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Liming effects on reproductive growth and yield components of maize grown on an acid rainforest soil

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Abstract

Maize was planted on limed and unlimed plots to study the effect of soil acidity on reproductive growth and yield components of the crop in Owerri southeastern Nigeria. Eight (8) maize varieties (Factor A) and two lime levels (0 and 2 t ha^{-1}, Factor B) were arranged as a factorial experiment in a randomised complete block design with three replications. The number of days to 50 % anthesis and silking, anthesis-silking interval (ASI), physiological maturity and grain filling duration were measured to determine the effect on reproductive development. The effect on yield and yield components were determined by measuring the number of grain rows cob^{-1}, grains row^{-1}, grains cob^{-1}, weight of hundred seeds and grain yield. Soil acidity induced the distortion of the synchrony in maize flowering by a 45.9 % increase in ASI. This caused a reduction in yield components and ultimately reduced grain yield by 35.5 %. Among the varieties, AK 9928-DMRSR, OBA SUPER II and AMA TZBR C1 with ASI of 3.0, 4.0 and 4.0 days respectively, were the least affected by distortion of synchrony in flowering. These varieties also had the highest grain yield (3.3, 2.9 and 3.1 t ha^{-1}, respectively), greatest number of grains cob^{-1} (kernel number, 358, 327 and 339) and were therefore the best among this set of maize varieties under the prevailing acid soil conditions.

Keywords: Anthesis-silking interval, flowering synchrony, kernel number, lime, southeastern Nigeria

1 Introduction

In maize (*Zea mays* L.), primary yield components include the number of cobs/plant, number of rows cob^{-1}, number of grains row^{-1}, kernel number and weight of 100 grains (Milander, 2015). Among these, changes in grain yield are probably most closely associated with changes in kernel number. Kernel number is a function of the rate and duration of differentiation of spikelets, cessation of development of spikelets prior to the initiation of silks, fertilisation which requires synchronisation of flowering of tassel and ears and kernel abortion after fertilisation (Jacobs & Pearson, 1991; Carcova *et al.*, 2000). Therefore, changes in grain yield are determined by factors affecting the entire reproductive phase of maize development. In order to develop management options for improved grain yield on acid soils, it is necessary to understand the effects of soil acidity on maize reproductive traits.

Soil acidity is one of the major abiotic stresses which limit crop production and it is a major constraint to maize production throughout the humid tropics (The *et al.*, 2001). In the tropics, the major factors responsible for the development of soil acidity are the occurrence of high rainfall resulting in the gradual depletion of soil bases and removal of soluble salts and more readily soluble minerals, the application of ammonium containing fertilisers which generate nitrate and hydrogen ions when oxidised by soil bacteria and the decomposition of organic matter and root respiration with the formation of organic acids such as carbonic acid (Harter, 2007). In southeastern Nigeria, most soils are derived from coastal plain sands, sand stones and basement complex rocks (Akpan-Idiok, 2012). They are characterised by low organic matter, low soil pH, nutrient deficiencies and a preponderance of free aluminium (Onwuka *et al.*, 2007). Widespread deficiency of phosphorus (P) has also been reported on the

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acid sandy soils of southeastern Nigeria (Akinmutimi, 2014) and particularly of the soils of Ihiagwa in Imo state, Nigeria (Uzoho & Oti, 2005). But while it is generally accepted that maize yields are reduced on acid soils, few data exist on the effect of soil acidity on its production (Mbah & Nkpaji, 2010). Most research efforts address aluminium effects on root growth and varietal tolerance mechanisms (Mattiello, 2010; Silva, 2012). The results from such research have no doubt generated a large pool of relevant information. However, knowledge is lacking on the effects of soil acidity on parameters which contribute to grain yield since this has a direct impact on household income and food security. This study was therefore conducted to evaluate the performance of maize varieties on limed and unlimed soil to assess the effects of soil acidity on reproductive growth and yield components of maize in Owerri, southeastern Nigeria.

2 Materials and methods

Location of the study

The experiment was conducted at the Teaching and Research Farm of School of Agriculture and Agricultural Technology, Federal University of Technology Owerri (Latitude 50° 20" N 50° 27" N and Longitude 70° 00" E 70° 07" E). This location is situated within the Southeast humid forest zone of Nigeria. Soil type was Arenic Hapludiult (USDA, 1999) and a climax vegetation of Siam weed (*Chromolaena odorata*) mixed with some stands of cassava (*Manihot esculenta*) which must have regrown from stems left after the last harvest. Prior to setting up the field experiment 15 soil samples from different locations of the study site were taken at 0–20 cm and bulked to obtain a composite. The samples were then air-dried, sieved using a 2 mm diameter sieve and the fine soil samples were analysed for selected physical and chemical properties using standard procedures. Particle size fractions were determined after dispersion with calgon (Gee & Or, 2002), pH in 1:2.5 soil/water ratio using glass electrode of the pH meter, available P (Olsen & Sommers, 1982), total N (Bremner, 1996), organic matter (Nelson & Sommers 1996) and exchangeable cations (Thomas, 1996).

Treatments and design of experiment

The experiment was a 8×2 factorial arranged in a randomised complete block design. The treatments comprised eight maize varieties as Factor A and two lime levels as Factor B. The sixteen treatment combinations were replicated three times. Seven of the maize varieties were obtained from the International Institute for Tropical Agriculture (IITA) Ibadan, while a landrace which served as control was obtained from Awaka in Owerri North Local Government Area of Imo State, Nigeria. The maize varieties included two hybrids (OBA SUPER I and OBA SUPER II), five open pollinated cultivars (AK-9928-DMRSR, ACR-95TZE COMP4 C3, EV 99 QPM, TZM COMP 32 and AMA TZBR C1) and the landrace OKA AWAKA. The lime levels were 0 and 2 t ha^{-1} of calcium hydroxide (Ca(OH)2). The liming material was evenly broadcast on each plot one week before planting and worked into the soil with a garden fork. Main plots measured 3.75×7.0 m while sub plots measured 3.75×3.0 m. NPK fertiliser (20:10:10) was applied in two split doses at 3 weeks after planting (WAP) and at tasseling, at the rate of 120 kg N ha^{-1}, 60 kg $P_2 0_5$ ha^{-1} and 60 kg $K_2 0$ ha^{-1}. Two seeds of maize were sown per hole at a spacing of 0.75×0.25 m and thinned to one plant per stand at 3 WAP to yield a population of 53,333 plants ha^{-1}.

Data collection and statistical analysis

The number of days to 50 % anthesis and silking, anthesis-silking interval, physiological maturity and grain filling duration were measured to determine the effect of liming on reproductive development. Liming effects on yield and yield components were determined at harvest by measuring the number of grain rows cob^{-1}, grains row^{-1}, grains cob^{-1}, weight of hundred seeds and grain yield. Days to 50 % anthesis and silking were determined by reckoning the number of days from sowing to the time 50 % of the plants in each plot had attained anthesis and silking. For each plot the anthesis-silking interval was calculated as the difference between the days to 50 % silking and 50 % anthesis. Physiological maturity was determined as the number of days from sowing to the time of black layer formation, while grain filling duration was the difference between the number of days to black layer formation (physiological maturity) and 50 % silking. Grain yield was determined after harvesting at 15 WAP. Soil pH was determined again at harvest. Analysis of variance and correlation analysis procedures were carried out on the data using the Statistical Analysis System (SAS) (2002) package while means were separated using the Least Significant Difference (LSD) at 5 % level of probability.

3 Results

Soil physical and chemical properties

The physical and chemical properties of the soil sample were: pHwater before liming(5.28), pH in water after liming (5.6), sand content (88.24 %), silt (6.00 %), clay (5.76 %), total nitrogen (0.1 %), organic carbon (0.6 %), phosphorus (17.8 mg kg^{-1}), calcium (0.5 cmol kg^{-1}), magnesium (0.1 cmol kg^{-1}), potassium (0.11 cmol kg^{-1}), sodium (0.55 cmol kg^{-1}), aluminium (1.0 cmol kg^{-1}) and hydrogen

Table 1: *Comparative analysis of reproductive characters as affected by lime application among maize varieties on an acid Arenic Hapludiult in southeastern Nigeria*

	Maize varieties								
Lime ($t\ ha^{-1}$)	OBA SUPER I	AK-9928-DMRSR	ACR-95TZE COMP4 C3	EV 99 QPM	TZM COMP 32	OBA SUPER II	AMA TZBR C1	OKA AWAKA	Mean
				50 % Anthesis (in days)					
0	67.3	64.0	58.7	55.0	66.7	70.3	66.3	71.3	65.0
2	64.0	63.7	57.0	53.7	64.0	64.7	61.7	67.3	62.0
Mean	65.7	63.8	57.8	54.3	65.3	67.5	64.0	69.3	
LSD(0.05): Lime=1.20; Variety=2.40; Lime x Variety=n.s.									
				50 % Silking (in days)					
0	73.0	67.7	63.3	60.3	72.7	76.0	71.7	78.0	70.3
2	67.3	66.7	60.7	58.0	68.0	67.7	65.0	72.0	65.7
Mean	70.2	67.2	62.0	59.2	70.3	71.8	68.3	75.0	
LSD(0.05): Lime=1.50; Variety=3.00; Lime x Variety=n.s.									
				Anthesis-silking interval (in days)					
0	5.7	3.7	4.7	5.3	6.0	5.7	5.3	6.7	5.4
2	3.3	3.0	3.7	4.3	4.0	3.0	3.3	4.7	3.7
Mean	4.5	3.3	4.2	4.8	5.0	4.3	4.3	5.7	
LSD(0.05): Lime=0.57; Variety=1.14; Lime x Variety=n.s.									
				Physiological maturity (in days)					
0	100.3	96.7	90.7	86.7	101.3	99.7	99.3	103.7	97.3
2	94.7	97.0	88.3	85.0	98.3	96.7	96.0	102.0	94.8
Mean	97.5	96.8	89.5	85.8	99.8	98.2	97.7	102.8	
LSD(0.05): Lime=1.42; Variety=2.84; Lime x Variety=n.s.									
				Grain filling duration (in days)					
0	27.3	29.0	27.3	26.3	28.7	23.7	27.7	25.7	27.0
2	27.3	30.3	27.7	27.0	30.3	29.0	31.0	30.0	29.1
Mean	27.3	29.7	27.5	26.7	29.5	26.3	29.3	27.8	
LSD(0.05): Lime=1.32; Variety=2.64; Lime x Variety=n.s.									

(0.4 $cmol\ kg^{-1}$). This showed that the soil was sandy loam in texture with a base saturation of 59.0 % of cation exchange capacity (CEC) and aluminium accounting for 98.8 % of the exchangeable acidity

Response to lime application

Lime application at 2 $t\ ha^{-1}$ raised soil pH from 5.2 to 5.6. In unlimed plots the number of days to 50 % anthesis, the number of days to 50 % silking, anthesis-silking interval and physiological maturity were 3, 5, 2 and 3 days higher than with liming which also reduced grain filling duration by 2 days (Table 1). Lime application significantly increased number of grain rows cob^{-1} from 12.2 to 12.9 (5.7 %), number of grains row^{-1} from 22.3 to 26.3 (17.9 %), number of grains cob^{-1} from 273 to 341 (24.9 %), weight of hundred seeds from 19.8 to 22.6 g (19.6 %) and grain yield from 2.0 to 3.1 $t\ ha^{-1}$ (58.5 %, Table 2).

Differences among maize varieties

The local variety OKA AWAKA attained 50 % anthesis significantly later (at 69 days) than other varieties except OBA SUPER II (68 days) while the variety EV 99 QPM attained 50 % anthesis significantly earlier (54 days) than the other varieties (Table 1). The varieties ACR 95 TZE COMP C3 and EV 99 QPM attained 50 % silking significantly earlier than the other varieties while OKA AWAKA silked significantly later than the other varieties.

The anthesis-silking interval (ASI) was largest in OKA AWAKA (6 days) which was significantly greater than the ASI in OBA SUPER I (5 days), OBA SUPER II, AMA TZBR C1, ACR 95TZE COMP4 C3 (4 days) and AK 9928-DMRSR (3 days). The local variety, OKA AWAKA, attained physiological maturity significantly later (at 103 days) after sowing than all other varieties while EV 99 QPM attained

Table 2: *Comparative analysis of grain yield and yield components as affected by lime application among maize varieties on an acid Arenic Hapludiult in southeastern Nigeria*

	Maize varieties								
Lime ($t\,ha^{-1}$)	OBA SUPER I	AK-9928-DMRSR	ACR-95TZE COMP4 C3	EV 99 QPM	TZM COMP 32	OBA SUPER II	AMA TZBR C1	OKA AWAKA	Mean
	Grain rows per cob (number)								
0	12.4	13.0	12.4	11.4	11.8	11.9	11.3	13.7	12.2
2	13.1	13.6	12.2	11.8	12.4	13.4	12.8	13.9	12.9
Mean	12.7	13.3	12.3	11.6	12.1	12.7	12.0	13.8	
LSD(0.05): Lime=0.63; Variety=1.26; Lime x Variety=n.s.									
	Grains per row (number)								
0	23.2	26.0	17.5	21.8	21.5	24.4	23.9	19.8	22.3
2	27.1	27.9	23.3	25.6	24.0	26.7	31.6	24.1	26.3
Mean	25.1	26.9	20.4	23.7	22.8	25.6	27.7	21.9	
LSD(0.05): Lime=2.49; Variety=4.98; Lime x Variety=n.s.									
	Grains per cob (number)								
0	289.3	336.9	220.0	249.7	251.6	294.0	271.7	271.8	273.1
2	354.3	379.6	287.3	302.0	297.6	360.2	405.4	343.6	341.2
Mean	321.8	358.2	253.6	275.8	274.6	327.1	338.6	307.7	
LSD(0.05): Lime=42.52; Variety=n.s; Lime x Variety=n.s.									
	Weight of hundred seeds (g)								
0	19.2	20.4	16.5	18.2	19.8	21.0	19.0	17.0	18.9
2	18.7	23.8	26.1	24.2	21.4	21.3	24.9	20.8	22.6
Mean	18.9	22.1	21.3	21.2	20.6	21.1	22.0	18.9	
LSD(0.05): Lime=1.95; Variety=n.s; Lime x Variety=n.s.									
	Grain yield ($t\,ha^{-1}$)								
0	2.0	2.7	1.3	1.6	2.0	2.5	2.1	1.6	2.0
2	2.5	3.9	3.0	2.7	2.3	3.2	4.1	2.9	3.1
Mean	2.2	3.3	2.2	2.2	2.1	2.9	3.1	2.2	
LSD(0.05): Lime=0.56; Variety=1.11; Lime x Variety=n.s.									

physiological maturity significantly earlier (at 86 days) than all other varieties.

The varieties AK 9928-DMRSR and TZM COMP 32 had a grain filling duration of 30 days which was significantly greater than grain filling duration in EV 99 QPM (27.0 days) and OBA SUPER II (26.0 days). Grain filling duration in AMA TZBR C1 (29.0 days) was also significantly greater than grain filling duration in OBA SUPER II. There were no significant lime × variety interaction effects on 50 % anthesis, 50 % silking, ASI, physiological maturity and grain filling duration. The number of grain rows cob^{-1} was significantly greater in OKA AWAKA (13.8) than ACR 95TZE COMP4 C3 (12.3), TZM COMP 32 (12.1), AMA TZBR C1 (12.0) and EV 99 QPM (11.6). AK 9928-DMRSR also had significantly greater number of grain rows cob^{-1} (13.3) than AMA TZBR C1 (12.0) and EV 99 QPM (11.6). The number of grains row^{-1} in AMA TZBR C1(27.7) and AK 9928-DMRSR (26.9) did not differ significantly, but these varieties had significantly greater number of grains row^{-1} when compared to OKA AWAKA (21.9) and ACR 95TZE COMP4 C3 (20.4). OBA SUPER II also had significantly greater number of grains row^{-1} (25.6) than ACR 95TZE COMP4 C3. Grain yield in AK 9928-DMRSR (3.3 $t\,ha^{-1}$) was significantly greater compared to EV 99 QPM (2.2 $t\,ha^{-1}$), ACR 95TZE COMP4 C3 (2.2 $t\,ha^{-1}$) and TZM COMP 32 (2.1 $t\,ha^{-1}$). The open pollinated varieties, AK 9928-DMRSR and AMA TZBR C1 which out yielded the local variety by 48 and 38 % respectively, showed the highest grain yields among the varieties evaluated, while OBA SUPER II with 28 % more yield than the local variety was the higher yielding of the two hybrid varieties. These three varieties had the best yield in the order AMA TZBR C1> AK 9928-DMRSR> OBA SUPER II when lime was applied, and when no lime was applied

Table 3: *Correlation coefficients of some maize reproductive and yield parameters on an acid Arenic Hapludiult in southeastern Nigeria*

	Silking	*Grains row^{-1}*	*Rows cob^{-1}*	*Grains cob^{-1}*	*Wt. of 100 seeds*	*Grain yield*	*ASI*
Tasseling	0.97266*	-0.11601	0.19733	-0.01601	-0.27948	-0.12054	0.33270
Silking		-0.26927	0.06932	-0.18322	-0.36531	0.27217	0.54010*
Grains row^{-1}			0.43300*	0.93453*	0.61987	0.87717*	-0.68188*
Rows cob^{-1}				0.71842*	0.21436	0.57656*	-0.43872*
Grains cob^{-1}					0.56458	0.90561*	-0.69782*
Wt. of 100 seeds						0.81145*	-0.62482*
Grain yield							-0.67239*

* significant correlation; ASI: anthesis-silking interval

they were still the best but in the order AK 9928-DMRSR> OBA SUPER II> AMA TZBR C1. There were no significant lime × variety interaction effects on maize grain yield and yield components (Table 2).

The result of correlation analysis (Table 3) indicate that grain yield correlated positively and significantly with the number of grains row^{-1}, number of rows cob^{-1}, number of grains cob^{-1}, and weight of hundred seeds. The number of grains cob^{-1}, had the greatest association with grain yield. The anthesis-silking interval correlated significantly but negatively with grain yield and yield components.

4 Discussion

Aluminium toxicity is a well-known problem at the study site (Onwuka *et al.*, 2007), and occurs in soils of pH < 5.5 and increases in intensity as pH decreases below 5.0 (Uzoho, 2010). Application of lime must have reduced aluminium in the soil solution while calcium from the liming material replaced aluminium on the colloidal complex (Brady & Weil, 1999; Sun *et al.*, 2000) thereby increasing pH. Acidity in the soil delayed the time of anthesis and silking by three and five days, respectively (4.8 and 7.0 %) and consequently increased the ASI by two days (45.9 %). This is indicated by an increase in the number of days to 50 % anthesis and silking without soil liming. Usually, under favourable conditions, maize silks emerge 2-3 days after pollen shed (anthesis). Since pollen shed continues for 14 days or more, there is an overlap with silk emergence and period of receptivity (Danquah *et al.*, 2001). Therefore a close synchrony between anthesis and silk emergence is required for high kernel set in maize (Barnabas *et al.*, 2008). Generally, abiotic stress factors characteristically reduce kernel number in maize by increasing the anthesis-silking interval (Bolanos & Edmeades, 1993). When drought stress occurs just before or during flowering, silk emergence is delayed while anthesis is largely unaffected (Faud-Hassan *et al.*, 2008) resulting in an increased anthesis-silking interval (Kamara *et al.*, 2003; Ali *et al.*, 2011). In this study therefore, increase in ASI resulted from a soil acidity-induced distortion of the synchrony in flowering which probably led to increase in the number of unpollinated flowers and consequently increase in the number of aborted kernels (Bolanos & Edmeades, 1996; Barbieri *et al.*, 2000). Hence, soil acidity reduced grain rows cob^{-1} by 5.4 %, grains row^{-1} by 15.2 %, grains cob^{-1}by 20.0 %, weight of hundred seeds by 16.4 % and grain yield by 35.5 %.

The distortion of synchrony in flowering due to soil acidity varied among the maize varieties with the open pollinated cultivar AK 9928-DMRSR being the least affected and the landrace OKA AWAKA the most affected. This indicates the existence of variability among maize varieties in tolerance to acidity (Tandzi *et al*, 2018). A negative, significant correlation between ASI and grain yield and yield components indicated that reduced ASI was necessary for improved maize performance under stress (Campos *et al*, 2004). Among the yield components, the number of grains cob^{-1} (kernel number) was closely correlated with grain yield. This agrees with the report of Andrade *et al.*, (2000) that maize grain yield is closely associated with kernel number. Accordingly AK 9928-DMRSR, OBA SUPER II and AMA TZBR C1, with the highest kernel number and grain yield as well as the lowest ASI, were the best among this set of maize varieties. However, in this study acidity effects on maize performance did not depend on the maize variety since the effect of lime × variety interaction was not significant. Therefore, the differences among this set of maize varieties are due to genotypic or other environmental factors.

5 Conclusions

Soil acidity reduced grain yield of maize through delayed flowering, distorted flowering synchrony and reduced yield components. The best performing maize varieties had the lowest ASI and the highest kernel number. These traits could serve as basis for selecting maize varieties adapted to the acid soil conditions in the humid forest zone.

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Conflict of interest

The authors hereby declare no conflict of interests.

References

Akinmutimi, A. L. (2014). Effects of cocoa pod husk ash and NPK fertilizer on soil nutrient status and sweetpotato yield in an Ultisol in Southeastern Nigeria. *International Journal of Advanced Research*, 2 (2), 814–819.

Akpan-Idiok, A. U. (2012). Physicochemical degradation rate and vulnerability potential of soils formed on coastal plain sands in southeast Nigeria. *International Journal of Agricultural Research* 7 (7): 358–366.

Ali, Z., Basra, S. M. A., Murir, H., Mahmood, A. & Yousaf, S. (2011). Mitigation of drought stress in maize by natural and synthetic growth promoters. *Journal of Agriculture and Social Sciences*, 7, 56–62.

Andrade, F. H., Otegui, M. E & Vega, C. (2000). Intercepted radiation at flowering and kernel number in maize. *Agronomy Journal*, 92, 92–97.

Barbieri, P. A., Sainz Rozas, H. R., Andrade, F. H & Echeverria, H. E. (2000). Row spacing effects at different levels of nitrogen availability in maize. *Agronomy Journal*, 92, 283–288.

Barnabas, B., Jager, K. & Feher, A. (2008). The effect of drought and heat stress on reproductive process in cereals. *Plants Cell and Environment*, 31, 11–38.

Bolanos, J. & Edmeades, G.O. (1993). Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield, biomass and radiation utilization. *Field Crops Research*, 31, 233–252.

Bolanos, J. & Edmeades, G. O. (1996). The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. *Field Crops Research*, 48, 65–80.

Brady, N. C. & Weil, R. R. (1999). The nature and properties of soils. Prentice Hall Inc. New Jersey. o Bremner, J. M. (1996). Nitrogen-total, In: Sparks D. L. (ed.). Methods of Soil Analysis. Part 3. Chemical Methods, Vol. 5 of Soil Science Society of America Book Series, Soil Science Society of America/ American Society of Agronomy, Madison, WI, pp. 1085–1122.

Campos, H., Cooper, M., Habben, J. E., Edmeades, G. O. & Schussler, J. R. (2004). Improving drought tolerance in maize: a view from industry. *Field Crops Research*, 90 (1), 19–34.

Carcova, J., Uribelarrea, M., Borras, L., Otegui, M. E. & Westgate, M. E. (2000). Synchronous pollination within and between ears improves kernel set in maize. *Crop Science*, 40, 1056–1061.

Danquah, E. Y., Sallah, P. Y. K., Blay, E. T. & Abogyenuamah, F. (2001). Evaluation of local maize collections for drought tolerance. *Ghana Journal of Agricultural Science*, 34, 63–70.

Fuad-Hassan, A., Tardieu F. & Turc, O. (2008). Drought-induced changes in anthesis-silking interval are related to silk expansion: A spatio-temporal growth analysis in maize plants subjected to soil water deficit. *Plant, cell and environment*, 31, 1349–1360.

Gee, G. W. & Or, D. (2002). Particle size an.alysis. In: Dane, J. H. and Topps, G. C. (eds.). Methods of soil analysis, Part 4. Physical methods. Soil Sci. Soc. Am. Book Series No. 5, ASA and SSSA, Madison, WI. pp. 255–293.

Harter, R. D (2007). Acid soils of the tropics. Revised 2007 ECHO Technical note.

Jacobs, B. S. & Pearson, C. J. (1991). Potential yield of maize determined by rates of growth and development of ears. *Field Crops Research*, 27, 281–298.

Kamara, A. Y., Menkir, A., Badu-Apraku, B. & Ibikunle, O. (2003). Reproductive and stay-green trait responses of maize hybrids improved open-pollinated varieties and farmer's local varieties to terminal drought stress. *Maydica*, 48, 29–37.

Mattiello, L., Kirst, M., da Silva, F. R., Jorge, R. A. & Menossi, M. (2010). Transcriptional profile of maize roots under acid soil growth. *BMC Plant Biology*, 10, 196–209.

Mba, C. N. & Nkpaji, D. (2010). Response of Maize (*Zea mays* L.) to different rates of wood ash application in acid Ultisol in Southeast Nigeria. *Journal of American Science*, 6 (1), 53–57.

Milander, J. J. (2015). Maize yield and components as influenced by environment and agronomic management. Theses, Dissertations and Student Research in Agronomy and Horticulture. Paper 86. http://digitalcommons.unl.edu/agronhortdiss/86

Nelson, D. W. & Sommers, L. E. (1996). Total carbon, organic carbon and organic matter. In: Sparks, D. L. (ed.): Methods of soil analysis. ASA. SSSA. Madison, Wisconsin, USA. pp. 961–1010.

Olsen, S. R. & Sommers, L. E. (1982). Phosphorus. In: Page, A. L, Miller, R. H. & Keeney, D. R. (eds). Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy, Madison,WI. pp. 403–430.

Onwuka, M. I., Osodeke, V. O. & Okolo, N. A. (2007). Amelioration of soil acidity using cocoa husk ash for maize production in Umudike area of Southeast Nigeria. *Tropical and Subtropical Agroecosystems*, 7, 41–45.

Silva, S. (2012). Aluminum toxicity targets in plants. *Journal of Botany*, Vol. 2012, Article ID 219462, pp. 8 doi: 10.1155/2012/219462

Statistical Analysis System Institute Inc. (2002). SAS/STAT User's guide. SAS, Cary, NC.

Sun, B., Poss, R., Moreau, R., Aventurier, A. & Fallavier, P. (2000). Effect of slake lime and gypsum on acidity alleviation and nutrient leaching in an acid soil from southern China. *Nutrient Cycling in Agroecosystems*, 57 (3), 215–223.

Tandzi, L. N., Mutengwa, C. S., Ngonkeu, E. L. M. & Gracen, V. (2018). Breeding maize for tolerance to Acid soils: A review. *Agronomy*, 8 (84), 1–21.

The, C., Horst, W. J., Calba, H., Welcker, C. & Zonkeng, C. (2001). Identification and development of maize genotypes adapted to acid soil of the tropics. In: Badu-Apraku, B., Fakorede, M. A. B., Ouedraogo, M. & Carsky, R.J. (Eds). Proceedings of a regional maize workshop. Cotonou 4-7 May 1999.

Thomas, G. W. (1996). Soil pH and soil acidity. In: Sparks D. L. (ed.): Methods of soil analysis. Part 3. Chemical methods. Soil Science Society of America, Madison, WI. pp. 475–490.

USDA (1999). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2^{nd} Edition. USDA-NRCS Agric. Handbook 436. U.S Govt. Printing Office, Washinton, DC.

Uzoho, B. U. (2010). Nitrogen and phosphorus dynamics of municipal solid waste compost amended Ultisol in Southeastern, Nigeria. Ph.D Thesis. 210 p.

Uzoho, B. U. & Oti, N. N. (2005). Estimation of phosphorus requirement of maize in selected soils of southeastern Nigeria using P-Sorption Isotherm. *Nigerian Agricultural Journal*, 36, 157–168.