Physiological and morphological changes associated with selection for yield under low soil nitrogen in maize (*Zea mays* L.)

Udo, E.F.[1]*, Ajala, S.O.[1], Olaniyan, A.B.[2]
[1]International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.
[2]Department of Agronomy, University of Ibadan, Ibadan, Nigeria.
*enoobong_udo@yahoo.com

Introduction

Recurrent selection methods have been widely used by maize breeders for population improvement. Studies have also shown that correlated gains have also been obtained in physiological traits that promote efficiency in growth, development, and partitioning in plants (Duvick 2005). Gains in grain yield from selection have been reported in the populations used in this study (Ajala et al. 2012) but little information is available on the physiological traits that may have resulted in the observed increase in yield. The study was therefore carried out to identify the morphological and physiological traits that accompanied yield changes in the populations that had undergone two to three cycles of selection for tolerance to low soil nitrogen and to determine the relationship between the physiological traits and yield of maize.

Materials and methods

The experiments were conducted at IITA-Ikenne (6˚87' N, 3˚7' E,) and Ibadan (7˚30'N, 3˚54' E) stations, Nigeria. The tropical populations used for this study were: TZL Comp 1-W, BR 9928 DMRSR, Acr 97 TZL Comp 1-W, LNTP-W, LNTP-Y, and TZPB Prol. developed in IITA, Ibadan. Trials at Ikenne were planted in each of low-N (45 kgN/ha) and high-N (90 kgN/ha) environments obtained by supplying the balance of required nitrogen from previously depleted fields, while trials in Ibadan were planted in three high-N and one low-N environments generated in similar way to that of Ikenne. Trials in each N-block were laid out as a randomized complete block (RCBD) with four replications. The N-fertilizer levels were separated from one another by 5 m to minimize N movement. For each N-level, plots consisted of two rows of 5 m length spaced at 0.75m between rows and at 0.25m between hills within the row. The rows were bordered by an early maturing shorter variety to aid collection of data from the two test rows. Both low and high-N blocks received 45 kgN/ha from NPK 15:15:15 application at 2 weeks after sowing (WAS), while the high-N blocks received an additional 45 kgN/ha from application of Urea at 6 WAS. Normal agronomic practices were maintained all through the growth period of the crops.

One of the two test rows was used for yield determination while the other row was used for destructive sampling. Data collected were plant height, anthesis-silking interval, and leaf chlorophyll concentration using SPAD. Destructive sampling was done at 6 and 10 WAS. Leaf area was measured using a leaf area meter LICOR 3100. Plant parts were separated in the laboratory and dried for 72 hours at 75 ˚C in a forced draft oven to constant weight. From the dry weight and leaf area measurements, the following growth parameters were computed on the basis of the formula used by Watson (1952) : Leaf area index (LAI), Leaf area ratio (LAR), Leaf area duration (LAD), Crop growth rate (CGR), and Net assimilation rate (NAR). At harvest, cob length (cm), ears per plant, number of kernels per row, 100 kernel weight, and kernel rows were determined. Grain yield was measured in mg/ha adjusted to 15% moisture content.

ANOVA for RCBD was carried out on agronomic and physiological traits using the GLM procedure from SAS statistical software (SAS Institute Inc. 2013). Correlation coefficients were also determined between agronomic traits. Gains from selection for the two populations that had recently undergone two cycles of selection for enhanced levels of tolerance to low-N were estimated using regression analyses with cycles of selection evaluated in each population as the independent variable and the corresponding trait as the dependent variable. The comparison of means of different cycles of selection in each population was also done by partitioning the cycle's sum of squares into linear contrasts.

Results

- CGR and SPAD chlorophyll readings had significant positive correlation with grain yield ($P < 0.01$) under low and high-N conditions (Table 1).
- LAD increased in Acr TZL Comp1-W, TZPB Prol., and TZL Comp1-W in response to selection in both low and high N ($P < 0.05$). Improved cycles of BR9928 DMRSR, LNTP-Y, and TZPB Prol. had higher LAI values than the earlier versions in both N-conditions (Table 2).
- CGR increased in response to selection in Acr TZL Comp1-W, BR9928 DMRSR, and TZL Comp1-W at 90 kgN/ha and in Acr TZL Comp1-W, LNTP-W, and TZL Comp1-W at 90 kgN/ha (Table 2).
- Significant yield gains were obtained in Acr97 TZL Comp1-W, TZPB Prol., and TZLComp1-W at 45 kgN/ha. At 90 kgN/ha, yield increased in subsequent cycles of selection in Acr97 TZL Comp1-W, LNTP-W, TZPB Prol., and TZL Comp 1-W (Table 3).
- Increment in Acr97 TZL Comp1-W was accompanied by increment in kernel rows, 100 kernel weight and number of kernels per row, while the increment in grain yield gain obtained in LNTP-W was accompanied by an increment in 100 kernel weight at both low and high-N environments (Table 3).

Table 1. Correlation coefficients between selected agronomic and yield traits and physiological traits at silking of populations of maize grown under low-N and high-N conditions at Ikenne and Ibadan.

	N-level	Plant height (cm)	Anthesis-Silking interval (days)	Kernel rows	No. of Kernels	100 Kernel weight (g)	Grain yield (Mg/ha)
LAI	Low-N	0.34ns	–0.15ns	–0.40ns	0.09ns	–0.28ns	0.08ns
	High-N	0.11ns	0.36ns	–0.16ns	–0.06ns	–0.26ns	0.06ns
LAR (cm^2/g)	Low-N	0.56^{*}	–0.03ns	0.22ns	0.33ns	–0.39ns	$–0.52^{*}$
	High-N	0.44^{*}	0.02ns	–0.38ns	0.05ns	0.12ns	–0.32ns
LAD (days)	Low-N	0.20ns	–0.19ns	–0.02ns	0.25ns	–0.22ns	0.06ns
	High-N	0.21ns	0.06ns	–0.16ns	–0.11ns	–0.16ns	0.08ns
CGR ($g/m^2/day$)	Low-N	–0.18ns	–0.11ns	–0.21ns	0.48^{*}	0.29ns	0.46*
	High-N	0.10ns	0.16ns	0.15ns	0.56^{*}	0.40ns	0.61^{**}
Total dry Weight (g/plant)	Low-N	0.32ns	0.02ns	–0.12ns	–0.10ns	0.47^{*}	0.67^{**}
	High-N	0.57^{**}	0.42ns	0.21ns	0.44ns	0.57^{*}	0.71^{**}
Leaf Chlorophyll (SPAD)	Low-N	–0.35ns	0.15ns	0.02^{ns}	–0.08ns	0.63^{**}	0.84^{***}
	High-N	–0.07ns	0.10ns	0.26^{ns}	0.38ns	0.66^{**}	0.71^{**}

*, **significant at 0.05 and 0.01 probability levels, respectively; ns: not significant

Table 2. Means of physiological traits obtained from the evaluation of different cycles of selection for tolerance to low soil nitrogen (N) in six maize populations at two N levels in Ikenne and Ibadan, Nigeria in 2012 and 2013.

Population	Leaf area index		Leaf area duration (days)		Leaf area ratio (cm2/g)		Crop growth rate (g/m2/day)		Net assimilation rate (g/m2/day)		Anthesis-silking interval	
	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha
Acr 97 TZL Comp1-W	2.68	3.23	33.44	39.23	60.92	51.82	14.46	23.93	5.34	8.84	1.50	1.25
Acr 97 TZL Comp1-W LN C1	2.82	3.26	38.15	44.12	64.46	60.21	18.41	26.23	6.05	9.44	1.50	1.25
Significance of change	*ns*	*ns*	*	*	*ns*	*	*	*	*ns*	*ns*	*ns*	*ns*
BR9928 DMRSR C0	2.17	2.86	35.72	35.69	62.10	58.01	14.57	19.00	5.49	6.51	2.00	1.00
BR9928 DMRSR LN C1	2.90	3.37	36.44	37.30	69.07	62.42	15.21	21.60	6.72	7.89	1.25	1.00
Significance of change	*	*	*ns*	*ns*	*	*	*ns*	*	*	*	*	*ns*
LNTP-W C3	2.59	3.09	32.07	35.94	49.43	52.64	14.56	19.56	6.23	7.10	1.75	1.50
LNTP-W C4	2.89	3.04	37.82	36.71	50.01	54.41	16.23	22.21	7.42	8..90	1.00	1.00
LNTP-W C5	2.85	3.61	38.85	39.86	58.74	58.58	19.00	23.56	8.50	9.86	1.25	0.75
b-value	0.13	0.26	3.39	1.96	4.66	2.97	2.22	2.00	1.08	1.38	-0.50	-0.25
Significance of change	*ns*	*ns*	*ns*	*ns*	*	*	*	*ns*	*	*	*	*ns*
LNTP-Y C6	2.64	3.00	34.57	41.19	50.96	46.85	16.23	18.67	6.99	7.32	1.75	1.25
LNTP-Y C7	2.97	3.47	39.43	40.66	56.08	46.06	17.63	23.45	7.52	8.45	1.25	1.50
LNTP-Y C8	3.25	3.87	39.52	43.12	56.39	52.46	18.00	24.22	7.97	9.23	1.25	1.50
b-value	0.31	0.44	2.50	0.96	2.72	3.00	0.89	2.78	0.49	0.95	0.25	0.13
Significance of change	*	*	*ns*	*ns*	*ns*	*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
TZPB Prol.C3 LN SYN	2.68	3.35	33.28	37.47	64.05	52.21	15.17	20.00	6.71	7.68	1.25	1.50
TZPB Prol.C4	3.28	3.24	36.54	38.28	61.62	56.34	16.23	22.45	7.18	8.43	2.00	1.00
TZPB Prol. C5	3.37	4.04	42.20	48.14	65.01	56.99	18.00	25.15	8.41	9.70	1.50	1.25
b-value	0.35	0.35	4.46	5.34	0.48	2.39	1.42	2.57	0.85	1.01	0.25	-0.25
Significance of change	*	*	*	*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
TZL Comp 1-W C6	2.68	3.48	34.75	38.64	58.10	52.61	15.33	22.43	6.28	8.45	1.75	1.75
TZL Comp 1-W C6 LNC1	2.80	3.25	37.92	43.96	63.10	65.71	19.32	26.34	7.56	10.35	1.50	1.00
Significance of change	*ns*	*ns*	*	*	*	*	*	*	*	*	*ns*	*

*. significant at 0.05 probability level; ns: not significant

Table 3. Means of yield and yield traits obtained from the evaluation of different cycles of selection for tolerance to low soil nitrogen (N) in six maize populations at two N levels in Ikenne and Ibadan, Nigeria in 2012 and 2013.

Population	Cob length (cm)		Ears per plant		No. of kernels per row		100 grain weight (g)		Kernel rows		Grain yield (Mg/ha)	
	45 kgN/ha	90 kgNha	45 kgNha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha	45 kgN/ha	90 kgN/ha
Acr 97 TZL Comp1-W	16.06	18.10	0.95	1.02	32.42	34.92	28.75	32.22	13.33	14.83	3.50	5.23
Acr 97 TZL Comp1-W LN C1	17.85	18.36	1.04	1.04	34.28	36.37	30.73	35.17	15.16	16.30	4.27	5.99
Significance of change	*	*ns*	*ns*	*ns*	*	*	*	*	*	*	*	*
BR9928 DMRSR C0	17.34	17.14	0.94	1.06	32.87	32.29	26.60	26.67	12.59	14.16	3.20	4.23
BR9928 DMRSR LN C1	17.79	17.52	1.05	0.99	32.83	32.59	32.16	31.11	14.12	14.17	3.55	4.60
Significance of change	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	**	**	*	*ns*	*ns*	*ns*
LNTP-W C3	17.37	18.54	0.90	1.06	34.06	36.76	30.07	33.28	13.37	13.54	2.85	4.00
LNTP-W C4	17.75	19.05	0.94	1.03	35.16	37.90	32.00	34.66	14.04	14.17	4.17	5.59
LNTP-W C5	19.03	19.38	0.97	1.01	35.99	38.29	32.11	36.47	13.96	14.58	3.51	5.97
b-value	0.83	0.42	0.04	0.03	0.97	0.77	1.02	1.60	0.34	0.52	0.33	0.96
Significance of change	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*	*	*ns*	*ns*	*ns*	**
LNTP-Y C6	16.29	16.60	1.00	1.14	33.58	32.71	29.79	34.62	13.58	13.55	3.50	5..37
LNTP-Y C7	17.54	17.63	1.06	1.26	33.61	33.83	30.30	35.63	13.41	13.77	3.86	5.56
LNTP-Y C8	18.46	17.77	1.02	1.15	33.71	33.82	31.09	35.60	13.67	14.13	3.87	5.42
b-value	1.19	0.59	0.01	0.01	0.06	0.57	0.65	0.49	0.05	0.29	0.19	0.03
Significance of change	*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
TZPB Prol.C3 LN SYN	16.76	16.64	1.15	1.36	30.33	34.00	29.51	34.20	13.00	13.55	3.23	4.72
TZPB Prol.C4	17.34	18.00	1.29	1.36	32.27	35.67	30.88	35.23	12.93	13.87	4.10	5.13
TZPB Prol. C5	17.96	18.61	1.15	1.36	33.45	35.46	32.92	36.32	14.34	14.68	4.41	5.70
b-value	0.60	0.98	0.00	0.00	1.56	0.73	0.71	0.53	0.67	0.56	0.59	0.50
Significance of change	*ns*	*	*ns*	*ns*	*ns*	*ns*	*	*ns*	*ns*	*ns*	*	*
TZL Comp 1-W C6	16.76	17.20	0.96	0.91	31.08	33.50	29.50	32.43	13.00	14.28	3.06	4.41
TZL Comp 1-W C6 LNC1	17.10	17.87	1.04	1.06	32.21	34.25	30.12	33.25	13.08	15.34	3.52	5.69
Significance of change	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*	**

*. **significant at 0.05, 0.01 probability levels, respectively; ns: not significant

Conclusions

- Crop growth rate and chlorophyll concentration were the traits most associated with grain yield under low soil nitrogen.
- Response to selection was significant in some populations while additional cycles of selection will be required in others to significantly shift gene frequencies in the desired direction.

References

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