## _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**

8 **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). High soil compaction induced more root growth in the uncompacted soil and periphery of the soil core than the compacted zone. 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.

9
10 _Keywords: Maize, NPK fertilizer, Poultry manure, Soil compaction, Soybean_
11
12 **1. INTRODUCTION**

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

24
25 The sensitivity of a given soil to compaction depends on the soil properties, mostly on
26 texture, structure [4], moisture content and clay mineralogy. Accordingly, Défossez et al.
27 [5] reported that the most important factor in making decisions about cultural operations is
28 soil water due to its influence on soil compaction. Soil compaction may result from natural,
29 as well as, human and animal induced processes. For instance, treading of wet soils by
30 animals causes soil compaction [2, 6]; Human activities such as the use of agricultural
31 machinery also induce compaction [7, 8]. The most yield limiting soil compaction is caused

32  by wheels from heavy equipment, particularly on wet soils [1]. Tillage induced compaction
33  layer is mostly referred to as hardpan or plough pan and occurs just below the plough
34  depth [3]. Soil compaction, especially in the subsoil layers may restrict deep root growth
35  and plant access to subsoil water in the mid to late growing season when rainfall is usually
36  sparse and evapotranspiration is high [3, 9]. Muhammad et al. [10] reported that the
37  adverse effect of soil compaction on water flow and storage may be more serious than its
38  direct effect on root growth. Root response to soil compaction depends on the presence
39  and distribution patterns of pores having a diameter greater than the roots and on pore
40  continuity; a soil matrix with larger pores are essential for optimal crop yields [11]. Soil
41  compaction restricts root growth resulting in poor anchorage and susceptibility of plants to
42  uprooting during grazing [12].
43
44  Amelioration of soil compaction can be achieved through biological drilling in which root
45  channels left by previous crops reduce the effects of subsoil compaction on subsequent crop
46  root growth [9, 13, 14], no-tillage practice, [15], subsoiling [3, 12, 16, 17], cultivar
47  improvement [18], and soil amendments [19]. These strategies have resulted in increased
48  crop yields, although uncertainties regarding their application still remain. Addition of soil
49  amendments increases the competitive advantage of the crop for nutrient uptake. This
50  provides crops with the needed nutrients necessary for their growth and development, and
51  reduces the limitations posed to root growth by compaction. The present study was thus,
52  conducted to ass the effects of soil compaction and fertilization on the root growth and
53  distribution of maize and soybean. The two crops were selected based on the fact that
54  maize is the largest staple crop, while soybean is an emerging major crop in Ghana.
55  Additionally, dicots (soybean) and monocots (maize) respond differently to the impact of soil
56  compaction, hence the need and there is the need to investigate this phenomenon in
57  Ghanaian soils.
58
59  **2. MATERIALS AND METHODS**

60  **2.1 Experimental set up and design**

61  The study was conducted at the Department of Horticulture, Kwame Nkrumah University of
62  Science and Technology (KNUST), Kumasi. The set up comprised two pot (12 L buckets)
63  experiments with soil samples classified as Orthi-Ferric Acrisol [20] grown with maize and
64  soybean. Each experiment was conducted with 36 buckets for maize and soybean. Each
65  bucket was graduated at 2 L interval and had a surface area of 0.07 m$^2$. Each bucket
66  assembly consisted of a top 2 L space for watering, followed by a 2 L soil core (1.3 Mg m$^{-3}$),
67  and a bottom 8 L core for the 3 levels of compaction (1.3, 1.5 and 1.7 Mg m$^{-3}$). The buckets
68  had three drainage holes at the bottom, and were arranged on raised wooden platforms.
69  Two different experiments were conducted with maize (*Zea mays* L.) and soybean (*Glycine*
70  *max* L.) as test crops. Each experiment was a 3×4 factorial arranged in a Completely
71  Randomized Design (CRD) with three replications. The treatments were soil at three
72  compaction levels (i.e., bulk densities of 1.3, 1.5 and 1.7 Mg m$^{-3}$), and four levels of fertilizer
73  amendments: control (no fertilizer), 100% poultry manure (applied at 15 g/pot), 100%
74  15:15:15 NPK fertilizer (applied at 2.89 g/pot) and ½ rate each of poultry manure and
75  15:15:15 NPK fertilizer (applied at 7.5 g poultry manure + 1.45 g 15:15:15 NPK/pot).
76
77  **2.2 Soil compaction**

78  The soil cores were packed at different bulk densities to give a two-layered core with the aid
79  of a 2 kg metal block dropped from a height of 30 cm onto the soil surface overlaid with a
80  wooden board. First, half of the required mass of air-dried soil was packed into the bottom 8
81  L volume of the bucket. This was followed by overlaying the soil with a wooden board, and
82  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
83  densities, respectively. The board was then removed and the rest of the soil was packed on
84  top of the top half of the bucket. The soil was again covered with wooden board, the 2 kg

85  metal mass was dropped 8, 10 and 12 times for the 1.3, 1.5 and 1.7 Mg m$^{-3}$, respectively. A
86  2 L soil core with a bulk density of 1.3 Mg m$^{-3}$ was imposed over each of the bottom 8 L core
87  using with two drops of the metal block. The mass of soil to attain the 1.3, 1.5 and 1.7 Mg m$^{-}$
88  $^{3}$ bulk densities were 10.4, 12.0 and 13.6 kg, respectively.
89
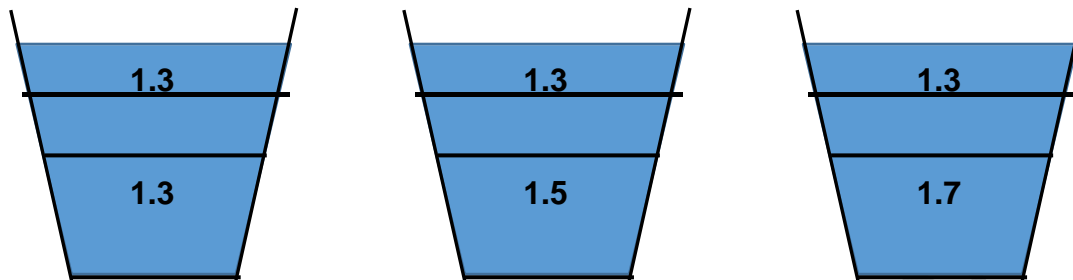


91  **Figure 1.** Preparation of buckets for the experiment

93  **2.3 Planting**

94  Three seeds were sown per soil core assembly (i.e., pot). This was thinned to two seedlings
95  per pot after 7 days. The maize and soybean varieties used were "Obaatanpa" (an open
96  pollinated variety) and "Anidaso", respectively. Early on, germination test was conducted to
97  determine seed viability of both crops. After sowing; water loss was estimated and
98  compensated for by weighing every 2 days, and plants were watered using a watering can.
99  Perforations were made at the bottom of each pot to facilitate drainage. The assemblies
100  were then arranged on raised wooden platforms.
101



103  **Plate 1.** Experimental layout of maize under the different treatments

106



**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.

4

135



136

137  **Plate 3.** Inverted soil columns showing maize root growth at different soil bulk densities: A =
138  1.3 Mg m$^{-3}$; B = 1.5 Mg m$^{-3}$; C = 1.7 Mg m$^{-3}$

139
140  **2.5.2 Root penetration ratio**

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

152
153  **3. RESULTS AND DISCUSSION** **The differences between roots in the soil compaction**
154  **of corn and soybean plants also have an effect due to the root structure of eaves**
155  **and pile. The root of soybean were affect  by given fertilizers. Because the**
156  **fertilizers affect the formation of nodozite. These situations should also be**
157  **expressed in discussions. It would be better. Congratulations, nice research**

158  **3.1 Root distribution**

159  The mean relative root biomass distribution of maize and soybean as affected by soil
160  compaction are presented in Table 1. In maize, the relative root biomass distribution in the
161  uncompacted soil layer ranged from 69.60 – 90.78% for the 1.3 and 1.7 Mg m$^{-3}$, respectively
162  with a trend of 1.7 > 1.5 > 1.3 Mg m$^{-3}$. Increasing bulk density therefore resulted in more root
163  biomass accumulation in the relatively loose top soil. The converse was true in the
164  compacted soil cores with values between 9.22% for the 1.7 Mg m$^{-3}$ and 30.40% for the 1.3
165  Mg m$^{-3}$ in an order of 1.3 > 1.5 > 1.7 Mg m$^{-3}$. This implies less root accumulation in the
166  compacted core as the bulk density of the compacted layer increased. These trends were
167  similar for the soybean. The respective range of relative root biomass for the 1.3 and 1.7 Mg
168  m$^{-3}$ in the uncompacted and compacted soil was 69.59 – 90.77%, and 9.2 – 30.4%. The
169  characteristic distribution of roots in compacted soil presented in this study has similarly

170 been reported by [21, 22]. Chen and Weil [9] also observed greater root proliferation in the
171 loose layer above the compacted layer for rapeseed and rye.

172
173
174 **Table 1.** Relative root mass of maize and soybean in the uncompacted and compacted soil
175 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 |

176 Lsd = Least significant difference; PM = Poultry manure
177
178 This pattern of root biomass distribution is ascribed mainly to the magnitude of mechanical
179 impedance in the soil. When soils are compacted, the bulk density is increased and the
180 number of larger pores is reduced while smaller pores increase. In such situations, the
181 forces of roots necessary for deformation and displacement of soil particles for root
182 proliferation increase and readily become limiting with a consequent reduction in root
183 growth. There is also a tendency of roots to grow horizontally/laterally in the uncompacted
184 layer above the compacted soil core [1]. As shown in several studies [e.g. 1, 9, 21, 23], the
185 observed greater root biomass in the uncompacted than compacted soil in this study could
186 be the result of as a compensatory response to the increased mechanical impedance and
187 reduced total porosity and aeration porosity associated with compaction of the soil core. The
188 results further lend credence to the observation of Materechera et al. [24, 25] that monocot
189 and dicot species respond differently to changes in soil with dicots being better in
190 penetrating compacted soil than monocots. Thus, as indicated earlier, total effective root
191 biomass was more sensitive in maize than soybean to increases in soil compaction with the
192 reduction in the effective root biomass at 1.3 Mg m$^{-3}$ being 50 and 59% at 1.5 and 1.7 Mg m$^{-3}$,
193 respectively with the corresponding figures for soybean as 22 and 14%.
194
195 Effective root biomass of maize was also more responsive to soil amendments with the
196 percentage increases over the control (no amendment) being 42, 43 and 62 under PM, ½
197 PM + ½ NPK and NPK, respectively. The corresponding values for soybean were 37, 38 and
198 53%. Besides these observations, the results revealed variable impacts of soil amendments
199 on total effective root biomass (compacted + uncompacted root biomass) and their
200 distribution in the compacted and uncompacted layers. While all the soil amendments
201 increased effective root biomass at each level of soil compaction over the control (Table 2),
202 variable impacts were recorded in the case of relative root biomass distribution. In maize,
203 while relative root biomass in the uncompacted soil was increased over that of the control, it
204 was reduced in the compacted soil. The increases were 4, 11 and 18% under PM, ½ PM +
205 ½ NPK and NPK, respectively, with corresponding reductions of 6, 15 and 27%. Implicitly,
206 the decrease in the relative root biomass in the compacted soil core was compensated for

207    by the increased fibrous roots in the uncompacted layer. In the case of soybean, although
208    the relative root biomass accumulation in the uncompacted soil was relatively greater than
209    that of maize, the application of soil amendments tended to slightly decrease the relative
210    root biomass over that of the control. The percentage reduction was 3, 5 and 8% under
211    NPK, ½ PM + ½ NPK and PM respectively. The corresponding increases in the compacted
212    core were 10, 18 and 27%. The variable characteristic distribution of different rooting
213    systems (fibrous and tap root for maize and soybean) in the soil profile and their response to
214    soil compaction, nutrient and water uptake could have accounted for the observed
215    differences in the relative root biomass distribution in the compacted and uncompacted soil.
216    In the presence of only one compacted layer, as may occur under conventional tillage and
217    simulated in this study, a reduction in root growth in the compacted zone is often
218    compensated for by higher growth rates in loose soil above or below the compacted zone
219    [21]. Detailed examination of the relative root distribution (Table 1) under the various soil
220    amendments showed that in the uncompacted top layer, roots were greater under NPK than
221    poultry manure for Maize. Thus, potential nutrient and water uptake for metabolic activities
222    and stem elongation would be expected to be greater under NPK than PM. Generally, the
223    relative root distribution of soybean in the uncompacted top layer was greater than maize
224    under all the treatments.
225
226    **3.2 Root restriction**

227    The results of the impact of soil compaction on the peripheral root distribution along the soil
228    core are presented in Table 2 for both maize and soybean. The peripheral relative root
229    biomass for maize ranged from 27.70 – 39.22% in the order of 1.7 < 1.3 < 1.5 Mg m$^{-3}$. The
230    same trend was observed in soybean with the values ranging between 40.40 and 43.56%.
231    The peripheral root distribution increased as bulk density increased from 1.3 Mg m$^{-3}$ – 1.5
232    Mg m$^{-3}$ and declined at 1.7 Mg m$^{-3}$. The peripheral root biomass was greater in soybean
233    than in maize. The response of the soybean to soil compaction was to induce more root
234    growth in the uncompacted soil and periphery of the soil core than the compacted zone. The
235    same trend, nonetheless, was observed in maize, except that the magnitude was greater in
236    soybean. With regard to the soil amendments, the peripheral relative root biomass for maize
237    ranged from 28.96 to 42.72% in the increasing order of ½ PM + ½ NPK < NPK < PM <
238    control and 34.24 to 49.60% in the NPK < ½ PM + ½ NPK < control < PM for both maize
239    and soybean, respectively. In maize the highest peripheral relative root biomass was
240    recorded by the control where no soil amendment was applied and the least value was
241    recorded by ½ PM× ½ NPK (Table 2). This indicates the importance of soil amendments in
242    enhancing the magnitude of effective roots. Also, the synergistic effect of both organic and
243    inorganic amendment was evident as ½ PM + ½ NPK performed better than the sole
244    amendments. In soybean, the sole NPK amendment recorded the least value of the
245    peripheral relative root distribution, this also indicates that most of the effective roots
246    produced under the sole NPK penetrated both the compacted and the uncompacted layer.
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261

262
263
264
265
266
267 **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 |

268 $^{†}$Amendment x Bulk density interactions; BD = Bulk density; PM = Poultry manure; UL =
269 Uncompacted layer; CL = Compacted layer; PSC. = periphery of soil core
270
271 The compaction x soil amendment interaction in maize (Table 2) revealed a tendency of the
272 soil amendments (except ½ PM + ½ NPK fertilizer) to decrease peripheral root growth at 1.3
273 and 1.5 Mg m$^{-3}$ and an increase at 1.7 Mg m$^{-3}$. The ½ PM + ½ NPK fertilizer increased the
274 peripheral root biomass of maize as soil compaction levels increased. Implicitly, the values
275 of the peripheral root biomass represent the proportion of the total root mass presenting
276 ineffective root surfaces for nutrient and water uptake which obviously would constrain shoot
277 growth and biomass yield. These confounding impacts are often neglected in most pot
278 experiments, yet they are important in the interpretation of results and potential extrapolation
279 to field conditions. An additional observation in this study was the accumulation of loose
280 roots at the base of the soil core, apparently originating from the peripheral root growth.
281 These are indicative of root volume restriction ("bonsai" effect) which tends to inhibit shoot
282 growth caused by limited nutrients and water supply to the shoots with the magnitude of
283 reduction in root and shoot dry matter increasing with decreasing pot size. However, in pot

284 experiments, as in this study, the growth is through the unrestrictive path encounter of roots
285 with impeding soil compacted layers results not only in the restrictive root growth and
286 oxygen supply, but induced counter root responses. Apart from growing and spreading
287 horizontally in the loose soil above the compacted zone which deprives them of the full use
288 of moisture and nutrients in the deeper layer, roots tend to follow tortuous paths in search of
289 least resistant paths [11 ,26]. In the field, growth is through available larger interaggregate
290 and biopores greater than root diameter [14].
291
292 **3.3 Root penetration ratio**

293 The results of the impact of soil compaction and soil amendments and their interactions are
294 presented in Table 3. The effect of soil compaction showed a general decrease in root
295 penetration ratio (RPR) with increasing bulk density. At a base of 0.33, RPR of maize was
296 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,
297 the differences were not significant ($P$ = .05). In the case of soybean RPR varied from 0.14
298 to 0.31 for the 1.7 and 1.3 Mg m$^{-3}$, respectively. While there was no significant difference in
299 the values at 1.3 and 1.5 Mg m$^{-3}$, values for the latter were significantly greater than those
300 for 1.7 Mg m$^{-3}$. The percentage reduction in RPR at 1.7 Mg m$^{-3}$ was 13 and 55% compared
301 to those at 1.5 and 1.3 Mg m$^{-3}$, respectively. These results indicated that the impact of soil
302 compaction on root proliferation was more severe on soybean than maize.
303
304 **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 |

305     Lsd = Least significant difference; [†]Amendment x Bulk density interactions
306

307     One of the most important factors which affects roots penetration is soil bulk density [27].
308     High bulk densities adversely affects roots elongation and proliferation within a soil profile
309     [26]. At the higher bulk density, 1.7 Mg m$^{-3}$, the soil became so dense that root penetration
310     through the compacted zone was impeded. Thus, fewer roots were able to exit the
311     compacted soil core. This is not surprising since in sandy loams, as was used in this
312     experiment, bulk densities in the range of 1.6 and 1.8 Mg m$^{-3}$ restrict root penetration [28].
313     According to NRC [29], when the bulk density of soil increase to a critical level, root
314     penetration is restricted and root growth is reduced. Beyond the critical level, roots are
315     unable to penetrate the soil and root growth is prevented. These changes affect the
316     productivity of the plant and can lead to lower yield and/or higher cost of production. At the
317     bulk density of 1.7 Mg m$^{-3}$, the maize and soybean were stunted and drought stressed.
318     Limited root penetration on compacted soil have been found to aggravate the effects of
319     drought in reducing soybean yield [30]. According to Marschner [21], for a given soil bulk
320     density, the mechanical impedance increases as the soil dries. This is due to increased
321     particle mobility indicating an increase in the forces required to displace and deform soil
322     particles, and resultant suppression of root elongation. This, in turn, could restrict water and
323     nutrient uptake and poor plant growth and yield.
324

325     The impact of soil amendments was an increase in RPR over the control. The adverse
326     impact of soil compaction was therefore ameliorated by the application of soil amendments.
327     In the case of maize, RPR ranged from 0.22 to 0.39 with a decreasing trend of NPK > ½ PM
328     + ½ NPK > PM > control. NPK recorded significantly ($P$ = .05) greater RPR than all other
329     amendments and the Control with a percentage increase over the latter being 46%. The
330     RPR of the PM and ½ PM+ ½ NPK were also significantly ($P$ = .05) greater than the control
331     with increment in the range of 27-29%. In soybean, RPR varied between 0.14 and 0.28 in
332     the order of NPK = ½ PM + ½ NPK > PM > control. However, the RPR of all the
333     amendments did not differ significantly ($P$ > .05) from each other but were significantly
334     greater than the Control with an increment of 46-50%. The compaction x amendments
335     interaction significantly ($P$ = .05) influenced RPR of maize but not soybean. At each level of
336     compaction, each of the soil amendments improved RPR but more so by NPK. The addition
337     of soil amendments provided readily available nutrients to the roots thereby improving root
338     growth and vigour for enhanced penetration of the compacted soil. Under such conditions,
339     uptake of water and nutrients is also improved for the benefit of shoot growth and biomass
340     yield.
341

342     **4. CONCLUSION**

343     Increasing soil compaction resulted in the accumulation of most of the root biomass in the
344     uncompacted soil above the compacted layer. The addition of soil amendments increased
345     the relative root biomass of maize in the uncompacted soil while that in the compacted soil
346     where reduced. In the case of soybean, although the relative root biomass accumulated in
347     the uncompacted soil was relatively greater than that of maize, the application of soil
348     amendments tended to slightly decrease the relative root biomass over that of the control.
349     High soil compaction induced more root growth in the uncompacted soil and the periphery of
350     the soil core than the compacted zone. The peripheral relative root biomass was greater in
351     soybean than in maize according to the trend, with highest production in the 1.3 Mg m$^{-3}$ soil
352     layer. Application of soil amendments reduced the peripheral relative root biomass of both
353     crops. In maize, the least peripheral relative root biomass was recorded by the ½ PM x ½
354     NPK while the sole NPK amendment recorded the least peripheral relative root distribution
355     in soybean. The results showed soil compaction and amendments, as well as their
356     interaction, to distinctly influence the roots distribution of maize and soybean. The impact of
357     increasing soil compaction on both crops was manifested in a greater accumulation of root
358     biomass in the top uncompacted soil than the compacted soil cores.
359

360  **REFERENCES**

361  [1]. Wolkowski R, Lowery B. Soil Compaction: Causes, Concerns, and Cures (A3367).
362       2008; 8p.
363  [2]. Drewry JJ, Littlejohn RP, Paton, RJ. A survey of soil physical properties on sheep and
364       dairy farms in Southern New Zealand. New Zealand J. Agric. Res., 2000; 43: 251-258.
365  [3]. McKenzie RH. Agricultural soil compaction: causes and management. Agri- facts.
366       Practical information for Alberta's Agriculture Industry. Agdex. 2010; 510-1. 10p.
367  [4]. Hakansson I, Lipiec J. A review of the usefulness of relative bulk density values in
368       studies of soil structure and compaction. Soil Till. Res. 2000; 53 (2): 71-85.
369  [5]. Défossez P, Richard G, Boizard H, O'Sullivan MF. Modelling change in soil compaction
370       due to agricultural traffic as function of soil water content. Geod. 2003; 116: 89-105.
371  [6]. Tuffour HO, Bonsu M, Khalid, AA. Assessment of soil degradation due to compaction
372       resulting from cattle grazing using infiltration parameters. Int. J. Sci. Res. Environ. Sci.
373       2014; 2(4): 139-149. http://dx.doi.org/10.12983/ijsres-2014-p0139-0149.
374  [7]. Hadas A. Soil compaction caused by high axle loads. Review of concepts and
375       experimental data. Soil Till. Res. 1994; 28 (2-3): 253-276.
376  [8]. Soane BD, Van Ouwerkerk C. Soil compaction: A global threat to sustainable land use.
377       Adv. GeoEcol. 1998; 31: 517-525.
378  [9]. Chen G, Weil RR. Root growth and yield of maize as affected by soil compaction and
379       cover crops. Soil Till. Res. 2009; 117 (2011) 17-27.
380  [10]. Muhammad R, Gul DK, Muhammad H, Shahid A. Impact of soil compaction on root
381        length and yield of corn (*Zea mays*) under irrigated Condition. Middle-East J. Sci. Res.
382        2012; 11 (3): 382-385.
383  [11]. Lampurlanes J, Cantero-Martinez C. Soil bulk density and penetration resistance under
384        different tillage and crop management systems and their relationship with barley root
385        growth. Agron. J. 2003; 95: 526-536.
386  [12]. Crush JR, Thom ER. Review: The effects of soil compaction on root penetration,
387        pasture growth and persistence. Pasture Persistence-Grassland Res. Practice Series.
388        2011; 15: 73-78.
389  [13]. Cresswell HP, Kirkegaard JA. Subsoil amelioration by plant roots – the process and
390        the evidence. Aust. J. Soil Res. 1995; 33, 221-239.
391  [14]. Williams SM, Weil RR. Crop cover root channels may alleviate soil compaction effects
392        on soybean crop. Soil Sci. Soc. Am. J. 2004; 68:1403-1409.
393  [15]. Kemper WD, Schneider NN, Sinclair TR. No-till can increase earthworm populations
394        and rooting depths. J. Soil Water Conserv. 2011; 66 (1): 13-17.
395  [16]. Burgess CP, Chapman R, Singleton PL, Thom ER. Effects of livestock treading and
396        mechanical loosening of soil. Proceedings of the New Zealand Soc. Soil Sci. Gisborne.
397        1998; pp. 99-100.
398  [17]. Raza W, Yousaf S, Niaz A, Rasheed MK, Hussain I. Subsoil compaction effects on soil
399        properties, nutrient uptake and yield of maize fodder (*Zea mays* L.). Pak. J. Bot. 2005;
400        37(2): 933-940.
401  [18]. Ghaderi A, Smucker AJM, Adams MW. Breeding implications of stress induced by soil
402        compaction. Auphytica. 1984; 33: 377-385.
403  [19]. Bowden CL. Effects of organic soil amendments on soil physiochemical and crop
404        physiological properties of field grown corn (*Zea mays* L.) and Soybean (*Glycine Max*
405        L.). Thesis submitted to the faculty of the Virginia Polytechnic Institute and State
406        University in partial fulfillment of the requirements for the Degree of Master of Science
407        in Crop and Soil Environmental Sciences. 2006; 12p.
408  [20]. FAO. Soil map of the world. Revised Legend. World Soil Research Report No 60. FAO
409        Rome. 1990.

410  [21]. Marschner H. Mineral nutrition of higher plants. Second edition, Academics Press.
411       Harcourt Brace and company (Publishers). 1995; 889p.
412  [22]. Lipiec J, Medvedve VV, Birkas M, Dunitru E, Lyndina TE, Russeva S, Eulasjar E. Effect
413       of soil compaction on root growth and crop yield in Central and Eastern Europe. Int.
414       Agrophys, 2003; 17: 61-69.
415  [23]. Houlbrooke DJ. Subsoiling and soil compaction effects on soil physical properties and
416       pasture response.  Unpublished MSc thesis, University of Waikato, 1996; 155 p.
417  [24]. Materechera S A, Dexter AR, Alston AM. Penetration of very strong soils by seedling
418       roots of different plant species. Plant Soil. 1991; 135:31-41.
419  [25]. Materechera SA, Alston AM, Kirby JM, Dexter AR. Field evaluation of laboratory
420       techniques for predicting the ability of roots to penetrate strong soil and of the influence
421       of roots on water sorptivity. Plant Soil. 1993; 149: 149-158.
422  [26]. Bengough AG, Mullins CE. Mechanical impedance to root growth: a review of
423       experimental techniques and root growth responses. J. Soil Sci. 1990; 41: 341-358.
424  [27]. Unger PW, Jones OR. Long-term tillage and cropping systems affect bulk density and
425       penetration resistance of soil cropped to dryland wheat and grain sorghum. Soil Till.
426       Res. 1998; 45:39-57.
427  [28]. Landon JR. Booker Tropical Soil Manual. A handbook for soil survey and agricultural
428       land evaluation in the tropics and subtropics. 1991; pp. 1-474.
429  [29]. NRC (National Research Council). Soil and water quality: An agenda for agriculture.
430       Washington, DC. 1993. National Academy Press (Publishers).
431  [30]. Buttery BR, Tan CS, Drury CF, Park SJ, Armstrong RJ, Park KY. The effects of soil
432       compaction, soil moisture and soil type on growth and nodulation of soybean and
433       common bean. Can. J. Plant Sci. 1998; 78:571-576.

## ACKNOWLEDGMENTS

## 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.