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Full Length Research Paper

Water movement and retention in a mollic andosol mixed with raw mature chickpea residue

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Organic manures affect soil properties, however, little is known about raw mature crop residue effects on water movement and storage in soils of low density like Andosols. It was hypothesized that water movement and storage in an andosol would be affected if the soil was mixed with raw mature crop residue. Therefore, the objective was to determine the water status in an andosol mixed with raw mature chickpea (*Cicer arietinum*) residue. Two treatments; amended and unamended soils were investigated. Saturated hydraulic conductivity was determined following the constant head method. Plant available water was estimated after determining water retention using the pressure plate apparatus at 3 and 1500 kPa water tension. The saturated hydraulic conductivity was approximately two-fold higher in the amended compared to the unamended soil. Water retention and plant available water were not affected by the raw mature chickpea residue. Since the bulk density was ~0.9 Mg/m^3 in both treatments, porosity was similar. Therefore, increased aggregate stability was the most likely reason for the increased water movement in the amended soil. Addition of crop residues into such as a soil could be desirable in situations where it is necessary to enhance water flow in the soil profile without affecting water storage and plant available water, for example to improve the bearing capacity of wet mollic Andosols during tillage.

Key words: Aggregate stability, soil texture, soil organic matter, water retention, bulk density.

INTRODUCTION

Manures are indispensable boosters for soil fertility and many studies have demonstrated that plant nutrients like nitrogen, phosphorus and potassium are released upon their decomposition (Danga et al., 2009). Besides soil fertility, manures also improve soil physical properties. Studies have adduced evidence that in coarse textured soils, CO_2, which is a simple product of decomposition, may be used as a rapid indicator of soil aggregate stability and water movement. High CO_2 evolution coincided with high aggregate stability and water movement (Wakindiki and Yegon, 2011). Whereas the benefits of green manure and decomposition are widely acknowledged, literature on the physical behavior of soil immediately after mixing with undecomposed manure is limited. Wesseling et al. (2009) performed an experiment on the effect of raw organic amendment on the hydrological behaviour of coarse-textured soils and found out that addition of peat significantly decreased hydraulic conductivity and increased water retention. Conclusions from many early experiments assumed that raw organic matter affected soil water status indirectly through modification of structure of coarse textured soils. Feustal and Byers (1936) added varying amounts of raw peat moss to sand and clay loam and reported increased available water content for sand but not for clay loam soil.

Likewise, Kelley (1954) included soil structure and texture but not organic matter in a review of the factors affecting available water content. Later, Jamison and Kroth (1958) evaluated 271 soil samples and found significant positive correlation between soil organic matter (SOM) content and available water content but

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discounted this direct relationship and instead attributed it to soil texture. More experimental evidence showing a direct relationship between SOM and water holding capacity became common in 1990s. Hudson (1994) demonstrated that water holding capacity was improved by SOM. Further advances were made at the beginning of this decade as interest moved from the static view of soil water parameters like available water and water holding capacity to dynamic terms of soil water potential. Buytaert et al. (2002) and Rawls et al. (2003) reported that SOM was an important soil property influencing soil water retention compared to soil texture. Organic matter has a lower density compared to that of mineral soil and so it has direct impact on the soil physical properties like bulk density and porosity (Hillel, 1998).

On the other hand, Andosols are characterised by low bulk density, typically less than 1.0 mg/m^3 in the surface horizon (FAO/ISRIC/ISSS, 1998). Andosols are generally fertile and occur in many volcanic regions of the world but their productivity is often limited by phosphate fixation. To alleviate the phosphate fixation, manures are often incorporated (IUSS Working group WRB, 2006). The unique fractal structure of the dominant clay, allophane, make Andosols excellent sequesters of soil organic carbon (Chevallier et al., 2010). Despite the phenomenal influence of raw organic inputs on the soil physical properties, few investigations have paid attention to the effect of undecomposed crop residue on water movement and retention in Andosols. Wesseling et al. (2009) cautioned that addition of raw organic matter into soils increases the risk of ponding and runoff if the hydraulic conductivity is significantly reduced. It was hypothesized that water movement and storage in soils with inherent low bulk density like Andosols would be affected if the soil is mixed with raw mature crop residue. Therefore, the objective was to determine saturated hydraulic conductivity, water retention and plant available water in Andosols immediately after mixing with raw mature chickpea (*Cicer arietinum*) residue.

MATERIALS AND METHODS

Site management and sampling

Soils were obtained from the top 0.15 m layer in an experimental site in Njoro in Kenya. The site is located at latitude 0°23′ S, longitude 35° 35′ E, and 2200 m above sea level. In this humid area rain falls in two distinct seasons, commonly referred to as long rain season (LRS) and short rain season (SRS). The LRS is between April and August and the SRS is between late October and December. The soils are fertile, well-drained mollic Andosols (Jaetzold and Schmidt, 1983). In this region, wheat is grown during the LRS and the land is left fallow during the SRS. So in five consecutive cropping seasons, between 2003 and 2006, we tested the possibility of introducing chickpea as a SRS crop and use its residue to enhance the soil productivity (Danga et al., 2009). So land that had been fallow for at least five years was ploughed at the start of the SRS in 2003 and divided into two 0.5 ha portions.

One portion was planted with chickpea and the other portion was left fallow. These portions are hereafter referred to as “amended” and “unamended” respectively. At the end of the crop growing season (SRS, 2003), mature chickpea was harvested and its dry residue incorporated using hand tools back into the upper 0.15 m soil layer in readiness for the wheat growing season during the LRS in 2004. The incorporated dry mature chickpea residue had a C:N ratio of 20:1 (Wakindiki and Yegon, 2011). Immediately after incorporating the residue two batches; undisturbed and disturbed soil samples were collected from the amended and unamended portions. Undisturbed samples for the determination of saturated hydraulic conductivity were collected in aluminium cylinders with 0.05 m diameter and 0.05 m height while samples for the determination of moisture retention were collected in aluminium cylinders with 0.05 m diameter and 0.03 m height. Each cylinder was secured with lids on both open sides during transportation. The disturbed soil samples, for the determination of soil texture and aggregate stability, were collected using a spade from 0 to 0.15 m layer and put in paper bags.

Saturated hydraulic conductivity, moisture retention and plant available water

The lids were carefully removed from the undisturbed soil cores. One side of each core was then covered with cheesecloth. The samples were slowly saturated with tap water from below for 48 h. Saturated hydraulic conductivity (K_{sat}, cm/h) was then determined using the constant head method (Reynods and Elrick, 2002) and estimated using Equation 1:

$$Q = K_{sat} \frac{A(h+L)t}{L} \qquad (1)$$

Where Q was the volume of water that passed through each core in time t, L was the length of the core, A was the cross section area of the core, and h was the height of water on the core. Afterwards, core samples were oven-dried at 105°C for 48 h and weighed to determine the dry bulk density of the soil as described by Grossman and Reinsch (2002). The bulk density ρb, mg/m^3 was then calculated using Equation 2:

$$\rho_b = \frac{M_s}{V_t} \qquad (2)$$

Where M_s was the mass of oven dry soil and V_t was the total volume of the core sample. Water retention at 3 and 1500 kPa was determined using the pressure plate apparatus (Dane and Hopmans, 2002). The soil samples were removed from the pressure plate apparatus after equilibration and their respective moisture contentsω, mg/mg, was determined gravimetrically using Equation 3:

$$\omega = \frac{M_w}{M_s} \qquad (3)$$

Where M_w was the mass of water and M_s was the mass of dry soil. The gravimetric water content was then converted to volumetric water content by multiplying it with the bulk density. The difference between water content at 3 and 1500 kPa moisture tensions was assumed to be the plant available water.

Soil texture and aggregate stability

The soil texture was determined on the disturbed samples following

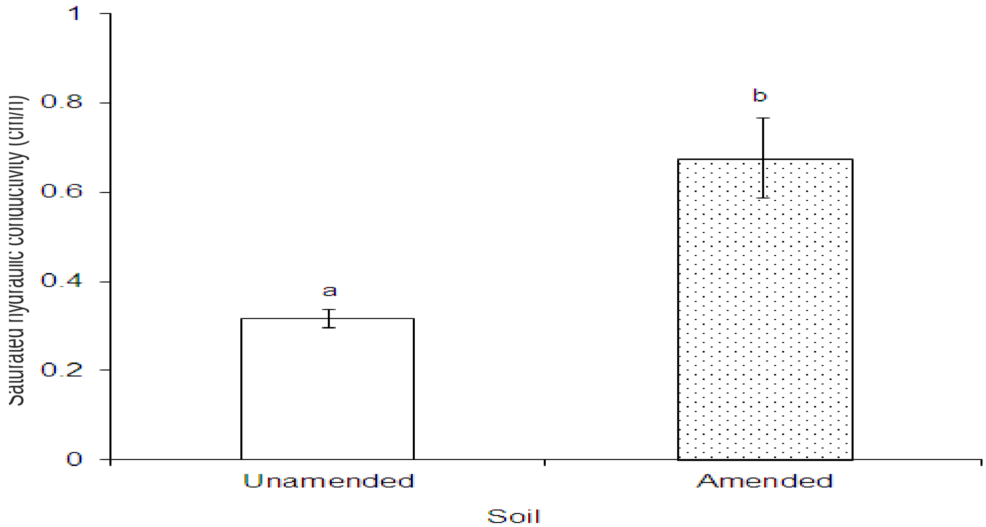

Figure 1. Saturated hydraulic conductivity in the unamended and amended soils. Different letters above the treatment values indicate significant difference (P ≤ 0.05). Bars indicate standard error.

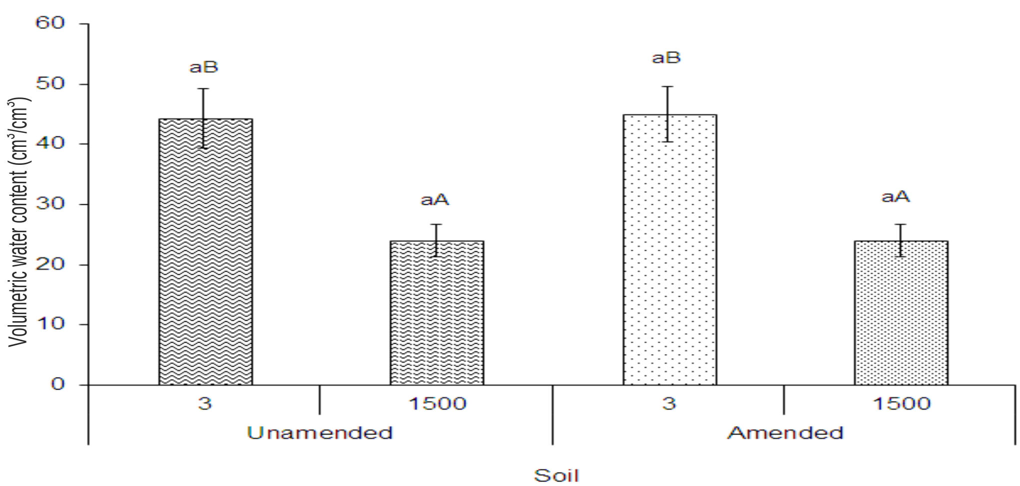

Figure 2. Volumetric water content in the unamended and amended soils at 3 and 1500 kPa. Different lowercase letters above the treatment values at the same matric suction and different uppercase letters above the treatment values at different matric suctions indicate significant difference (P = 0.05). Bars indicate standard error.

the hydrometer method as described by Gee and Or (2002). The aggregate fraction sizes were determined by sieving the soil samples in a net of sieves of 2, 1, 0.5, 0.25 and 0.1 mm diameter. The soil in each sieve was then weighed and expressed as a percentage of the total weight of the soil. The aggregate stability was expressed by calculating the mean weight diameter (MWD, mm) of the six classes:

$$MWD = \sum_{i=1}^{6} \overline{x_i} w_i \quad (4)$$

Where w_i was the weight fraction of aggregates in the size class i with mean diameter $\overline{x}$ (Le Bissonnais, 1996).

Statistical analysis

The means were analyzed using the t-test (Steel and Torrie, 1980).

RESULTS

The saturated hydraulic conductivity in the amended soil was approximately two-fold higher compared to that in the unamended soil (Figure 1). Therefore, addition of raw mature chickpea residue made it easier for the water to flow in the soil under saturated conditions. However, water retention (Figure 2) and plant available water (Figure 3) were not significantly affected by the incorpora-

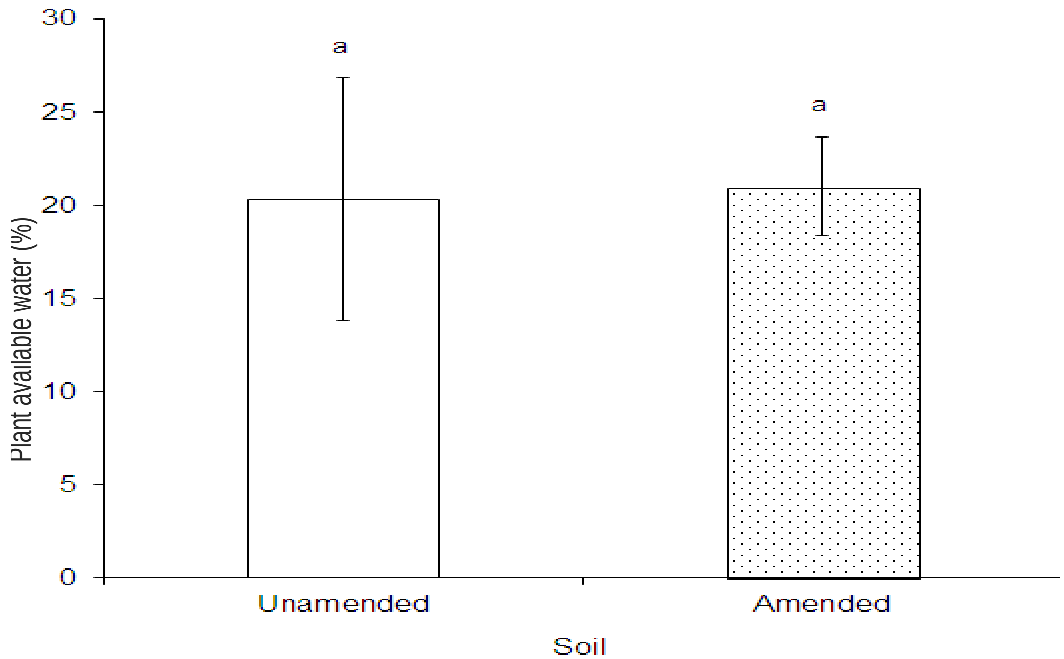

Figure 3. Plant available water in the unamended and amended soils. Different letters above the treatment values indicate significant difference (P = 0.05). Bars indicate standard error.

Table 1. Some physical properties of the mollic andosol used in the study.

Soil	Bulk density	%			Mean weight diameter
	Mg/m^3	Clay	Silt	Sand	
Unamended	0.96	35	43	22	0.35[a]
Amended	0.96	35	43	22	1.25[b]

Different letter following mean weight diameter value indicate a significant difference. (P = 0.05).

-tion of the chickpea residue. The aggregate stability in the amended soil was significantly higher than in the unamended soil, while the bulk density, which was ~0.9 mg/m^3 was not affected by the amendment (Table 1).

DISCUSSION

Saturated hydraulic conductivity indicates the ease with which soil pores in saturated soil permit water to move. Quantitatively, it measures the capacity of a saturated soil to transmit water under the influence of hydraulic gradient (Hillel, 1998). The same hydraulic gradient was maintained in both treatments. Therefore a possible reason for the increased saturated hydraulic conductivity in the amended soil was increased aggregate stability (Table 1). Since the bulk density was approximately 0.9 mg/m^3 in both treatments, there was no increase in porosity. Similarly, Lado et al. (2004) found that in the absence of raindrop impact, the saturated hydraulic conductivity of the soil was enhanced by organic matter. However, contradicting results were reported in sand mixtures by Wesseling et al. (2009), suggesting that organic matter decreased saturated hydraulic conductivity. In our experiment the soil was a silty clay loam (Table 1), suggesting that in finer soils, raw manures enhance saturated hydraulic conductivity.

In general, the amount of water retained in any soil at low values of moisture tension depends primarily upon the gravitational potential, while at higher moisture tension, adsorptive potential become dominant (Hillel, 1998; Dane and Hopmans, 2002). In our study, water retention for both treatments was not significantly different (Figure 2). Likewise, the plant available water for both treatments was similar (Figure 3). Hitherto, many experiments have demonstrated enhanced water retention when SOM is increased in soils (Jamison and Kroth, 1958; Rawls et al., 2003; Wesseling et al., 2009) but our results contrast these earlier findings probably because the soil texture was finer. Therefore, addition of crop residues into fine-textured soil could be desirable in situations where it is necessary to enhance water flow in the soil profile without affecting the plant available water capacity. For example, Andosols are known to be highly susceptible to compaction due to their low bearing capacity when highly hydrated (IUSS Working group WRB, 2006). So it might be reasonable to incorporate crop residues to enhance water transmission and release and facilitate operations like tillage. Nonetheless there is little evidence to support this hypothesis.

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