthesis, grain filling and physiological maturity (Table 3). Yield data were recorded on plot basis after drying and threshing.

Data analysis

Analysis of variance was performed using R-4.2 and linear correlations were employed to indicate associations between the parameters Minitab version-16.

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance showed significant variation among genotypes at 0.01% on grain yield and normalized difference vegetation index at all growing stages except at physiological maturity in sandy clay soils (Table 4) indicating that the genotypes respond differently to spectral reflectance. The results also exhibited a large difference on NDVI scores at different growth stages. For instance, the average NDVI record in sandy clay soil was 0.76, 0.63, 0.52, 0.37 and 0.16 at booting, heading, anthesis, grain filling and maturity, respectively (Table 4). In clay soil, the analysis of variance revealed that significant variation among genotypes at 0.01% on NDVI

Table 1. Names and sources of durum wheat varieties and breeding lines used in the study.

No.	Name	Source	No.	Names	Sources
1	Arendato	Released variety	33	IL-PV-6	CIMMYT
2	Cocorit	Released variety	34	LRPL-86	Landrace
3	Boohai	Released variety	35	LRPL-215	Landrace
4	Quamy	Released variety	36	IL-PV-20	Landrace
5	Assasa	Released variety	37	IL-PV-17	CIMMYT
6	Ginchie	Released variety	38	IL-ID-2	CIMMYT
7	Ude	Released variety	39	IL-ID-3	CIMMYT
8	Yerer	Released variety	40	IL-ID-4	CIMMYT
9	Denbi	Released variety	41	IL-ID-5	CIMMYT
10	Hitosa	Released variety	42	IL-ID-6	CIMMYT
11	Werer	Released variety	43	IL-ID-7	CIMMYT
12	Mangudo	Released variety	44	IL-ID-8	CIMMYT
13	Mangudo	Released variety	45	IL-ID-9	CIMMYT
14	Tob-66	Released variety	46	IL-ID-10	CIMMYT
15	Gerado	Released variety	47	IL-ID-11	CIMMYT
16	Ejersa	Released variety	48	IL-ID-12	CIMMYT
17	Utuba	Released variety	49	IL-ID-13	CIMMYT
18	Toletu	Released variety	50	IL-N-8	CIMMYT
19	Kilinto	Released variety	51	ID-N-11	CIMMYT
20	Bichena	Released variety	52	IL-IDO-2	CIMMYT
21	Flakit	Released variety	53	IL-IDO-3	CIMMYT
22	LRPL-1	Landrace	54	IL-IDO-4	CIMMYT
23	LRPL-6	Landrace	55	IL-IDO-5	CIMMYT
24	LRPL-2	Landraces	56	IL-IDO-6	CIMMYT
25	LRPL-8	Landraces	57	IL-IDO-7	CIMMYT
26	LRPL-18	Landraces	58	IL-IDO-8	CIMMYT
27	LRPL-14	Landraces	59	IL-IDO-9	CIMMYT
28	LRPL-9	Landraces	60	IL-IDO-10	CIMMYT
29	LRPL-11	Landraces	61	IL-IDO-11	CIMMYT
30	LRPL-3	Landraces	62	IL-IDO-12	CIMMYT
31	LRPL-7	Landraces	63	IL-NLM-3	CIMMYT
32	LRPL-4	Landraces	64	IL-NLM-13	CIMMYT

was recorded at different growth stages except at physiological maturity and grain yield. The NDVI recorded was 0.76 at booting, 0.70 at heading, 0.64 at anthesis, 0.52 at grain filling and 0.15 at physiological maturity (Table 5). The finding of this study suggested that the genotypes ability to absorb the reflectance is reduced due to senescence. Several authors (Syeda et al., 2014; Salah et al., 2015; Nasir et al., 2020) reported that NDVI scores reduced from the vegetative to reproductive stages and dropped to lower levels at physiological maturity.

The trends were similar in both soil types although the average values at each developmental stage in light textured soil was low and showed sharp reduction (Figure 1), indicating the existence of soil moisture variations in maintaining and supplying different soil types to the plant. Both sandy clay and clay soil showed a significant effect on the development of photosynthetically active leaf area. Plants raised under sandy clay soils had a mean NDVI value of 0.49, while that grown under clay soil was 0.55. Although the differences were not visible under visual evaluations when the measurements were carried out at booting and 50% heading, the records showed a significant reduction from booting to heading with mean value of 0.76 and 0.63 in sandy clay soil. The trend was similar and decreased from 0.76 at booting to average value of 0.70 at heading in clay soil. This indicates that there would be an effect on photosynthetically active leaf area. Likewise, NDVI recorded 10 days after heading showed a similar trend on the reduction of green area compared to the earlier stages in both soil textures.

The genotypes under sandy clay soil again showed low NDVI value (0.49) compared to clay pelli-vertisols (0.55) across different growth stages. The reduction of NDVI

Table 2. Physical and chemical characteristics of soil at Debre-Zeit experimental station.

Type	Soil EC Ds/m	Soil %TN	Soil % C	Soil CEC Meg/100 soil	Soil pH	Class
Light	0.12	0.08	1.00	18.9	7.3	Sandy Clay
Black	0.16	0.11	1.05	27.2	6.9	Clay

EC=Electrical conductivity, TN=total nitrogen, CEC=Cation exchange capacity.

Table 3. Crop developmental stages used for measuring normalized difference vegetation index at Debre-Zeit Sandy clay and clay soils, 2016 rainy season.

Stage	Date of record		Days after planting	
	Light soil	Black soil	Light soil	Black soil
Booting	16 Sep. 2016	17 Sep. 2016	47	49
Heading	27 Sep. 2016	28 Sep. 2016	58	60
Anthesis	7 Oct. 2016	8 Oct. 2016	68	70
Grain filling	18 Oct. 2016	19 Oct. 2016	79	81
Maturity	02 Nov. 2016	03 Nov. 2016	95	97

Source: Alemayehu et al. (2019).

Table 4. Mean squares, minimum, maximum and means of grain yield (gm/1m^2) and Normalized Differences Vegetation Index (NDVI) values of 64 durum wheat genotypes tested at Debre-Zeit sandy clay soil. 2016 rainy season.

SOV	Df	GY	NDVI BT	NDVI HD	NDVI AN	NDVI GF	NDVI MT
Rep.	1	12551	0.004	0.022	0.011	0.023	0.00061
Geno.	63	3795**	0.0076**	0.017**	0.015**	0.008**	0.00087^{ns}
Error	49	1675	0.003	0.0038	0.004	0.003	0.00078
Min.		105.7	0.60	0.44	0.36	0.26	0.12
Max.		323.6	0.84	0.76	0.66	0.50	0.21
Mean		212.5	0.76	0.63	0.52	0.36	0.16
CV(%)		20.5	8.1	14.6	16.6	17.8	13.3

SOV=Source of variation, NDVI BT=Booting, NDVI HD=Heading, NDVI AN=Anthesis, ND GF=Grain filling, NDVI=MT=maturity

Table 5. Mean squares, minimum, maximum and means of grain yield (gm/1m^2) and Normalized Differences Vegetation Index (NDVI) values of 64 durum wheat genotypes tested at Debre-Zeit clay soil 2016 rainy season.

SOV	Df	GY	NDVI BT	NDVI HD	NDVI AT	NDVI GF	NDVI MT
Rep.	1	416	0.000226	0.004395	0.000488	0.000612	0.00006
Geno.	63	5094^{ns}	0.005133*	0.007143**	0.007368**	0.008914**	0.0003^{ns}
Error	49	3634	0.0033	0.002451	0.002098	0.002337	0.0002
Min.		103.4	0.61	0.52	0.48	0.35	0.11
Max.		316.9	0.84	0.80	0.74	0.66	0.18
Mean		202.2	0.77	0.70	0.64	0.52	0.15
CV (%)		24.9	6.7	8.5	9.5	12.8	8.4

SOV=Source of variation, NDVI BT=Booting, NDVI HD=Heading, NDVI AN=Anthesis, ND GF=Grain filling, NDVI=MT=Maturity.

value continued in similar trend when the plants reached grain filling stage ranging from 0.27 to 0.51 and 0.35 to 0.66 in sandy clay and clay vertisols, respectively.

NDVI recorded at different growth stages in two soil textures are illustrated in Figure 1. NDVI value reached a maximum prior to reproductive stages, and a slight decreasing tendency was observed at heading and further slight reduction at anthesis. The decreasing trend

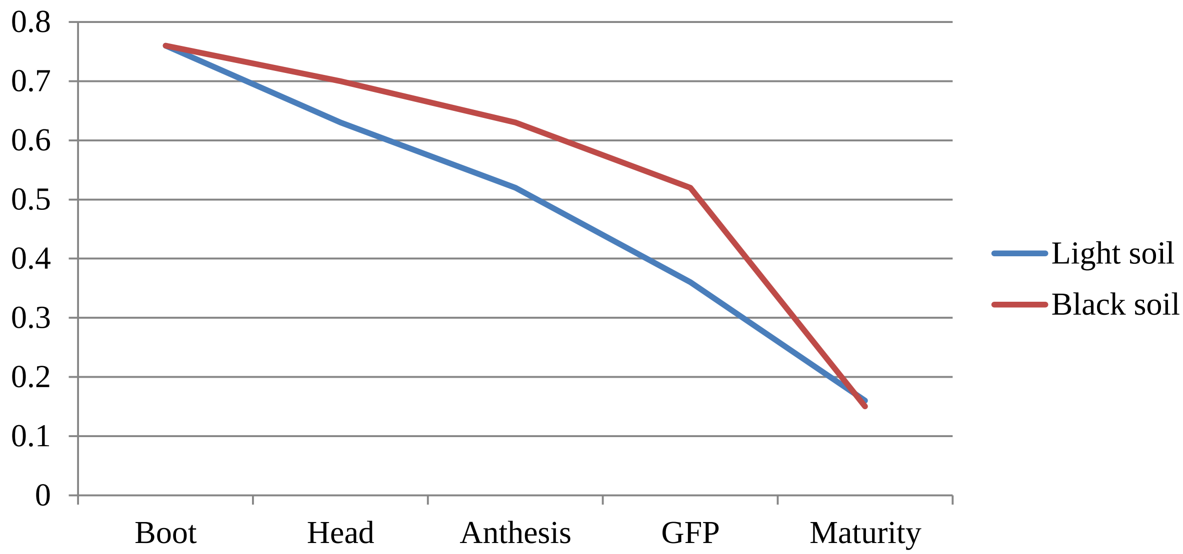

Figure 1. NDVI recorded at different growth stages for 64 durum wheat genotypes tested at Debre-Zeit sandy clay (light) and clay soils (black), 2016.

Table 6. Correlation on above diagonal (clay) and below diagonal (sandy clay).

Traits	Grain yield	NDVI Booting	NDVI Heading	NDVI Anthesis	NDVI Grain filling	NDVI Maturity
Grain yield		0.37**	0.28^{ns}	0.33**	0.37**	0.013^{ns}
NDVI Booting	0.37**		0.81**	0.71**	0.59**	0.013^{ns}
NDVI Heading	0.39**	0.88**		0.85**	0.74**	0.25^{ns}
NDVI Anthesis	0.41**	0.80**	0.94**		0.78**	0.25*
NDVI grainfiling	0.42**	0.67**	0.85**	0.89**		0.30*
NDVI Maturity	0.19^{ns}	0.41**	0.51**	0.61**	0.59**	

****=** Significant at 0.01, ns=non-significant.

in NDVI values was similar and sharp from grain filling stage where maximum variation between genotypes in NDVI scores was observed (Syeda et al., 2014). A soil variation on the values of NDVI was minimized at the time when genotypes reached physiological maturity.

Correlation analysis

Correlation of NDVI traits with performance traits with yield at sandy clay and clay are presented in Table 6. The correlations were weaker (0.33-0.37) in clay soils which were less favorable for grain yield compared to sandy clay soils (0.37-0.42). The association was medium to high strength indicating that there is a significant relationship between NDVI values and the yield. The correlation was smallest at booting stage, increased at heading and anthesis and reached maximum during grain filling stage in sandy clay soil. In clay soil, the correlation was small and non-significant at heading, became significant with a slight strength at anthesis, and had relatively strong association at grain filling stage. It also clearly showed that NDVI scores highly significantly and consistently associated with yield were at grain filling stage in both soil environments, indicating that early selection of better yielding genotypes of wheat under terminal moisture can be identified. Similar finding was reported by Son et al. (2014) that grain filling stages are the right stage to get maximum variability and association with yield could be obtained. NDVI at maturity showed a non-significant and very weak correlation under both soil textures. This could be due to the severity of moisture stress which resulted in the reduction of the NDVI values associated to loosing leaf green pigment, yellowing and presence of low variation between genotypes at maturity in staying green trait. Mean NDVI values generally reached peak at booting; however, values during grain filling period were found to be the most correlated to the final grain yield in both soils, suggesting that it is the right stage for making earlier selections and estimating grain yield. Similar studies on NDVI suggested that grain filling stages display the maximum potentials for estimating yield (Spitko et al., 2016; Shanahan et al., 2001). Similarly, Nieves et al. (2000) indicated that under rain-fed conditions, the spectral reflectance indices measured at any crop stage were positively correlated (P < 0.05) with yield.

Conclusion

The results of the study showed that the durum wheat genotypes varied significantly based on NDVI scores from booting to grain stages at both sandy clay and clay soil types but showed limitation on differentiation of the genotypes at physiological maturity. The results also revealed that normalized difference vegetation index (NDVI) is significantly correlated with grain yield under stress conditions. The grain filling stage was found to be the most appropriate stage to evaluate the genotypes under sandy clay and clay soils using NDVI as a screening tool. Although the correlation values between grain yield and NDVI records at different stages were relatively very strong, it is evident that integrating NDVI in the process will improve the rate of genetic progress and better complement the breeding process or screening of genotypes under drought. NDVI allowed better yielding lines to be identified; for instance, the genotypes 29, 30, 31, 21 and 16 were among the top yielding lines and showed consistently high NDVI values at different growth stages in both types of soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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