Original Research Article

Root growth responses of maize (*Zea mays* L.) and soybean (*Glycine max* L.) to soil compaction and fertilization in a Ferric Acrisol

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ABSTRACT

Mechanical impedance to root growth is one of the most important factors determining root elongation and proliferation within a soil profile. Two pot experiments were made at the Department of Horticulture, KNUST, Kumasi, Ghana, to determine the impact of subsurface compaction and different fertilizer amendments on the root growth of maize (*Zea mays* L.) and soybean (*Glycine max* L.). The experiments were arranged in a factorial Completely Randomized Design (CRD) with three replications. Maize and soybean were sown in 72 plastic buckets (36 for each crop) of 12 L volume filled with a Ferric Acrisol. The treatments were different levels of compaction, using bulk density as proxy – 1.3, 1.5 and 1.7 Mg m^{-3}, and fertilizer amendments of 100% poultry manure (15 g/pot), 100% NPK fertilizer (2.89 g/pot) and 50% rate each of poultry manure (7.5 g/pot) and NPK fertilizer (1.45 g/pot). The highest toot growth occurred in the uncompacted soil and along the periphery of the soil core. The applied soil amendments significantly increased the root penetration ratio (RPR) of both crops in relation to the control. The shoot biomass of both crops decreased with increasing soil bulk density. All the applied soil amendments significantly increased the shoot biomass of maize and soybean over the control. The magnitude response of the crops to the soil amendments was greater in soybean than in maize.

Keywords: Maize, NPK fertilizer, Poultry manure, Soil compaction, Soybean

1. INTRODUCTION

Soil compaction results from the physical consolidation of soil by an applied force. This consequently destroys the structure, reduces porosity, limits water and air infiltration, increases resistance to root penetration, and often results in reduced crop yield [1]. The processes of tillage induced soil compaction as outlined by [1 – 3] are as follows: (i) when soils are cultivated repeatedly at the same depth. The weight of the tillage equipment (discs, wheels or cultivator shovels) causes compression of the soil and smearing at the base of contact between the soil and tillage implement (ii) As soil particles are compressed, the pore space is reduced, thereby reducing the space available in the soil for air and water (iii) If the applied force is great enough, soil aggregates are destroyed (iv) The result is a dense soil with few large pores that has poor internal drainage and limited aeration.

The sensitivity of a given soil to compaction depends on the soil properties, mostly on texture, structure [4], moisture content and clay mineralogy. Accordingly, Défossez et al. [5] reported that the most important factor in making decisions about cultural operations is soil water due to its influence on soil compaction. Soil compaction may result from natural, as well as, human and animal induced processes. For instance, treading of wet soils by animals causes soil compaction [2, 6]; human activities such as the use of agricultural machinery also induce compaction [7, 8]. The most yield limiting soil compaction is caused by wheels from heavy equipment, particularly on wet soils [1]. Tillage induced compaction layer is mostly referred to as hardpan or plough pan and occurs just below the plough depth [3]. Soil compaction, especially in the subsoil layers may restrict deep root growth and plant access to subsoil water in the mid to late growing season when rainfall is usually sparse and evapotranspiration is high [3, 9]. Muhammad et al. [10] reported that the adverse effect of soil compaction on water flow and storage may be more serious than its direct effect on root growth. Root response to soil compaction depends on the presence and distribution patterns of pores having a diameter greater than the roots and on pore continuity; because a soil matrix with larger pores are essential for optimal crop yields [11]. Soil compaction restricts root growth resulting in poor anchorage and susceptibility of plants to uprooting during grazing [12].

Amelioration of soil compaction can be achieved through biological drilling in which root channels left by previous crops reduce the effects of subsoil compaction on subsequent crop root growth [9, 13, 14], no-tillage practice, [15], subsoiling [3, 12, 16, 17], cultivar improvement [18], and soil amendments [19]. These strategies have resulted in increased crop yields, although uncertainties regarding their application still remain. Addition of soil amendments increases the competitive advantage of the crop for nutrient uptake. This provides crops with the needed nutrients necessary for their growth and development, and reduces the limitations posed to root growth by compaction. The present study was thus, conducted to ass the effects of soil compaction and fertilization on the root growth and distribution of maize and soybean. The two crops were selected based on the fact that maize is the largest staple crop, while soybean is an emerging major crop in Ghana. Additionally, dicots (soybean) and monocots (maize) respond differently to the impact of soil compaction, hence the need and there is the need to investigate this phenomenon in Ghanaian soils.

2. MATERIALS AND METHODS

2.1 Experimental set up and design

The study was conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. The set up comprised two pot (12 L buckets) experiments with soil samples classified as Orthi-Ferric Acrisol [20] grown with maize and soybean. Each experiment was conducted with 36 buckets for maize and soybean. Each bucket was graduated at 2 L interval and had a surface area of 0.07 m^2. Each bucket assembly consisted of a top 2 L space for watering, followed by a 2 L soil core (1.3 Mg m^{-3}), and a bottom 8 L core for the 3 levels of compaction (1.3, 1.5 and 1.7 Mg m^{-3}). The buckets had three drainage holes at the bottom, and were arranged on raised wooden platforms. Two different experiments were conducted with maize (*Zea mays* L.) and soybean (*Glycine max* L.) as test crops. Each experiment was a 3×4 factorial arranged in a Completely Randomized Design (CRD) with three replications. The treatments were soil at three compaction levels (i.e., bulk densities of 1.3, 1.5 and 1.7 Mg m^{-3}), and four levels of fertilizer amendments: control (no fertilizer), 100% poultry manure (applied at 15 g/pot), 100% 15:15:15 NPK fertilizer (applied at 2.89 g/pot) and ½ rate each of poultry manure and 15:15:15 NPK fertilizer (applied at 7.5 g poultry manure + 1.45 g 15:15:15 NPK/pot).

2.2 Soil compaction

The soil cores were packed at different bulk densities to give a two-layered core with the aid of a 2 kg metal block dropped from a height of 30 cm onto the soil surface overlaid with a wooden board. First, half of the required mass of air-dried soil was packed into the bottom 8 L volume of the bucket. This was followed by overlaying the soil with a wooden board, and dropping a metal mass of 2 kg 5, 7 and 9 times to obtain the 1.3, 1.5 and 1.7 Mg m^3 bulk densities, respectively as shown in Figure 1. The board was then removed and the rest of the soil was packed on top of the top half of the bucket. The soil was again covered with wooden board, the 2 kg metal mass was dropped 8, 10 and 12 times for the 1.3, 1.5 and 1.7

Mg m^{-3}, respectively. A 2 L soil core with a bulk density of 1.3 Mg m^{-3} was imposed over each of the bottom 8 L core using with two drops of the metal block. The mass of soil to attain the 1.3, 1.5 and 1.7 Mg m^{-3} bulk densities were 10.4, 12.0 and 13.6 kg, respectively.

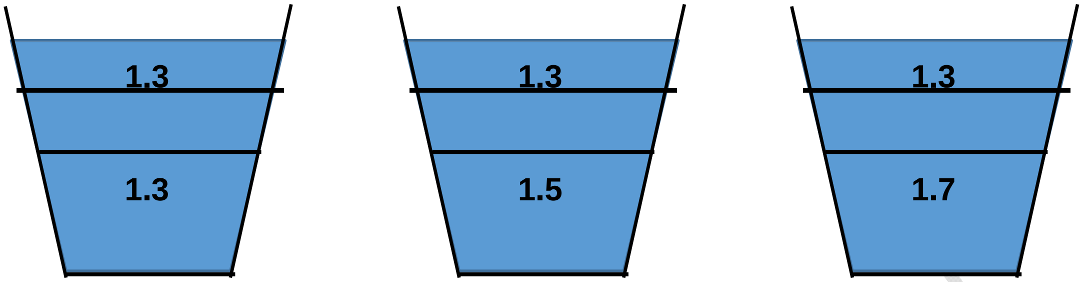

Figure 1. Preparation of buckets for the experiment

2.3 Planting

Three seeds were sown per soil core assembly (i.e., pot). This was thinned to two seedlings per pot after 7 days. The maize and soybean varieties used were “Obaatanpa” (an open pollinated variety) and “Anidaso”, respectively. Early on, germination test was conducted to determine seed viability of both crops. After sowing; water loss was estimated and compensated for by weighing every 2 days, and plants were watered using a watering can. Perforations were made at the bottom of each pot to facilitate drainage. The assemblies were then arranged on raised wooden platforms as shown in Plates 1 and 2.

Plate 1. Experimental layout of maize under the different treatments

Plate 2. Experimental layout of soybean under the different treatments

2.4 Application of soil amendments

Mineral fertilizer N equivalent of 0.42 g was used as the basis for the amount of poultry manure to apply. With an N content of 2.79 % in the poultry manure, this gave 15 g. The 15 g of poultry manure contained 2.79 % N, 0.95 % P and 3.46 % K, which supplied 0.42 g N, 0.32 g P_2O_5 and 0.62 g K_2O per pot. Thus, the following quantities of soil amendments were applied:

i. Control- no amendments
ii. 100 % NPK= 2.89 g 15:15:15 NPK fertilizer/pot
iii. 100 % NPK= 15 g Poultry manure/pot
iv. ½ Rate NPK + ½ Rate Poultry manure = 1.45 g 15:15:15 NPK + 7.5 g Poultry manure/pot

2.5 Data collection and analyses

2.5.1 Root growth

The roots in the soil cores were retrieved after washing off the soil over a nest sieves and weighing the cleaned roots. The fresh root mass was obtained after cutting the soil core into two, comprising a top layer of 1.3 Mg m^{-3} and the bottom layer of the compacted treatments. The total fresh root mass comprised the roots in the top soil core (designated non compacted 1.3 Mg m^{-3}), the bottom core of the compacted treatments (1.3, 1.5. and 1.7 Mg m^{-3}) and the roots that passed between the soil core and the bucket (i.e. roots along the soil core). The latter was obtained by scrapping the roots along the soil core with a knife. The dry mass was recorded by weighing after oven drying the sample at 60°C for 48 hours. The relative root mass distribution (%) at the uncompacted zone, compacted zone and along the soil column were determined by calculating the percentage in relation to the total root mass (uncompacted layer + compacted layer + along the soil column). In relation to the effective root biomass, only the roots at the uncompacted and compacted zones were considered.

Extruded soil columns of the various compaction levels showing the root growth patterns of maize are presented in Plate 3.

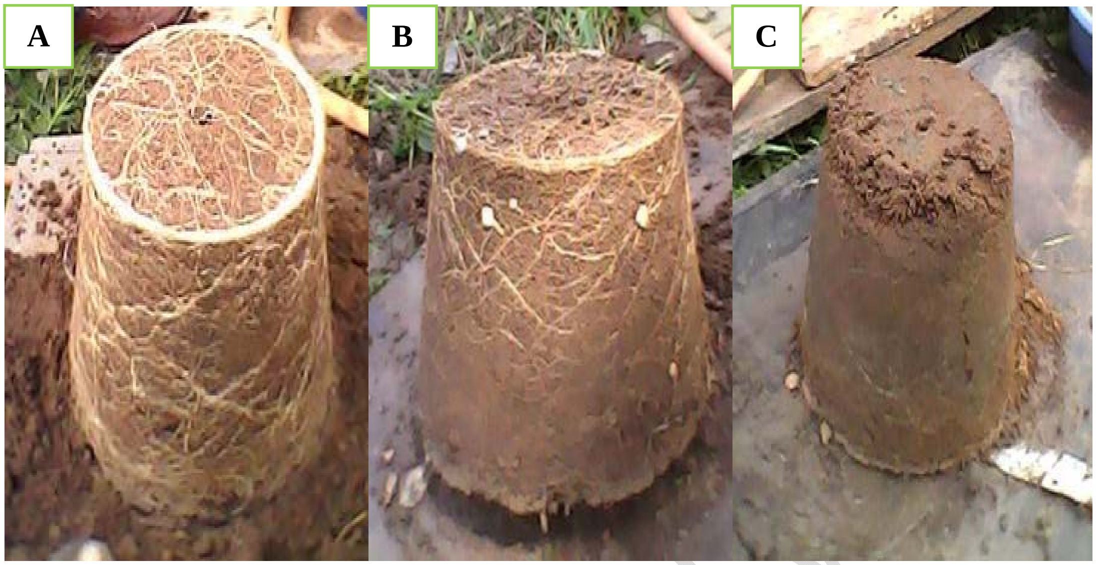

Plate 3. Inverted soil columns showing maize root growth at different soil bulk densities: A = 1.3 Mg m^{-3}; B = 1.5 Mg m^{-3}; C = 1.7 Mg m^{-3}

2.5.2 Root penetration ratio

Root penetration ratio (RPR) is defined as the number of roots that entered the compacted bottom core divided by the number of roots that exited the same core. The number of roots that entered the bottom core was obtained after using a sharp knife to separate the top layer of 1.3 Mg m^{-3} from the compacted bottom layer, staining the roots on top of the compacted layer with methylene blue and counting the roots with the aid of a hands lens. The compacted core was then turned upside down and the roots exiting the core counted after staining with methylene blue. For accuracy, the roots that passed between the compacted soil core from the top and the bucket were discarded. Only the roots that were found in the soil were counted and used for the calculation. The data collected were subjected to analysis of variance using GenStat statistical package (12th Edition). The Least significant difference (Lsd) at 5% was used to compare treatment means.

3. RESULTS AND DISCUSSION

3.1 Root distribution

The mean relative root biomass distribution of maize and soybean and how they were affected by soil compaction, are presented in Table 1. In maize, the relative root biomass distribution in the uncompacted soil layer ranged from 69.60 – 90.78% for the 1.3 and 1.7 Mg m^{-3}, respectively with a trend of 1.7 > 1.5 > 1.3 Mg m^{-3}. Increasing bulk density therefore resulted in more root biomass accumulation in the relatively loose top soil. The converse was true in the compacted soil cores with values between 9.22% for the 1.7 Mg m^{-3} and 30.40% for the 1.3 Mg m^{-3} in an order of 1.3 > 1.5 > 1.7 Mg m^{-3}. This implies less root accumulation in the compacted core as the bulk density of the compacted layer increased. These trends were similar for the soybean. The respective ranges of relative root biomass for the 1.3 and 1.7 Mg m^{-3} in the uncompacted and compacted soils were 69.59 – 90.77%, and 9.2 – 30.4%, respectively. The characteristic distribution of roots in compacted soil presented in this study has similarly been reported by [21, 22]. Chen and Weil [9] also observed greater root proliferation in the loose layer above the compacted layer for rapeseed and rye.

Table 1. Relative root mass of maize and soybean in the uncompacted and compacted soil layers

Bulk density (Mg m^{-3})	**Maize**		**Soybean**	
	Uncompacted layer	Compacted layer	Uncompacted layer	Compacted layer
1.3	69.60	30.40	69.59	30.41
1.5	72.36	2.71	72.40	27.60
1.7	90.78	9.22	90.77	9.22
Amendment (g/pot)				
Control	56.10	43.89	81.07	18.92
PM	58.57	41.42	74.25	25.74
NPK	68.17	31.82	78.88	21.11
½ PM + ½ NPK	62.75	37.24	76.81	23.18
Lsd (%)				
Bulk density	3.46	8.47	5.83	6.89
Amendment	3.21	1.76	1.88	1.32

Lsd = Least significant difference; PM = Poultry manure

This pattern of root biomass distribution is ascribed mainly to the magnitude of mechanical impedance in the soil. When soils are compacted, the bulk density is increased and the number of larger pores is reduced while smaller pores increase. In such situations, the forces of roots necessary for deformation and displacement of soil particles for root proliferation increase and readily become limiting with a consequent reduction in root growth. There is also a tendency of roots to grow horizontally/laterally in the uncompacted layer above the compacted soil core [1]. As shown in several studies [e.g. 1, 9, 21, 23], the observed greater root biomass in the uncompacted than compacted soil in this study could be the result of as a compensatory response to the increased mechanical impedance and reduced total porosity and aeration porosity associated with compaction of the soil core. The results further lend credence to the observation of Materechera et al. [24, 25] that monocot and dicot species respond differently to changes in soil with dicots being better in penetrating compacted soil than monocots. Thus, as indicated earlier, total effective root biomass was more sensitive in maize than soybean to increases in soil compaction with the reduction in the effective root biomass at 1.3 Mg m^{-3} being 50 and 59% at 1.5 and 1.7 Mg m^{-3}, respectively with the corresponding figures for soybean as 22 and 14%.

Effective root biomass of maize was also more responsive to soil amendments with the percentage increases over the control (no amendment) being 42, 43 and 62 under PM, ½ PM + ½ NPK and NPK, respectively. The corresponding values for soybean were 37, 38 and 53%. Besides these observations, the results revealed variable impacts of soil amendments on total effective root biomass (compacted + uncompacted root biomass) and their distribution in the compacted and uncompacted layers. While all the soil amendments increased effective root biomass at each level of soil compaction over the control (Table 2), variable impacts were recorded in the case of relative root biomass distribution. In maize, while relative root biomass in the uncompacted soil was increased over that of the control, it was reduced in the compacted soil. The increases were 4, 11 and 18% under PM, ½ PM + ½ NPK and NPK, respectively, with corresponding reductions of 6, 15 and 27%. Implicitly, the decrease in the relative root biomass in the compacted soil core was compensated for by the increased fibrous roots in the uncompacted layer. In the case of soybean, although the relative root biomass accumulation in the uncompacted soil was relatively greater than that of maize, the application of soil amendments tended to slightly decrease the relative root biomass over that of the control. The percentage reduction was 3, 5 and 8% under NPK, ½ PM + ½ NPK and PM, respectively. The corresponding increases in the compacted core were 10, 18 and 27%. The variable characteristic distribution of different rooting systems (fibrous and tap root for maize and soybean) in the soil profile and their response to soil compaction, nutrient and water uptake could have accounted for the observed differences in the relative root biomass distribution in the compacted and uncompacted soil. In the presence of only one compacted layer, as may occur under conventional tillage and simulated in this study, a reduction in root growth in the compacted zone is often compensated for by higher growth rates in loose soil above or below the compacted zone [21]. Detailed examination of the relative root distribution (Table 1) under the various soil amendments showed that in the uncompacted top layer, roots were greater under NPK than poultry manure for Maize. Hence, potential nutrient and water uptake for metabolic activities and stem elongation would be expected to be greater under NPK than PM as a result of the synchronization of nutrient release and uptake by the crop grown; integration of organic amendments with mineral fertilizers could thus serve as a substitute for mineral fertilizers, particularly, among small scale farmers [26]. Generally, the relative root distribution of soybean in the uncompacted top layer was greater than maize under all the treatments.

3.2 Root restriction

The results of the impact of soil compaction on the peripheral root distribution along the soil core are presented in Table 2 for both maize and soybean. The peripheral relative root biomass for maize ranged from 27.70 – 39.22% in the order of 1.7 < 1.3 < 1.5 Mg m^{-3}. The same trend was observed in soybean with the values ranging between 40.40 and 43.56%. The peripheral root distribution increased as bulk density increased from 1.3 Mg m^{-3} – 1.5 Mg m^{-3} and declined at 1.7 Mg m^{-3}. The peripheral root biomass was greater in soybean than in maize. The response of the soybean to soil compaction was to induce more root growth in the uncompacted soil and periphery of the soil core than the compacted zone. The same trend, nonetheless, was observed in maize, except that the magnitude was greater in soybean. With regard to the soil amendments, the peripheral relative root biomass for maize ranged from 28.96 – 42.72% in the increasing order of ½ PM + ½ NPK < NPK < PM < control and 34.24 – 49.60% in the NPK < ½ PM + ½ NPK < control < PM for both maize and soybean, respectively. In maize the highest peripheral relative root biomass was recorded by the control where no soil amendment was applied and the least value was recorded by ½ PM× ½ NPK (Table 2). This indicates the importance of soil amendments in enhancing the magnitude of effective roots. Also, the synergistic effect of both organic and inorganic amendment was evident as ½ PM + ½ NPK and performed better than the sole amendments. In soybean, the sole NPK amendment recorded the least value of the peripheral relative root distribution, this also indicates that most of the effective roots produced under the sole NPK penetrated both the compacted and the uncompacted layer.

Table 2. Relative root mass of maize and soybean as affected by soil compaction

Bulk density (Mg m^{-3})	**Maize**			**Soybean**		
	UL (%)	CL (%)	PSC. (%)	UL (%)	CL (%)	PSC (%)
1.3	43.94	24.21	31.84	39.46	17.24	43.33
1.5	37.84	22.94	39.22	40.89	15.59	43.56
1.7	42.91	29.32	27.70	54.08	5.50	40.40
Amendments (g/pot)						
Control	32.11	25.12	42.72	42.11	9.83	48.08
PM	38.34	27.12	34.52	56.22	19.49	49.60
NPK	47.36	22.11	30.52	35.93	9.62	34.24
½ PM + ½ NPK	44.57	26.45	28.96	45.10	13.61	41.32
[†]Interactions						
Control x 1.3	27.29	22.78	49.94	-	-	-
Control x 1.5	28.81	25.05	46.10	-	-	-
Control x 1.7	49.25	30.59	20.15	-	-	-
NPK x 1.3	50.69	20.69	28.60	-	-	-
NPK x 1.5	44.41	20.23	35.21	-	-	-
NPK x 1.7	41.97	29.82	28.92	-	-	-
PM x 1.3	42.77	26.57	30.64	-	-	-
PM x 1.5	28.86	24.29	47.23	-	-	-
PM x 1.7	39.28	33.47	27.23	-	-	-
½ PM + ½ NPK x 1.3	44.62	28.18	27.18	-	-	-
½ PM + ½ NPK x 1.5	45.92	23.77	30.29	-	-	-
½ PM + ½ NPK x 1.7	43.05	24.39	39.98	-	-	-
Lsd (5%)						
Bulk density	3.21	2.14	2.46	3.02	1.78	1.11
Amendments	2.37	2.22	2.53	3.41	4.35	2.41
[†]Interactions	3.11	2.71	2.65	ns	ns	ns

[†]Amendment x Bulk density interactions; BD = Bulk density; PM = Poultry manure; UL = Uncompacted layer; CL = Compacted layer; PSC. = periphery of soil core

The compaction x soil amendment interaction in maize (Table 2) revealed a tendency of the soil amendments (except ½ PM + ½ NPK fertilizer) to decrease peripheral root growth at 1.3 and 1.5 Mg m^{-3} and an increase at 1.7 Mg m^{-3}. The ½ PM + ½ NPK fertilizer increased the peripheral root biomass of maize as soil compaction levels increased. Implicitly, the values of the peripheral root biomass represent the proportion of the total root mass presenting ineffective root surfaces for nutrient and water uptake which obviously would constrain shoot growth and biomass yield. These confounding impacts are often neglected in most pot experiments, yet they are important in the interpretation of results and potential extrapolation to field conditions. An additional observation in this study was the accumulation of loose roots at the base of the soil core, apparently originating from the peripheral root growth. These are indicative of root volume restriction ("bonsai" effect) which tends to inhibit shoot growth caused by limited nutrients and water supply to the shoots with the magnitude of reduction in root and shoot dry matter increasing with decreasing pot size. However, in pot experiments, as in this study, the growth is through the unrestrictive path encounter of roots with impeding soil compacted layers results not only in the restrictive root growth and oxygen supply, but induced counter root responses. Apart from growing and spreading horizontally in the loose soil above the compacted zone which deprives them of the full use of moisture and nutrients in the deeper layer, roots tend to follow tortuous paths in search of least resistant paths [11 ,27]. In the field, growth is through available larger interaggregate and biopores greater than root diameter [14].

3.3 Root penetration ratio

The results of the impact of soil compaction and soil amendments and their interactions are presented in Table 3. The effect of soil compaction showed a general decrease in root penetration ratio (RPR) with increasing bulk density. At a base of 0.33, RPR of maize was reduced by 12% at 1.5 Mg m^{-3} and 9% at 1.7 Mg m^{-3}. With values ranging from 0.29 to 0.33, the differences were not significant (*P* = .05). In the case of soybean RPR varied from 0.14 to 0.31 for the 1.7 and 1.3 Mg m^{-3}, respectively. While there was no significant difference in the values at 1.3 and 1.5 Mg m^{-3}, values for the latter were significantly greater than those for 1.7 Mg m^{-3}. The percentage reduction in RPR at 1.7 Mg m^{-3} was 13 and 55% compared to those at 1.5 and 1.3 Mg m^{-3}, respectively. These results indicated that the impact of soil compaction on root proliferation was more severe on soybean than maize.

Table 3. Root penetration ratio of maize and soybean in the different soil layers

Bulk density (Mg m^{-3})	**Penetration ratio**	
	Maize	Soybean
1.3	0.33	0.31
1.5	0.29	0.27
1.7	0.30	0.14
Amendments (g/pot)		
Control	0.22	0.14
Poultry manure	0.30	0.26
NPK fertilizer	0.39	0.28
½ Poultry Manure + ½ NPK Fertilizer	0.31	0.28
†Interactions		
Control x 1.3	0.27	-
Control x 1.5	0.23	-
Control x 1.7	0.15	-
NPK Fertilizer x 1.3	0.33	-
NPK Fertilizer x 1.5	0.42	-
NPK Fertilizer x 1.7	0.33	-
PM x 1.3	0.30	-
PM x 1.5	0.20	-
PM x 1.7	0.40	-
½ PM + ½ NPK fertilizer x 1.3	0.33	-
½ PM + ½ NPK fertilizer x 1.5	0.30	-
½ PM + ½ NPK fertilizer x 1.7	0.30	-
Lsd (5%)		
Bulk density	0.06	0.06
Amendments	0.07	0.07
†Interactions	0.13	ns

Lsd = Least significant difference; †Amendment x Bulk density interactions

One of the most important factors which affects roots penetration is soil bulk density [28]. High bulk densities adversely affects roots elongation and proliferation within a soil profile [27]. At the higher bulk density, 1.7 Mg m^{-3}, the soil became so dense that root penetration through the compacted zone was impeded. Thus, fewer roots were able to exit the compacted soil core. This is not surprising since in sandy loams, as was used in this experiment, bulk densities in the range of 1.6 and 1.8 Mg m^{-3} restrict root penetration [29]. According to NRC [30], when the bulk density of soil increase to a critical level, root penetration is restricted and root growth is reduced. Beyond the critical level, roots are unable to penetrate the soil and root growth is prevented. These changes affect the productivity of the plant and can lead to lower yield and/or higher cost of production. At the bulk density of 1.7 Mg m^{-3}, the roots of maize and soybean were stunted and drought stressed. Limited root penetration on compacted soil have been found to aggravate the effects of drought in reducing soybean yield [31]. According to Marschner [21], for a given soil bulk density, the mechanical impedance increases as the soil dries. This is due to increased particle mobility indicating an increase in the forces required to displace and deform soil particles, and resultant suppression of root elongation. This, in turn, could restrict water and nutrient uptake and poor plant growth and yield.

The impact of soil amendments was an increase in RPR over the control. The adverse impact of soil compaction was therefore ameliorated by the application of soil amendments. In the case of maize, RPR ranged from 0.22 to 0.39 with a decreasing trend of NPK > ½ PM + ½ NPK > PM > control. NPK recorded significantly (*P* = .05) greater RPR than all other amendments and the Control with a percentage increase over the latter being 46%. The RPR of the PM and ½ PM+ ½ NPK were also significantly (*P* = .05) greater than the control with increment in the range of 27-29%. In soybean, RPR varied between 0.14 and 0.28 in the order of NPK = ½ PM + ½ NPK > PM > control. However, the RPR of all the amendments did not differ significantly (*P* > .05) from each other but were significantly greater than the Control with an increment of 46 – 50%. The compaction x amendments interaction significantly (*P* = .05) influenced RPR of maize but not soybean. At each level of compaction, each of the soil amendments improved RPR but more so by NPK. The addition of soil amendments provided readily available nutrients to the roots thereby improving root growth and vigour for enhanced penetration of the compacted soil. Under such conditions, uptake of water and nutrients is also improved for the benefit of shoot growth and biomass yield.

4. CONCLUSION

Increasing soil compaction resulted in the accumulation of most of the root biomass in the uncompacted soil above the compacted layer. The addition of soil amendments increased the relative root biomass of maize in the uncompacted soil while that in the compacted soil where reduced. In the case of soybean, although the relative root biomass accumulated in the uncompacted soil was relatively greater than that of maize, the application of soil amendments tended to slightly decrease the relative root biomass over that of the control. High soil compaction induced more root growth in the uncompacted soil and the periphery of the soil core than the compacted zone. The peripheral relative root biomass was greater in soybean than in maize according to the trend, with highest production in the 1.3 Mg m^{-3} soil layer. Application of soil amendments reduced the peripheral relative root biomass of both crops. In maize, the least peripheral relative root biomass was recorded by the ½ PM × ½ NPK while the sole NPK amendment recorded the least peripheral relative root distribution in soybean. The results showed soil compaction and amendments, as well as their interaction, to distinctly influence the roots distribution of maize and soybean. The impact of increasing soil compaction on both crops was manifested in a greater accumulation of root biomass in the top uncompacted soil than the compacted soil cores.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in group effort by all authors. Authors CQ, SIB, AA, and HOT designed the study and wrote the protocol. Authors SIB, AA, HOT, CQ and CM conducted the study, generated and analyzed the data. Authors SIB, AA, HOT and CQ prepared the manuscript. Authors SIB, AAA, HOT and CM managed the literature searches. All authors reviewed the pre-submission draft, read and approved the final manuscript.