Journal of Energy and Natural Resource Management (JENRM), Vol. 9, No. 1, 65-76, 2023
Received: 30 December 2022; Revised: 21 April 2023; Accepted: 27 April 2023

Soil degradation by compaction: Impact on nitrogen uptake, maize growth characteristics, and soil fertility attributes under soil amendment application

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Abstract
Studies on the effect of compacted soil layers and organic amendment on maize productivity under rain-fed conditions have not received extensive attention, especially, in Ghana. Therefore, nitrogen uptake, dry matter accumulation, grain yields, and soil properties in response to poultry manure (PM) were evaluated using field and pot experiments under varied compaction levels in the semideciduous agroecological zone of Ghana. Three levels of PM: 0, 4, and 6 t ha^{-1} were evaluated, whereas experimental plots were compacted to 1.7, 1.5, and 1.3 Mg m^{-3} and 1.9, 1.7, 1.5, and 1.3 Mg m^{-3} bulk density (P_b), respectively in the field and pot experiments. Each of the experiments was replicated thrice in a factorial arranged in a complete randomised design and randomized complete block design for the pot and field experiment respectively. Application of PM enhanced maize N uptake, dry matter accumulation, soil properties, and subsequent maize grain yields ($p < 0.05$). Under the field condition, amendment application at 6 t ha^{-1} recorded peak stover N uptake (137.20 kg ha^{-1}) and dry stover mass (7323 kg ha^{-1}) at the tasselling growth stage. Short-term impacts of amendments on chemical properties were observed for pH, and OC but not K, P, and N. On the contrary, the imposition of compacted treatments limited N uptake, dry biomass weight, soil properties, and grain yield. Peak grain yield of 3 t ha^{-1} was observed with rates of 6 and 4 t PM ha^{-1}. From our results, PM at 4 t ha^{-1} is vital for enhanced maize yields and soil productivity under soils not exceeding 1.5 Mg m^{-3} soil restrictive layers.

Keywords
Bulk density, compaction, nitrogen uptake, restrictive layers, stover dry weight, soil fertility attributes

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DOI: 10.26796/jenrm.v9i1.227
Received: 30 December 2022 ; **Received in revised form:** 21 April 2023; **Accepted:** 27 April 2023; **Published:** 31 May, 2023

Contents

1. Introduction

Maize, a staple crop in Africa especially in Ghana, accounts for about 60 % of the entire cereal yields in the sub-region (Adu-Gyamfi et al., 2019). In Ghana, maize is usually cultivated under rain-fed conditions with the associated erratic climatic conditions (Badu-Apraku et al., 2018). As reported by FAOSTAT (2019), the yield per hectare in most farmers' fields in Ghana was 1700 kg ha^{-1}, which is the below-reported yields of 4000 - 6000 kg ha^{-1} from on-station trials (Ragasa et al., 2018). Reduced crop yields on smallholder farmers' fields have been attributed to soil fertility decline, pest and weed infestation, and poor rainfall distribution (Berdjour et al., 2020). Maize has been reported to positively respond to good management including water and amendment application, especially N-based fertilizers. Nitrogen (N) is very key in plant nutrition exerting significant influence on growth and boosting crop yield (Wang et al., 2017). Nitrogen modulates many plants' biochemical processes including enzyme activation, mineralization, and forms part of amino acids and chlorophyll molecules (Arif et al., 2017). However, the uptake of nitrogen is typically influenced by several factors including N pools and fluxes and soil management practices (Pessarakli, 2014).

In the last two centuries, the population of mankind has increased drastically from 0.85 billion to over 8 billion (Singh et al., 2018). To increase the output of the total yield per hectare of crops, and thus ensure food security around the globe, mechanization of operations in agriculture has evolved. Therefore, mechanization of farm activities has become imperative to increase food production around the world (Forbord and Vik, 2017). However, soil compactions arising from the mechanization of operations are a major biophysical constraint to the productivity of croplands and significantly influence nutrient uptake and crop growth. According to Balesdent et al. (2000), agricultural soils must be resistant to varying levels of land degradation to attain sufficient crop production, thus enhancing food security. Khalid et al. (2014) reported that good soil physical properties are required for nutrient uptake by crops.

Compaction adversely impacts key soil functions which ultimately affect crop yields (Agbeshie et al., 2020; Thomas et al., 2022). Soil compaction is often characterized by increased dense packing of the soil, reduced permeability, and decreased porosity which are all used as indicators in soil compaction studies (Hansson et al., 2019). Soils with high bulk densities affect nutrient and moisture uptake by affecting root permeability and water infiltration, percolation, and capillary rise (Rakkar et al., 2017). Studies from Grzesiak et al. (2015) noted a reduction in biomass dry yield when soil compaction increased from 1.1–1.6 Mg m^{-3} under commercial corn production in Poland. In a similar study in Sweden, Arvidsson and Håkansson (2014) recorded declined yield and plant growth for both monocots and dicots with restrictive layers beyond 1.45 Mg m^{-3}. Hence, the overall impact of increased soil bulk density is accelerated erosion and decreased plant development and yield.

Reports on the detrimental effects of compaction on soil properties, nutrient uptake, crop growth, and yield have been documented by several scientists globally (Duttmann et al., 2014; Pott et al., 2019). Field studies on nutrient uptake, crop growth, development, and subsequent yield under compacted soils are difficult, expensive, and time-consuming (Ocloo, 2011; Colombi et al., 2017). Consequently, studies on soil compaction are typically examined under laboratory environments in controlled conditions. However, data from such laboratory studies may lead to over or underestimations of measured parameters, which may differ from field experiments (Logah et al., 2011; Agbeshie et al., 2020). Also, there is a research gap on the compensatory influence of poultry manure (PM) amendments on soil compaction with regard to nutrient availability, uptake, and growth of crops in Ghana under field conditions. The relevance of such useful information cannot be overlooked in this period of intense agricultural mechanization. The few works on soil compaction in Ghana by Ocloo (2011) and others were greenhouse based and only examined growth response to varying levels of soil bulk density, a proxy of soil compaction. This study was therefore conducted on a Haplic Plinthosol to examine the influence of organic amendment on N uptake, maize growth, and soil physicochemical parameters in compacted soils under field and pot conditions.

2. Materials and methods

2.1 Description of the study site

The field experimentation was undertaken under rain-fed conditions at the Faculty of Agriculture Research Station, Anwomaso, of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

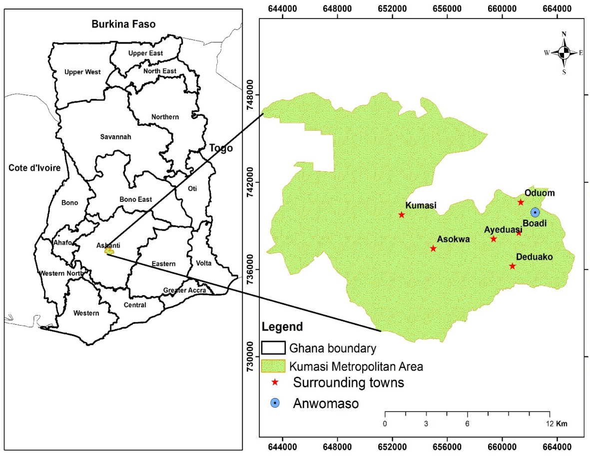

Figure 1. A map showing Anwomaso, Kumasi.

Specifically, Agriculture Research Station at Anwomaso is geographically located at 6.69514° N and 1.52477°

W within Kumasi Metropolitan Area, Ghana (Figure 1). The study area experiences a bimodal rainfall pattern with the passage of the Inter-Tropical Convergence Zone (ITCZ), and records a mean annual temperature and rainfall amounts of 26-30 0C and 1500 mm, respectively. Soils in the study area are classified as Haplic Plinthosol (Parker, 2016) and developed over a weathered sandstone (Adu, 1992).

2.2 Experimental design and treatment combinations

The study was a factorial experiment organised in a completely randomized design and randomized complete block design for the pot and field experiments respectively, with three replications. The experimental factors were composed of three (3) soil bulk density levels (P_b) (1.7, 1.5, and 1.3 Mg m^{-3}) and three (3) amendment levels (6, 4, and 0 t ha^{-1} PM) under the field condition. However, a fourth P_b level of 1.9 Mg m^{-3} was added to the pot experiment (Table 1) making a total of twelve treatment combinations, with the field experiment summing up to nine treatment combinations.

Table 1. Description of experimental treatments

Factor(A): Poultry Manure (PM)	**Treatment Description**	**Factor(B): Soil Bulk Density (P_b)**	**Treatment Description**
	Unit = t ha^{-1}		Unit = Mg m^{-3}
P1	PM of 0	P_{b1}	Pb at 1.3
P2	PM of 4	P_{b2}	Pb at 1.5
P3	PM of 6	P_{b3}	Pb at 1.7
		*P_{b4}	Pb at 1.9

2.3 Land preparation and crop management

The initial mean soil P_b at the experimental field was 1.57 Mg m^{-3} before field preparation. The experimental field was thoroughly disc ploughed and followed by a disc harrow, after which the desired compacted treatments were imposed using a Bomag BW 755 (weight of 1.025 t) hand roller compactor. Furthermore, compacted treatments of 1.5 and 1.7 Mg m^{-3} were achieved by 5 and 7 passes by the hand roller compactor respectively. After ploughing and harrowing the field, a P_b of 1.28 Mg m^{-3} was obtained and represented a compacted treatment of 1.3 Mg m^{-3}. A spacing of 80 x 40 cm was used to sow maize seeds after lining and pegging the field. The overall population for maize was 66,666 plants ha^{-1} at two (2) seeds per stand.

For the pot experiment, the soils used were gathered within the same site as the field study (Anwomaso). A total of 108 pots were filled to obtain the desired Pb with soil after air-drying. The volume for each pot was 0.0012 m^3 and was filled with 15.38, 17.74, 20.11, and 22.47 kg soil to represent P_b of 1.3, 1.5, 1.7, and 1.9 Mg m^{-3}. In all, 3 pots were used to represent each treatment which was replicated 3 times. Planting was done on September 2, 2013, with the Omankwa maize variety which is a high-quality protein maize, early maturing (95 days) with a reported on-station grain yield of 5000 kg ha^{-1}. Soil amendments (PM) at 4 and 6 t ha^{-1} were applied two weeks after sowing by side placement to respective treatment plots. The total amount of rainfall received during the growing season was 467.9 mm (September – December 2013) as shown in Figure 2. Weeding was done when necessary whilst pests were controlled with Lamda 2.5 EC. For the pot experiment, however, watering was done by estimating water loss and compensated every two days.

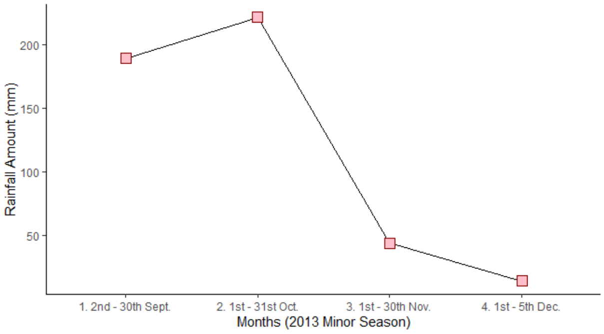

Figure 2. Mean monthly rainfall (mm) received at Anwomaso during the growing season.

2.4 Soil sampling and laboratory analyses

Before land preparation, an assessment of soil fertility attributes was determined. Ten soil core samples (0-15 cm soil depth) were randomly collected using the cylinder core method as described by Agbeshie and Abugre (2021). At the maturity stage, soil samples were collected at the base of ten tagged plants in each treatment plot to determine soil physicochemical properties. All samples collected were bulked, representative of each treatment plot, and passed through a 2 mm sieve. Soil fertility attributes were determined using standard procedures as detailed by Soils Laboratory Staff (1984). In the determination of soil Pb, undisturbed soil core samples were used. Assessment of the nutritive status of the amendment (poultry manure) applied was done following standard procedures as described by AOAC (2006).

2.5 Plant sampling and analyses

Within the treatment plot, 3 maize plants at both tasselling stage (V12) and physiological maturity stage (R6) were sampled for tissue analysis to determine N content. However, at the R6 growth stage, the plant samples were divided into stover (stem, leaves, and husk) and ear (grains and cobs) and analysed distinctly for their N contents. Maize N uptake at the different growth stages was subsequently determined using the formulae:

N uptake (kg ha^{-1}) = Stover/Ear N (%) x Stover/Ear yield (1)

At the R6 growth stage, maize cobs were harvested from each treatment plot in both experiments. This was performed to estimate maize economic yield (grain) (kg ha^{-1}). Moisture content for grain yield estimation was adjusted at 15.5% as proposed by Pordesimo et al. (2005).

2.6 Data analysis

All measurements collected from both experimentations were subjected to analysis of variance (ANOVA) using R statistical programme (Version 3.6). A significant assessment of treatment means was done using Least significant difference (LSD) at 5% probability. To establish relationships and synergy that existed between the measured soil and crop parameters (e.g. P_b and pH, stover N uptake at V12 and R6, grain yield, ear dry weight at R6), the Pearson correlation analysis in R software was used.

3. Results

3.1 Initial soil fertility attributes and amendment characterization

Initial soil fertility attributes in Table 2 revealed that mean soil organic carbon was 1.36 %, whilst mean pH and P were 5.91 and 5.12 mg kg^{-1} respectively. Soil total N, nitrite-nitrogen (NO_{3-}-N), and ammonium-nitrogen (NH_{4+}-N) also recorded mean values of 0.13, 4.16, and 11.00 mg kg^{-1} respectively (Table 2). Recorded sand, silt, and clay at the study site were 65.76, 29.24, and 5.00 % with a textural class of sandy loam. From Table 2, the water content of the soil was 9.46 % with a bulk density (P_b) of 1.57 Mg m^{-3}, translating to a porosity of 42 %.

The nutritive content of applied poultry manure (PM) in both pot and field experiments is presented in Table 2. From Table 2, the recorded mean values of N and OC in the PM were 2.15 % and 44.77 %. Also, the recorded ratios of lignin-to-nitrogen and carbon-to-nitrogen (C: N) were 11.52 and 20.81 respectively (Table 2).

3.2 Nitrogen uptake of maize in response to soil compaction and amendment

From the ANOVA results in Table 3, the application of soil amendment under varied soil compaction levels significantly influenced the N uptake of maize ($p < 0.05$). Highest PM addition of 6 t ha^{-1} registered maximum stover N uptake at the vegetative growth stage (V12) in both field (137.20 kg ha^{-1}) and pot (95.10 kg ha^{-1}) experiments (Table 3). Stover N uptake at the physiological maturity stage (R6) increased by 151 % and 175.5 % when the application rate increased from 0 to 4 t ha^{-1} and 0 to 6 t ha^{-1} PM respectively (field experiment). Interestingly, the mean maize ear N uptake was higher than the mean stover N uptake at the R6 stage (Table 3).

Maize N uptake varied considerably under different soil compaction levels ($p < 0.05$) (Table 3). As shown in Table (3), soil P_b at 1.3 Mg m^{-3} recorded the maximum N uptake at the various crop growth stages in both experiments. At the V12 growth stage, increased soil compaction caused a substantial decline in stover N uptake in both experiments ($p < 0.05$) (Table 3). Furthermore, increased P_b from 1.3 to 1.7 Mg m^{-3} resulted in a 16 % decline in stover N uptake (field experiment), whilst a decline of 29.92 % in stover N uptake was recorded when P_b rose to 1.9 from 1.3 Mg m^{-3} (pot experiment). Similarly, N uptake at R6 recorded a decreasing trend in both stover and ear when P_b increased from 1.3 to 1.7 Mg m^{-3} and then to 1.9 Mg m^{-3} under field and pot conditions respectively ($p < 0.05$).

Table 2. Description of experimental treatments

Soil		Soil amendment (Poultry Manure)	
Physical attributes	Value	Chemical attributes	Value
Sand (%)	65.76	N (%)	2.15
Silt (%)	29.24	P (%)	0.90
Clay (%)	5.00	K (%)	0.50
Soil texture	Sandy loam	OC (% 44.77)	44.77
Bulk density (P_b) (Mg m^{-3})	1.57	Ca	0.10
Porosity (%)	42	Mg	0.01
Water content (%)	9.46	Lignin	24.75
Chemical attributes	Value	Polyphenol (%)	3.39
Total N (%)	0.13	C: N ratio	20.81
NO_{3-}-N (mg kg^{-1})	4.16	C:P ratio	49.76
NH_{4+}-N (mg kg^{-1})	11.00	Polyphenol: N ratio	1.53
OC (%)	1.36	Lignin: N ratio	11.52
Available Bray 1 P (mg kg^{-1})	5.12		
pH	5.91		
Exchangeable bases (cmol$_{(+)}$ kg^{-1})			
K^+	0.13		
Mg^{2+}	1.47		
Ca^{2+}	3.88		
Na^+	0.08		
ECEC (cmol$_{(+)}$ kg^{-1})	5.65		

At V12, the highest stover N uptake was recorded under the interactive effect of P_3P_{b2} and P_3P_{b1} with mean values of 146.00 (field conditions) and 124.70 kg ha^{-1} (pot conditions). Nevertheless, the interactive effect of P_1P_{b2} and P_1P_{b4} recorded the least stover N uptake at V12 under field and pot experiments respectively (Table 3). At the R6 growth stages, the imposition of compacted treatments resulted in the decline in stover and ear N uptake (Table 3). However, the addition of amendments caused an overall increased N uptake in both experimentations (Table 3).

Table 3. N uptake as under varied compaction and amendment application

Treatments	Field experiment			Pot experiment		
	V12 Stover N Uptake (kg ha^{-1})	R6 Stover N Uptake	R6 Ear N Uptake	V12 Stover N Uptake	R6 Stover N Uptake	R6 Ear N Uptake
PM (t ha^{-1})						
0	69.00	35.10	43.50	39.50	21.14	28.65
4	116.80	88.50	117.50	86.50	52.14	80.66
6	137.20	96.70	112.60	95.10	55.06	87.63
LSD (0.05)	24.54	5.71	12.45	9.57	6.13	4.46
CV (%)	10.10	3.40	6.00	5.70	6.30	3.00
P_b (Mg m^{-3})						
1.3	114.00	83.20	98.20	86.90	48.77	71.14
1.5	114.30	68.40	89.60	73.50	44.20	70.43
1.7	94.70	68.60	85.70	73.50	42.35	64.43
1.9	N/D	N/D	N/D	60.90	35.81	56.58
LSD (0.05)	25.37	5.91	6.90	7.00	1.99	4.32
CV (%)	15.80	4.80	2.80	7.80	3.60	1.70
Interaction effects						
P_1P_{b1}	73.30	37.10	43.70	43.40	23.58	33.46
P_1P_{b2}	66.60	33.10	43.90	36.50	21.45	29.84
P_1P_{b3}	67.20	35.00	42.80	43.40	20.59	27.90
P_1P_{b4}	N/D	N/D	N/D	34.70	18.95	23.39
P_2P_{b1}	129.70	100.50	126.30	107.20	59.49	88.39
P_2P_{b2}	130.20	80.70	118.00	85.80	55.61	82.64
P_2P_{b3}	90.40	84.20	108.20	80.60	50.96	79.07
P_2P_{b4}	N/D	N/D	N/D	72.40	42.51	72.54
P_3P_{b1}	139.00	112.00	124.70	110.00	63.24	91.56
P_3P_{b2}	146.00	91.60	107.00	98.30	55.52	98.82
P_3P_{b3}	126.60	86.60	106.10	96.40	55.50	86.33
P_3P_{b4}	N/D	N/D	N/D	75.60	45.96	73.81
LSD (0.05)	39.53	9.23	13.81	12.69	6.10	7.21
CV (%)	22.90	7.80	7.40	9.60	4.70	6.60

LSD = Least significant difference (0.05); N/D = Not determined; CV = Coefficient of variation; PM= Poultry manure; P_b = Soil bulk density;
P_3, P_2, and P_1 is PM at 6, 4 and 0 t ha^{-1} respectively; P_{b3}, P_{b2}, P_{b3}, and P_{b4} is P_b at 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}.

3.3 Stover dry weight under varied soil compaction and amendment application

Restrictive soil layers and soil amendment additions statistically differed ($p < 0.05$) with respect to maize dry biomass at tasselling and maturity growth stages (Table 4). At the vegetative growth stage (V12) of the crop, dry weight under poultry manure application was in the order 6 > 4 > 0 t ha^{-1} with mean values of 7323, 6119, and 3354 kg ha^{-1}, respectively. During the R6 stage, dry stover weight and ear dry weight followed similar trends as dry stover weight at V12 under PM application ($p < 0.05$) (Table 4). Nevertheless, additions of 6 and 4 t ha^{-1} manure produced mean stover dry weight and ear dry weight that were comparable to each other at V12 and R6 ($p > 0.05$).

As evident from Table 4, an increase in soil P_b reduced stover dry weight at V12. Compacted plots of 1.3 Mg m^{-3} recorded the maximum stover dry weight at V12 with values of 4080 and 5977 kg ha^{-1} under field and pot experiment respectively (Table 4). As expected, compaction levels at 1.7 and 1.9 Mg m^{-3} under the field and pot experiment respectively recorded the least ear dry weight measurements of 3402 and 2219 kg ha^{-1}, respectively (Table 4). Moreover, under the field experiment, the interaction between PM at 6 t ha^{-1} and P_b of 1.3 Mg m^{-3} (P_3P_{b1}) resulted in peak stover dry weight of 7785 and 5901 kg ha^{-1} at V12 and R6, whilst the peak ear dry biomass at R6 was also observed in P_3P_{b1} with a value of 5008 kg ha^{-1}.

Table 4. Impact of poultry manure and varied bulk densities on maize dry weight

Treatments	Field experiment			Pot experiment		
	V12 Stover Dwt. (kg ha^{-1})	R6 Stover Dwt.	R6 Ear Dwt	V12 Stover Dwt.	R6 Stover Dwt.	R6 Ear Dwt.
PM (t ha^{-1})						
0	3354	2364	1900	2030	1624	1242
4	6119	5514	4446	4495	3596	3071
6	7323	5586	4501	4668	3734	3245
LSD (0.05)	1457.10	90.70	118.10	467.10	373.70	169.00
CV (%)	11.50	0.90	1.40	5.50	5.50	3.00
P_b (Mg m^{-3})						
1.3	5977	4726	3924	4080	3264	2756
1.5	5490	4489	3521	3863	3090	2581
1.7	5328	4248	3402	3694	2955	2522
1.9	N/D	N/D	N/D	3287	2630	2219
LSD (0.05)	429.10	79.70	182.20	169.00	135	127.30
CV (%)	13.20	0.60	2.30	5.10	5.10	2.60
Interaction effects						
P_1P_{b1}	3771	2414	2043	2193	1755	1423
P_1P_{b2}	3057	2379	1848	2048	1638	1285
P_1P_{b3}	3235	2300	1811	2021	1617	1226
P_1P_{b4}	N/D	N/D	N/D	1859	1487	1036
P_2P_{b1}	6376	5864	4719	4923	3938	3343
P_2P_{b2}	6318	5494	4444	4740	3792	3034
P_2P_{b3}	5662	5184	4174	4382	3506	3098
P_2P_{b4}	N/D	N/D	N/D	3936	3149	2810
P_3P_{b1}	7785	5901	5008	5124	4099	3502
P_3P_{b2}	7095	5595	4273	4800	3840	3425
P_3P_{b3}	7088	5260	4222	4680	3744	3242
P_3P_{b4}	N/D	N/D	N/D	4066	3253	2810
LSD (0.05)	1432.00	129.80	268.60	471.20	376.90	228.30
CV (%)	7.50	1.70	4.90	4.60	4.60	5.10

Dwt.= Dry weight; LSD= Least significant difference (0.05); N/D= Not determined; CV= Coefficient of variation; PM= Poultry manure; P_b= Soil bulk density;
P_3, P_2, and P_1 is PM at 6, 4 and 0 t ha^{-1} respectively; P_{b1}, P_{b2}, P_{b3}, and P_{b4} is P_b at 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}.

3.4 Compensatory effect of the amendment on varied soil bulk densities

As anticipated, the addition of soil amendments to treatment plots resulted in a decline of soil P_b after maize harvest as shown in Table 5. In both experiments, the control treatments generally observed an increase in soil P_b over their initial values. Conversely, a compensatory impact of PM on soil Pb was recorded especially at an application rate of 6 t ha^{-1} (Table 5). Under both field and pot conditions, a decline in soil P_b by 1.3-2.4 % was recorded when 4 t ha^{-1} PM was applied. Under field conditions, a reduction of 2.4 % was observed when 4 and 6 t PM ha^{-1} was applied in a 1.7 Mg m^{-3} P_b soil.

Table 5. Compensatory effect of amendments on soil compaction levels after harvest

Treatment	Bulk density (Mg m^{-3})	
	Field experiment	Pot experiment
Amendment x compaction		
P_1P_{b1}	1.35	1.31
P_1P_{b2}	1.56	1.53
P_1P_{b3}	1.70	1.71
P_1P_{b4}	N/D	1.92
P_2P_{b1}	1.30	1.29
P_2P_{b2}	1.48	1.48
P_2P_{b3}	1.66	1.69
P_2P_{b4}	N/D	1.90
P_3P_{b1}	1.33	1.29
P_3P_{b2}	1.47	1.49
P_3P_{b3}	1.66	1.68
P_3P_{b4}	N/D	1.88
LSD (0.05)	0.03	0.02
CV (%)	1.10	0.60

N/D = Not determined; CV = Coefficient of variation; LSD = Least significant difference (0.05); PM = Poultry manure; Pb = Soil bulk density; P_3, P_2, and P_1 is PM at 6, 4 and 0 t ha^{-1} respectively; P_{b1}, P_{b2}, P_{b3}, and P_{b4} is Pb at 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}.

3.5 Response of maize grain yield to soil compaction and soil amendments

From the analysis, the addition of PM to treatment plots significantly impacted ($p < 0.05$) maize grain yields (Figure 3-A and -B). Poultry manure application to treatment plots under field conditions recorded mean grain yield values ranging from 1.28 to 3.00 t ha^{-1}, with the highest and lowest grain yields recorded in amendment rates of 6 and 0 t ha^{-1} respectively. Maize grain yields under pot experimentation revealed comparable trends as registered in the field experiment with the amendments additions and ranked as $0 < 4 < 6$ t ha^{-1} PM with corresponding yield values of 1.05, 2.42, and 2.45 t ha^{-1} respectively (Figure 3-B). As observed from both experiments, the rise in compaction levels resulted in the decline of maize grain yields in all amended plots (Figure 3-A and -B). Nevertheless, the addition of 4 and 6 t ha^{-1} manure in a P_b of 1.3 Mg m^{-3} (that is P_2P_{b1} and P_3P_{b1} respectively) resulted in maximum yields of 3.16 and 3.32 t ha^{-1} (field experiment) (Figure 3-A).

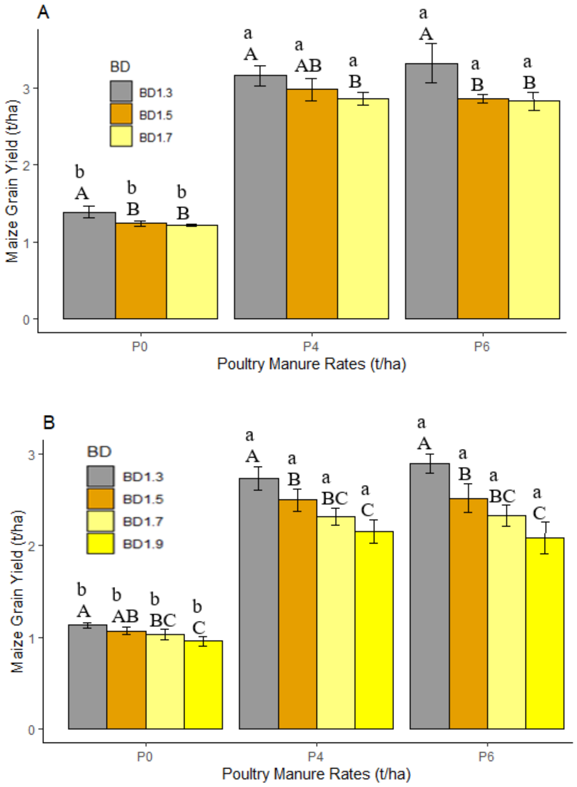

Figure 3. Maize grain yields under different soil bulk densities and soil amendment
Note: 3A= maize grain yields in the field experiment; 3B= maize grain yields in the pot experiment; Lower-cased alphabets imply differences within the same Pb across different PM application rates; Capital-cased letters indicate differences between the three (field experiment) and four (pot experiment) Pb.

3.6 Impact of amendments and compaction on soil fertility attributes after harvest

Application of PM caused statistical differences ($p < 0.05$) to pH, OC, and available P in both experiments (Tables 6 and 7). However, within one growing season, the impact of PM was not pronounced in the mean values of total N and exchangeable K ($p > 0.05$) (Tables 6 and 7). Likewise, the imposition of different soil P_b generally did not significantly impact soil chemical attributes in both experiments (Tables 6 and 7). Under field conditions, the highest amendment rate of 6 t PM ha^{-1} resulted in a 5.75 % rise in pH from the initial soil sample of 5.91 (Table 2) to 6.25 after harvest (Table 6). Similarly, OC, total N, available P, and exchangeable K significantly increased after PM application in both experiments (Tables 6 and 7) over their respective initial values in Table 2. The rise in soil P_b caused a decline in pH, OC, N, P, and K such as P_b of 1.7 and 1.9 Mg m^{-3} under field and pot experimentations respectively (Tables 6 and 7). Generally, the interactive effects of P_2P_{b1} and P_3P_{b1} in both experiments registered the highest soil chemical properties (Tables 6 and 7).

Table 6. Soil chemical attributes in the treatment plots after harvest (field experiment)

Treatments	Soil Chemical Attributes				
	pH	OC (%)	N (%)	P (mg kg^{-1})	K (cmol(+)kg^{-1})
PM (t ha^{-1})					
0	5.72	1.17	0.14	13.20	0.12
4	5.95	1.54	0.15	20.20	0.16
6	6.25	1.62	0.14	10.80	0.12
LSD (0.05)	0.24	0.04	NS	NS	0.02
CV (%)	2.00	3.30	3.60	35.50	34.70
P_b (Mg m^{-3})					
1.3	6.00	1.43	0.14	11.30	0.14
1.5	5.97	1.32	0.15	20.00	0.13
1.7	5.95	1.29	0.14	12.90	0.13
LSD (0.05)	NS	NS	NS	NS	NS
CV (%)	1.80	3.90	1.20	41.20	6.90
Interaction effects					
P_1P_{b1}	5.74	1.19	0.14	7.90	0.09
P_1P_{b2}	5.67	1.14	0.16	20.20	0.15
P_1P_{b3}	5.76	1.12	0.14	11.30	0.12
P_2P_{b1}	5.98	1.61	0.15	20.20	0.19
P_2P_{b2}	5.83	1.55	0.15	23.60	0.14
P_2P_{b3}	6.04	1.43	0.13	16.90	0.14
P_3P_{b1}	6.27	1.63	0.14	5.80	0.13
P_3P_{b2}	6.43	1.62	0.14	16.00	0.10
P_3P_{b3}	6.06	1.53	0.15	10.60	0.11
LSD (0.05)	0.28	0.05	NS	NS	NS
CV (%)	2.50	10.90	10.30	59.30	39.60

Dwt.= Dry weight; LSD= Least significant difference (0.05); N/D= Not determined; CV= Coefficient of variation; PM= Poultry manure; P_b= Soil bulk density;
P_3, P_2, and P_1 is PM at 6, 4 and 0 t ha^{-1} respectively; P_{b1}, P_{b3}, P_{b3}, and P_{b4} is Pb at 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}.

3.7 Correlation analysis

The correlation analysis in Figures 4 and 5 revealed that soil bulk density was negatively correlated with all maize agronomic parameters measured for both studies. Under rain-fed conditions, dry stover biomass at V12 and R6 were significantly positively correlated ($p < 0.05$) with grain yield with a correlation coefficient (r) of 0.88 and 0.99, respectively (Figure 4). Moreover, ear N uptake at R6 was significantly positively correlated ($p < 0.05$) with maize grain yields with an r-value of 0.98. There was a perfect positive correlation ($r = 1$) observed between ear dry at R6 with grain yield. Similar correlation coefficient results were recorded in the pot experiment (Figure 5). As observed from Figures 4 and 5, an increase in soil pH resulted in increased maize growth characteristics and nutrient uptake.

Table 7. Soil chemical attributes in the treatment plots after harvest (pot experiment)

Treatments	Soil Chemical Attributes				
	pH	OC (%)	N (%)	P (mg kg^{-1})	K ($cmol_{(+)}kg^{-1}$)
PM (t ha^{-1})					
0	5.70	1.21	0.15	8.23	0.11
4	6.08	1.51	0.15	13.82	0.17
6	6.29	1.61	0.16	12.49	0.13
LSD (0.05)	0.33	0.03	NS	2.34	NS
CV (%)	1.00	2.08	13.2	9.90	21.80
P_b (Mg m-3)					
1.3	6.11	1.48	0.17	12.10	0.15
1.5	6.01	1.44	0.15	11.69	0.12
1.7	5.95	1.40	0.14	12.14	0.13
1.9	6.02	1.37	0.15	10.12	0.14
LSD (0.05)	NS	0.05	NS	NS	NS
CV (%)	2.50	4.00	8.50	9.00	16.80
Interaction effects					
P_1P_{b1}	5.74	1.29	0.16	7.92	0.10
P_1P_{b2}	5.67	1.26	0.15	8.78	0.09
P_1P_{b3}	5.76	1.23	0.14	7.98	0.12
P_1P_{b4}	5.62	1.22	0.13	8.24	0.12
P_2P_{b1}	6.31	1.61	0.22	13.87	0.19
P_2P_{b2}	5.93	1.55	0.15	12.29	0.17
P_2P_{b3}	6.04	1.43	0.14	16.23	0.14
P_2P_{b4}	6.05	1.44	0.15	12.89	0.17
P_3P_{b1}	6.27	1.65	0.14	14.51	0.17
P_3P_{b2}	6.43	1.62	0.15	14.01	0.11
P_3P_{b3}	6.06	1.59	0.15	12.22	0.12
P_3P_{b4}	6.40	1.57	0.15	9.23	0.14
LSD (0.05)	0.35	0.05	NS	NS	NS
CV (%)	2.40	9.70	29.20	21.90	31.00

LSD= Least significant difference (0.05); NS= Not significant at 0.05 probability; CV= Coefficient of variation; PM= Poultry manure; P_b = Soil bulk density; P_3, P_2, and P_1 is PM at 6, 4 and 0 t ha^{-1} respectively; P_{b1}, P_{b2}, P_{b3}, and P_{b4} is P_b at 1.3, 1.5, 1.7 and 1.9 Mg m^{-3}.

Figure 4. Pearson correlation analysis between maize agronomic parameters at V12 and R6 and soil pH and P_b at R6 (field experiment). Note: V12SDwt and R6SDwt = stover dry weight at V12 and R6 respectively; V12SNupt and R6SNupt = Stover N uptake at V12 and R6; R6pH and R6Pb = pH and bulk density at R6 growth stage; R6EDwt and R6ENupt = ear dry weight and ear N uptake at R6 growth stage, respectively.

Figure 5. Pearson correlation analysis between maize agronomic parameters at V12 and R6 and soil pH and P_b at R6 (pot experiment). Note: V12SDwt and R6SDwt = stover dry weight at V12 and R6 respectively; V12SNupt and R6SNupt = Stover N uptake at V12 and R6; R6pH and R6Pb = pH and bulk density at R6 growth stage; R6EDwt and R6ENupt = ear dry weight and ear N uptake at R6 growth stage, respectively.

4. Discussion

4.1 Characterization of soils and poultry manure used at the study site

Chemically, the initial soil pH was moderately acidic (Landon, 2014) which could be explained by the leaching of basic cations out of the soil as a result of the high total rainfall (1500 mm) per year received in the experimental site. The soils at the study site generally recorded low OC, N, P, and K, indicating low fertility status. Such low soil fertility attributes may arise from none-to-low addition of soil amendments, nutrient mining by crops, accelerated erosion, coupled with high nutrient mineralization arising from high atmospheric temperatures in SSA, affirming the statement that most tropical soils are low fertility (Senkoro et al., 2018; Agbeshie et al., 2022). From the results in Table 2, the soil was sandy loam in texture with an initial soil P_b of 1.57 Mg m^{-3} and porosity of 42 %, which indicated moderate soil compaction.

Nutritive assessment of soil organic amendment is vital to understand its net mineralization or immobilization processes when applied. As shown in Table 2, the poultry manure (PM) suggested its usage as a nitrogen-based fertilizer due to its high N content of 2.15 %. Ashworth et al. (2020) opined that N contents ranging from 2 – 3 % in organic amendment can stimulate the release of nutrients following decomposition or mineralization. Furthermore, a C: N ratio of 20.80 highlighted its high N mineralization potential following application (Lazicki et al., 2020). The C:P, Lignin: N, and Polyphenol: N ratios of 49.76, 11.52, and 1.53 respectively (Table 2) of the organic amendment also suggested its high nutrient value (Cordovil et al., 2017).

4.2 N uptake and stover dry weight of maize in response to soil compaction and amendment

Nutrient uptake is a useful indicator in cropping systems as a means to quantify a plant's ability to take up and utilize available nutrients for growth and yield (Zhang et al., 2017). Nitrogen is recognised as a key plant nutrient influencing vegetative growth and subsequent grain yield in maize production (Schlegel and Havlin, 2017). Under field conditions, the results showed that the addition of PM to experimental plots at V12 registered a higher stover N uptake (69.28 % - 98.84 %) relative to the control (Table 3), signifying the status of amendment application to soils. The findings of this study attest to previous works of Agegnehu et al. (2016) who alluded that the addition of manure contains essential nutrients (e.g. N) for plant growth upon their release into the soil. Similar results were also recorded at the R6 growth stage with the application of PM recording higher N uptake over the control. However, the observed N uptake at R6 was higher in the ear than that of the stover. This is associated with the fact that the ear serves as a sink with high metabolic functions which cause the remobilization of nutrients from other portions of the plant to the grain as the maize crop ages (Liu et al., 2017).

Similarly, N adsorption decreased as bulk density levels increased in both experiments (Table 3). At the R6 growth stage, a reduction of 12.73 – 17.55 % was observed when Pb rose to 1.7 from 1.3 Mg m^{-3}. Declined N uptake as P_b increased could be ascribed to restricted root development which resulted in reduced root penetration and thus insufficient N supply. In their study on soil compaction and crop growth, Wang et al. (2019) reported that high soil compaction above 1.5 Mg m^{-3} resulted in the decline of K, N, and Mg via poor root growth and penetration.

The study revealed that dry stover biomass at V12 and R6 and ear dry biomass at R6 was influenced by PM and compaction. Interestingly, there was a linear trend in stover dry weight from the control plot up to the application of 4 t ha^{-1} PM but increased at a diminishing rate when 6 t ha^{-1} PM was applied in both experiments (Table 4). In both experiments, the addition of 6 t ha^{-1} manure registered the peak dry stover weight at each of the various maize growth stages ($p < 0.05$). The increase in dry stover biomass at V12 and R6 could be due to the release of macro and micronutrients from the PM for plant uptake during the growing period. Adeyemo et al. (2019) adduced that the application of 6 Mg ha^{-1} manure increased dry stover and ear weight by providing essential nutrients, especially N, and improving other soil physical parameters including water content and compaction. Although increased compaction reduced dry biomass weight, the addition of PM resulted in a significant increase in dry weight by altering soil physicochemical parameters, confirming previous studies of Are et al. (2017) and Ozlu et al. (2019).

4.3 Compensatory effect of the amendment on soil properties after harvest

Undoubtedly, the application of PM encouraged alteration in soil physicochemical attributes. As expected, the addition of soil amendment to treatment plots led to the lowering of P_b in the experiment (Table 5). At a high compaction level (1.7 and 1.9 Mg m^{-3}), a compensatory effect was observed with a high application rate of 6 t ha^{-1} PM. In the present study, a compensatory effect of 4 and 6 t PM ha^{-1} rates generally decreased soil P_b by 1.3 – 2.4% in both experiments relative to the initial levels of compaction. Other authors have reported similar findings on the influence of PM on soil P_b under maize cultivation (Ozlu et al., 2019; Wang et al., 2019). In a case study in Nigeria, Ojeniyi et al. (2013) recorded about a 14% reduction in soil P_b when 5 t ha^{-1} PM was added to a highly compacted soil under cocoyam production. The remediating impact of PM on soil P_b could be attributed to its addition in the soil by improving aeration and increasing soil biopores (Are et al., 2017), and increasing the OC content of the soil.

Furthermore, the addition of organic amendment increased soil pH, changing from moderately acidic (Table 2) to slightly acidic (Tables 6 and 7) in both experiments. Soil pH has been shown to control nutrient availability for maize uptake and was evident from this study showing a strong positive correlation with grain yield, attesting to previous studies of Ojeniyi et al. (2013). Poultry manure application increased N, P, K, and OC and thus exhibited a substantial influence on N availability and uptake. Such addition of poultry manure elevated microbial activities thereby enhancing nutrient availability and cycling over the un-amended plots, confirming the assertions that PM improves soil properties and subsequent grain yields (Zhihui et al., 2016; Ashworth et al., 2020).

4.4 Response of maize grain yield to soil compaction and soil amendments

Maize grain yields obtained from this study under both pot and field experiments were lesser than the reported yield for the Omankwa maize variety (5 t ha^{-1}) (CSIR-Crop Research Institute, 2011). Nevertheless, application of PM at 6 t ha^{-1} revealed increased maize yields of 3 t ha^{-1} under field conditions and 2.5 t ha^{-1} in the pot experiment, which are significantly higher than recorded maize yields (1.7 t ha^{-1}) under small-scale farmer fields (Agbeshie et al., 2020). Lower maize yields recorded in the study could be due to moisture stress from the low rainfall amount (467.90 mm) (Figure 2) received under the field conditions compared to the FAO (2015) recommended water requirement of 500-800 mm. Also, the introduction of compaction resulted in declined maize yields in both experiments, as evident from the correlation matrix in Figures 4 and 5. Compaction negatively affects root growth (Hansson et al., 2019) and results in reduced N uptake (Table 3) which ultimately declined maize yields. However, the application of PM offsets the negative impacts of compaction in amended plots by reducing P_b (Are et al., 2017) and augmenting plant available nutrients (Agegnehu et al., 2016) for increased yields over unfertilized plots.

5. Conclusion

Considering the data obtained in this study under the categorization of papers reviewed based on the type of study and methodology used to conduct the study, it emerged that studies that are conducted to detect fake news in the media space using machine learning techniques only had the majority of the papers whereas papers that had combined both machine learning and other techniques such as deep learning had a minority of the papers. This analysis proved that machine learning techniques only cannot solve the canker of fake news on social media but combining machine learning techniques with other novelty like deep learning, convolutional neural networks, and artificial intelligence can provide an alternative and improved way of mitigating the spread of fake news on social media. From the results of the systematic literature review conducted, it is quite clear that more attention and resources need to be invested in the area of fake news detection using machine learning to mitigate the canker of fake news, especially on social media, and also to provide enough literature for the academic domain or world. Understanding the mechanisms between the influence of organic amendment applications on N uptake, dry matter accumulation, soil chemical attributes, and maize growth is key in elucidating maize productivity under varied soil compaction levels. In the study, the addition of manure and imposition of varied compaction levels generally impacted N uptake, stover weight, grain yields, and soil fertility attributes. The increase in soil compaction greater than 1.5 Mg m^{-3} decreased N uptake. However, the application of organic amendments in compacted soils resulted in an increase in N uptake which was comparable to the amended uncompacted plots and significantly greater than the unamended plots. Application of 6 t ha^{-1} manure generally led to the highest maize yields of 3 and 2.45 t ha^{-1} under field and pot experiments respectively by altering the soil properties and improving N status. However, such effects were not statistically different from the manure rate at 4 t ha^{-1} PM; a case of diminishing returns (Liebig's law of minimum). From this study, it is recommended that the application of poultry manure at 4 t ha^{-1} is required for increased N uptake, dry matter accumulation, soil fertility status, and ultimately maize productivity in less than 1.7 Mg m^{-3} compacted soils. However, higher application rates greater than 4 t ha^{-1} will significantly alleviate the impacts of compaction in this era of mechanised agriculture.

Declaration of Competing Interest

The authors declare no competing interest

Data Availability

Data will be made available on request

Funding

The authors received no funding from external sources

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