SCHOLEDGE International Journal Of Multidisciplinary & Allied Studies
ISSN 2394-336X, Vol.07, Issue 02 (2020)
Pg 45-73.
Paper URL: link.thescholedge.org/1210

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Effect of Soil Site on Sugar Cane (*Saccharum Officinarum* L.) Growth over Time in The Mangrove (*Rhizophora* Spp.) Forest Ecosystem of Ogonokom-Abua, Rivers State, Nigeria

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ABSTRACT

Sugar cane was planted on three soil units or sites delineated in a mangrove forest ecosystem in Ogonokom-Abua, Rivers State, Nigeria in the 2009/2010 cropping year. The sites were selected based on their differences in water regime viz: non-flooded, partially flooded and completely flooded on a 6-hourly basis by saline tidewater from the Atlantic Ocean. The experiment was, essentially, to determine the productive capacity of the soils in their natural setting, without any amendment whatsoever. The plants produced the highest growth indices in soil unit 1 followed rather distantly by those in unit II and, lastly, by the ones in unit III. The agricultural potential of older soils that have been uplifted above the tidal flood level represented by soil unit 1 needs to be exploited for the cultivation of sugar cane with imperatives for appropriate management practices to increase the productive capacity of the soils. On the other hand, younger soils in the flood basin such as units II and III in the present study need to be preserved to perform their critical role to protect the mangrove ecosystem in the State, in particular, and elsewhere in the Niger Delta region.

Keywords: Flooding, Mangrove, Productivity, Stool, Tidewater.

INTRODUCTION

The present study was conducted at Ogonokom-Abua in Abua-Odual Local Government Area LGA) of Rivers State, Nigeria, in the mangrove forest vegetation belt in the Niger Delta. The mangrove vegetation belt in Rivers State is generally anchored by two major soil types – soils of "soft mud" and "peaty clay". In Ogonokom-Abua situated in the Degema "Hulk" geologic unit, a different type exists that also carries mangrove vegetation - soils of "saline sands" (Ilaco-Nedeco 1966, Ayolagha and Onuegbu, 2002). The latter type is closely related to the "Ogoni Sands" that are extremely sandy in texture and very low in nutrient content (Aroh, 2003). The soils are uncultivated as their "soft mud" and "peaty clay" counterparts due to sundry growth-limiting soil conditions, particularly recurrent flooding by saline tidewater. Adverse effects of flooding and salinity on soils and most land plants are fairly well researched and reported (Maas, 1990, Onuegbu, 1997, Shea, 2000, Reddy *et al.*, 2000, Singer and Munns.1996, Striker *et al.*, 2005. Colmer and Voesenek, 2009).

As a result, the vast areas of mangrove forestlands in Rivers State, occurring in eleven out of twenty-three Local Government Areas (LGAs) of the State (Ayolagha and Onuegbu, 2002) have remained largely untapped (Akpan-Idiok and Esu, 2004). With a population density of 261 persons per square kilometer in Rivers State (Ayolagha and Onuegbu, (2002), pressure on dryland areas have necessitated the search for ways to explore the agricultural potential of mangrove swamp soils in Rivers State, nay the Niger Delta region. However, this depends on whether the crop (s) to be introduced will withstand the perceived soil constraints in the area. Whereas mangrove swamp soils offer the great prospects for massive forest trees establishment (Aluko *et al.*, 2001), it is not clear or known if sugar cane will grow to maturation stages in the mangrove ecosystem in Rivers State, Nigeria. Therefore, the cultivation of sugar cane in the study area deserves scientific enquiry. The aim of the present investigation was conceived to determine soil properties at different sites in a mangrove forest ecosystem and relate these to productivity indices of sugar cane (*Saccharum officinarum* L). The crop being a grass plant and largely water-loving like paddy rice (*Oryza sativa*), it is thought that some of its varieties or cultivars may be grown in the mangrove forest ecosystem with a reasonable result.

MATERIALS AND METHODS

Experimental site or study area

The present study was conducted at Ogonokom-Abua in Abua-Odual Local Government Area (LGA) of Rivers State, Nigeria, and located in the mangrove forest vegetation belt in the Niger Delta (Figs. 1 and 2).

The experimental plot was sub-divided qualitatively into three blocks/replicates representing soil sites or units with different moisture regimes as described below.

Block/Replicate I > Soil Site/Unit No. I: Non-flooded, i.e., previously flooded but has been raised far above the flood level of tidewater, thus, the unit had 0% flood incidence;

Block/Replicate II > Soil Site/Unit No. II: Daily flooded partially, i.e., one-half of the land space in the unit was flooded at each full tide all through the year, thus, the site/unit had 50% flood incidence and comprised properties of sites/units I and III in equal proportions in the experiment;

Block/Replicate III > Soil Site/Unit No. III: Daily flooded completely during every high tide, or 100% flood incidence throughout the year.

Plot size per block, according to Amosun (2000) and Amosun (2001) was 6 meters x 5 meters = $30m^2$. Size of each experimental unit = 1.5m x 1.25m = $1.875m^2$. Size of alley between blocks = 6m x 3m x 2 No. = $36m^2$. Plant spacing was 1.0m inter-row with 25cm end-lap and 1.25m between rows (Amosun, 2000). Two rows were provided to accommodate four sugar cane setts in each experimental unit in order to allow for unexpected crop failure.

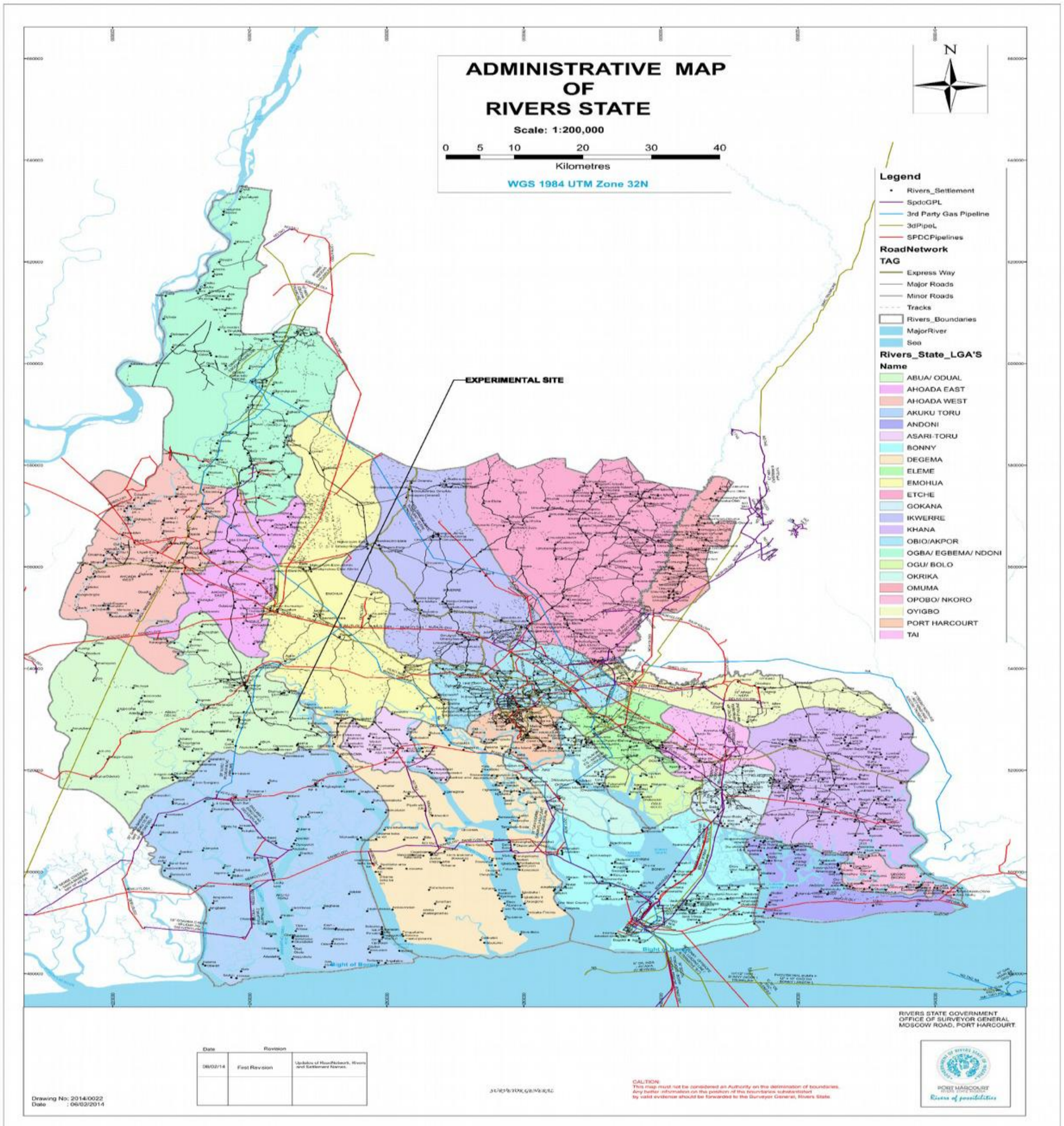
Raising of sugar cane seed nursery

All planting materials were raised under a shade in a nursery in the vicinity of the experimental site. Nursery bags were filled with topsoil devoid of any form of basal fertilizer or lime application.

Transplanting and data collection on growth parameters

Sprouted sugarcane setts were transplanted to the field thirty days after planting (30 DAP) into nursery bags. The experiment spanned through 12 calendar months from time of planting into nursery bags up to the maturity of the "plant crop". Plant sampling or data collection was done at 3, 6, 9 and 12 months after transplanting (MAT).

Growth measurement or data collection was made on the following sugar cane parameters: (i) Number of tillers per stool; (ii) Plant height per stool; (iii) stalk girth (iv); number of internodes per stem; (v) internodes length (vi) number of green leaves per stem; (vii) leaf length; (viii) leaf width and (ix) leaf sheath length. The Analysis of Variance (ANOVA), linear regression and correlation, and Student's t-test statistical tools were used for data analyses and mean separation was done using Duncan's Multiple Range Test (DMRT).


ADMINISTRATIVE MAP
OF
RIVERS STATE
Scale: 1:200,000
Kilometres
WGS 1984 UTM Zone 32N
EXPERIMENTAL SITE
Legend
Rivers_Settlement
SpdcGPL
3rd Party Gas Pipeline
3dPipeL
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First Revision

Fig. 2. Location Map of Experimental Site in Ogonokom-Abua, Rivers State, Nigeria.

Simple Linear Regression and Correlation analyses were employed to establish relationships or Regression showing trends in sugar cane growth parameters over time (i.e., age of the plant), and strength of relationships or Correlation between the two variables i.e., growth parameters and time. The following interpretations of the value of r were employed in describing strength of relationship/correlation between the two variables as described by Mac'Odo (1997):

$\pm$ 0.8 to $\pm$ 1.0 (High correlation)
$\pm$ 0.6 to $\pm$ 0.79 (Moderate correlation)
$\pm$ 0.4 to $\pm$ 0.59 (Fair correlation)
$\pm$ 0.2 to $\pm$ 0.39 (Slight correlation)
0.0 to $\pm$ 0.19 (No correlation or Negligible / Chance relationship).

The Student's t-test was applied using four pairs of readings ($n = 4$) i.e., 3, 6, 9, and 12 months after transplanting (MAT) with n-2 degrees of freedom (in a small sample with $n < 8$) to test for significant correlation between sugar cane growth parameters and time in a 2-tailed test at $\alpha = 0.05\%$ level of significance i.e., 95% confidence level. Thus,
Reject Null Hypothesis H_o if:

$t_{computed} > t_{critical} = 4.303$

OR $t_{computed} < - t_{critical} = 4.303.$

RESULTS AND DISCUSSION

Number of tillers or tiller production

Tiller production ranged from 1.63 to 2.63 with a cumulative average of 2.30, 2.07 and 1.93 per stool in soil sites I, II and III, respectively (Table 1). Cumulative tiller production in the site I exceeded the combined average of 2.10 per stool at the three sites while sites II and III produced tillers below this average value, especially in site III with the least performance. In general, tiller formation declined from the site I through II to III, which shows that there were better growth conditions in site I. The relative advantages of the site I over sites II and III include the lower levels of sodium and aluminum toxicities, freedom from flooding and better soil depth for plant root development as well as *higher amounts of available phosphorus, total nitrogen, lower exchangeable acidity and salinity levels, all of which might have contributed to providing more conducive growth conditions than sites II and III.*

*Tiller production sh*owed a mean quarterly or 3-monthly range of 1.77 to 2.46 per stool in which site I recorded a greater number of tillers than sites II and III at 3 and 6 months after transplanting (MAT) while sites I and II were at *par* at 9 and 12 MAT and site III still recorded the least number of tillers in the quarterly figures. As the canes, the aged average number of tillers increased from 3 to 12 MAT even as the increase within the sites was inconsistent. The more-or-less steady increase in tiller production over time is shown in the linear trend lines and regression equations associated with them in Fig.3. All three soil sites had positive (+) x-values with site II having the greatest rate of increase with +0.338 in the number of tillers produced over time, followed by the site I with +0.183 and, lastly, site III with +0.118.

The strength of relationship or correlation coefficient between tiller production and time (r^2 x 100) is 90.0, 83.1 and 37.7 percent in soil sites II, I and III, respectively. Only sites I and II had a highly correlated relationship of r = ±0.8 – ±1.0 between tiller production and time but which was not statistically significant (α = 0.05), while it was moderately correlated in soil site III with r = ±0.6 – ±0.79 (Fig.3). Further observation of the data shows, however, that within each of the 3, 6, 9 and 12 MAT quarterly intervals, there were no statistically significant differences between soil sites I, II and III in the production of tillers as shown in Table 2. The results of the study show that tiller production in the canes did not differ significantly between sites I, II and III.

Plant height

Plant height ranged from 37.64 to 83.18cm with mean cumulative values of 61.49, 49.26 and 50.71cm per stool in soil sites I, II and III, respectively (Table 1). Soil site I produced the greatest cumulative average sugar cane height which was far above the overall average of 53.82cm per stool while sites II and III fell below this value. Furthermore, average stem heights in soil site I at 6, 9 and 12 MAT were 54.48, 68.73 and 83.18cm per stool, respectively, and these were more than the quarterly or 3-monthly average values of 53.15, 55.36 and 66.30cm per stool in these periods. Similar to tiller production, soil site I had the greatest stem heights while, in this case, the distinction between sites II and III was difficult to state.

Table 1. Field data on the effect of soil sites or units on sugar cane growth parameters, 2009.

Sugarcane growth parameter	Soil Site (Soil Unit)	3-Monthly Average 3 MAT	6 MAT	9 MAT	12 MAT	**Cumulative Site total**	**Cumulative Site Mean**
Number of Tillers / Stool	I	2.00	2.31	2.25	2.63	9.19	**2.30**
	II	1.69	1.69	2.25	2.63	8.26	**2.07**
	III	1.63	2.13	1.81	2.13	7.70	**1.93**
	Quarterly total	**5.32**	**6.13**	**6.31**	**7.39**	**Grand total**	**Grand mean**
	Quarterly mean	**1.77**	**2.04**	**2.10**	**2.46**	**25.15**	**2.10**
Plant height / Stool (cm)	I	39.58	54.48	68.73	83.18	245.97	**61.49**
	II	37.64	46.61	49.80	62.98	197.03	**49.26**
	III	44.17	58.35	47.56	52.74	202.82	**50.71**
	Quarterly total	**121.39**	**159.44**	**166.09**	**198.90**	**Grand total**	**Grand mean**
	Quarterly mean	**40.46**	**53.15**	**55.36**	**66.30**	**645.82**	**53.82**
Single Stalk Girth / Stool (cm)	I	5.08	5.76	5.80	5.59	22.23	**5.56**
	II	4.81	4.94	4.33	4.43	18.51	**4.63**
	III	5.11	4.88	2.83	2.91	15.73	**3.93**
	Quarterly total	**15.00**	**15.58**	**12.96**	**12.93**	**Grand total**	**Grand mean**
	Quarterly mean	**5.00**	**5.19**	**4.32**	**4.31**	**56.47**	**4.71**

Number of Internodes / Stool	I	2.19	6.31	11.81	14.81	35.12	**8.78**
	II	2.56	5.75	9.69	11.94	29.94	**7.49**
	III	3.69	7.50	6.94	7.69	25.82	**6.46**
	Quarterly total	**8.44**	**19.56**	**28.44**	**34.44**	**Grand Total**	**Grand mean**
	Quarterly mean	**2.81**	**6.52**	**9.48**	**11.48**	**90.88**	**7.57**
Single Internode Length (cm)	I	2.33	3.64	3.93	3.00	12.90	**3.23**
	II	3.48	3.49	3.23	2.79	12.99	**3.25**
	III	3.76	4.49	2.91	2.86	14.02	**3.51**
	Quarterly total	**9.57**	**11.62**	**10.07**	**8.65**	**Grand total**	**Grand mean**
	Quarterly Mean	**3.19**	**3.87**	**3.36**	**2.88**	**39.91**	**3.33**
Number of Green Leaves / Stem	I	7.06	7.19	6.38	5.69	26.32	**6.58**
	II	6.38	6.38	5.00	5.13	22.89	**5.72**
	III	6.06	6.06	3.63	3.00	18.75	**4.69**
	Quarterly total	**19.50**	**19.63**	**15.01**	**13.82**	**Grand total**	**Grand mean**
	Quarterly mean	**6.50**	**6.54**	**5.00**	**4.61**	**67.96**	**5.66**
Leaf Length / Stem (cm)	I	106.62	115.21	117.29	114.40	453.52	**113.38**
	II	89.06	96.95	100.31	96.00	382.32	**95.58**
	III	89.29	87.11	64.01	59.49	299.90	**74.98**
	Quarterly total	**284.97**	**299.27**	**281.61**	**269.89**	**Grand total**	**Grand mean**
	Quarterly Mean	**94.99**	**99.76**	**93.87**	**89.96**	**1,135.74**	**94.65**
Leaf Width / Stem (cm)	I	2.30	2.58	2.96	2.74	10.58	**2.65**
	II	2.58	2.03	2.09	2.04	8.74	**2.19**
	III	2.00	2.09	1.34	1.39	6.82	**1.71**
	Quarterly total	**6.88**	**6.70**	**6.39**	**6.17**	**Grand total**	**Grand mean**
	Quarterly mean	**2.29**	**2.23**	**2.13**	**2.06**	**26.14**	**2.18**
Leaf sheath Length (cm)	I	21.64	25.04	23.74	22.74	93.16	**23.29**
	II	15.81	22.66	20.74	20.08	79.29	**19.82**
	III	24.54	22.82	13.72	13.13	74.21	**18.55**
	Quarterly total	**61.99**	**70.52**	**58.20**	**55.95**	**Grand total**	**Grand mean**
	Quarterly mean	**20.67**	**23.51**	**19.40**	**18.65**	**246.66**	**20.56**

MAT = Months after transplanting.

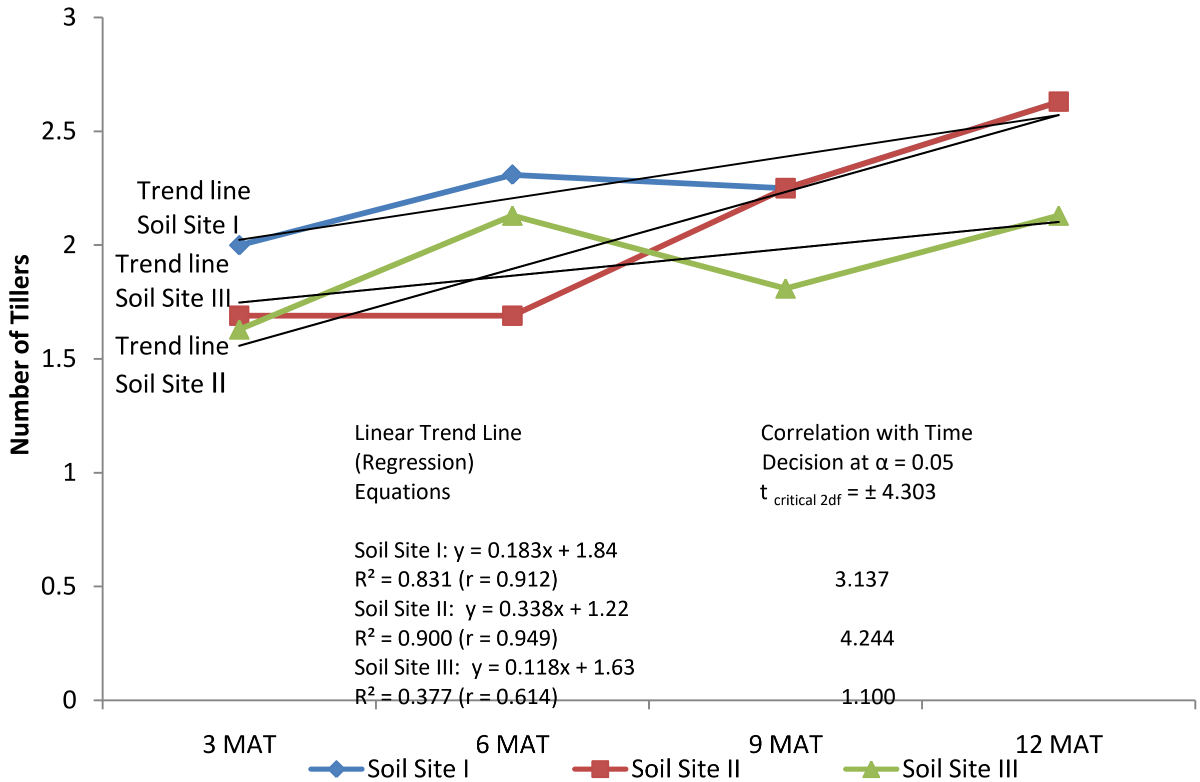

Fig. 3 Trends in the effect of soil site on average number of tillers per stool.

Table 2. Quarterly average tiller production and plant height in test sugar cane from three soil sites, 2009.

	Tiller Production				Plant height			
	3MAT	6 MAT	9MAT	12MAT	3MAT	6MAT	9MAT	12MAT
Site I	2.00a	2.31a	2.25a	2.63a	39.58a	54.48ab	68.73a	83.18a
Site II:	1.69a	1.69a	2.25a	2.63a	37.64a	46.61b	49.80b	62.98ab
Site III:	1.63a	2.13a	1.81a	2.13a	44.17a	58.35a	47.56b	52.74b
	NS	NS	NS	NS	NS			

Means with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$
MAT = Months after transplanting.

However, no single soil site had superlative stem height consistently from 3 to 12 MAT. Within each soil site, whereas stem height generally increased with time from 3 to 12 MAT, this was not the case with site III which decreased from 9 to 12 MAT. The initial gain in stem height experienced in soil site III from 3 to 6 MAT may have been facilitated by an abundance of soil moisture; the soil being underwater longer than at other sites. The most active uptake of nutrients, especially N and K, as well as water takes place within the first six months during tillering and early internodes elongation to cause height increase in sugar cane (Jadoski *et al.* 2010). However, it may seem that the adverse effect of salts in soil unit III of 36.5 $dS.m^{-1}$ as shown in Table 3 became overbearing from 6 to 9 MAT resulting in a decrease in plant height that continued up to 12 MAT. This view is substantiated by the number of experimental plots in which the plants dried up after six months of growth in a soil that was saturated with highly saline tidewater (Table 3).

There were a steady increase in average plant height at 3, 6, 9 and 12 MAT time periods only in soil sites I and II (Fig. 4). In particular, the steep increase in plant height in soil site I suggest the existence of quite favourable growth conditions than in site II that showed similar but less radical growth. The distinction is more obvious between sites I and III. It was earlier shown that soil site III was prone to complete flooding by tidewater twice daily and, thus, characterized by reduction reactions that were uncongenial to plant growth. In waterlogged soil, oxygen (O_2) becomes depleted if microbes and plant roots consume it in respiration faster than it is replaced from the atmosphere (O'Shea, 2000). The direct effect of oxygen depletion in flooded soil is the reduction of plant carbon fixation or the rate of photosynthesis (Kume, 2017, Else *et al.*, 1996). In the short term, photosynthesis can drop as a result of the restriction of CO_2 uptake due to stomata closure following leaf dehydration and turgor loss in guard cells (Bradford, 1982). If flooding continues in time, a decrease in the photosynthetic capacity of mesophyll cells leads to a further reduction of photosynthesis (Bradford, 1982). Thus, the poor growth recorded with respect to tiller production and plant height in canes from site III may have resulted from decreased photosynthetic activities in the plants occasioned by frequent flooding in the soil site.

In flood sensitive species like *Solanum lycopersicum*, *Pisum sativum*, *Helianthus annulus*, and *Nicotiana tabacum*, a few hours after the soil becomes flooded, water uptake by roots is reduced (Jackson and Drew, 1984). In sugar cane, uptake of moisture is drastically reduced due to a lack of oxygen in the root zone (Gomathi *et al.*, 2014). A further reduction occurs when the roots die due to prolonged scarcity of oxygen. In addition, restricted aeration is usually followed by serious nutrient deficiency symptoms. Sugar cane leaves often show a yellowing and scorched appearance in flooded soil which suggests apparent nitrogen deficiency and other nutritional imbalances (Humbert, 1968). In the present study, sugar cane, growth rates in soil site III were drastically reduced indicating that photosynthetic reserves were not stored during this period of their struggle for survival, thus, stimulating the plants to approach maturation in what may be termed “induced” or “forced” maturation (Keren, 2000). The rate of transpiration follows the same trend with photosynthesis. Transpiration rates by sugar cane plants are drastically curtailed under flooded conditions as cane leaves assume tightly curled positions similar to those under drought indicating reduced supply of moisture within cane tissues. Thus, the reduction in plant height of canes in soil site III was traceable to flood stress leading to decreased photosynthetic activity and transpiration rates.

Table 3. Average values of soil chemical characteristics in the study area, 2009.

Soil Unit/ Site	pH H_2O	P $Mg.kg^{-1}$	Total N	Org C	C/N Ratio	Ca	Mg	K	Na	CEC	EA	ECEC	Al Sat	ESP	BS	EC dSm^{-1}
			<-----%----->			<----------------------- $Cmol_c.kg^{-1}$ ------------------------>							<------------ % ------------>			
I	4.8	17.46	0.12	1.46	12.27	3.75	1.98	0.13	0.13	5.98	1.10	7.08	12.95	2.16	83.49	20.0
II	4.7	17.48	0.18	2.57	14.28	7.10	3.90	0.18	1.46	12.64	4.33	16.96	20.73	11.59	76.57	21.0
III	4.5	15.71	0.22	3.53	16.41	7.33	4.11	0.15	1.61	13.18	12.70	25.88	38.10	12.75	58.78	36.5

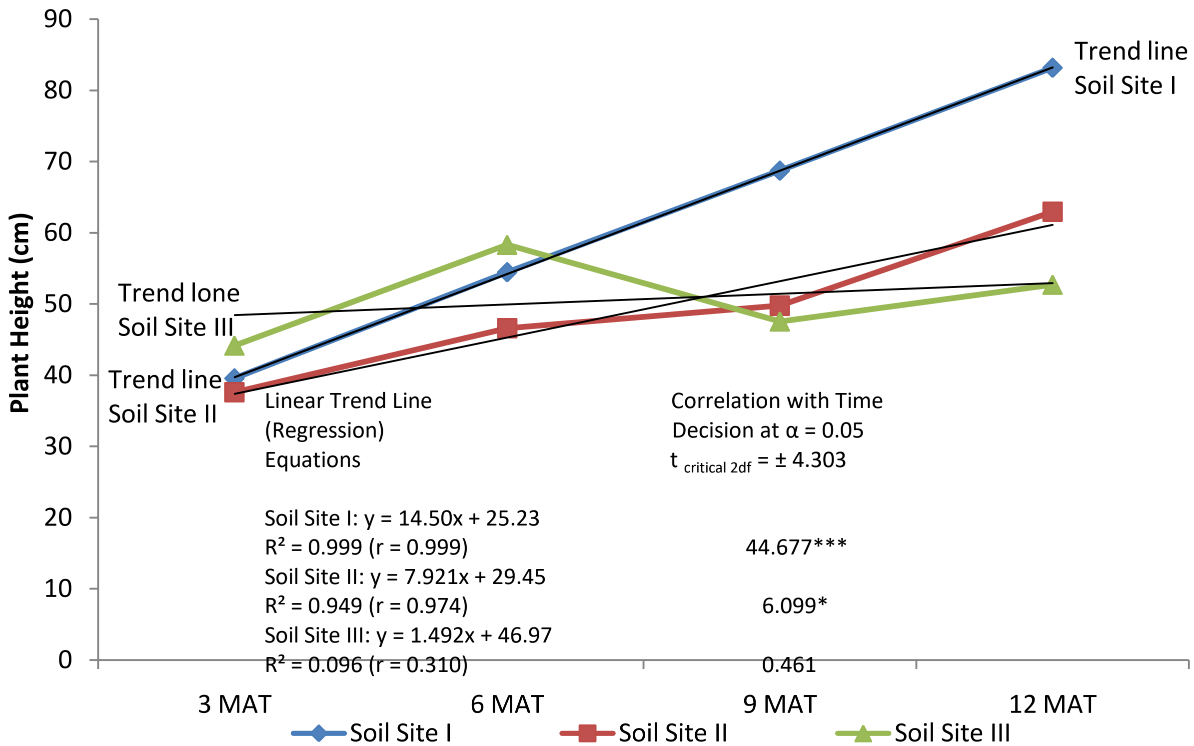

Fig. 4. Trends in the effect of soil site on average plant height of test canes.

The regression equations reveal positive x-values in soil sites I, II and III although site I had the highest rate of increase of +14.500 in plant height per unit time while site II recorded +7.921 and site III had the least with just +1.492. Furthermore, the regression equations show that soil sites I, II and III had 99.9, 94.9 and 9.6 percent of the increase in plant height resulting from increases in time. Accordingly, the relationship between plant height and time was highly correlated (r = ±0.08 - ±1.0) in soil sites I and II, especially in the site I that the relationship was very highly significant. This implies that the canes in soil site I continued to increase in height over time despite the environmental growth-restricting conditions in which they were growing. Result of analysis further shows that average plant heights of the test canes in soil sites I, II and III were significantly different at 6, 9 and 12 MAT in which site III was plainly different from site II at 6 MAT; site I different from sites II and III at 9 MAT; and the site I different from site III at 12 MAT (Table 2). Thus, the superlative performance of the canes in soil site I is clearly demonstrated, especially from 9 to 12 MAT.

Stalk girth

Stalk girth of the test canes ranged from 2.91 to 5.80cm with cumulative average values of 5.56, 4.63 and 3.93cm per stool in soil units I, II and III, respectively (Table 1). As it was with tiller production and plant height, stalk girth was highest in soil unit I followed distantly by unit II, and lastly unit III. Here too, soil unit I produced average stalk girths which were more than those in sites II and III within the 3-monthly periods, except in site III that it was highest at 3 MAT. This may still not be unconnected with the availability of soil moisture to facilitate faster growth at the early stages of the plants' development. Also, soil site I had quarterly averages of stem girths that were higher than the combined mean values of 5.00, 5.19, 4.32 and 4.31cm at 3, 6, 9 and 12 MAT, respectively, thus suggesting better overall performance in soil site I compared with sites II and III. On the whole, only soil site I maintained a fairly consistent increase in stem girth from 3 up to 9 MAT and dropped only during the maturation period from 9 to 12 MAT.

The canes in soil unit I had positive x-values indicating a rise in stem girth while units II and III had negative values or decline as shown in Fig. 5. However, only 37.4 and 59.2 percent of the increase and decrease in cane girth resulted from increases in time in soil sites I and II, respectively. On the other hand, the rate of decrease was as much as 82.3 percent in soil unit III, thus indicating a drastic drop in stem girth due to severe soil conditions identified at the site.

The relationship between stalk girth and time was moderately correlated (r = ±0.6 - ±0.79) in soil sites I and II while it was highly correlated (r = ±0.8 - ±1.0) though not statistically significant in site III. This implies that canes in soil unit III had unequalled and increasingly stressful soil conditions that virtually propelled them toward elimination as they aged; the site being subject to a myriad of constraints limiting their growth.

The regression equations show a slight rate of increase in stem girth in soil unit I (+0.157), and the rate of decrease in unit II was also trivial (-0.175) while in soil unit III, the rate of decrease was exceptionally steep (-0.865). In all, cane plants in soil unit I barely survived with slight height increment but were still better than those in soil units II and III.

Statistical analysis shows that at 9 MAT, soil units I, II and III were significantly different from each other (Table 4). At 12 MAT, both soil units I and II were significantly different from unit III. The results depict a generally poor performance in girth expansion in the canes even in the light of the scant increase in soil unit I. It will appear that stalk girth expansion is generally more responsive to soil constraints than tiller formation and height increase in sugar cane. Soil conditions were, by and large, quite unfavourable for the growth of the canes in all the soil units, but more so in soil units II and, especially in III.

Number of internodes

An average number of internodes produced by the canes ranged from 2.19 to 14.81 with cumulative mean values of 8.78, 7.49 and 6.46 per stem in soil units I, II and III, respectively (Table 1). Soil unit I produced the highest cumulative average number of nodes that was much more than the overall average of 7.57 nodes per stem while sites II and III had numbers that fell below this value, which was worse in site III. Viewed over time, node formation in the plants generally increased from 3 to 12 MAT in all three soil units, except for a break in unit III at 9 MAT. It is likely that, in soil unit III, the initial tolerance of the plants to soil constraints up to 6 MAT had collapsed as they grew older beyond 6 MAT. It is known that the sensitivity of crops to soil salinity changes from one stage of growth to the next (Islam and MacDonald, 2004, De Oliveira *et al.*, 2013). Most plants are relatively salt-tolerant during germination, but become more sensitive during emergence, early growth and, possibly, much later in their development. This must have been what happened with the cane after attaining six months of growth.

Despite the abysmal performance of the canes in soil unit III, internodes production generally increased over time in all the soil units with quarterly average values of 2.81, 6.52, 9.48 and 11.48 internodes per stem at 3, 6, 9 and 12 MAT respectively. Soil unit I recorded the greatest rate of increase in the number of internodes with +4.336, followed by unit II with +3.208 and lastly unit III with +1.144 (Fig. 6). Accordingly, 99.0, 98.8 and 62.3 percent of the increase in internodes production resulted from increases in time in soil units II, I and III, respectively.

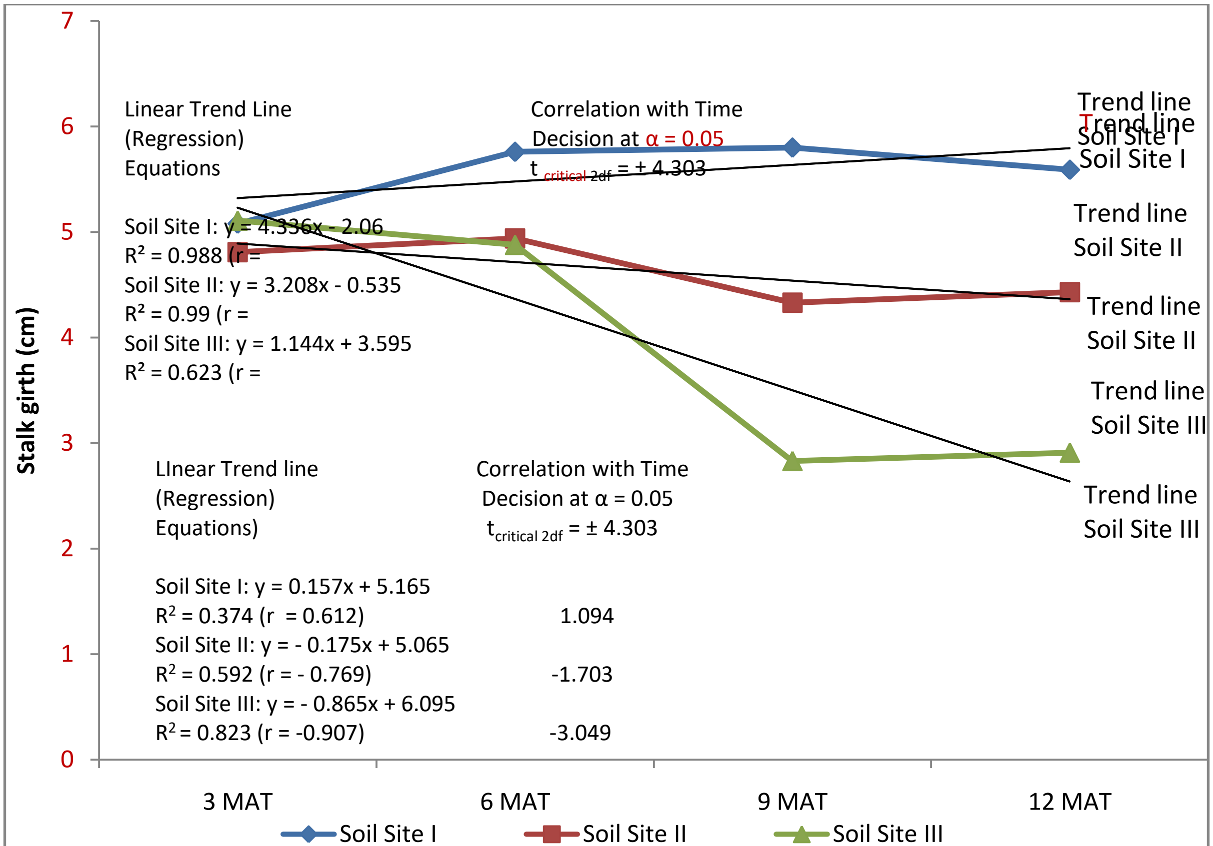

Fig. 5. Trends in the effect of soil site on average stalk girth per stool

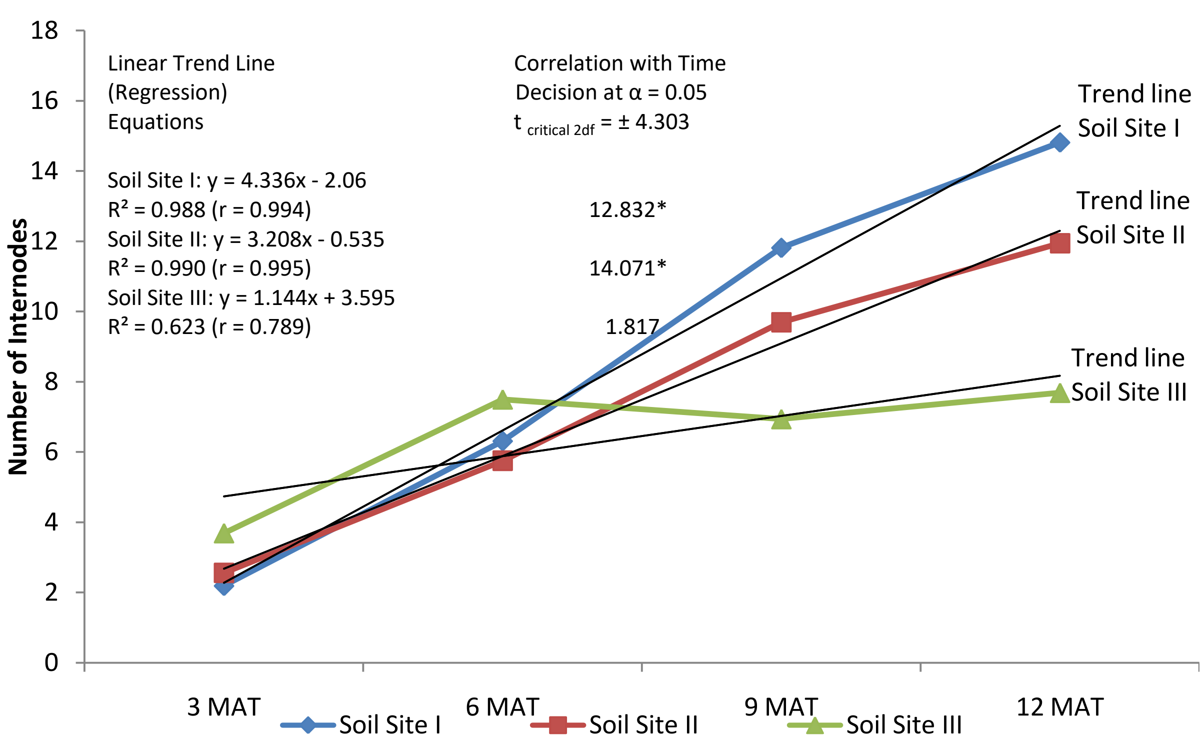

Fig. 6. Trends in the effect of soil site on average number of internodes per stool.

Table 4. Quarterly average stalk girth and number of internodes in test sugar cane from three soil sites, 2009.

	Stalk girth (cm)				Number of internodes			
Location	3MAT	6 MAT	9MAT	12MAT	3MAT	6MAT	9MAT	12MAT
Site I	5.08a	5.76a	5.80a	5.59a	2.19b	6.31ab	11.81a	14.81a
Site II:	4.81a							
Site III:	5.11a	4.94a	4.33b	4.43a	2.56ab	5.75b	9.69ab	11.94a
	NS							
		4.88a	2.83c	2.91b	3.69a	7.50a	6.94b	7.69b
		NS						

Means with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$
MAT = Months after transplanting.

The results demonstrate better growth conditions that prevailed in soil units I and II, much more than in unit III as these concerned the formation of internodes to bring about height increase in the canes. Indeed, there are indications of extreme growth-limiting conditions in soil unit III.

The results further point to a highly correlated and statistically significant relationship between node formation and time with the age of the canes in soil units I and II ($r = \pm 0.8$ - ± 1.0) while that in unit III was moderately correlated ($r = \pm 0.6$ - ± 0.79). Analysis of the data on internodes number shows significant differences between soil units I, II and III from 3 to 12 MAT (Table 4). Soil unit I was significantly different from soil unit III at 3, 9 and 12 MAT. Soil unit II was also significantly different from unit III at 6 and 12 MAT. Internodes production in soil unit II was fairly comparable to that in unit I even as the performance was much better in the latter, especially from 9 to 12 MAT growth stages.

Internodes length

Internodes length ranged from 2.33 to 4.49cm with cumulative averages of 3.23, 3.25 and 3.51cm in soil units I, II and III, respectively (Table 1). In this instance, internodes length in soil unit III outstripped those in units I and II, which was made possible by the matchless performance at 3 and 6 MAT wherein internodes lengths of 3.76 and 4.49cm exceeded the quarterly average values of 3.19 and 3.87cm, respectively (Table 1). However, internodes length at the periodic intervals was quite irregular such that there was no clear-cut pattern among the soil units. Nevertheless, internodes length considered over the twelve months period across the three soil sites shows an overall increase from 3 to 6 MAT and a decline from 9 to 12 MAT, except in soil unit I that internodes length increased up to 9 MAT.

The drop in internodes length soon after 6 MAT may have been caused by the severity of growth inhibitors in the environment such as soil saturation or flooding resulting in oxygen depletion in soil unit III; unbearable sodium and aluminium toxicity and salt effects on cane plant tissues in soil units II and III; and nutrient deficiencies and or imbalance coupled with the scorching action of acid soil on the plants in soil unit I, among other soil limitations. Except in soil unit I that recorded a positive trend line indicating an increase in internodes length with time, units II and III recorded a steady decline as seen in Fig. 7. About 84.1 and 50.7 percent of the decrease in internodes length resulted from increases in time in soil units II and III, respectively. On the contrary, a minor 17.3 percent of the increase in internodes length was due to increase in time in soil unit I. The rate of increase in internodes length was +0.230 in soil unit I viewed against the rates of decline of -0.233 in unit II and -0.428 in unit III that was most severely impacted by soil constraints.

The relationship between internodes length and time was fairly correlated in soil unit I ($r = \pm0.4$ - ±0.59) while it was high but not significantly correlated in unit II ($r = \pm0.8$ - ±1.0), and moderately correlated in unit III ($r = \pm0.6$ - ±0.79). Across the three soil sites as well as within the quarterly intervals, however, there were significant differences in internodes length between soil units I and III only at 3 MAT (Table 1). At all other times, there were no significant differences between soil units I, II and III as internodes length in the plants were equally impacted by growth-restricting soil conditions at the three sites, particularly from 6 to 12 MAT growth stages, although to varying degrees of severity.

Number of green leaves

The average number of green leaves produced by the plants ranged from 3.00 to 7.19 in which cumulative mean values were 6.58, 5.72 and 4.69 per stem in soil units I, II and III, respectively (Table 1), thus indicating a drop from units I to III. Soil units I and II recorded cumulative average values that were each greater than the grand mean of 5.66 green leaves per stem while unit III fell below this overall average (Table 1). The same trend of the reduced number of green leaves from soil units I to III was observed within each of the 3, 6, 9 and 12 MAT time periods.

However, while soil unit I clearly produced green leaves in excess of the 3-monthly averages of 6.50, 6.54, 5.00 and 4.61 at 3, 6, 9 and 12 MAT, respectively, soil unit II recorded same only at 12 MAT and unit III never got to achieve this feat all throughout the experiment duration. In the light of obvious drawbacks in growth conditions identified in the study, the implication is that, in spite of its peculiar constraint of high soil acidity, soil unit I provided relatively milder limitations to the canes than did unit II, which itself was more tolerable than unit III.

Although leaf production appeared to be constant from 3 to 6 MAT in soil units II and III, the general fall in numbers from 9 to 12 MAT was substantial enough to influence the pattern of growth as shown in the trend lines in Fig. 8. In particular, leaf production was grossly hampered in soil unit III; down from an average of 6.06 green leaves per stem at 3 MAT to just 3.0 at 12 MAT. The regression equations show that the greatest reduction in the number of green leaves produced was in soil unit III with -1.161 and the least decline in unit I with -0.492 while unit II with -0.513 was in-between. In addition, 84.3, 75.7 and 87.1 percent of the drop in the number of green leaves may be attributed to increases in time in soil units I, II and III, respectively.

The relationship between leaf production and time was high but not significantly correlated in soil units I, II and III ($r = \pm 0.8$ - ± 1.0). Statistical analysis revealed that soil units I and III recorded significant differences at 9 MAT while unit III differed from units I and II at 12 MAT (Table 5).

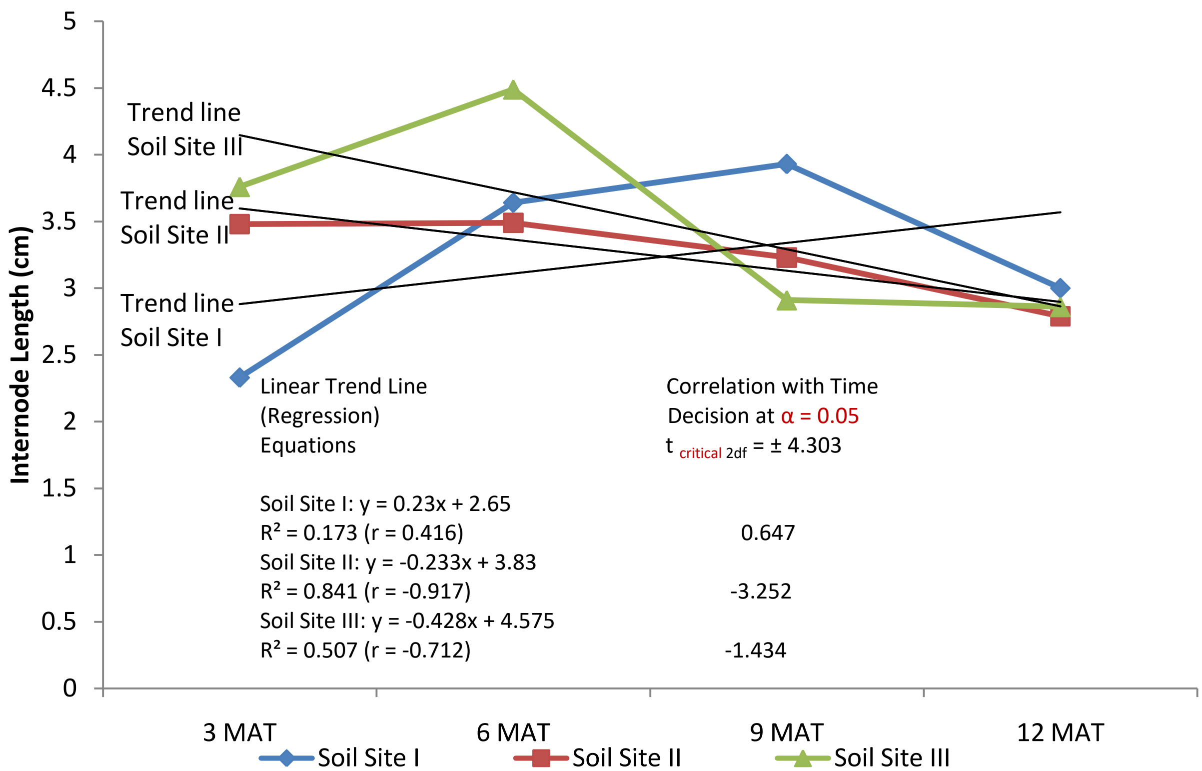

Fig. 7 Trends in the effect of soil site on average internode length per stem.

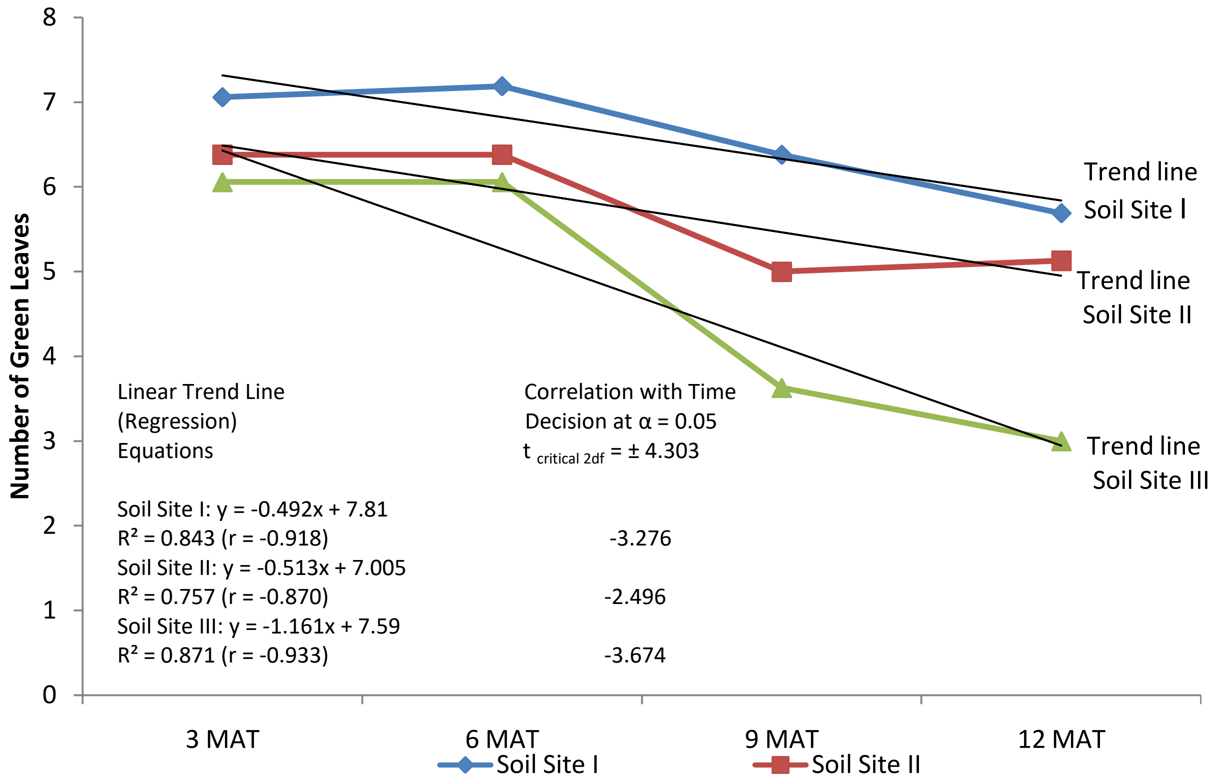

Fig. 8 Trends in the effect of soil site on average number of green leaves per tem.

Table 5. Quarterly average internodes length and number of green leaves in test sugar cane from three soil sites, 2009.

	Internodes length (cm)				Number of green leaves			
Location	3MAT	6 MAT	9MAT	12MAT	3MAT	6MAT	9MAT	12MAT
Soil site I	2.33b	3.64a	3.93a	3.00a	7.06a	7.19a	6.38a	5.69a
Soil site II	3.48ab	3.49a	3.23a	2.79a	6.38a	6.38a	5.00ab	5.13a
Soil site III	3.76a	4.49a NS	2.91a NS	2.86a NS	6.06a NS	6.06a NS	3.63b	3.00b

Means with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$
MAT = Months after transplanting.

In essence, cane plants in soil unit III seem to have experienced much more unfavourable soil conditions than those in units I and II, among which was flooding that was accentuated by high salt content of 36.5 $dS.m^{-1}$ reported earlier. Lack of free oxygen to cane plant roots and the presence of toxic gases such as methane in the flooded soil may have been detrimental to cane growth in soil site III (Singer and Munns, 1996, Else *et al*., 1996), thus, resulting in the reduction of carbon fixation in the test canes (Bradford and Hsiao, 1982). In flood-sensitive species, closure of stomata with or without leaf dehydration and reduction of transpiration can occur within just a few hours of flooding Gomathi *et al*., 2014). The resultant effect of flooding is, therefore, gross reduction in growth and vigour of growing plants, or death in worse scenarios Else *et al*., 1996). Soil unit III was classified as marginally fertile and unfit for agriculture in another report from the present study and this is corroborated here by the scanty green leaves recorded in the cane plants, which also reflects their poor health status at the site.

Leaf length

Average leaf length ranged from 59.49 to 117.29cm with cumulative mean values of 113.38, 85.58 and 74.98cm per stem in soil units I, II and III, respectively (Table 1); decreasing from soil units I to III. Both soil units I and II recorded leaf lengths that were more than the overall average of 94.65cm per stem while those from unit III fell below this value. It is quite remarkable that only in soil unit III did leaf length fail to get higher than the initial value of 89.29cm per stem at 3 MAT. This is seen as a clear expression of severe constraints to cane growth in the unit. Over time, soil unit I produced leaf lengths greater than the 3-monthly average values of 94.99, 99.76, 93.87 and 89.96cm per stem at 3, 6, 9 and 12 MAT respectively.

The trend lines in Fig. 9 show positive x-values that indicate increases in leaf length in soil units I and II at a rate of increase of +2.542 and +2.418, respectively. In soil unit III, however, the rate of decrease was a whooping -11.250, which implied a sharp drop in leaf length over time. Only 49.4 and 43.6 percent of the increase in leaf length was attributable to increases in time in soil units I and II while as much as 88.8 percent of the decrease in leaf extension resulted from increases in time in soil unit III. Accordingly, the relationship between leaf length and time was moderately correlated in soil units I and II ($r = \pm 0.6$ - ± 0.79) while that in unit III was highly correlated ($r = \pm 0.8$ - ± 1.00) though not significant.

Soil unit I was significantly different from unit III all through from 3 to 12 MAT, same with soil units I and II but only at 3 and 6 MAT while canes from soil unit II were significantly different from those from unit III at 9 and 12 MAT (Table 6).

Leaf width

Leaf width ranged from 1.34 to 2.96cm with cumulative mean values of 2.65, 2.19 and 1.71cm per stem in soil units I, II and III, respectively (Table 1). Soil units I and II produced cumulative average leaf widths greater than the grand mean value of 2.19cm per stem. Soil unit I also recorded leaf widths that surpassed the 3-monthly mean values of 2.29, 2.23, 2.13 and 2.06cm at 3, 6, 9 and 12 MAT, respectively. Also, leaf width in soil unit II exceeded the quarterly average values of 2.29 only at 3 MAT. Soil unit III remained the worst all through the 3 to 12 MAT time periods and this conforms to earlier assertions that the site had more than just a few growth limitations. In actual scores, the plants in soil unit I performed best, followed closely by those in unit II, while in unit III, leaf width expansion suffered severely due to adverse soil conditions from 6 to 12 MAT. There was, thus increasing deterioration in soil conditions with a simultaneous reduction in the growth of the test sugar cane from soil sites I to III.

Except in soil unit I in which leaf width increased slightly from 3 to 9 MAT, there were decreases in leaf width in soil units II and III as shown in the trend lines in Fig. 10. Indeed, leaf width plummeted in soil unit III to a dismal 1.39cm per stem at 12 MAT. About 62.4 percent of the increase in leaf width in soil unit I was due to increase in time. On the contrary, 57.9 and 71.1 percent of the decrease in leaf width resulted from an increase in time in units II and III, respectively. While the relationship between leaf width and time was moderately correlated ($r = \pm 0.6$ - ± 0.79) in soil units I and II, that in unit III was highly but not significantly correlated ($r = \pm 0.8$ - ± 1.00). Comparatively, soil unit I was significantly different from soil unit II at 6 and 9 MAT and from soil unit III at 9 and 12 MAT. In this instance, soil unit II was more like soil unit III as there were no significant differences between the two soil sites over time (Table 6).

Leaf sheath length

The average leaf sheath length produced by the plants ranged from 13.13 to 25.04cm with cumulative average lengths of 23.29, 19.82 and 18.55cm in soil units I, II and III, respectively (Table 1). Leaf sheath length decreased from soil units I to III with the unit I having a cumulative average that was more than the overall mean value of 20.56cm across the three soil sites. In addition, soil unit I produced leaf sheath lengths higher than the 3-monthly mean values of 20.67, 23.51, 19.40 and 18.65cm per stem at 3, 6, 9 and 12 MAT, respectively, which was achieved in soil unit II at 9 and 12 MAT while unit III recorded same only at 3 MAT.

The drop in leaf sheath length from soil units I to III corresponds with the decline in the other growth parameters of the number of green leaves, leaf length and leaf width discussed earlier.

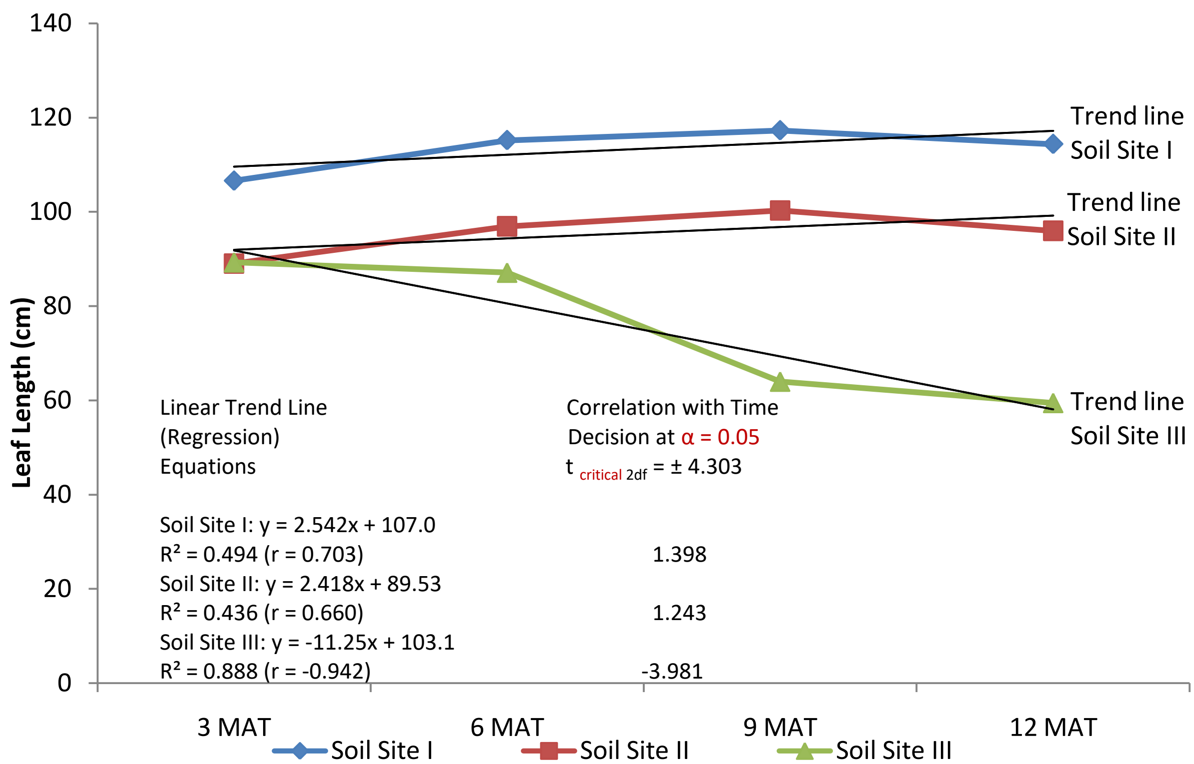

Fig. 9: Trends in the effect of soil site on average single leaf length per stem.

This clearly shows the progressive deterioration in soil conditions with the attendant reduction in the growth performance of the cane plants from soil sites I to III.

Over time and across the three soil sites, leaf sheath length generally decreased from 3 to 12 MAT with values of 20.66 to 18.65cm notwithstanding the greater performance in unit III at 3 MAT. The early advantage in greater leaf sheath length produced in soil unit III can be likened to those of plant height, number of internodes and internodes length all of which were attributable to the apparent sufficiency of available soil moisture and was overturned by the compounding effects of excess water and high salts or salinity in the soil solution. The general outlook, therefore, shows one of moderate to low rates of increase in leaf sheath length over time in soil units I with +0.200 and II with +1.089 respectively; while unit III had a steep drop of -4.333 as shown in the trend lines and regression equations in Fig. 11.

The trend is another evidence of stiffer growth conditions in soil unit III relative to units I and II as was the case in the preceding discussions. The increase in leaf sheath length was 3.1 and 23.6 percent due to increases in time in soil units I and II, respectively. On the other hand, as much as 87.8 percent of the decrease in leaf sheath length was attributable to the increase in time in soil unit III. Clearly, soil conditions in unit III negatively impacted on leaf sheath length rather relentlessly as the canes aged from 3 up to 12 MAT.

Table 6. Quarterly average leaf length and leaf width in test sugar cane from three soil sites, 2009.

	Leaf length (cm)				Leaf width (cm)			
Location	3MAT	6 MAT	9MAT	12MAT	3MAT	6MAT	9MAT	12MAT
Soil site I	106.62a	115.21a	117.29a	114.40a	2.30a	2.58a	2.96a	2.74a
Soil site II	89.06b	96.95b	100.31a	96.00a	2.58a	2.03b	2.09b	2.04ab
Soil site III	89.29b	87.11b	64.01b	59.49b	2.00a (NS)	2.09ab	1.34b	1.39b

Means with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$
MAT = Months after transplanting.

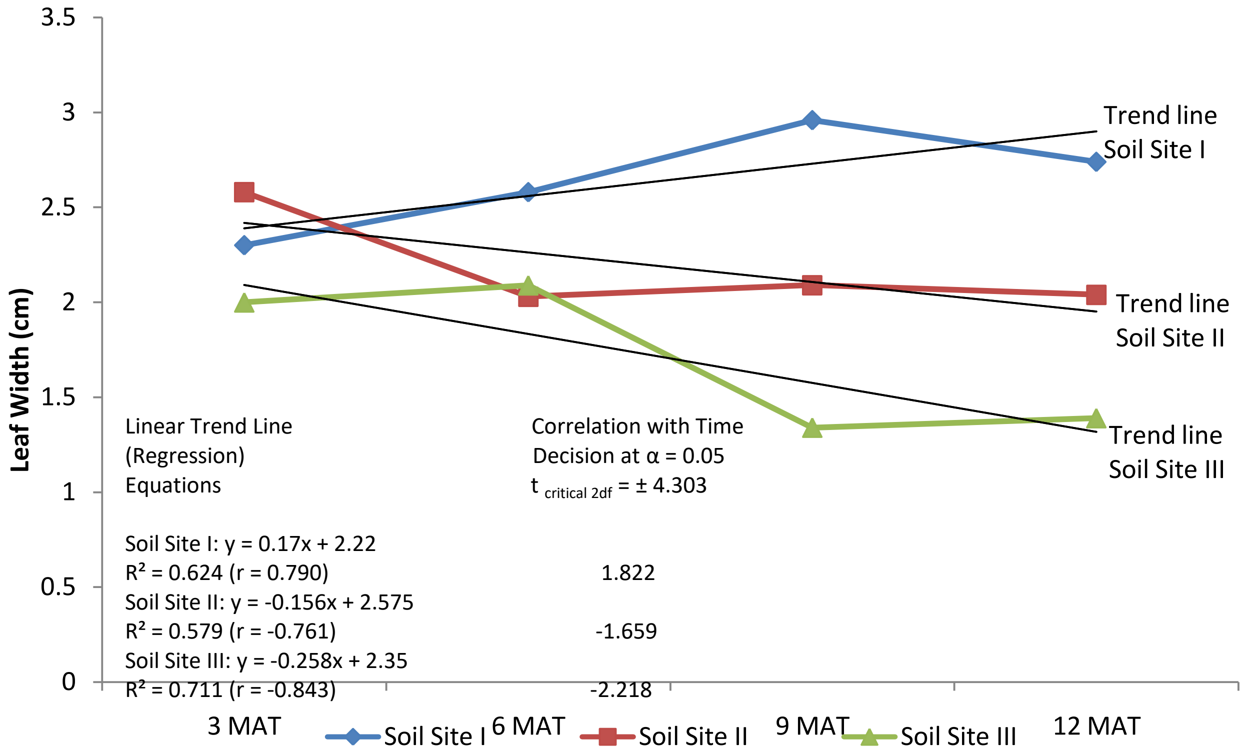

Fig. 10. Trends in the effect of soil site on single leaf width per stem.

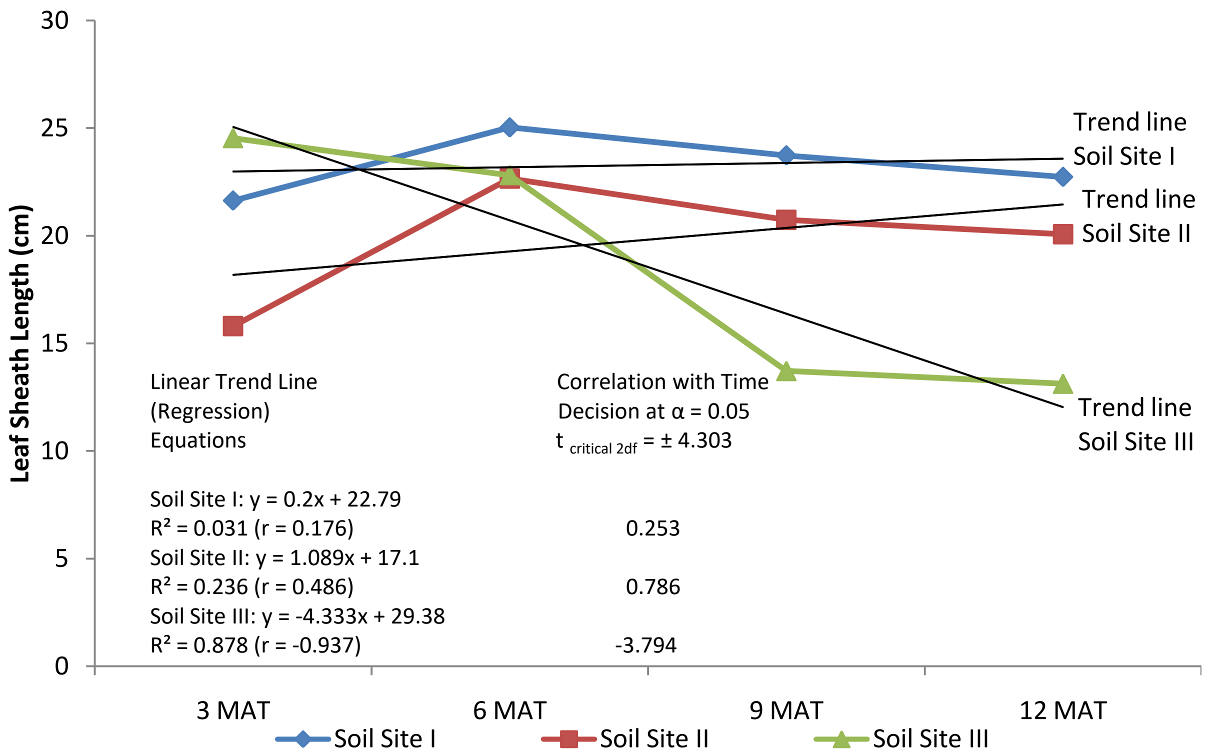

Fig. 11: Trends in the effect of soil site on average leaf sheath length per stem.

The relationship between leaf sheath length and time was slight in soil unit I ($r = \pm0.0 - \pm0.19$), fairly correlated in unit II ($r = \pm0.4 - \pm0.59$) and highly but not significantly correlated ($r = \pm0.8 - \pm1.00$) in soil unit III. Critical observation of the result showed significant differences in leaf sheath length between soil units I and II on the one hand, and unit III on the other at 9 and 12 MAT (Table 7), thus, indicating the co-dominance of soil units I and II over unit III with respect to leaf sheath length in the cane plants during these periods, even as actual leaf sheath lengths were greater in soil unit I.

Table 7. Cumulative average leaf sheath length in test sugar cane from three soil sites, 2009.

Location	3 MAT	6 MAT	9 MAT	12 MAT
Soil site I	21.64a	25.04a	23.74a	22.74a
Soil site II	15.81a	22.66a	20.74a	20.08a
Soil site III	24.54a	22.82a	13.72b	13.13b
	NS	NS		

Means with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$
MAT = Months after transplanting.

SUMMARY

Differences in soil properties were reflected in the growth performance of sugar cane in the study area. In soil unit or site I, the canes produced the highest average number of tillers, internodes, green leaves and achieved the greatest cumulative average plant height, stalk girth, leaf length, leaf width, and leaf sheath length that exceeded both the overall average and 3-monthly mean values at 3, 6, 9 and 12 months after transplanting (MAT). Growth indices of the plants in soil unit III were the least while those in unit II were midway between units I and III. There was, therefore, progressive deterioration in soil condition with the attendant reduction in the growth of the crop from sites I to III.

The relationship between growth parameters of the canes and time or age was highly correlated in a number of traits. Internodes length and the number of internodes were significantly correlated with time in soil units I and II, whereas all other parameters were not significantly correlated. Furthermore, soil unit I was significantly different from unit II in leaf width and leaf sheath length as well as from unit III in plant height, stalk girth, number of internodes, internodes length, number of green leaves, leaf length, leaf width, and leaf sheath length. Soil unit II was also significantly different from soil unit III in stalk girth, the number of internodes and green leaves, leaf length, and leaf sheath length.

Soil conditions were largely unfavourable for the growth of the canes in all the soil units or sites. Cane plants in soil unit I barely survived in the face of severe acidity but performed better than canes in soil unit II and, especially, soil unit III. Inauspicious soil conditions occasioned by the frequency and duration of flooding coupled with toxic levels of sodium and aluminium as well as intense salinity in soil unit III altogether were drastic enough to have adversely affected physiological activities in the cane plants in the unit. The canes experienced the same adverse soil conditions in soil unit II although to a lesser degree of severity.

CONCLUSION

It can be concluded that soil unit/site I have a relatively higher prospect in productive agriculture, although manageably so without any soil amendment, whatsoever, and is followed by unit II. Soil unit III will hardly support healthy plant growth except those that are naturally adapted to such harsh soil conditions as in the present study. The experiment has shown that sugar cane crop can grow to maturation stages in the study area despite several soil-related constraints in the environment.

Acknowledgment

The first author acknowledges the support given to him by the Bayelsa State Government and Vice-Chancellor through the continued payment of his salary which enabled the successful completion of the studies. The second author thanks the Vice-Chancellor, Michael Okpara University of Agriculture to supervise and involve in the study. The third author while being instrumental to the procurement of the test cane varieties for the study also provided constructive direction as well as being involved in the scrutiny, literature search and fine-tuning of the manuscript from the first draft to its final version for publication. He is appreciative of the Executive Director, National Cereals Research Institute, Badeggi for permission to participate in the study.

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