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Soil-traits interactions and path analysis of growth and fertility indicators driving sugarcane (Saccharum officinarum L.) yield in the Nigerian Southern Guinea Savanna

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Optimizing sugarcane yield under variable soil conditions requires a deep understanding of the interactions between plant traits and soil fertility parameters. This study investigated the direct and indirect contributions of key growth attributes and soil properties to sugarcane (*Saccharum officinarum* L.) yield in the Southern Guinea Savanna of Nigeria. Field trials were conducted at Badeggi during the 2018 and 2019 rainy seasons. Growth parameters, including stalk height, stalk girth, and Brix content and soil fertility indicators (organic carbon, total nitrogen, and available phosphorus) were measured and analyzed using correlation and path coefficient analysis. Cane yield showed strong positive correlations with stalk height, stalk girth, and soil organic carbon across both seasons. Path analysis identified stalk girth (31.6% in 2018; 19.1% in 2019) and stalk height (7.5% in 2018; 19.3% in 2019) as the most influential direct contributors to yield. Soil nutrients and Brix content contributed indirectly, primarily through their enhancement of structural growth traits. The analytical model accounted for 71.2% and 80.4% of yield variability in 2018 and 2019, respectively. These findings underscore the pivotal role of stalk morphology and nutrient-enriched soils particularly organic carbon and phosphorus in driving cane yield. The results advocate for an integrated approach that combines varietal selection for structural vigor with site-specific nutrient management to sustainably enhance sugarcane productivity in savanna agroecosystems.

Keywords: Sugarcane yield, stalk traits, soil fertility, path analysis, organic carbon

INTRODUCTION

Sugarcane (Saccharum officinarum) is a member of the Poaceae family, a group of large tropical and subtropical grasses widely cultivated within 30° latitude north and south of the equator (Verma et al., 2022). Globally, sugarcane accounts for approximately 75% of total sucrose production (Bassey et al., 2020; 2024). While it is primarily grown for raw sugar, sugarcane has gained renewed interest as a vital source of renewable energy, particularly due to its role in ethanol production (Sarwar Khan et al., 2021; Romeu da Silva et al., 2025).

Despite its economic importance, Nigeria’s national average sugarcane yield remains below 65 t/ha, significantly lower than the global average of 175.1 t/ha (NSDC, 2022; Bassey et al., 2024). The relationship between sugarcane growth and yield components has been widely explored. Abo-Elwafa et al. (2021) and Desalegn et al. (2023) reported significant positive correlations between cane yield and various traits, including germination percentage, number of shoots, number of millable canes, stalk diameter and length, number and length of internodes, stalk weight, and number of green leaves. In contrast, top weight showed a positive but non-significant correlation with yield (Verma et al., 2021), while Brix content was negatively correlated with cane yield at all stages.

Understanding how developmental factors influence yield is essential for successful crop improvement. One effective approach is path coefficient analysis, which allows researchers to break down the observed correlation between traits into direct and indirect effects (Khan et al., 2022; Verma et al., 202). Introduced by Dewey and Lu (1959), this method provides insight into which traits have a more meaningful, causative impact on yield. For instance, it can reveal whether plant height influences yield directly or through its effect on other traits like stalk girth or leaf area. This insight helps breeders focus on the most yield-contributing characteristics, ultimately improving selection efficiency and crop performance. While this study focuses primarily on correlation analysis, it adopts a similar philosophy by evaluating the associations between agronomic, soil, and weed parameters and their collective contribution to cane yield under the agroecological conditions of Badeggi, Nigeria.

MATERIALS AND METHODS

A field experiment was conducted at the upland sugarcane experimental field of National Cereals Research Institute, Badeggi (Lat. 90 45’ N, Long. 60 07’ E and 89 m above sea level) in the southern Guinea savanna agro-ecological zone of Nigeria in 2018 and 2019 wet and dry season. The average annual rainfall during the experimental was 1504 mm in 2018 and 1045 mm in 2019 while the mean air temperature was 35 to 38 oC in 2018 and 34 to 36 oC in 2019.

Composite soil samples were taken before field establishment from ten spots along a diagonal and at harvest from each treatment plot from 0 to 15 cm depth, and subjected to routine analyses. Particle size analysis was done by the Bouyoucos hydrometer method (Gee and Or, 2002). Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson et al. 1996). Total N was determined by the micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). The Olsen method was used to determine available phosphorus, and flame photometry for exchangeable potassium (Okalebo et al. 2002). Soil pH was determined in 1:2 soil–water ratio using digital electronic pH meter.

Before cultivation, the vegetative cover of the experimental site was manually cleared, ploughed and harrowed with a tractor in the first week of February 2016 and 2017. The land was fully irrigated before planting by pumping water from a stream using a 3.5 HP water pump with a 12.5 cm diameter hose. Thereafter, the land was marked out into plots with bunds at the edges for water retention. Gross plot size was 5 m x 4 m (20 m2) consisting of 4 sugarcane rows, and net plot size was 5 m x 2 m (10 m2) consisting of 2 sugarcane rows. Each row was spaced at 1 m apart. Tender healthy young stalks of six months old sugarcane were used as planting material. The stalks were cut into setts each containing three eye buds, planted continuously end-to-end without intra-row spacing in shallow sunken bed. The application of pre-emergence (PE) diuron was done immediately after planting at 2.0 kg a.i ha-1. The trash mulch was applied at a thickness of 1, 3 and 5 cm (Henrique et al., 2013) for 3, 6 and 9 t ha respectively, with a small opening left of the setts which were closed up after sprouting. The application of post-emergence (POE) 3-maize force at 179.2 g ha [metolachlor 375 g L-1 plus terbuthylazine 125 g L plus mesotrione 37.5 g L-1] was applied at 5 weeks after planting (WAP). The NPK fertilizer was applied at 150 kg N, 60 kg P2O5 and 90 kg K2O in equal halves at planting and 10 WAP. Irrigation water was applied at 41.3 L per plot once per week from February to April. Rainfall was supplemented with irrigation in May which was the establishment of the rainy season.

The treatments consisted of a factorial combination of two sugarcane genotypes [Chewing cane (Bida local and Industrial cane (NCS 001)], four rates of sugarcane trash mulch rates (0, 3, 6, 9 t ha-1) and four weed management practices [weedy check, five monthly hoe weeding (5 MHW), pre-emergence (PE) application of diuron at 2 kg a.i ha-1 + post-emergence (POE) application of 3 – maize force at 179.2 g ha-1 + 2 MHW, and PE diuron + POE 3-maize force] making a total of 32 treatments arranged as a split-plot in a Randomized Complete Block Design and replicated three times. Weed management practices and trash mulching were allocated to the main plot, while

sugarcane genotypes were the subplot. The gross plot size was 5 m x 4 m (20 m2), while the net plot size was 5 m x 2 m (10 m2). Each net plot consisted of four rows of 5 m length.

RESULTS AND DISCUSSION

The correlation analysis of sugarcane traits at Badeggi during the 2018 and 2019 rainy seasons revealed important relationships between cane yield (C_YLD), plant growth characteristics, and soil nutrient status (Tables 1 and 2). Notably, cane yield showed significant positive correlations with key growth traits such as stalk height (SH) and stalk girth (SG), as well as with soil properties including organic carbon (O.C), total nitrogen (T.N), available phosphorus (AVP), potassium (K), and brix content (BC) in both years.

Stalk height and girth were strongly associated with higher cane yield: r = 0.770** and 0.538** in 2018, and r = 0.365* and 0.633** in 2019. This indicates that taller and thicker stalks contribute substantially to yield, likely due to greater biomass and juice accumulation. These findings support previous reports highlighting stalk dimensions as reliable predictors of cane yield (Patil et al., 2020; Vigneshwari and Shanthi, 2023).

Soil fertility parameters also played a critical role. Organic carbon and nitrogen were positively and significantly correlated with cane yield across both seasons (O.C: r = 0.537** in 2018, r = 0.587** in 2019; T.N: r = 0.513** in 2018, r = 0.568** in 2019). Similarly, available phosphorus and potassium also showed strong positive relationships with yield (AVP: r = 0.526** in 2018, r = 0.536** in 2019; K: r = 0.526** in 2018, r = 0.426* in 2019). These results underscore the importance of maintaining a balanced soil nutrient profile to support optimal plant growth and productivity. The findings align with earlier research indicating that organic amendments and balanced fertilization strategies can significantly enhance both yield and sugar recovery in sugarcane (Ijaz et al., 2023).

Interrelationships among soil nutrients were particularly strong, especially between organic carbon and total nitrogen (r = 0.945** in 2018, r = 0.982** in 2019), and also between these nutrients and both available phosphorus and potassium. This suggests that increasing soil organic matter content through practices like green manuring or composting can enhance overall nutrient availability and thus support better crop performance (Patil et al., 2023). Additionally, Bassey et al. (2023) and 2024 reported similar findings of increase crop performance due to nutrient accumulation arising from trash mulch application.

Brix content, an indicator of sugar accumulation, was moderately correlated with yield (r = 0.512** in 2018 and r = 0.368 in 2019). This suggests that, beyond biomass, the concentration of sugars in the stalk also contributes meaningfully to total yield. Similar relationships between biomass and Brix content have been reported in other crops, such as sorghum and grafted melon cultivars (Ercan et al., 2024; Sun et al., 2024).

Conversely, weed biomass had a significant negative correlation with cane yield in both years (r = -0.433* in 2018, r = -0.542** in 2019). This clearly indicates that weed competition significantly reduces sugarcane yield by limiting access to vital resources such as light, water, and nutrients. Effective weed management is therefore critical to maximizing yield potential. This observation is consistent with findings that early-season weed interference can lead to yield losses of 30–60% if not adequately managed (Horvath et al., 2023; Shittu and Abdullahi, 2022 a and b).

This study highlights that achieving high cane yield depends on a combination of vigorous plant growth, fertile soil, and effective weed control. The results reinforce the importance of integrated agronomic practices specifically, nutrient management, organic matter enhancement, and timely weed suppression for sustainable sugarcane production.

Partition of the correlation matrix

Tables 3 and 4 and Figures 1 and 2 illustrate how total correlation is divided into direct and indirect effects of specific growth and soil factors on sugarcane yield during the 2018 and 2019 rainy seasons at Badeggi. The analyses highlight the significance of stalk morphology and soil nutrient traits in influencing yield, while also pointing out the complex interactions among these factors.

During the 2018 season, stalk girth exhibited the highest direct contribution to cane yield (31.6%), followed by stalk height (7.5 %), with other traits such as Brix content, soil organic carbon, total nitrogen, and available phosphorus contributing minimally through direct effects. The most prominent indirect contribution came from stalk height via stalk girth (26.8 %), indicating that taller plants with thicker stalks significantly enhance yield potential. This supports findings from recent sugarcane studies showing that structural growth traits, especially stalk diameter, are strong yield predictors due to their association with biomass and sugar accumulation (Ahmad et al., 2019; Ittah and Obok, 2019).

In contrast, the 2019 season showed a shift in the magnitude of direct effects, with stalk height (19.3%) and stalk girth (19.1%) emerging almost equally as top contributors to yield. This suggests a stronger role of plant height under the 2019 conditions, possibly due to improved growing environments or genotypic variation. Brix content (1.94%) and available phosphorus (1.55%) also showed increased direct effects in 2019, indicating that, although secondary to structural traits, quality and soil-related factors can play more substantial roles under favorable conditions. These findings align with the work of Mebrahtom et al. (2018), who reported that cane yield is closely tied to tiller number, stalk diameter, and plant height, with variable influence from soil fertility parameters depending on the growing environment.

Indirectly, the highest positive contributions in 2019 included stalk height via Brix content (6.03%), and total nitrogen via available phosphorus (1.64%), reinforcing the importance of nutrient synergy in driving yield. However, several traits showed unusually high or negative indirect effects, such as Brix content via organic carbon (-144.7%) and organic carbon via available phosphorus (-393.5 %). These extreme values likely reflect multicollinearity or suppressor effects within the path model common in complex soil-plant systems (Zaheer et al., 2019). Despite this, the total variation in cane yield explained by the path model was relatively high: 71.2% in 2018 and 80.4% in 2019, indicating that the selected traits substantially account for yield performance across both seasons.

Overall, the consistent influence of stalk girth and stalk height across both years affirms their central role in sugarcane yield improvement. These structural traits are often used as proxies for biomass production and juice volume, making them critical targets in breeding and management programs (Khan et al., 2018; Sun et al., 2024). Conversely, while soil nutrients and Brix content showed limited direct effects, their cumulative indirect contributions especially through their enhancement of stalk growth highlight their supportive role in yield formation. Effective soil nutrient management, particularly for nitrogen and phosphorus, remains essential for maximizing the expression of yield-contributing morphological traits (Patil et al., 2023).

CONCLUSION

This study established that stalk height and stalk girth are the most critical direct contributors to sugarcane yield under the conditions of the Nigerian Southern Guinea savanna. Correlation analysis confirmed strong positive associations between cane yield and both plant structural traits and soil organic matter content. Path coefficient analysis revealed that while growth traits had dominant direct effects, soil nutrients such as phosphorus and organic carbon exerted significant indirect effects by enhancing those traits. These results reinforce the value of combining genotypic selection for stalk vigor with site-specific soil fertility management to boost cane productivity. The

integrated use of correlation and path analysis provided a clearer understanding of trait interrelationships, explaining over 70% of the variation in yield. This approach offers a robust model for guiding breeding and agronomic decisions in sugarcane production systems in sub-humid environments.

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