



Soil Compaction and Soil Amendments on the Growth and Biomass Yield of Maize (*Zea mays* L.) and Soybean (*Glycine max* L.)

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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.

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ABSTRACT

Two factorial pot experiments arranged in a Completely Randomised Design (CRD) with three replications were carried out to assess the impact of different levels of soil compaction and fertilizer amendments on root growth and biomass yield of maize (*Zea mays* L.) and soybean (*Glycine max* L.) plants. The treatments were different rates of bulk densities – 1.3, 1.5 and 1.7 Mg m⁻³ and fertilizer amendments comprising 100% poultry manure (applied at 15 g/plant), 100% 15:15:15 NPK fertilizer (applied at 2.89 g/plant) and 50% rate each of poultry manure and NPK fertilizer (applied at 7.5 g poultry manure + 1.45 g NPK/plant), and control (no fertilizer amendments). Soil compaction reduced the heights of maize and soybean plants. Increasing soil compaction resulted in the accumulation of most of the root biomass in the uncompacted soil above the compacted layer.

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Application of soil amendments increased the relative root biomass of maize plants in the uncompacted soil, while that in the compacted soil was reduced. In the case of soybean plants, although the relative root biomass in the uncompacted soil was relatively greater than that of maize plants, application of soil amendments tended to slightly decrease the relative root biomass to that of 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 plants over the control. The magnitude of response of the crops to the soil amendments was greater in soybean than in maize plants. Soil compaction and amendments significantly influenced root/shoot ratio of both crops. The root/shoot ratio decreased with increasing compaction from 1.3 to 1.5 Mg m⁻³, however, at 1.7 Mg m⁻³, the root/shoot ratio increased. The fertilizer amendments significantly influenced the root/shoot ratio of maize but not soybean plants. The fertilizer amendments increased the biomass of both roots and shoots, being higher in the former than in the latter. The fertilizer amendments x compaction interactions showed that the root/shoot ratio was influenced by the type of crop, and the confounding effects of factor interactions on the relative increases/decreases in shoot and root growth. Overall, soil compaction accounted for 52 to 100% of the variations in the magnitude of the measured parameters of maize plants, and 62 to 98% for soybean plants. The ideal bulk density for shoot biomass production of both crops should, therefore, be within the range of 1.3 – 1.5 Mg m⁻³. At soil bulk density of 1.5 Mg m⁻³ and above, soil amendment should be added to ameliorate the negative impact of soil compaction.

Keywords: Fodder; maize; poultry manure; root/shoot biomass ratio; soil compaction; soybean.

1. INTRODUCTION

The urgent need to feed the increasingly growing populations worldwide calls for farmer motivation, especially in Sub-Saharan Africa. In Ghana, for instance, farmers are provided with inputs such as machinery (mainly tractors), fertilizers and improved seeds. This is to ensure a paradigm shift from the use of simple farming tools such as the hoes and cutlasses to mechanized farming. This invariably shortens the time needed to cultivate the soil and subsequently solves the problems associated with inadequate farm labour. Although tractor mounted implements ensure efficiency on farms, indiscriminate use may cause physical degradation of the land with soil compaction being a major problem. Soil compaction caused by heavy machinery with high inflation pressure of the tires on wet soils happens mostly during soil tillage [1]. It results in reduced soil porosity, high soil bulk density and root penetration resistance [2 – 4]. These impede germination, seedling emergence, root and shoot growth and crop yield as a result of reduced soil fertility, aeration, hydraulic properties and, water and nutrient uptake [5 – 8]. It must, however, be emphasized that soil compaction in agricultural fields are not only attributed to tractor mounted implements. Grazing animals and other anthropogenic activities are also contributing factors. Texture, moisture, structure and initial bulk density are soil factors which affect plants' response to compaction [9].

Currently, considerable attention is being paid to soil physical properties which may possibly inhibit the growth and development of roots and seedlings of crops in the field. This is due to the fact that problems associated with soil compaction are becoming more severe as the use of bigger and heavier farm machinery is promoted. According to Oldeman et al. [10], about 18 million hectares of land in Africa has been degraded by compaction resulting in sealing and crusting of soil. Increasing the productivity of these lands will require the amelioration of soil compaction for prolific crop growth and yield. The study of root tolerance to soil compaction particularly under different soil amendments in the field where environmental conditions cannot be controlled is difficult, expensive and time consuming. Therefore, studies have been carried out in fairly controlled environments to facilitate the choice of interventions to adopt in order to deal with the problem of soil compaction. In the field, this approach is time consuming and very expensive. Controlled experiments in the laboratory, however, offer a good opportunity in the screening of crop genotypes for tolerance to soil compaction [11]. While much is known about the negative effects of soil compaction on the growth and yield of many crops, the impact of combined soil amendments and compaction caused by conventional tillage has not been extensively researched [12]. Furthermore, the use of soil amendments to reduce the adverse impact of soil

compaction on root growth has received less research attention. It is in the light of these research gaps that this study was carried out to contribute to the much needed information and knowledge on the impact of soil amendments in enhancing root growth and tolerance to soil compaction for sustained crop growth and yield.

2. MATERIALS AND METHODS

2.1 Experimental Set Up and Design

Two pot experiments were conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. Soil samples, classified as Orthi-Ferric Acrisol [13] were collected from a depth of 0 – 40 cm from the Plantations Section of the Department of Crop and Soil Sciences, KNUST. A total of 72 12 L volume plastic buckets were used for the experiments; 36 buckets each for maize and soybean plants. Each bucket was graduated at 2 L interval and had a surface area of 0.07 m². 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.

2.2 Soil Compaction

In order to obtain and replicate the desired bulk densities, it was necessary to standardize the method of packing of the soil into the bucket. The volume of the bucket was obtained from the litre graduations (2 L intervals). The soil cores were packed to the various bulk densities by dropping a 2 kg metal block from a height of 30 cm onto the soil surface which was completely overlaid by a wooden board. For the bulk densities of 1.3, 1.5 and 1.7 Mg m⁻³, half of the requisite air-dried soil was packed into the bottom 8 L volume of

the bucket, the wooden shield was placed on the soil surface, and the metal mass dropped 5, 7 and 9 times, respectively. The shield was then removed and the rest of the soil packed onto the first half using the wooden shelve and the metal mass and drops of 8, 10 and 12 times for the 1.3, 1.5 and 1.7 Mg m⁻³, respectively (Fig. 1). The 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 the shield and 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 was 10.4, 12.0 and 13.6 kg, respectively.

2.3 Preparation of Pots for Plants and Planting

Each layered pot comprised a top 2 L space for watering, a middle 2 L soil of 1.3 Mg m⁻³, and a bottom 8 L soil for the different compaction levels (i.e., 1.3, 1.5, and 1.7 Mg m⁻³) (Fig. 1). Germination test was conducted on the maize and the soybean to determine viability. Following that, three seeds were sown per pot, which was thinned to two seedlings per pot after 7 days. After sowing, water loss was estimated and compensated for by weighing every 2 days, and plants were watered using a watering can. The buckets had three drainage holes at the bottom to facilitate the removal of excess water, and arranged on raised wooden platforms (Plates 1 and 2).

The maize (*Zea mays* L.) and soybean (*Glycine max* L.) varieties used as test crops were “Obaatanpa” (an open pollinated variety) and “Anidaso”, respectively. 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% or sole

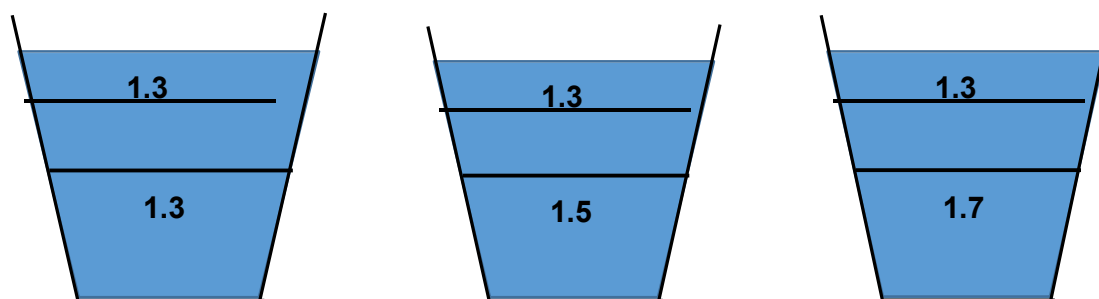


Fig. 1. Preparation of buckets for the experiment



Plate 1. Maize plants at 4 weeks after planting under different compaction levels



Plate 2. Soybean plants at 4 weeks after planting under different compaction levels

poultry manure (applied at 15 g/plant), 100% or sole 15:15:15 NPK fertilizer (applied at 2.89 g/plant) and 50% each of poultry manure and 15:15:15 NPK fertilizer (applied at 7.5 g poultry manure/plant + 1.45 g 15:15:15 NPK/plant). A summarized description of the physicochemical properties of the soil and manure is presented in Table 1.

2.4 Data Collection and Analyses

2.4.1 Shoot and root growth

A tape measure was used to measure plant heights at 2 weeks' intervals until harvesting of

biomass at 60 days after planting. Plant shoot samples were cut at the soil surface level, and the samples were oven-dried at 105°C for 30 minutes to destroy the tissues. They were later dried at 80°C until the weight was constant, and were weighed for the dry shoot mass. The fresh root mass was obtained after cutting the soil core into two, i.e., the 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 uncompacted 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

Table 1. Physicochemical properties of soil and poultry manure

Property	Soil	Poultry manure
Organic carbon (%)	1.20	33.92
Total N (%)	0.06	2.79
*P	10.25	0.95
K (%)	1.10	3.46
C/N ratio	20.00	12.16
pH (1:1 H ₂ O)	4.02	8.50
Ca (cmol/kg)	10.40	8.74
Mg (cmol/kg)	2.60	1.46
Na (cmol/kg)	0.80	2.03
Sand (%)	61.23	0.33
Silt (%)	27.64	-
Clay (%)	11.13	-
Texture	Sandy loam	-

*P = Available P in soil (mg/kg) and total P in manure (%)

was obtained by scrapping the roots along the peripheries of the soil core with a knife. The roots in the soil cores were retrieved after washing off the soil over a nest of sieves, and weighing the cleaned roots. The dry mass was recorded by weighing after oven drying the sample at 60°C for 48 hours.

2.4.2 Nutrient uptake

A sample of the oven dried shoot and root samples at 60°C for 48 hours were shredded, sub-sampled and milled into fine powder in a stainless steel puck mill. The milled plant materials were analysed for N, P and K contents by standard procedures.

2.4.3 Statistical analysis

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 Plant Height

The analysis of variance showed soil compaction and amendments to significantly ($P = .05$) influence the height of maize and soybean plants (Table 2). Plant height used as an indicator of growth of both crops, generally followed the normal growth curve of plants with time, increasing from 7 – 60 days after planting (DAP) at which time the study was terminated. The productivity of soil depends not only on its

physical properties but chemical and biological properties. This was corroborated by the results obtained from the application of mineral fertilizers and poultry manure, which significantly ($P = .05$) increased the height of both maize and soybean plants (Table 2). The interaction effect of soil compaction and fertilizer amendments ($P = .05$) was significant on the height of maize plants, but not soybean plants.

The mean height at harvest ranged from 76.83 – 124.92 cm under bulk densities of 1.7 and 1.3 Mg m⁻³, respectively. The corresponding values for soybean plants were 31.83 and 45.50 cm. In all cases the differences among the 3 levels of bulk density were significant ($P = .05$). A comparison of plant height at 1.3 Mg m⁻³ as base value, showed a progressive reduction of 20 and 38% for maize plants, and 15 and 30% for soybean plants at 1.5 and 1.7 Mg m⁻³, respectively. Between the bulk densities of 1.5 and 1.7 Mg m⁻³, plant height reduction was 23 and 18% for maize and soybean plants, respectively. Muhammad et al. [14] observed that plant height is a genetic characteristic which is modified by environmental factors at the active growth stages. The results from the present study have indicated that increasing soil compaction significantly ($P = .05$) reduced the height of maize and soybean plants, with the former being more sensitive than the latter to compaction. The reduction in plant height could be due to factors that limited cell elongation which include impedance to root growth, poor soil aeration and

Table 2. Impacts of soil compaction and fertilizer amendments on the plant height of maize and soybean plants

Bulk density (Mg m^{-3})	Plant height (cm)	
	Maize	Soybean
1.3	124.92	45.50
1.5	99.58	38.67
1.7	76.83	31.83
Lsd (5%)	4.05	1.74
Soil amendment (g/plant)		
Control	97.00	33.11
Sole PM	100.67	42.00
Sole NPK	105.33	38.11
50% PM + 50% NPK	98.78	41.44
Lsd (5%)	4.68	2.01
^T Interaction		
Control x 1.3	123.67	
Control x 1.5	90.33	
Control x 1.7	77.00	
Sole NPK x 1.3	132.00	
Sole NPK x 1.5	110.67	
Sole NPK x 1.7	73.33	
Sole PM x 1.3	122.67	
Sole PM x 1.5	100.67	
Sole PM x 1.7	78.67	
50% PM + 50% NPK x 1.3	121.33	
50% PM + 50% NPK x 1.5	96.67	
50% PM + 50% NPK x 1.7	78.33	
Lsd (5%)	8.10	

Lsd = Least significant difference; PM = Sole poultry manure; ^TSoil amendment x Bulk density interaction

low water and nutrient uptake as reported by Asady et al. [11] and Lowery and Schuler [15].

The height of maize plants (Table 2) followed the trend of sole NPK > sole PM > 50% PM + 50% NPK > control with a range of 97 – 105 cm; minimum and maximum values were recorded under control, and sole NPK, respectively. The differences between sole NPK, and both the control, and 50% PM + 50% NPK were significant, as well as, that between the control and PM. However, the height differences between PM and the half rates of both NPK and PM (i.e., integrated application), and NPK were not significant. The sole NPK produced the tallest plants in contrast to sole PM. The height of soybean plants was in the order of PM > 50% PM + 50% NPK > sole NPK > control with a range of 33.11 – 42.00 cm; minimum and maximum values were observed under the control and sole PM, respectively. Significant differences ($P = .05$) were observed between the control and all the soil amendments; and between sole PM and both sole NPK and the half rates of NPK and PM. The results as presented showed that soil fertility improvement through

mineral fertilizer and poultry manure application is essential for the growth of the test crops, and a better expression of their potential genetic heights. Under these conditions, more nutrients are made available for uptake for the needed metabolic activities for cell elongation and growth. Application of soil amendments to the different levels of compacted soils tended to enhance plant height relative to compacted soil without amendments. The plant heights of both crops at soil bulk densities of 1.3 and 1.5 Mg m^{-3} was highly ameliorated under sole NPK than sole PM and 50% PM + 50% NPK. However, at 1.7 Mg m^{-3} , the latter treatments were more effective than sole NPK. The beneficial effects of organic matter on soil physical properties, such as bulk density and porosity could be implicated in these observations.

3.2 Dry Shoot Biomass Yield

Soil compaction significantly ($P = .05$) influenced the shoot biomass of maize and soybean plants (Table 3). In the case of maize plants, shoot biomass ranked as 1.3 > 1.5 > 1.7 Mg m^{-3} with a range of 69.95 – 115 g/plant for the 1.7 and 1.3

Table 3. Impacts of soil compaction and fertilizer amendments on shoot biomass of maize and soybean plants

Bulk density (Mg m^{-3})	Shoot biomass (g/plant)	
	Maize	Soybean
1.3	115.72	69.84
1.5	92.62	57.70
1.7	69.95	32.66
Lsd (5%)	4.42	1.63
Soil amendment (g/plant)		
Control	78.43	35.56
Sole PM	109.05	67.91
Sole NPK	87.39	49.64
50% PM + 50% NPK	96.17	60.50
Lsd (5%)	5.11	1.89
[†] Interaction		
Control x 1.3	111.02	48.90
Control x 1.5	91.55	41.67
Control x 1.7	59.60	16.10
Sole NPK x 1.3	133.23	87.65
Sole NPK x 1.5	104.48	68.12
Sole NPK x 1.7	89.43	47.97
Sole PM x 1.3	92.87	64.42
Sole PM x 1.5	77.42	57.90
Sole PM x 1.7	65.00	26.59
50% PM + 50% NPK x 1.3	125.75	78.39
50% PM + 50% NPK x 1.5	97.02	63.13
50% PM + 50% NPK x 1.7	65.76	39.98
Lsd (5%)	8.85	3.27

Lsd = Least significant difference; PM = Sole poultry manure; [†] Soil amendment x Bulk density interactions

Table 4. Percentage increments in shoot biomass yield by soil amendments at each level of soil compaction

Soil amendment (g/plant)	1.3 Mg m^{-3}		1.5 Mg m^{-3}		1.7 Mg m^{-3}	
	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)
Control	-	-	-	-	-	-
Sole NPK	17	44	12	39	33	66
Sole PM	-	24	1	28	23	39
50% PM + 50% NPK	18	38	6	34	9	60

PM = Sole poultry manure

Mg m^{-3} , respectively. The difference among the treatments were significant ($P = .05$). All the soil amendments significantly increased the shoot biomass of maize and soybean plants over the control. Shoot biomass of maize plants ranged from 78.43 – 109.05 g/plant for the control and sole NPK, respectively with a trend of sole NPK > 50% PM+ 50% NPK > sole PM > control. In all cases, the differences among the treatments were significant ($P < .05$). The increases in shoot biomass over the control were 28, 18 and 10% under sole NPK, 50% PM+ 50% NPK, and sole PM, respectively. The shoot biomass of soybean plants followed the same trend as maize plants,

with yield ranging between 35.56 and 67.91 g/plant. Yield increments over the control were 48, 41 and 28% under sole NPK, 50% PM+ 50% NPK, and PM, respectively. The magnitude of response to soil amendments was greater in soybean plants than in maize plants. The soil compaction x amendments interactions significantly influenced shoot biomass yield of both maize and soybean plants. It revealed the magnitude of the soil amendments in increasing the biomass yield at each level of soil compaction. The depressive effect of soil compaction on shoot yield was therefore ameliorated by soil amendments.

Table 5. Impacts of soil compaction and fertilizer amendments on effective root biomass of maize and soybean plants

Bulk density (Mg m^{-3})	Effective root biomass (g/plant)	
	Maize	Soybean
1.3	67.87	10.49
1.5	33.98	8.17
1.7	27.64	9.05
Lsd (5%)	2.34	1.73
Soil amendment (g/plant)		
Control	24.34	5.83
Sole PM	49.10	13.82
Sole NPK	63.99	14.79
50% PM + 50% NPK	59.15	13.88
Lsd (5%)	2.41	1.68
†Interaction		
Control x 1.3	27.97	5.58
Control x 1.5	25.23	3.46
Control x 1.7	19.81	8.46
Sole NPK x 1.3	105.55	13.72
Sole NPK x 1.5	50.13	11.61
Sole NPK x 1.7	36.29	11.93
Sole PM x 1.3	74.73	11.25
Sole PM x 1.5	27.31	7.25
Sole PM x 1.7	23.67	9.40
50% PM + 50% NPK x 1.3	63.23	11.42
50% PM + 50% NPK x 1.5	33.24	10.35
50% PM + 50% NPK x 1.7	30.80	6.43
Lsd (5%)	5.88	3.47

Lsd = Least significant difference; PM = Sole poultry manure; †Soil amendment x Bulk density interaction

Shoot biomass therefore, decreased with increasing soil bulk density as reported in several studies [e.g. 15 – 17]. The reduction in shoot biomass of maize plants as bulk density increased from 1.3 – 1.5 Mg m^{-3} , and 1.7 Mg m^{-3} was 20 and 40%, respectively. Shoot biomass of soybean plants (Table 3) varied from 32.66 – 69.84 g/plant for the 1.7 and 1.3 Mg m^{-3} , respectively with significant differences ($P = .05$) among the treatments. The reduction in shoot biomass, using bulk density of 1.3 Mg m^{-3} as a base gave 17 and 57% at the 1.5 and 1.7 Mg m^{-3} , respectively. The adverse impact of soil compaction on shoot biomass in both soybean and maize plants was greatest at 1.7 Mg m^{-3} , being higher in the soybean plants. The response of shoot biomass of both maize and soybean plants to increasing bulk density appears to suggest that the optimum bulk density for shoot biomass production is 1.3 Mg m^{-3} , with a range between 1.3 and 1.5 Mg m^{-3} . The magnitude of response, however seem to be influenced by the stage of growth, as well as the fertility level of the soil. In this context, Ocloo [18] found the ideal range of bulk density for the growth of maize and soybean seedlings to be

within a range of 1.1 – 1.5 Mg m^{-3} , with 1.3 Mg m^{-3} as the most preferable in terms of shoot biomass yield and root penetration ratio. Beutler and Centurion [19], reported that soybean growth and yield started to decline beyond a bulk density of 1.36 Mg m^{-3} on soil with no fertilizer and 1.48 Mg m^{-3} on soils that received fertilizer treatment.

The reduction in shoot biomass yield with increasing soil compaction may be attributed to one or a combination of the adverse conditions that were created in the soil environment. In this study, increasing soil compaction with its concomitant increase in soil bulk density to 1.7 Mg m^{-3} reduced both total and aeration porosities, with the later below the artificial critical level of 10% for favourable gaseous exchange. The implication of these conditions includes increased impedance to root growth, which in turn, reduced the requisite water and nutrient uptake for satisfactory root and shoot growth. The reduced aeration porosity and its negative impact on gaseous exchange resulting in reduced oxygen supply and accumulation of carbon dioxide could have adversely affect root

Table 6. Impact of soil compaction on root/shoot ratio of maize and soybean plants

Bulk density (Mg m⁻³)	Maize (per plant)	Soybean (per plant)
1.3	0.59	0.15
1.5	0.37	0.14
1.7	0.40	0.27
Lsd (5%)	0.04	0.08
Soil amendments (g/plant)		
Control	0.29	0.50
Sole PM	0.56	0.25
Sole NPK	0.51	0.27
50% PM + 50% NPK	0.44	0.23
Lsd (5%)	0.05	0.20
[†]Interaction		
Control x 1.3	0.25	0.11
Control x 1.5	0.28	0.08
Control x 1.7	0.33	0.54
Sole NPK x 1.3	0.79	0.16
Sole NPK x 1.5	0.48	0.17
Sole NPK x 1.7	0.41	0.25
Sole PM x 1.3	0.80	0.18
Sole PM x 1.5	0.35	0.13
Sole PM x 1.7	0.37	0.36
50% PM + 50% NPK x 1.3	0.50	0.15
50% PM + 50% NPK x 1.5	0.34	0.16
50% PM + 50% NPK x 1.7	0.47	0.16
Lsd (5%)	0.08	0.19

Lsd = Least significant difference; PM = Sole poultry manure; [†]Soil amendment x Bulk density interaction

Table 7. Pearson correlation matrix of soil compaction and crop parameters (*P* = .05)

Maize	Coefficient of correlation				
	BD	PH	SB	ERB	RSR
BD		-1.00	-1.00	-0.93	-0.80
PH			0.99	0.89	0.66
SB				0.87	0.64
ERB					0.93
RSR					
Soybean					
BD		-1.00	-0.98	-0.62	0.83
PH			0.96	ns	-0.69
SB				ns	-0.85
ERB					ns
RSR					

BD = Bulk density; PH = Plant height; SB = Shoot biomass; ERB = Effective root biomass; RSR = Root/Shoot ratio

growth and indirectly affect shoot growth. Similar observations have been reported in numerous studies [e.g. 5, 11, 14, 18, 20]. Efforts to increase and sustain crop growth and yield on compacted soils include breaking compacted layers through ripping by tines and subsoiling [21 – 23], biological drilling [12], and ameliorating the negative impact of compaction through the application of mineral and organic sources of

nutrients to enhance vigorous root growth [19, 24, 25].

The percentage increments by soil amendments in shoot biomass yield at each level of soil compaction, using the yield from the control as standard are presented (Table 4). In both crops, the impact was greatest under sole NPK and at the highest level of soil compaction. The

Table 8. Impact of different soil compaction levels and soil amendments on the uptake of nutrients by maize and soybean plants

Bulk density (Mg m ⁻³)	Maize (g/plant)			Soybean (g/plant)		
	N	P	K	N	P	K
1.3	2.44	2.50	2.46	1.50	1.57	1.40
1.5	1.21	1.22	1.23	0.76	0.78	0.71
1.7	0.84	0.87	0.47	0.41	0.46	0.22
Lsd (5%)	0.43	0.44	0.70	0.25	0.25	0.34
Soil amendment (g/plant)						
Control	1.12	0.66	2.13	0.48	0.29	0.93
Sole PM	1.08	0.72	0.41	0.69	0.49	0.28
Sole NPK	2.03	3.44	1.24	1.29	2.16	0.78
50% PM + 50% NPK	1.76	1.30	1.78	1.10	0.82	1.12
Lsd (5%)	0.50	0.51	1.39	0.29	0.29	0.40
^T Interaction						
Control x 1.3	1.79	1.31	3.74	0.80	0.59	1.66
Control x 1.5	1.10	0.53	2.12	0.50	0.25	0.98
Control x 1.7	0.48	0.13	0.53	0.13	0.04	0.14
Sole NPK x 1.3	3.66	5.21	1.91	2.41	3.43	1.26
Sole NPK x 1.5	1.45	2.70	0.99	0.94	1.76	0.64
Sole NPK x 1.7	0.97	2.42	0.81	0.52	1.30	0.44
Sole PM x 1.3	1.32	1.21	0.69	0.92	0.84	0.48
Sole PM x 1.5	1.05	0.72	0.41	0.78	0.53	0.30
Sole PM x 1.7	0.88	0.23	0.13	0.36	0.10	0.05
50% PM + 50% NPK x 1.3	2.98	2.27	3.52	1.87	1.43	2.21
50% PM + 50% NPK x 1.5	1.27	0.91	1.41	0.82	0.59	0.92
50% PM + 50% NPK x 1.7	1.02	0.71	0.42	0.62	0.43	0.23
Lsd (5%)	0.86	0.89	1.39	0.50	0.50	0.69

Lsd = Least significant difference; PM = Sole poultry manure; ^TSoil amendment x Bulk density interaction

magnitude of impact was greater on soybean than on maize plants as indicated earlier by the main effects of soil amendments. The effect of poultry manure was also greatest under the 1.7 Mg m⁻³ than the other bulk densities.

The results have shown the need for soil amendments in enhancing shoot biomass yield, but more so on compacted soils and for soybean cultivation. The need for mineral fertilizer in enhancing crop growth on soils low in nitrogen and soil organic matter has also been demonstrated, even in the case of soybean plants contrary to the general notion that nitrogen-fixing legumes do not need fertilizers, especially, N. On such soils, as was used in this study, N would be needed. In this context, integrated plant nutrition, using combined mineral and organic sources of nutrients could be an advantage considering the near additive effects of the 50% NPK+ 50% PM on shoot biomass yield observed in this study. In soybean plants, the calculated sum of half biomass yield of sole NPK and sole PM was 78.2, 62.95 and 36.3 g/plant at the 1.3, 1.5 and 1.7 Mg m⁻³, respectively. The corresponding yields of the

50% NPK+ 50% PM were 78.39, 63.13 and 39.98 g/plant. In maize plants, the sum of the sole NPK and sole PM were 113.06, 90.95 and 77.22 g/plant at the 1.3, 1.5 and 1.7 Mg m⁻³. The corresponding yields of the 50% PM+ 50% NPK were 125.75, 97.02 and 65.76 g/plant.

3.3 Root Biomass

The results of this study (Table 5) showed that soil compaction and amendments and their interactions significantly ($P = .05$) affected root biomass yield, distribution and penetration ratio. In this study, total effective root biomass refers to the sum of the mass of roots retrieved from the uncompacted and compacted soil cores excluding those between the inner walls of the buckets and soil cores (i.e., roots along the peripheries of the soil cores). Total effective dry root biomass of maize plants ranged from 27.64 and 67.87 g/plant for the 1.7 and 1.3 Mg m⁻³, respectively. The differences in root biomass among the 3 levels of compaction were significant ($P = .05$). The reductions in root biomass as bulk density increased from 1.3 – 1.5, and 1.7 Mg m⁻³ were 50 and 59%,

respectively. With regard to soybean plants, total dry root biomass ranged between 8.17 and 10.49 g/plant for the 1.5 and 1.3 Mg m⁻³, respectively following a trend of 1.3 > 1.7 > 1.5 Mg m⁻³. Root biomass at 1.3 Mg m⁻³ was significantly ($P = .05$) greater than those under 1.5 and 1.7 Mg m⁻³, which did not significantly differ ($P > .05$) from each other. The reduction in total root biomass relative to that of the 1.3 Mg m⁻³ was 22 and 14 % under 1.5 and 1.7 Mg m⁻³, respectively.

The results of this study showed that the application of soil amendments significantly influenced the total root biomass of both maize and soybean plants. Total dry root biomass of maize plants was in the order of sole NPK > 50% PM + 50% NPK > sole PM > control with a range of 24.34 – 63.99 g/plant representing the control and sole NPK, respectively. All the soil amendments significantly ($P = .05$) out yielded the control. Root biomass under the sole NPK was significantly greater than those under the sole PM, and 50% PM + 50% NPK, which did not differ significantly ($P > .05$). Considering the control as base value, the percentage increases in root biomass of maize plants were 42, 43 and 62% under sole PM, 50% PM + 50% NPK and sole NPK, respectively. In the case of soybean plants, total biomass ranged from 5.83 – 12.42 g/plant, with a similar trend as that of maize plants. From a base value of 5.83 g/plant, sole NPK, 50% PM + 50% NPK and sole PM increased root biomass by 53, 38 and 37%, respectively. The impacts of the application of soil amendments in ameliorating soil compaction for root biomass yield was greater in maize than soybean plants. The development of extensive root system enhances the ability of plants to abstract nutrients and water from the soil. The constraining impact of soil compaction on root growth therefore tends to limit the availability of water and nutrients for satisfactory plant growth and yield [21, 27]. The results of the study have clearly demonstrated the ameliorative impacts of soil amendments in reducing the adverse effects of soil compaction on root biomass yield. The provision of readily available nutrients favoured root development and vigour for effective nutrient and water uptake from the soil. The subsequent translocation of the nutrients and water to the shoot may underscore significant increases in shoot biomass.

The ameliorative impact of soil amendments on soil compaction effects on root growth became more evident when the soil amendment and

compaction interactions were examined. The results as presented in Table 5 showed that at each level of soil compaction, all the soil amendments significantly increased total root biomass over the control (i.e., no amendment). The increases in root biomass were greater in maize than soybean plants. The magnitude of reductions in total root biomass indicated that the negative impact of soil compaction was greater on maize (a monocot) than soybean (a dicot) roots. A similar observation was reported by Materechera et al. [26]. Chen and Weil [27] also found that rye roots decreased more rapidly than rapeseed roots as bulk density increased. In order to sustain crop growth and yield in compacted soils, ameliorative strategies to address the adverse impacts of soil compaction on root growth and biomass production need to be developed. In this study, the application of adequate amounts of soil amendments has been found to offset the negative effects of soil compaction on root growth [24, 25, 28].

3.4 Root/shoot Biomass Ratio

The results (Table 6) showed soil compaction and amendments to significantly influence root/shoot ratio. The impact of soil compaction showed root/shoot ratio to range from 0.37 – 0.59 for maize plants, and 0.14 – 0.27 for soybean plants. In the maize plants, the significantly greater ratio at 1.3 Mg m⁻³ was reduced by 37% under 1.5 Mg m⁻³; in the soybean plants, the reduction was 7%. The implication is that, at the lower bulk densities, the reduction in root biomass resulting from increasing compaction was greater than in the shoot biomass. The tendency was for root/shoot ratio to decrease. This was evident in the current study by a reduction in shoot and root biomass yields of maize plants by 20 and 50%, respectively when bulk density increased from 1.3 – 1.5 Mg m⁻³. The corresponding decreases in soybean plants were 17 and 22%. However, beyond 1.5 Mg m⁻³, the tendency was for root/shoot ratio to increase with increasing soil compaction.

Increasing soil compaction from 1.5 – 1.7 Mg m⁻³ increased root/shoot ratio by 7 and 48% in the maize and soybean plants, respectively. The underlying reason in this case was that the reduction in shoot biomass yields of 24 and 43% in maize and soybean plants were greater than the decreases in their corresponding root biomass yields of 19 and 10% under 1.7 Mg m⁻³.

According to Marschner [20], the root cap as a sensor of stress due to the restriction of root growth in compacted soils was implicit in this process. The accumulation of Absciscic Acid (ABA) in the roots which is transported to the shoot was triggered; this subsequently resulted in depression of shoot growth by inhibiting cell extension in shoot tissues, and inducing stomatal closure. This area of research has received very limited research attention. Yet, studies on the interdependence of shoots and roots in many ways, and the role of phytohormones in their response to various stress conditions in the rooting zone are required to inform the development of strategies for sustainable plant growth and yield. Such stresses include moisture, nutrients, drought and compaction. It is, however, worthy to note the main findings of the impact of soil compaction on root/shoot ratio. The magnitude and direction of change in root/shoot ratio due to increasing soil compaction depend on the level of compaction and the type of crop. At the lower range of soil compaction (i.e., $1.3 - 1.5 \text{ Mg m}^{-3}$) as reported in this study, and $1.1 - 1.5 \text{ Mg m}^{-3}$ in Ocloo [18], root/shoot ratio decreased with increasing compaction. Beyond these ranges (i.e., $1.5 - 1.7 \text{ Mg m}^{-3}$) in this study, and $1.5 - 1.9 \text{ Mg m}^{-3}$ [18], root/shoot ratio increased with increasing soil compaction.

The application of soil amendments significantly ($P = .05$) influenced the root/shoot ratio of maize plants, but not soybean plants (Table 6). All the soil amendments increased root/shoot ratio in both maize and soybean plants over the control. In the maize plants, the root/shoot ratio was in a decreasing order of sole NPK > sole PM > 50% PM+ 50% NPK > control, with a range of 0.31 – 0.59 for the control and sole NPK, respectively. In the soybean plants, the range was 0.16 – 0.19 for the control and sole PM, with a trend of sole PM > sole NPK > 50% PM+ 50% NPK = control. The increments in the root/shoot ratio indicated that the application of soil amendments increased biomass yields of both root and shoot, especially in the roots. The increments in root biomass yield of maize plants were 62, 43 and 42% under sole NPK, 50% PM+ 50% NPK, and sole PM, respectively. The corresponding increases in shoot biomass were 28, 18 and 10%. In soybean plants, the increments in the root and shoot biomass yields were 53 and 48% under sole NPK, 37 and 28% under sole PM, and 38 and 41% under 50% PM+ 50% NPK.

A similar trend was observed under the amendment x compaction interactions (Table 6).

In all cases, soil amendments significantly ($P = .05$) increased the root/shoot ratio at each level of soil compaction. However, under each amendment x compaction interaction, root/shoot ratio tended to decrease with increasing bulk density in maize plants contrary to the observed increases in root/shoot ratio with increasing bulk density under the main effect of soil compaction. The latter scenario was observed in the case of soybean plants. The direction of change in the magnitude of root/shoot ratio is therefore not as simple and easily predictable. It seems to be influenced by the type of crop (cereal or legume) and the confounding effects of factor interactions on the relative increases/reductions in shoot and root growth. This can be viewed in the simple general observation that under abundant supply of essential nutrients, particularly N and P, root growth is stimulated, but more so in shoots in fertile than infertile soils [20, 29, 30]. The present study has amply shown soil amendments to ameliorate the adverse impact of soil compaction on root and biomass yields. This, obviously, has implications for the magnitude of the root/shoot ratio, which is the dry matter (photosynthate) portioned into the root as a proportion of that in the shoot. The beneficial effects of the manure (other than nutrients supply) such as soil moisture storage and availability could account for the greater soybean plant height recorded under all treatments that incorporated PM. This is indicative of the benefits of integrated plant nutrition [31, 32] involving the combination of mineral fertilizer and poultry manure.

The data on plant parameters were examined for correlations with bulk density to ascertain the direction of change (positive or negative) in the measured parameters with changes in bulk density (Table 7). This will facilitate the acquisition of relevant information regarding the response of the measured parameters of maize and soybean plants to changes in bulk density.

The results depicted the negative impact of increasing soil compaction on shoot biomass, effective root biomass, and the root/shoot ratio of maize and soybean plants. In the soybean plants, the root/shoot ratio increased with increasing bulk density. The coefficients of correlation (r) for maize plants were -1.0, -0.93, and -0.80 for shoot biomass, effective root biomass, and root/shoot ratio, respectively. Increasing soil compaction therefore, decreases the magnitude of these measured parameters.

The negative r for root/shoot ratio indicates that root biomass is depressed more than shoot biomass as soil compaction increases. An examination of the data revealed that root/shoot ratio of maize plants decreased as bulk density increased from $1.3 - 1.5 \text{ Mg m}^{-3}$ and increased from $1.5 - 1.7 \text{ Mg m}^{-3}$. However, the magnitude of the rise could not offset that of the fall, resulting in a general trend of decreasing root/shoot ratio. With regard to soybean plants, the r values -0.98, -0.62, and 0.83 for shoot biomass, effective root biomass, and root/shoot ratio, respectively. All the measured parameters except root/shoot ratio decreased in magnitude with increasing soil compaction. The positive correlation between bulk density and root/shoot ratio accords with the generally observed trend of the shoot being more depressed than the root with increasing soil compaction, which is the general response of plants to stresses, such as soil compaction, drought/moisture stress and nutrient deficiency [20].

3.5 Nutrient Uptake

The results on nutrient uptake as presented in Table 8 showed that uptake of N, P and K by maize and soybean plants decreased with increasing bulk density (i.e., uptake was in the order of $1.3 > 1.5 > 1.7 \text{ Mg m}^{-3}$). Thus, uptake of N, P and K at the 1.3 Mg m^{-3} was significantly ($P = .05$) higher than either of 1.5 or 1.7 Mg m^{-3} in both maize and soybean plants. Overall, nutrient uptake in maize plants ranged from $0.84 - 2.44 \text{ g N/plant}$, $0.87 - 2.50 \text{ g P/plant}$, and $0.47 - 2.46 \text{ g K/plant}$. The percentage reductions in N, P and K relative to 1.3 Mg m^{-3} were 50, 51 and 50% at 1.5 Mg m^{-3} , and 66, 64 and 81 Mg m^{-3} at 1.7 Mg m^{-3} , respectively. In the soybean plants, nutrient uptake in g/plant for sole NPK ranged between 0.41 and 1.50, 0.46 and 1.57 and, 0.22 and 1.40, respectively, wherein the highest and lowest uptakes were recorded under the 1.3 and 1.7 Mg m^{-3} treatments, respectively. Relative to bulk density at 1.3 Mg m^{-3} , the percentage reductions in the uptake of N, P and K were 49, 50 and 49, and 73, 71 and 84% at 1.5 and 1.7 Mg m^{-3} , respectively. The adverse soil conditions created by high soil compaction as observed in this study were highly evidenced by the reductions in nutrient uptake by both maize and soybean plants, as reported in several studies [e.g. 15, 20, 21].

The stimulation of root growth, evidenced by the increases in root biomass (Table 5) coupled with the availability of nutrients from soil amendments

increased the uptake of N, P and K over that of the control (i.e., no applied amendment) as presented in Table 8. In the maize plants, N uptake was highest ($P = .05$) under sole NPK, and lowest under sole PM and control, with a range of $1.08 - 2.03 \text{ g/plant}$. The uptake of P varied between 0.66 and 3.44 g/plant and followed a similar trend as observed for N. With regard to K, uptake ranged between 0.41 and 2.13 g/plant ; highest under the control and lowest under the application of PM. In the case of soybean plants, N, P and K uptake ranged between 0.48 and 1.29, 0.29 and 2.16, and 0.28 and 1.12 g/plant , respectively. Similar to maize plants, the trends in the magnitudes of uptake differed with the soil amendments for both N and P, wherein uptake was highest under NPK fertilizer and lowest under the control. Contrary to maize plants, uptake of K was highest under 50% PM + 50% NPK and lowest under sole PM application.

Overall, sole NPK and combined application of PM and NPK resulted in higher ($P = .05$) N and P uptakes relative to the control and sole PM treatments by both maize and soybean plants. It was thus, evident that application of NPK fertilizer enhanced N and P uptake by maize and soybean plants, possibly because of the readily availability of the minerals for uptake relative to the other amendments. Similar observation was made by Hakansson and Lipiec [28] and Onwonga et al. [33]. The ameliorative impact of soil amendments in reducing the adverse effect of soil compaction in nutrient uptake is also evidenced by the results on soil amendments x compaction interactions (Table 8). In both maize and soybean plants, this was more evident with the direct incorporation of N, P and K, (i.e., applications of 50% PM + 50% NPK and sole NPK fertilizer), especially for N and P uptakes. Application of soil amendments, however, tended to depress the uptake of K by both plants under the different soil compaction levels.

4. CONCLUSIONS

The study has clearly shown the impact of different levels of soil compaction, amendments and their interactions on the growth, biomass yield and nutrient uptake of maize and soybean plants. Soil compaction reduced crop growth, shoot and root biomass and root/shoot ratio of maize and soybean plants. The magnitude of reduction increased as bulk density increased. Soil compaction beyond 1.5 Mg m^{-3} adversely affected root and shoot biomass yield of maize

and soybean. Thus, the ideal bulk density for shoot biomass production of both crops should be 1.3 Mg m^{-3} or with a range of $1.3 \leq 1.5 \text{ Mg m}^{-3}$. The main effects of soil amendments manifested in the enhancement of the growth of maize and soybean plants over that of the control. Soil amendments enhanced plant height at each level of soil compaction. A similar impact was observed in root and shoot biomass yields of both crops. 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 plants in the uncompacted soil, while that in the compacted soil was reduced. In the case of soybean plants, although the relative root biomass accumulated in the uncompacted soil was relatively greater than that of maize plants, the application of soil amendments tended to slightly decrease the relative root biomass over that of the control.

The shoot biomass of both crops decreased with increasing soil bulk density. The soil amendments significantly increased the shoot biomass of maize and soybean plants over the control. The magnitude of the responses of both crops to the soil amendments was greater in soybean plants than in maize plants. Soil compaction and amendments significantly influenced root/shoot ratio of both crops. At bulk densities of $1.3 - 1.5 \text{ Mg m}^{-3}$, the root/shoot ratio decreased with increasing compaction. Beyond the bulk density of 1.5 Mg m^{-3} , the root/shoot ratio increased with increasing soil compaction. The magnitude of the increase (from $1.5 - 1.7 \text{ Mg m}^{-3}$) could not offset that of the decrease (from $1.3 - 1.5 \text{ Mg m}^{-3}$), resulting in a general trend of decreasing root/shoot ratio. The soil amendments increased the biomass of both roots and shoots, but more so in the former than the latter.

A more enhanced uptake of N and P by both maize and soybean plants was observed with the application of sole NPK, and combined PM and NPK due to their readily availability for uptake by a greater percentage of the root biomass. Uptake of N and P increased with decreasing compaction level (i.e., low bulk density) by both maize and soybean plants. Overall, nutrients uptake, with the exception of K was highly enhanced upon the application of the soil amendments. There is, therefore, the need for mineral fertilizers in enhancing crop growth in compacted soils, and soils low in N and organic matter, even for the production of soybean. Soil

amendments, especially, NPK fertilizer should be applied to enhance crop growth and development in compacted soils. Soil testing should be done to know the right amount of fertilizers to apply. Further studies should be conducted to investigate the growth parameters measured in the buckets to conditions in the field, and the parameters correlated to yield.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Reintam E, Kuht J, Loogus H, Nugis E, Trukmann K. Soil compaction and fertilisation effects on nutrient content and cellular fluid pH of spring barley (*Hordeum vulgare* L.). *Agron. J.* 2005; 3(2):189-202.
2. Czyz EA, Tomaszewski J, Dexter AR. Response of spring barley to changes of compaction and aeration of sandy soil under model conditions. *Int. Agrophys.* 2001;15:9-12.
3. Lipiec J, Hatano R. Quantification of compaction effects on soil physical properties and crop growth. *Geod.* 2003; 116:107-136.
4. Usaborisut P, Niyamapa T. Effects of machine-induced soil compaction on growth and yield of sugarcane. *Am. J. Agric. Biol. Sci.* 2010;5(3):269-273.
5. Ishag M, Hassan A, Saeed M, Ibrahim M, Lal R. Subsoil Compaction effects on crops in Punjab, Pakistan. I. Soil physical properties and crop yield. *Soil Till. Res.* 2001;57-65.
6. Passioura JB. Soil compactions and plant growth. *Plant cell Environ.* 2002;25:311-318.
7. Lampurlanes J, Cantero-Martinez C. Soil bulk density and penetration resistance under different tillage and crop management systems and their

- relationship with barley root growth. *Agron. J.* 2003;95:526-536.
8. Glab T. Effect of soil compaction on root system development and yields of tall fescue. *Int. Agrophys.* 2007;21:233-239.
9. Domzal H, Hodara J. Physical properties of three soils compacted by machine wheels during field operations. *Soil Till. Res.* 1991;19:227-236.
10. Oldeman IR, Hakkeling, RTA, Sombroek WG. (1991). World map of status of human induced soil degradation, an explanatory note. 181RC. Wageningen, Netherlands /UNEP, Nairobi, Kenya. 1991; 34.
11. Asady GW, Smucker JM, Adams M.W. Seedling test for the quantitative measurement of roots tolerances to compacted soil. *Crop sci.* 1985;25:802-806.
12. Williams SM, Weil RR. Crop cover root channels may alleviate soil compaction effects on soybean crop. *Soil Sci. Soc. Am. J.* 2004;68:1403-1409.
13. FAO. Soil map of the world. Revised Legend. World Soil Research Report No 60. FAO, Rome; 1990.
14. Muhammad R, Gul DK, Muhammad H, Shahid A. Impact of soil compaction on root length and yield of corn (*Zea mays*) under irrigated Condition. *Middle-East J. Sci. Res.* 2012;11(3):382-385.
15. Lowery B, Schular RT. Temporal effects of subsoil compaction on soil strength and plant growth. *Soil Sci. Soc. Am. J.* 1991;55:216-223.
16. Gediga K. Influence of subsoil compaction on the uptake of Ca from the soil profile and on maize yield. *Soil Till. Res.* 1991;19(2):351-355.
17. Motavalli PP, Anderson SH, Pengtham Ketrati P. surface compaction and poultry litter effects on corn growth nitrogen availability and physical properties of claypan soil. *Field crops Res.* 2003;84: 303-318.
18. Ocloo CY. The response of roots and biomass yield of soybean and maize seedlings to different levels of soil compaction. A thesis submitted to the department of crop and soil sciences, college of agriculture and natural resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in partial fulfilment of the requirements for the award of Master of Science Degree in Soil Science. 2011; 170.
19. Beutler AN, Centurion JF. Soil compaction and fertilization in soybean productivity. *Sci. Agric. (Piracicaba Brazil).* 2004;61:626-631.
20. Marschner H. Mineral nutrition of higher plants. Second edition, Academic Press. Harcourt Brace and company (Publishers). 1995;889.
21. Raza W, Yousaf S, Niaz A, Rasheed MK, Hussain I. Subsoil compaction effects on soil properties, nutrient uptake and yield of maize fodder (*Zea mays* L.). *Pak. J. Bot.* 2005;37(2):933-940.
22. McKenzie RH. Agricultural soil compaction: causes and management. *Agri- facts. Practical information for Alberta's Agriculture Industry.* Agdex 510-1. 2010;10.
23. Crush JR, Thom ER. (2011). Review: The effects of soil compaction on root penetration, pasture growth and persistence. *Pasture Persistence-Grassland Res. Practice Ser.* 2011;15: 73-78.
24. USEPA (United States Environmental Protection Agency). The Use of Soil Amendments for Remediation, Revitalization, and Reuse. Solid Waste and Emergency Response (5203P). USEPA/National Service Center for Environmental Publications. 2007;52.
25. Mackay AD, Gillingham A, Smith C, Budding P, Phillips P, Clarke-Hill W, Johnstone, P. Evaluation of the effects of grass species, irrigation, nitrogen fertilizer application and soil compaction on the response of modern dairy pastures to phosphorus fertilizer. *Proc. of the New Zealand Grassland Assoc.* 2010;72:153-158.
26. Materechera SA, Dexter AR Alston AM. Penetration of very strong soils by seedling roots of different plant species. *Plant Soil.* 1991;135:31-41.
27. Chen G, Weil RR. Root growth and yield of maize as affected by soil compaction and cover crops. *Soil Till. Res.* 2009;117: (2011)17-27.
28. Hakansson I, Lipiec J. A review of the usefulness of relative bulk density values in studies of soil structure and compaction. *Soil Till. Res.* 2000;53(2): 71-85.
29. Reich PB. Root/shoot relationships: Optimality in acclimation and adaption or

- the-Emperor's new clothes? Third edition, revised and expanded. Yoav W, Amram E, Uzi K. (Eds). Marcel Dekker, Inc. (Publishers). New York, Basel. 2002;205-220.
30. Agren IG, Franklin O. Root/shoot ratios, optimization and nitrogen productivity. *Annals of Bot.* 2003;92:795-800.
 31. Law-Ogbomo KE, Law-Ogbomo JE. The Performance of Zea mays as influenced by NPK Fertilizer application. *Not Sci. Biol.* 2009;1(1):59-62.
 32. Obidiebube EA, Achebe UA, Akparobi S, Kator PE. Effect of different levels of NPK (15:15:15) on the growth and yield of maize in rain forest agro-ecological zone. *Int. J. AgriSci.* 2012;2(12):1103- 1106.
 33. Onwonga RN, Lelei JJ, Macharia JK. Comparative effects of soil amendments on phosphorus use and agronomic efficiencies of two maize hybrids in acidic soils of Molo County, Kenya. *Am. J. Exp. Agric.* 2013;3(4):939-958.

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