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Soil weight determination for optimal growth and yield performances of pot-grown maize

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ABSTRACT

Root restriction, reduced growth and poor yield due to an insufficient quantity of soil are the major limitations of pot-grown maize (*Zea mays* L.). Hence, to determine the actual quantity of soil required for optimal growth and yield performances of pot-grown maize, two maize varieties; BR9943 DMR-SR (yellow) and BR9928 DMR-SR (white), were evaluated in pots of 5, 10, 20, 30 and 40 kg of topsoil in a 2 x 4 factorial (r = 4) using complete randomised design at the Institute of Agricultural Research and Training, Ibadan, Nigeria. Data were collected on plant height (PHT), leaf area (LA), cob length (CBT), number of kernels per row (K/R), number of rows per cob (R/C), number of kernels per cob (K/C) and total grain weight (TGW). The results obtained showed that all the evaluated parameters were significantly different at $P < 0.05$ across the soil weights. Maize planted in 30 kg of soil had the highest LA (774.25 cm^2), R/C (15.25), K/C (405.62) and TGW (73.84 g), compared with maize planted in 5 kg and 10 kg soils. Plant height and CBT were highest when 40 kg of soil was used. The maize varieties BR9928 DMR-SR (yellow) and BR9943 DMR-SR (white) were not significantly different across the growth and yield parameters except for LA, where the yellow maize (651.91 cm^2) had a substantially higher LA than the white maize variety (588.19 cm^2). Based on the results of this study, 30 kg of topsoil is recommended for optimum growth and yield performances of pot-grown maize.

Keywords: leaf area, maize, number of rows per cob, plant height

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop widely grown in both temperate and tropical regions. This cereal crop has remained an important staple for many households of different social backgrounds in sub-Saharan Africa. It is widely used in the preparation of several traditional foods, raw materials for breweries, livestock feed formulation, and in flour and feed mills (Olakojo, 2001; Olakojo et al., 2007). In comparison with other cereal crops, extensive research on plant management, ecological adaptability and genetic improvement of existing germplasm has been carried out successfully over the years on maize (Tsimba et al., 2013; Long et al., 2017; Lu et al., 2017). These were completed in the laboratory, in controlled environments and on the field by scientists of different disciplines. Over time, much research emphasis has been placed on the soil-crop management practices of field maize-grown, while little or no attention has been paid to maize research carried out in pots in controlled environments. However, pot size has been shown to affect several plant physiological processes, including nutrient efficiency (Carmi, 1983; Huang et al., 1996), rates of photosynthesis (Robbins and Pharr, 1988; Arp, 1991; Zakari et al., 2020), growth and grain yield of crops (Townend and Dickinson, 1995; Whitfield et al., 1996). This problem is basically due to the use of an insufficient quantity or reduced size of soil; hence the 'roots are bound' (Ray and Sinclair, 1998). The earlier report of Lu et al. (2017) affirms a close link between crop root systems and crop growth and development. Zhou et al. (2016) were of the view that a larger and more extensive root network in the soil profile enhances water and nutrient utilization efficiency leading to increased crop yield. Kang et al. (2022) highlighted the role of root density, root distribution and the anatomical characteristics of root structure in determining plant root system architecture. Efficient root system architecture improves the utilization of limited plant resources and enhances the yield and quality of crops. Adequate growth media has the potential to enhance efficient root system architecture for optimum plant growth. Feldman (1994) reported that, during an average period of growth, the root system of a single maize plant could spread over 200 cubic feet (178.24 cm) of soil and absorb 35 to 50 gallons (132.49 to 189.27 liters) of water. Depending on soil texture, the lateral spreading of a mature root system may reach 3 - 4 feet (91.44 - 121.92 cm) on all sides of the plant and penetrate to a depth of 5 - 6 feet (152.4 - 182.8 cm). Presently, there is a dearth of literature on the actual weight/size of soil required for optimum productivity of pot-grown maize, especially when maize is expected to be grown to the physiological maturity stage. Therefore, this study attempts to evaluate two maize varieties under different soil weights to determine the actual weights of topsoil required for optimal growth and yield performances of pot-grown maize. The information obtained from this study would not only assist plant scientists but will be valuable to urban farmers in Africa who have embraced sack farming, a new farming innovation where crops are grown in pots, cans, sacks and other containers (Peprah et al., 2014).

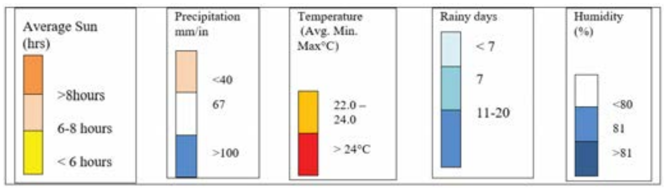
MATERIAL AND METHODS

Description of Experimental Site

The experiment was carried out between 12 January and 30 April 2021 at the screen house of the Institute of Agricultural Research and Training (I.A.R.&T), Moor Plantation, Apata, Ibadan, Nigeria (Lat.7◦22.5N and Long.3◦50.5E.). Ibadan is characterized by a bimodal rainfall pattern, with a long rainy season (between March and July) and a short rainy season (September to early October), following a short dry spell from November to February (Table 1).

Table 1. Weather averages for Ibadan

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	27.3 °C (81.1) °F	27.9 °C (82.3) °F	27.7 °C (81.9) °F	26.9 °C (80.4) °F	25.9 °C (78.6) °F	24.6 °C (76.4) °F	24 °C (75.2) °F	23.8 °C (74.8) °F	24.2 °C (75.6) °F	24.9 °C (76.9) °F	26.1 °C (79) °F	26.9 °C (80.4) °F
Min. Temperature °C (°F)	22.3 °C (72.1) °F	23.6 °C (74.5) °F	24.4 °C (76) °F	24.2 °C (75.5) °F	23.5 °C (74.4) °F	22.6 °C (72.7) °F	22 °C (71.5) °F	21.7 °C (71) °F	22.1 °C (71.8) °F	22.6 °C (72.6) °F	23.2 °C (73.7) °F	22.3 °C (72.2) °F
Max. Temperature °C (°F)	34.1 °C (93.4) °F	34.6 °C (94.3) °F	33.6 °C (92.5) °F	31.8 °C (89.3) °F	30.1 °C (86.2) °F	28.5 °C (83.2) °F	27.7 °C (81.8) °F	27.4 °C (81.4) °F	28.2 °C (82.8) °F	29.2 °C (84.6) °F	31 °C (87.8) °F	33.2 °C (91.8) °F
Precipitation / Rainfall mm (in)	17 (0)	30 (1)	67 (2)	114 (4)	176 (6)	214 (8)	218 (8)	206 (8)	215 (8)	159 (6)	39 (1)	12 (0)
Humidity (%)	56%	64%	74%	81%	86%	89%	88%	87%	88%	87%	81%	65%
Rainy days (d)	3	5	11	15	18	20	20	20	20	18	7	3
avg. Sun hours (hours)	8.4	7.7	6.7	5.8	5.2	4.4	4.1	3.5	4.0	4.6	6.0	8.0



Data: 1991 - 2021 Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days. Data: 1999 - 2019: avg. Sun hours. (https://en.climate-data.org/africa/nigeria/oyo/ibadan-529/).

Soil sample collection and analysis

Soil samples were taken randomly in replicates from the field at I.A.R.&T Ibadan. The soil samples were crushed and passed through a 2 mm sieve after air drying and analysed for physicochemical properties following standard procedures. Table 2 presents the results of the laboratory analysis for physiochemical soil traits Based on this result; the soil can be classified as sandy loamy soil. The pH is neutral, phosphorus content is moderate, the total organic carbon content is low (1.12), the total nitrogen content is low, the potassium content is moderate and the zinc content is moderate.

Treatments and Experimental Procedure

The treatments consisted of five different weights of topsoil (5 kg, 10 kg, 20 kg, 30 kg and 40 kg) placed into pots of volume 34500 cm^3 (34.5 litres) with height 58 cm and breadth of 48 cm which constituted the main plots arranged in four replicates, while the subplots consisted of two certified popular open-pollinated maize varieties (BR9928 DMR-SR– White and BR9943 DMR-

SR-Yellow) certified and released in 1999 by the Institute of Agricultural and Training, Ibadan, Nigeria). Two seeds of each of the maize varieties were sown in each pot. The seedlings were later thinned to one vigorous seedling per pot ten days after emergence.

Fertilizers (NPK 20-10-10 and urea) were applied accordingly at two and six weeks after planting, while hand weeding was carried out regularly.

Table 2. Laboratory analysis of physicochemical soil characteristics

Parameters	Unit	Value
pH	Water	6.75
Available P	mg/kg	19.05
Total Organic C	%	1.12
Total N	%	0.08
Exchangeable bases		
Ca	Cmol/kg	2.86
Mg	Cmol/kg	1.06
Na	Cmol/kg	0.8
K	Cmol/kg	0.51
Al+H	mg/l	0.07
ECEC	Cmol/kg	5.3
Micro-nutrients		
Cu	mg/kg	0.93
Zn	mg/kg	3.58
Fe	mg/kg	38.25
Mn	mg/kg	18.75
Particle size Distribution		
Sand	%	91.2
Silt	%	4.6
Clay	%	4.2

Data Collection and data analysis

- √ Plant height (cm): This was measured using measuring tape from the base to the apex of the stem
- √ The number of leaves per plant was determined by visual counting.
- √ Leaf Area (LA): Obtained by measuring the Length (L) and Width (W) of tagged leaves with a graduated ruler to obtain the leaf area (cm^2) using the equation, LA (cm^2) = 0.75 (L x W) (Francis et al.,1969).
- √ At harvest, the matured cobs were manually harvested at physiological maturity to obtain fresh Harvest weight (g) Fresh ears harvested at physiological maturity were weighed (22 % Moisture content) using a sensitive weighing scale
- √ Cob length (cm) – was determined using a measuring tape on each cob after the husk removal.
- √ Total Grain weight (TGW) (g) was determined after drying and shelling of the harvested maize cobs. This was obtained from the grain using an electronic weighing scale after drying to a 15% moisture level.

Obtained data were processed by using Statistical Tool for Agricultural Research (STAR, 2014), and means were separated using Fisher's Least Significant Difference (LSD) at $P < 0.05$.

RESULTS

Growth and yield traits of two maize varieties grown under varied soil weights in pots.

Table 3 presents the growth and yield traits of two maize varieties BR9943 DMR-SR and BR9928 DMR-SR as influenced by varying soil weights. There were no significant differences ($P < 0.05$) recorded in plant heights, harvest field weights, numbers of; kernel rows, kernels per cob, ear per plant, cob length and grain yield in the two maize varieties except for leaf area, which was significantly higher in BR9928 DMR-SR (651.91 cm^2) than BR9943 DMR-SR (588.19 cm^2).

Table 3. Growth and yield traits of two maize varieties grown under varied soil weights in pots

Treatment	LA(cm²)	PHT(cm)	FWT(g)	R/C	K/R	K/C	CBT(cm)	TGW(g)
Variety (V)								
BR9943 DMR-SR	588.19[b]	153.95	124.48	9.25	15.80	199.55	12.10	34.80
BR9928 DMR-SR	651.91[a]	150.51	120.85	9.90	17.15	247.85	10.07	42.44
Significance level	*	ns	ns	ns	ns	ns	ns	ns
Soil (SWT) Weights								
5 kg	475.56[c]	133.00[d]	34.51[c]	0.38[c]	0.01[c]	3.38[c]	6.46[d]	6.14[c]
10 kg	501.49[c]	160.00[c]	105.94[b]	10.25[b]	13.62[b]	173.62[b]	11.03[bc]	27.43[bc]
20 kg	645.35[b]	174.00[b]	104.53[b]	9.12[b]	14.50[ab]	179.75[b]	8.74[cd]	32.92[b]
30 kg	774.25[a]	190.00[b]	192.79[a]	15.25[a]	26.88[a]	405.62[a]	14.06[ab]	73.84[a]
40 kg	703.60[b]	210.00[a]	175.54[a]	12.88[ab]	27.38[a]	356.12[a]	15.15[a]	52.77[ab]
Mean	620.05	152.23	122.66	9.57	16.48	223.70	11.09	38.62
SD	134.05	31.40	69.91	6.26	13.57	194.79	4.54	31.88
$LSD_{(0.05)}$	62.07	18.85	46.82	4.37	12.63	175.34	3.32	26.43
(V * SW)	*	**	*	**	**	*	ns	ns

* **Significant at $P < 0.05$, 0.01 probability levels, ns = non-significant. Means with the same alphabets in the superscript within each column are not significantly different at $P < 0.05$ according to Fisher's LSD. LA = Leaf Area, PHT = Plant Height, FWT = Fresh Harvest Weight, R/C = Number of rows per cob, K/R = Number of kernels per row, K/C=Number of kernels per cob, CBT = Cob Length and TGW = Total grain weight, SD = Standard Deviation.

Maize grown in 30 kg (774.25 cm²) soil showed the highest leaf area compared to the other soil weights ($P < 0.05$), but there was no significant difference in maize leaf sizes grown in 40 kg (703.60 cm²) and 20 kg (645.35 cm²), respectively. However, leaf area was lowest in maize plants grown in 5 kg (475.8 cm²) and 10 kg (501.49 cm²) soils, respectively.

Maize plant heights were significantly influenced by varied soil weights in this trial, such that the highest plant height (210.0 cm) was recorded for maize grown in 40 kg soil, while no significant differences ($P < 0.05$) in plant heights were observed in maize grown in 30 kg (190.0 cm) and 20 kg (174.0 cm), respectively while 5 kg soil produced the lowest plant height of 133.0 cm.

There was no significant difference in the fresh harvest weights obtained for maize grown in 40 kg (175.54 g) and 30 kg (192.79 g) of soil ($P < 0.05$). Similarly, there was no significant difference in the weights of the fresh maize harvest obtained from maize grown in 20 kg (104.53 g) and 10 kg (105.94 g) soils. Fresh maize harvest weight was lowest in maize grown in 5 kg soil (34.5 g). The number of rows per cob was highest in maize grown in 30 kg (15.25), followed by 40 kg soil (12.88). There was no significant difference at $P < 0.05$, in the number of rows per cob in maize grown in 20 kg (9.12) and 10 kg (10.25), respectively, while 5 kg (0.38) soil had the least.

The number of kernels per row was highest in 30 kg (26.88) and 40 kg (27.38) soils and significantly higher than the number of kernels per row in maize cobs obtained from growing in 20 kg (14.50), 10 kg (13.62) and 5 kg (0.01) soils.

In this study, the number of kernels per cob was significantly influenced by different weights of soil. The highest number of kernels per cob was obtained from maize grown in 30 kg (405.62) and 40 kg (356.12) of soil, respectively. Similarly, no significant difference was observed in the number of kernels per cob in maize grown in 20 kg (179.75) and 10 kg (173.62) weights of soil at $P < 0.05$, respectively, but the number was lowest in 5 kg (3.38) of soil. The most extended cob length was observed in maize grown in 40 kg (15.15 cm), which was not significantly different from the cob length of maize grown in 30 kg of soil, but longer than cobs of maize grown in 10 kg (11.03 cm), 20 kg (8.74 cm) and 5 kg (6.46 cm) of soil. Total grain weight was highest in maize grown in 30 kg (73.84 g) weight of soil, but significantly ($P < 0.05$) higher than maize grown in 40 kg (52.77 g), 20 kg (32.73 g), 10 kg (27.43 g) and 5 kg (6.14 g) weights of soil.

Interactive effects of soil weights and maize variety on the evaluated growth and yield traits of pots-grown maize

As it is shown in Table 4, soil weight and variety interaction (*) effect on leaf area was significant ($P < 0.05$), 5 kg weight of Soil (WS)*BR9928DMR-SR (493.62 cm^2) was significantly higher than 5 kg WS*BR9943DMR-SR (457.50 cm^2), 10 kg WS*BR9928DMR-SR (557.28 cm^2) was significantly greater than 10 kg WS*BR9943DMR-SR (445.70cm^2), 20 kg WS*BR9928DMR-SR (680.25 cm^2) > 20 kg WS*BR9943DMR-SR (610.45 cm^2), 40 kg WS*BR9928DMR-SR (748.13 cm^2) > 40 kg WS* BR9943DMR-SR (659.08 cm^2).

The interaction effect of soil weight and maize variety on plant height was significant ($P < 0.05$). Five (5) kg WS*BR9928DMR-SR (116.50 cm) was significantly higher than 5 kg WS*BR9943DMR-SR (91.25 cm), similarly, 30 kg WS*BR9943DMR-SR (189.00 cm) > 30 kg WS*BR9928DMR-SR (169.25 cm), 40 kg*BR9943DMR-SR (181.00 cm) > 40 kg WS*BR9928DMR- SR (142.32 cm).

A significant interaction effect weight of fresh Harvest was observed at 20 kg WS* BR9943DMR-SR (151.82 g) >20 kg WS*BR9928DMR-SR (57.24 g), similarly 30 kg WS*BR9928DMR-SR (225.69 g) > 30 kg WS BR9943DMR-SR

A significant interaction effect was observed 10 kg WS*BR9928DMR-SR (14.00) >10 kg WS*BR9943DMR-SR (6.50), 20 kg WS*BR9943DMR-SR (12.75) > 20 kg WS* BR9928DMR-SR (5.50). Significant interaction effects on the number of kernels per row were observed at 20 kg WS*BR9943DMR-SR (20.75) > 20 kg WS* BR9928DMR-SR (8.25).

Table 4. Weights of soil and maize variety interaction effects on growth and yield traits of two maize varieties grown in pots

SWT	Maize Varieties	LA (cm^2)	PHT (cm)	FWT (g)	R/C	K/R	K/C	CBT (cm)	TGW (g)
5 kg	BR9943D MR-SR-W	457.50^a	91.25^b	28.85^a	0.00^a	0.00^a	3.75^a	7.63^a	0.72^a
	BR9928DMR-SR (Y)	493.62^a	116.50^a	40.17^a	0.75^a	0.00^a	3.00^a	5.30^a	0.56^a
10 kg	BR9943DMR-SR(W)	445.70^b	140.75^a	89.88^a	6.50^b	9.50^a	98.75^a	11.18^a	8.00^b
	BR9928DMR-SR(Y)	557.28^a	152.25^a	122.01^a	14.00^a	17.75^a	24.85^a	10.89^a	46.86^a
20 kg	BR9943DMR-SR(W)	610.45^b	167.75^a	151.82^a	12.75^a	20.75^a	263.50^a	11.96^a	46.57^a
	BR9928DMR-SR(Y)	680.25^a	172.25^a	57.24^b	5.50^b	8.25^b	96.00^b	5.50^a	19.27^a
30 kg	BR9943DMR-SR(W)	768.33^a	189.00^a	159.90^b	15.00^a	20.25^b	289.75^b	13.67^a	52.56^b
	BR9928DMR-SR(Y)	780.28^a	169.25^b	225.69^a	15.50^a	33.50^a	521.50^a	14.45^a	95.12^a
40 kg	BR9943DMR-SR(W)	659.08^b	181.00^a	191.97^a	12.00^a	28.50^a	342.00^a	16.05^a	55.14^a
	BR9928DMR-SR(Y)	748.13^a	142.32^b	159.12^a	13.75^a	26.25^a	370.25^a	14.25^a	50.41^a

Means designated with the same alphabets in the superscript within each pairwise comparison are not significantly different at $P < 0.05$, according to Fisher's Least significant difference. SWT = Soil weight, MLA = Leaf Area, PHT = Plant Height, FWT = Fresh Harvest Weight, R/C = Number of rows/cobs, K/R = Number of kernels per row, K/C = Number of kernels per cob, E/P = Number of ears per plant, CBT = Cob Length and TGW = Total Grain Weight.

There is a significant interaction effect on the number of kernels per cob at 20 kg WS*BR9943DMR-SR (263.50) > 20 kg WS*BR9928DMR-SR (96.00), 30 kg WS*BR9928DMR-SR (521.40)>30 kg WS*BR9943DMR-SR (289.75). Significant interaction effect on grain yield exists at 10 kg WS*BR9928DMR-SR (46.86 g) >10 kg WS*BR9943DMR-SR (8.00 g). Thirty (30) kg WS*BR9928 DMR-SR (95.12 g) >30 kg WS*BR9943DMR-SR (52.56 g)

DISCUSSION

Planting in controlled environments using pots is a common practice in most plant physiology research (Ray and Sinclair, 1998). Most often, a very broad margin exists between the agronomic performances of pot-grown maize compared with field-grown maize, especially when the maize is raised to the physiological maturity stage. Pot-grown plants are usually "root-bound" especially when grown in pots with a limited volume of soil (Ray and Sinclair, 1998).

However, to determine the actual size of soil required to fill a pot for optimal maize growth and yield performances. Two maize varieties, BR9943D MR-SR-W and BR9928D MR-SR-Y were sown in pots (volume 34500 cm^3, height 58 cm and breadth 48 cm) containing 5 kg, 10 kg, 20 kg, 30 kg and 40 kg of topsoil, respectively. The results revealed that the plants' heights, leaf areas and yield traits were significantly reduced in 5 kg, 10 kg and 20 kg soils compared to maize grown in 30 kg and 40 kg soils. The poor performances observed in plants grown in 5 kg, 10 kg and 20 kg soils could be attributed to stress acquired from mechanical impedance from the pots as the soil medium is not sufficient to support the growing root mass (Bengough et al., 2011, Fageria et al., 1991).

The impediment might have affected soil moisture and nutrient availability and distribution within the soil and to the plant roots zone, thereby limiting plant growth and yield performances (Mthandi et al., 2013). The 'dwarfing' responses due to root restriction as observed in maize grown in 5, 10 and 20 kg pots had been attributed to hydraulic and non-hydraulic factors (Hurley and Rowarth, 1999; Yong et al., 2010). On the other hand, significantly higher growth and yield performances recorded in 30 and 40-kg soils could be attributed to better rooting spaces and the large number of roots facilitated by larger soil sizes (Whitfield et al.,1996; Ray and Sinclair, 1998; Hammer et al., 2009; Chen-Chen et al., 2022). From the results of this study, 30 kg and 40 kg soil sizes appeared to have facilitated the availability of adequate moisture and nutrients and enhanced effective root system architecture and a corresponding increase in harvest yield (Kang et al., 2022).

Well-absorbed moisture and nutrients in 30 kg and 40 kg soils might have enhanced the development of tall maize plants with broader leaves of large surface areas, this corroborates the findings of Arp, (1991) which earlier reported a strong relationship between photosynthetic rate and pot size. The higher leaf areas indicate a more exposed surface area for the reception of photosynthetic active radiation and more stomata for well-efficient gaseous exchange. Therefore, no lesser comparatively higher yield is expected under such high moisture and nutrient facilitated by the well-developed rooting system provided by 30 and 40-kg soils, respectively (Wang et al., 2019; Tian et al., 2020; Trachsel et al., 2013; Chen et al., 2014).

CONCLUSION

Based on the findings of this study thirty kilograms (30 kg) of topsoil placed in a 34.5-liter pot appeared to be sufficient for planting maize to achieve optimum growth and grain yield performances, especially when growing maize to maturity is desired. It is also worth noting that the results were consistent in the two maize varieties used in this study. Therefore, growing maize in soil weighing more than 30 kg provides no additional benefits in terms of growth and yield performances but rather an unnecessary expenditure of labour and time. The information obtained in this study is essential for plant physiologist and most urban farmers who are interested in planting maize in sacks, cans and other containers. Further studies are hereby suggested for soil-size requirements for optimal performances of pot-grown hybrid maize varieties.

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