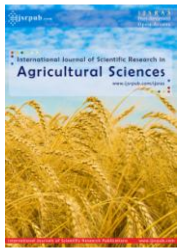
International Journal of Scientific Research in Agricultural Sciences, 1(2), pp. 16-22, 2014
Available online at http://www.ijsrpub.com/ijsras
ISSN: 2345-6795; ©2014 IJSRPUB
http://dx.doi.org/10.12983/ijsras-2014-p0016-0022



Full Length Research Paper

Influence of Poultry Manure and NPK Fertilizer on Hydraulic Properties of a Sandy Soil in Ghana

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Received 30 March 2014; Accepted 07 May 2014

Abstract. Field experiment was conducted during the 2008 major rainy season at the experimental field of the Department of Horticulture, Faculty of Agriculture, KNUST to test the effects of poultry manure (PM) and NPK fertilizer on the hydrological properties of a sandy soil. There were five treatments with five replications. The experiment was laid in Randomized Complete Block Design. Data were collected on the following soil properties: cumulative infiltration amount (I), sorptivity (S), steady state infiltrability (K_o) and saturated hydraulic conductivity (K_s). At the end of the experiment the control plot recorded the highest values of I, S, and K_o as 257 mm, 3.90 mm/s$^{1/2}$ and 0.07 mm/s, respectively. However the highest K_s was recorded as 1.72×10^{-4} on the sole NPK-incorporated plot which showed no significant difference from that recorded on the control plot (1.69×10^{-4}). Conversely, the plot with 9 t/ha PM recorded the lowest I value (159 mm). In the same way, the incorporation of poultry manure led to a significant decrease in S, K_o and K_s. The lowest S value was recorded on the 7 t/ha plots as 2.34 mm/s$^{1/2}$. However, K_o and K_s were lowest on the 9 t/ha plot as 0.04 mm/s$^{1/2}$ and 1.17×10^{-4} mm/s, respectively. Overall, the mineral fertilizer did not show any significant improvement in any of the parameters. Poultry manure was therefore found to improve the hydrological properties of the sandy soil. The significant decreases in water entry and movement suggest that poultry manure application can minimize excessive leaching of plant nutrients in sandy soil.

Keywords: Poultry manure, NPK fertilizer, Saturated hydraulic conductivity, Steady state infiltrability, Sorptivity

1. INTRODUCTION

Sandy soils have weakly developed profiles and a loose consistency (Henry, 2005). The major constraints of these soils are their low water retention, high water transmission and low nutrient content. Organic amendments have been proposed as an effective method to improve soil properties. Addition of organics like farm yard manure (FYM) and poultry manure (PM) have been found to improve soil physical properties and/or stabilize soil structure which in turn increase infiltration and reduce runoff (Rao et al., 1994; Khalid et al., 2014). For instance, Ibrahim and Gaheen (1999) reported that composts caused marked changes on soil infiltration rate. In this regard, organic amendments have been reported to have beneficial effects on soil hydrologic and hydraulic properties such as hydraulic conductivity and infiltration rate (Wanas, 2002). Again, like cattle manure, additions of poultry manure as a soil amendment have been found to decrease soil bulk density (Martens and Frankenberger, 1992; Brye et al. 2004; Weil and Kroontje, 1979). Following this, Wanas (2006) observed distinct increase in saturated hydraulic conductivity when compost was applied on a ploughed soil. However, application of organic residues significantly decreased hydraulic conductivity in Sudanese poor sandy soil (Mubarak et al., 2009).

Diana et al. (2008) reported positive effects of organic wastes on soil hydrologic hydraulic properties like infiltration rate and hydraulic conductivity. Jiao et al. (2006) reported that application of cattle manure at rate of 30 t ha^{-1} or greater significantly increased water stable aggregates of a sandy soil. This implied an improvement of the soil structure which might have positive effects on water retention capacity. Mubarak et al. (2009) observed that there was a decrease in water movement in sandy soils amended with organic residues. This offers a better chance for crops to absorb water and nutrients instead of nutrients being leached down rapidly. Wanas and Omran (2006) stated that the application of banana and cotton composts to sandy soil in Egypt had resulted in a direct decrease in drainable pores (responsible for water loss under gravity) and consequently, in the reduction of hydraulic conductivity of the soil. On the hand, Rao et al. (1994) reported that runoff from tilled plots was higher than that of untilled plots amended with FYM. This shows that tillage is not important as a soil and water conservation measure. Diana et al. (2008) reported positive effects of organic wastes on soil water retention and hydraulic conductivity. In spite of the volumes of work on the effects of organic amendments on soil physical properties, there is little report on their effects on soil hydraulic and hydrologic properties. Therefore, the objective of this study was to evaluate the effects of poultry manure on hydrologic as well hydraulic properties of a sandy soil.

2. MATERIALS AND METHODS

The work was done at the experimental farm of the Department of Horticulture, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science Technology, Kumasi Ghana. The area is within semi-deciduous forest zone and is subjected to marked wet and dry season with a bimodal rainfall pattern. The two rainfall peaks make two growing seasons possible. There is heavy rainfall from May-July, which is interrupted by a dry period of about four weeks in August; this is followed by another period of heavy rainfall from September to October. Dry season length is between 120 -130 days. Annual rainfall is about 1375 mm. Annual temperature ranges from 25^{o}C to 35^{o}C. The soil has been cultivated for a long time. It is sandy loam with little organic matter. The soil is well drained with considerable amount of gravel and a pH of 4.64.

The field was prepared by clearing the bush. It was then ploughed and harrowed. The field was then lined and pegged. The field was divided into 25 plots with a plot size of 2 m square. There were five treatments in the experiment with five replications (Table 2). The Randomize Complete Block Design was used in designing the experiment.

Table 1: Treatment detail

Treatment Code	Treatment combination
T1	5 t/ha PM + NPK Fertilizer (225 kg/ha)
T2	7 t/ha PM + NPK Fertilizer (225 kg/ha)
T3	9 t/ha PM + NPK Fertilizer (225 kg/ha)
T4	NPK Fertilizer (225 kg/ha)
T5	Control (No application of amendment)

Air-dried and ground manure samples were sieved through a 2 mm sieve and ignited at 450^{o}C for 2 h, the ash was extracted with HCl. The P was determined by ammonium molydate/ammonium vanadate method and K by flame photometry and Ca and Mg by EDTA titration. Determination of N was by the Kjeldahl method.

Field infiltration was measured with a cylinder infiltrometer of a diameter of 10 cm and driven into the soil to depth of 10 cm. A constant water level of 5 cm from the soil surface was maintained in the cylinder with water from a 1000 ml measuring cylinder. The vertical infiltration was measured in the cylinder for one hour. The initial infiltration was measured at 30 seconds interval for the first three minutes when infiltration was very fast after which the interval was increased as infiltration slowed down towards the steady state. Plots of cumulative infiltration amount (I) as a function of time (t) were obtained. Plots of infiltration rate (i) against time (t) to determine the steady state infiltrability (K_o) were done. Plots of Cumulative infiltration amount (I) as function of the square root of time ($t^{1/2}$) for the first five minutes were done to determine Sorptivity (S).

Core samples were obtained from each field. The saturated hydraulic conductivity measurements were made on the cores in the laboratory using the falling head permeameter method similar to that described by Bonsu and Laryea (1989). In the measurement, a cylinder of the same diameter was fitted to the top of the core to allow imposition of a hydraulic head. The cores were soaked in water overnight or until saturated. A large empty can with perforated bottom was filled with fine gravel. The core was placed on the gravel supported by a plastic sieve. The whole system was placed over a sink in the laboratory and water was gently added to give hydraulic head in the extended cylinder. The fall of the hydraulic head H_t at the soil surface was measured as a function of time t using a water manometer with a meter scale. K_s was calculated by the standard falling head equation as:

$$K_s = \left(\frac{AL}{A' t}\right) \ln\left(\frac{H_o}{H_t}\right) \qquad (1)$$

Where A is the surface area of the cylinder, A' is the surface area of the soil, H_o is the initial hydraulic head and L is the length of the soil sample. By rearranging equation (1), a regression of $\ln\left(\frac{H_0}{H_t}\right)$ on t with slope $b = K_s\left(\frac{A'}{LA}\right)$ obtained. Since $A = A'$ in this particular case, K_s was simply calculated as:

$$K_s = bL \qquad (2)$$

3. RESULTS

3.1. Effects of soil amendments on infiltration and infiltration parameters

Plots of the cumulative infiltration amounts of the various treatments and the control are shown in Figure 1. At one hour duration the control gave the highest value of 257 mm. The application of 9 t/ha PM + NPK recorded the lowest infiltration value of 159 mm. The application of 5 t/ha PM + NPK, 7 t/ha PM + NPK and NPK fertilizer recorded 198.7 mm, 182.9 mm and 207.3 mm, respectively. The initial infiltration at thirty seconds was also highest in the control which recorded 6.6 mm and the 7 t/ha PM recorded the lowest value of 4.7 mm. At thirty seconds the differences between the treatments were not significant but at one hour the control was significantly higher than all the treatments and the 9 t/ha PM was also significantly lower than all the treatments. The plots of cumulative infiltration as a function of time for the various treatments are presented in Fig.1.

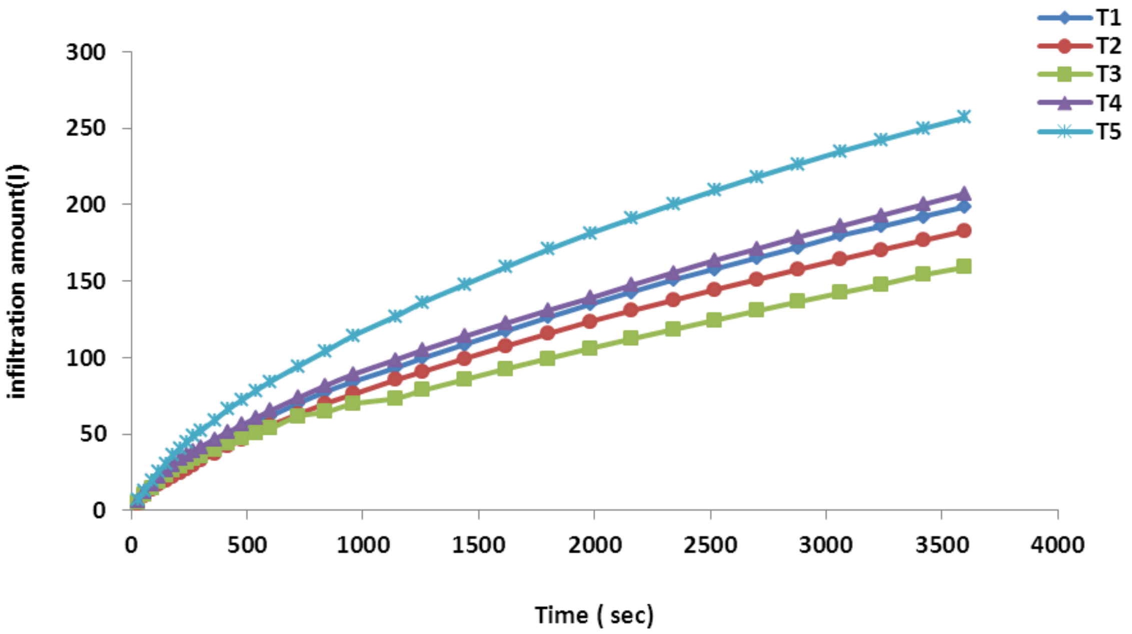

Fig. 1: The relationship between cumulative infiltration amount (I) and time

3.2. Sorptivity (S) and Steady state infiltrability

The plots of cumulative infiltration as function of square root of time for period of five minutes were obtained and the slopes of the graphs gave the values for the sorptivity. Sorptivity is the measure of the ability of the soil to absorb water. The sorptivity values were higher in the control and NPK fertilizer treatments without manure than the treatments with PM. The plots of infiltration rates as a function of time for all the treatments are shown in Fig. 2. The steady state infiltrability (K_o) was determined by extrapolating the line asymptotic to the x-axis to cut the y-axis. The K_o value for the control was the highest and the 9 t/ha application of PM was the lowest. The K_o values ranged from 0.04 mm/s for 9 t/ha PM to 0.07 mm/s for the control.

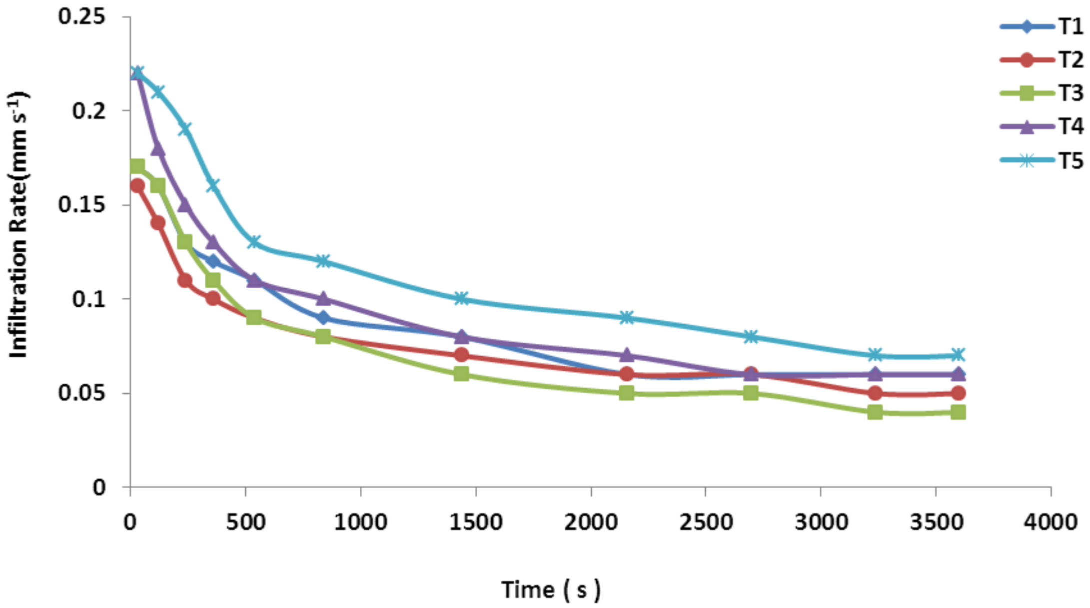

Fig. 2: The relationship between infiltration rate and time for the determination of steady state infiltrability

Table 2: Sorptivity (S) and Steady state infiltrability (K_o)

Treatment (t/ha)	S (mm/s$^{1/2}$)	K_o (mm/s)
5 t/ha PM+NPK	2.79	0.06
7t/ha PM+NPK	2.34	0.05
9 t/ha PM+NPK	2.65	0.04
NPK	3.05	0.06
Control	3.90	0.07

3.3. Effects of soil amendments on saturated hydraulic conductivity (K_s)

The NPK fertilizer treatment recorded the highest value of 1.72 x 10^{-4} m s^{-1} and the control recorded the second highest of 1.67 x 10^{-4} m s^{-1}. Saturated hydraulic conductivity values of 1.28 x 10^{-4} m s^{-1}, 1.20 x 10^{-4} m s^{-1} and 1.17 x 10^{-4} m s^{-1} were recorded for 5 t/ha PM + NPK, 7 t/ha PM + NPK and 9 t/ha PM + NPK, respectively. The results showed that K_s decreased as the amount of PM applied increased. The treatments with PM did not differ significantly among themselves. However they were significantly lower than the control and the NPK fertilizer treatments whose values did not differ significantly. These results are presented in Table 2.

Table 3: Effects of poultry manure plus NPK fertilizer on saturated hydraulic conductivity

Treatment (t/ha)	K_s (mm/s)
5 t/ha PM+NPK	1.28 x 10^{-4} (0.03)
7t/ha PM+NPK	1.20 x 10^{-4} (0.04)
9 t/ha PM+NPK	1.17 x 10^{-4} (0.02)
NPK	1.72 x 10^{-4} (0.04)
Control	1.69 x 10^{-4} (0.05)
LSD	0.25 x 10^{-4}
CV (%)	8.6

Values in brackets represent standard deviation.

4. DISCUSSION

The ability of the soil to transmit water depends on the arrangement of soil particles and aggregate stability (Martens and Frankenberger, 1992; Khalid et al., 2014). The infiltration amount was highest in the control treatment, followed by the NPK fertilizer treatment while the lowest infiltration amount was observed in the application of 9 t/ha PM + NPK. The infiltration amount reduced as the amount of PM application increased. This shows that PM had the ability to reduce the rapid rate of water entry into sandy soil. The reduction in infiltration amount could be attributed to the formation of surface crust resulting from desiccation of the soil surface upon the application of PM. Again, the low infiltration rate on the PM-treated plots could have arisen from water repellency resulting from soil hydrophobicity as influenced by organic coatings on the surfaces of the soil particles following desiccation. These processes may have led to a reduction in the macropores which favour the rapid infiltration in sandy soil. In line with this, Weil and Kroontje (1979) reported that the effects of poultry manure on water infiltration can be very complex. They found that water infiltration rates to be the slowest in the plots that received the highest rates of manure (poultry manure) which appeared to be due to the presence of a water resistant layer of manure (2.5 to 5 cm thick) in soil. In contrast to these observations, Martens and Frankenberger (1992) reported that the addition of animal manure and other amendments to soil greatly increased water infiltration which was directly related to the quantity of organic material applied.

During the early stages of infiltration, water transmittance is nearly uniform in all directions, independent of both the gravity and the geometry of the soil (Philip, 1969). This one-dimensional absorption or sorptivity (S) of water into a medium at time (t) is described by (Philip, 1969):

$$S = It^{1/2} \qquad (3)$$

The sorptivity and the steady state infiltrability were also higher in the control and the NPK fertilizer treatments and lower in the treatments with poultry manure application. Similarly, Martens and Frankenberger (1992) reported that incorporation of organic amendments with the exception of PM significantly increased sorptivity. The steady state infiltrability which is the infiltration flux at which free water become available at the soil surface at atmospheric pressure also decreased with increasing level of PM application. This supported the finding that PM reduces infiltration rate in sandy soil indicating that more water will be retained in the soil pores. Jiao et al. (2006) reported that application of cattle manure significantly increased water stable aggregates of sandy soil; that implies an improvement of soil structure which might have positive effect on water retention capacity of soil.

The hydraulic conductivity was highest in the control and the NPK fertilizer treatments. The hydraulic conductivity also decreased with the increasing level of PM, with the application of 9 t/ha PM + NPK being the least. This indicated that PM can reduce the rapid hydraulic conductivity of sandy soils. This reduction in hydraulic conductivity will improve soil moisture retention and prevent nutrient leaching in sandy soils. This observation confirmed the earlier studies by Wanas and Omran (2006) who reported that the application of banana and cotton compost to sandy soil in Egypt resulted in direct decrease in drainable pores and consequently reduction of hydraulic conductivity of the soil. The PM did not find binding site in order to form new aggregates but rather occupied part of the macropores which helped in reducing the hydraulic conductivity. Mubarak et al. (2009) also stated that application of organic residue significantly decreased hydraulic conductivity of Sudanese poor sandy soil. The present work has confirmed that PM can help decrease hydraulic conductivity of sandy soils. This condition is necessary to improve water retention and reduce excessive leaching of soil nutrients in sandy soils thereby improving crop growth and yield.

5. CONCLUSIONS AND RECOMMENDATIONS

Soil management practices have large effects on runoff and infiltration. The two important aspects of soil management are protection of soil surface from raindrop impact and improving soil structure by addition of organic materials. In this study, the addition of Poultry manure served as good source of organic amendment for the improvement of hydrologic and hydraulic properties of a sandy soil. The highest poultry manure application resulted in the highest improvement in hydrologic and hydraulic properties of the sandy soil. The NPK fertilizer alone did not show any significant improvement. Poultry manure can therefore be used as amendment for the improvement of soil hydrologic properties of a sandy soil. Implicitly poultry manure may improve the water retention behavior of sandy soils. Further study is required to determine the effect of poultry manure additions on soil-water content and hydrological properties in fine-textured soils.

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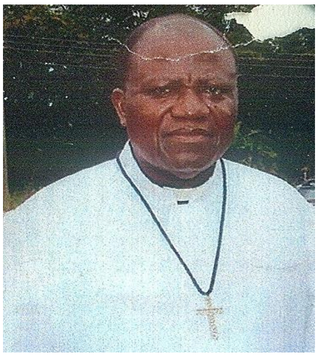

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