

*Full Length Research Paper*

# Effect of decomposition intensity of incorporated chickpea manure on stability and saturated hydraulic conductivity of a clay loam and clay soil

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Accepted 18 January, 2011

**The role of organic matter (OM) in soil aggregation and saturated hydraulic conductivity (K<sub>sat</sub>) has long been recognised but their dependence on the intensity of decay is less studied. The objective of this study was to determine the effect of decomposition intensity of incorporated chickpea manure on soil aggregate stability and K<sub>sat</sub>. Samples of a clay loam and clay soil were collected from the top 15 cm layer and amended with chickpea green or mature dry manure and incubated at 30 °C and ~60% water holding capacity. Decomposition intensity was determined by measuring CO<sub>2</sub> evolution using NaOH traps, aggregate stability by wet sieving and K<sub>sat</sub> by the constant head method. All determinations were made 3, 7 and 30 days after incubation and the data analysed following the general linear model for a 2 × 3 × 3 factorial in randomised complete block design. Evolution of CO<sub>2</sub> in both soils and manure was highest on day 7 compared to day 3 and 30. In both soils >60% of the soil aggregates were macroaggregates >0.5 mm but the relative proportion of microaggregates <0.5 mm increased from ~10 to ~20% in the control and to ~15% in the amended clay loam soil in the day 30 treatments. Decomposition intensity was increased by incorporating chickpea manure which resulted in improved soil aggregate stability and K<sub>sat</sub> especially in soil with low clay content. CO<sub>2</sub> which is a simple product of decomposition may be used as a rapid indicator of soil aggregate stability and water movement in agricultural soils.**

**Key words:** Green manure, organic matter, aggregate stability, chickpea, incubation, soil texture.

## INTRODUCTION

Incorporating manures in agricultural soils is a common practice that is often intended to add or sustain soil organic matter (OM) content and, on decomposition, improve soil physical properties (Smith et al., 1993). In general, decomposition is faster when manure is incorporated into the soil than if left on the surface (Danga and Wakindiki, 2009). Moreover, plant materials with low C:N (carbon to nitrogen) ratios decompose faster than those with high C:N ratio (Danga et al., 2009, 2010). For example, Onwonga (1997) observed rapid decomposition in the first ten days of incorporating

chickpea green manure with low C:N ratio. Furthermore, the manure lost 50% of its weight in 20 days, 67% in 30 days, 80% in 50 days and 94% in 90 days after incorporation. Villegas-Pangga et al. (2000) in a perfusion chamber experiment found that chickpea had released 47.7% of its C in 42 days whereas Lefroy et al. (1995) found that chickpea had released 58.9% C after 84 days. In general, these studies show that chickpea manure decompose fast and therefore, may alter soil physical properties within a short time.

The role of OM in soil structure formation and stabilization of aggregates is well acknowledged for example, Danga et al. (2010), Oades and Waters (1991), Tisdall and Oades (1982). The products of OM decomposition bind soil primary particles into aggregates

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**Table 1.** Some physical and chemical properties of the two studied soils.

Location	Texture class	Sand	Silt	Clay	OM	ESP	EC
		(%)					dS/m
Njoro	Clay loam	23	45	32	3.5	0.6	0.3
Tunyai	Clay	23	20	57	3.4	2.3	0.6

OM, Organic matter; ESP, exchangeable sodium percentage; EC, electrical conductivity.

**Table 2.** Some properties of the incorporated chickpea manure.

Manure	Ash	ADFwet	ADFnir	NDFwet	NDFnir	C	N	C:N
	(%)							
Green	6.2	44.5	51.2	32.6	34.1	45	3.7	12:1
Mature	10.8	41.7	57.9	30.7	41.9	45	2.2	20:1

ADFwet, Acid digestible fibre determined by wet digestion; ADFnir, acid digestible fibre determined by near infra red radiation; NDFwet, neutral digestible fibre determined by wet digestion; NDFnir, neutral digestible fibre determined by near infra red radiation.

physically and chemically, and this in turn, increases stability of the aggregates limiting their breakdown during wetting process (Le Bissonnais, 1996) especially in soils with low exchangeable sodium percentage (Golchin et al., 1995). Water movement in the soil is largely related to aggregate stability; the higher the aggregate stability the higher the rate of water movement (Wakindiki and Ben-Hur, 2002). Lado et al. (2004) found that for aggregate sizes of <2 mm and 2 to 4 mm under the absence of raindrop impact, the saturated hydraulic conductivity (Ksat) of the soil with high OM content (3.5%) was higher than that with low OM content (2.5%). The difference in hydraulic conductivity between the two soils was explained to be due to the structural degradation that occurred more in the low OM soil than in the high OM one.

Organic matter, aggregate stability and water movement in the soil are therefore closely related. However, there is little evidence to show if the intensity of decomposition of OM affects aggregate stability and Ksat. We hypothesised that the intensity of decomposition of legume manure alters the Ksat within a short time by affecting the aggregate stability depending on the soil texture. Therefore the objective of this study was to determine the effect of degree of decomposition of incorporated chickpea manure on aggregate stability and Ksat of a clay loam and clay soil.

## MATERIALS AND METHODS

### Soil and manure sampling and analysis

Soil samples were collected from the top 15 cm layer after scrapping the soil surface to remove debris and litter in two sites in Kenya. The two sites were Njoro at E 35° 35' S 0° 23' and Tunyai at E 37° 50' and S 0° 2'. The soil samples were air dried, crushed to pass through a 2 mm sieve and thoroughly mixed. The soil samples

were characterised using standard analytical procedures described by Rowell (1994) for soil texture, OM content, exchangeable sodium percentage (ESP) and electrical conductivity (EC) (Table 1). Chickpea Kabuli type variety ICCV 95423 was grown at Njoro and provided both green (at flowering) and mature dry plant samples (after harvesting). The plant samples were analysed following the methods described by Jones and Case (1990): total N by the Dumas method, Organic C by Walkley-Black procedure, lignin by both infra red gas analysis and wet digestion.

The properties of the green and mature dry manures used in this experiment are shown in Table 2.

### Soil-manure mixture preparation

The chickpea green or mature dry manure was oven dried for 72 h at 65°C, ground and sieved to pass a 1 mm sieve. It was then incorporated into composite soil samples obtained from the top 15 cm layer at the two sites at a rate of 5 mg/100 g soil. A control (soil without manure) was also prepared. All treated and control soil samples and control were prepared in triplicate and put in glass jars covered with perforated polyethylene sheet and incubated at 30°C and 60% water holding capacity.

### Intensity of decomposition

Sodium hydroxide traps were installed on day 3, 7 and 30 and removed after 24 h to determine CO<sub>2</sub> concentration. Excess 2N Barium chloride was added to the Sodium hydroxide solution to precipitate carbonates and the remaining sodium hydroxide was titrated with 0.1N Hydrochloric acid using Phenolphthalein as an indicator.

### Aggregate stability

The soil-manure mixture samples were oven dried at 40°C for 24 h and aggregate stability was measured according to Le Bissonnais (1996) fast wetting method. A 5g sample was immersed in 50 mL deionised water for 10 min. The water was sucked off with a pipette, and the sample was gently transferred to a 50 µm sieve previously immersed in ethanol. The sieve was gently moved up

and down in ethanol five times to separate the fragments < 50  $\mu\text{m}$  from those > 50  $\mu\text{m}$ . The remaining > 50  $\mu\text{m}$  fraction was oven dried and its size distribution was measured by gently dry sieving by hand on a column with sieves of 2000, 1000, 500, 250, 100 and 50  $\mu\text{m}$  diameter. The weight of each fraction was measured, the < 50  $\mu\text{m}$  was calculated as the difference between the initial weight and the sum of the weights of the other six fractions.

The aggregate stability of each sample was expressed as mean weight diameter (MWD) of the six classes as follows:

$$MWD = \sum_{i=1}^6 \overline{x_i} w_i$$

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

### Saturated hydraulic conductivity

The soil-manure mixture samples were packed in plastic columns at the same bulk density as the original soils from the two sites and were subjected to Ksat determinations. The Ksat was performed in 8 cm-long plastic columns with an internal diameter of 5 cm. The columns were packed with 100 g of the samples on top of 40 g acid-washed coarse quartz sand. The samples for each column were divided into 20 g portions, each of which was packed gently into the column to achieve a uniform bulk density. Each column was initially wetted from the bottom with 50 cmol<sub>c</sub> CaCl<sub>2</sub> using a peristaltic pump. After saturation was reached, three pore volumes of 50 cmol<sub>c</sub> CaCl<sub>2</sub>, followed by four pore volumes of distilled water was percolated through each column under saturation conditions.

The Ksat was determined by means of a constant-head mariotte bottle.

### Statistical analysis

The treatments were combinations of the three stages of manure decomposition (namely day 3, 7 and 30 after incubation) and the two types of manure (namely green and mature). The two soils constituted blocks. The data was subjected to correlation and analysis of variance using the general linear model for a 2 × 3 × 3 factorial in randomised complete block design on statistical software JMP<sup>®</sup> version 8 (JMP<sup>®</sup>, 2008). Mean separations were done using Fisher's protected least significant differences at  $P \leq 0.05$ .

## RESULTS

The texture of the soil from Njoro was clay loam while that of soil from Tunyai soil was clay. Both soils had low EC and ESP (Table 1). The manure C:N ratio was low. It was 12:1 in green manure and 20:1 in mature dry manure (Table 2). The evolution of CO<sub>2</sub> during the various stages of decomposition in the two soils is shown in Figure 1. In general, the decomposition intensity of OM measured as CO<sub>2</sub> evolution was higher in clay loam than in the clay soil in all the treatments. Evolution of CO<sub>2</sub> in the control treatment decreased with increase in the level of decomposition. In both clay loam and clay soils, CO<sub>2</sub> evolution was low on day 3 and 30, but significantly high

on day 7. The aggregate fraction sizes of both soils with advancing level of decomposition are shown in Figure 2.

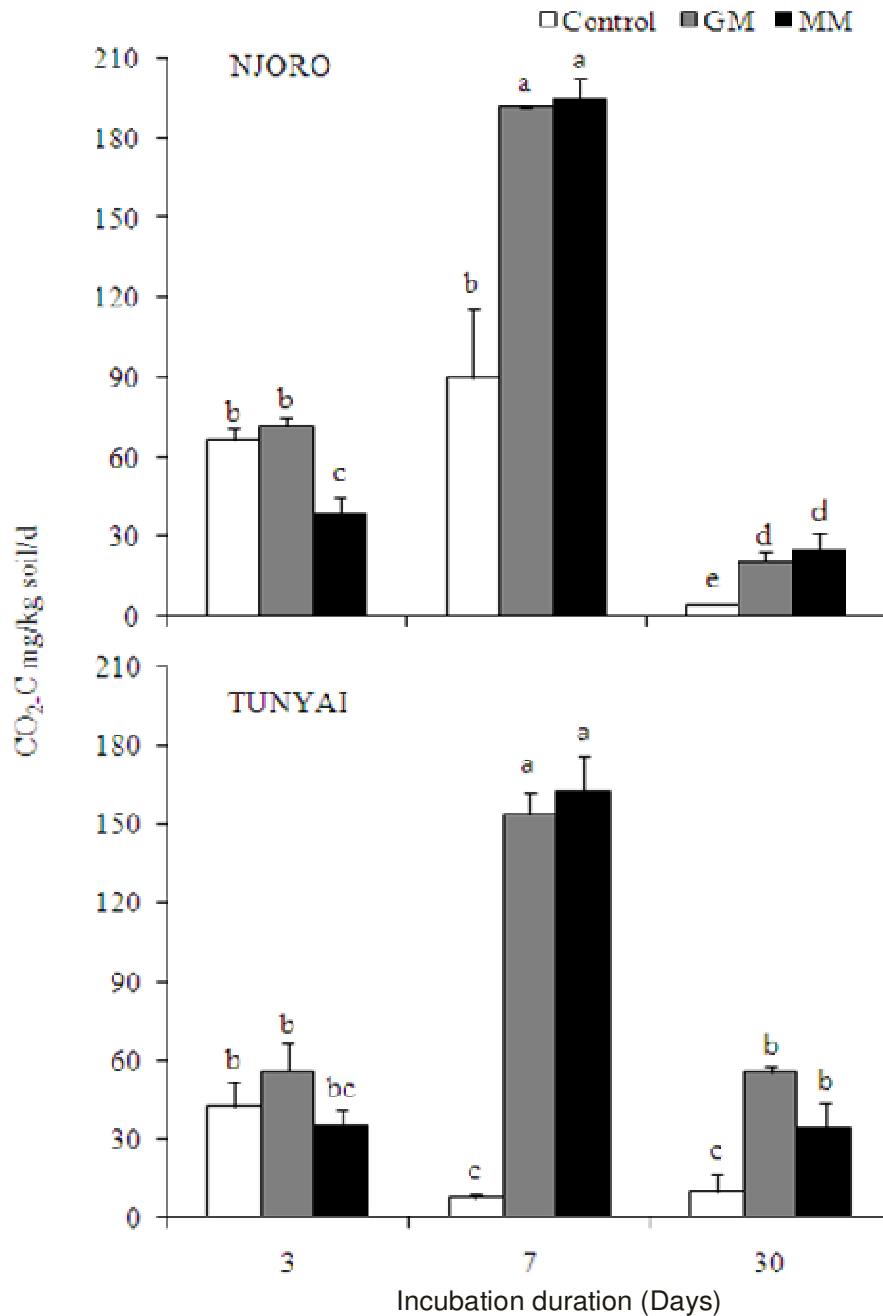
The relative proportion of the various aggregate sizes in all treatments in both soils did not change appreciably except in the clay loam soil in day 30 treatment. In both soils ~70% of the soil aggregates were >0.5 mm and 30% were <0.5 mm in day 3 and 7 treatments. In the day 30 treatment, the control in the clay loam soil had ~40% of the aggregates >0.5 mm and ~60% of the aggregates <0.5 mm while the amended soil had ~60% of the aggregates >0.5 mm and ~40% of the aggregates <0.5 mm. Moreover, the relative proportion of the smallest (<0.1 mm) aggregates was ~20% in the control and ~15% in the amended soil. Table 3 shows the MWD and Ksat values during the various manure decomposition stages. The MWD in the control treatment decreased with increasing level of decomposition in the clay loam soil but slightly increased in the clay soil. In the amended treatments, the MWD was significantly highest on day 7 relative to day 3 and 30 in clay loam soil but slightly increased with increasing level of decomposition in clay soil. The Ksat was highly variable in clay loam soil ranging from 39.8 to 110.9 cm/d in the control treatment. However, in this soil, Ksat was significantly high on day 7 compared to day 3 and 30 in all the treatments.

In clay soil Ksat values were in general, higher and less variable than those in clay loam soil. Figure 3 shows the relationship between the MWD and CO<sub>2</sub> evolution at the various stages of manure decomposition. There was a significant ( $R^2 = 0.86$ ) relationship between the MWD and the CO<sub>2</sub> that was being evolved in the clay loam soil. Increased CO<sub>2</sub> production led to increased MWD. However, in clay soil higher production of CO<sub>2</sub> led to a slight decrease in the MWD. The Ksat was less affected by CO<sub>2</sub> evolution in both soils as shown in Figure 4. However, clay loam soil showed a positive relationship. Higher evolution of CO<sub>2</sub> led to increased Ksat ( $R^2 = 0.49$ ).

## DISCUSSION

Decomposition was more intense in clay loam compared to clay soil. This was evident from the higher CO<sub>2</sub> evolution in clay loam than clay soil in all the treatments (Figure 1). Furthermore, there was intense decomposition on day 7 for both green and mature manure in both soils. This is why the amended treatments had a bell-shaped CO<sub>2</sub> evolution pattern which was low on day 3 and 30 but significantly high on day 7 (Figure 1). The manure used in this experiment had low C:N ratio (Table 2). Plant materials with low C:N ratio decompose fast (Danga et al., 2010). Onwonga (1997) observed that incorporated chickpea manure decomposed rapidly in the first ten days and only ~30% remained after 30 days.

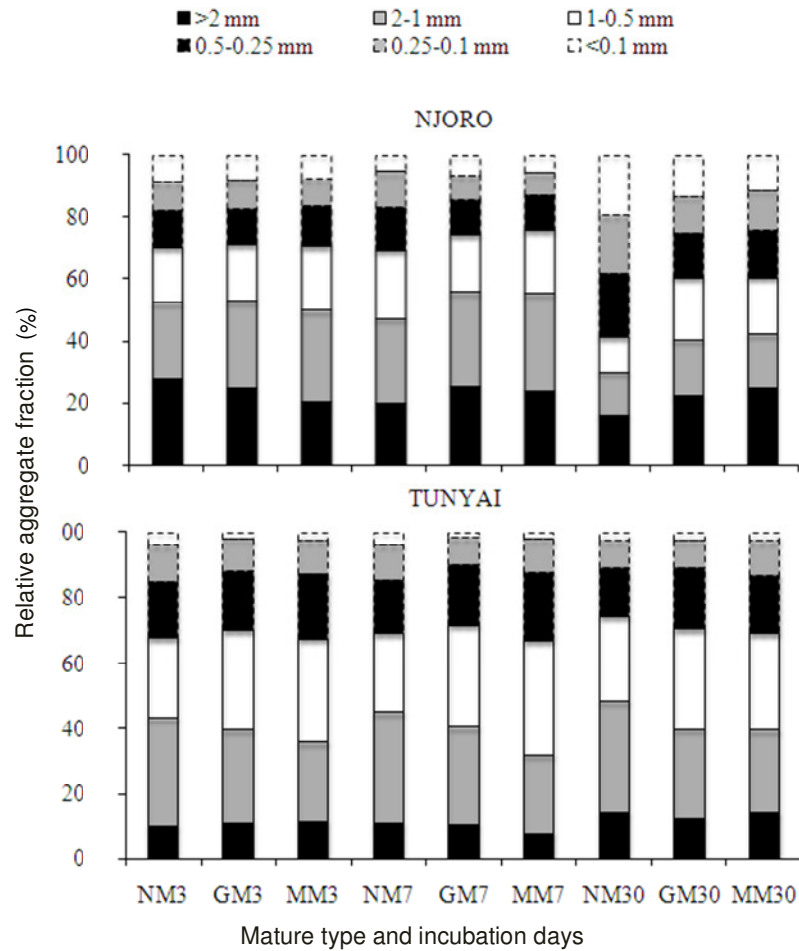
The dominant (~70%) aggregate sizes in both soils at various decomposition intensities, except in the clay loam soil in day 30 treatment, were similar and large (>0.5 mm)



**Figure 1.** Daily CO<sub>2</sub>-C evolution for the various treatments in soils from the two locations. Vertical bars represent standard error and different letters above the error bars for each soil show significant difference of the means. GM is green manure and MM is mature dry manure.

as shown in Figure 2. A decrease in the decomposition intensity in the day 30 treatment in the control in clay loam soil reduced the large aggregates (>0.5 mm) by half to ~40% while the smaller aggregates sizes (<0.5 mm) were increased one-fold (~60%). Therefore we concluded that decreased decomposition intensity immediately following high decomposition intensity was associated

with aggregate breakdown in clay loam soil. The soil aggregate stability in the control treatment decreased with increasing level of decomposition in the clay loam soil but slightly increased in clay soil. This is shown by the MWD results in Table 3. The higher the MWD was the higher the aggregate stability of the tested soil (Le Bissonnais, 1996).



**Figure 2.** Relative aggregate fractions for the various treatments in soils from the two locations. NM is the control, GM is green manure, MM is mature dry manure, 3, 7 and 30 are days after incubation.

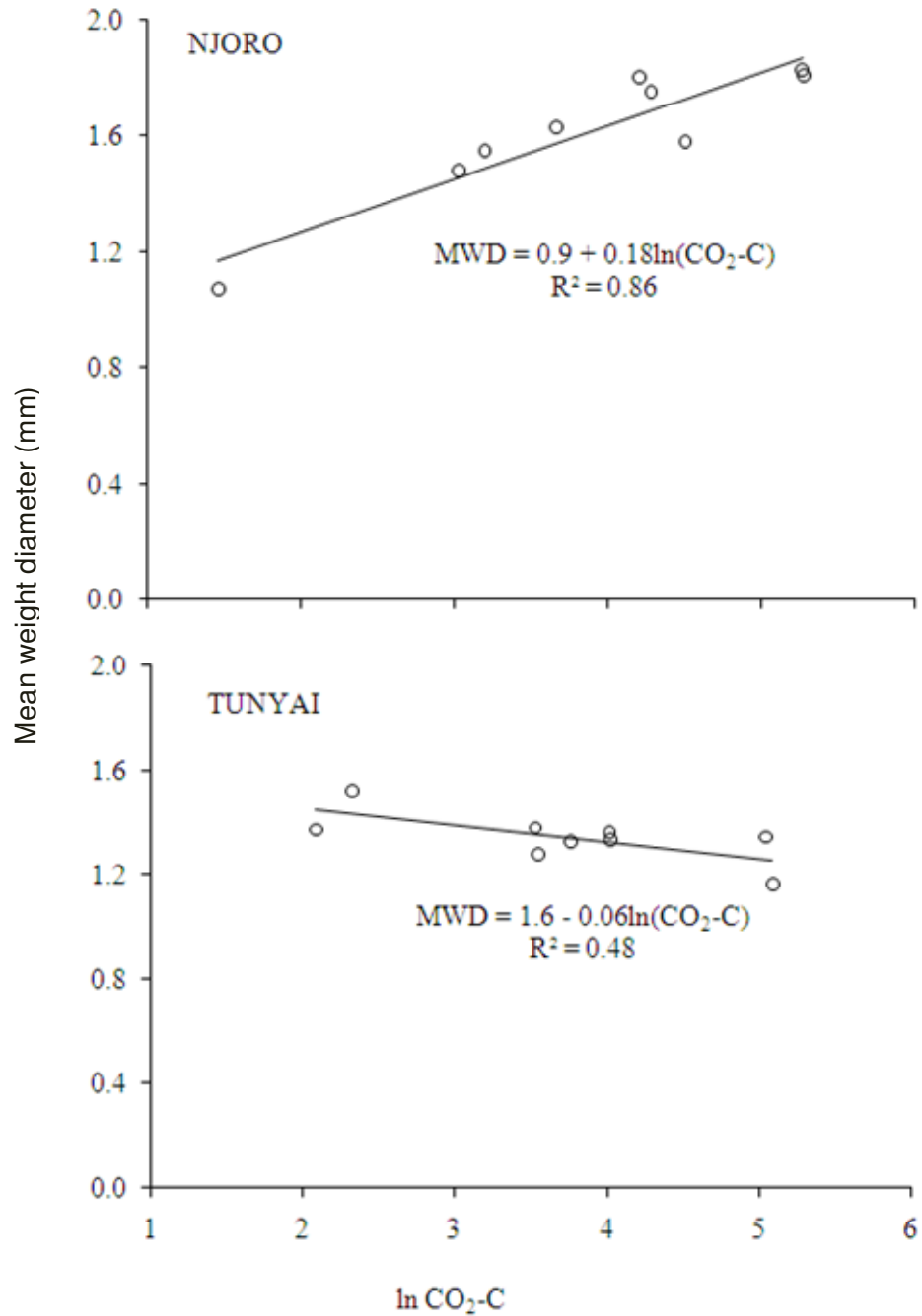
**Table 3.** Mean weight diameter (MWD) and Hydraulic conductivity (Ksat) during the various manure decomposition stages in soils from the two locations.

Location	Decomposition duration (days)	Manure type	MWD	Ksat
			mm	cm/day
Njoro	3	None	1.80a	68.5d
	3	Green	1.75b	95.8c
	3	Mature	1.63c	49.5e
	7	None	1.58d	110.9b
	7	Green	1.83a	102.0bc
	7	Mature	1.81a	145.5a
	30	None	1.07f	39.8f
	30	Green	1.48e	74.9d
	30	Mature	1.55d	69.9d
Tunyai	3	None	1.33d	106.8b
	3	Green	1.33d	239.6a
	3	Mature	1.28e	29.5c
	7	None	1.37bc	135.3b

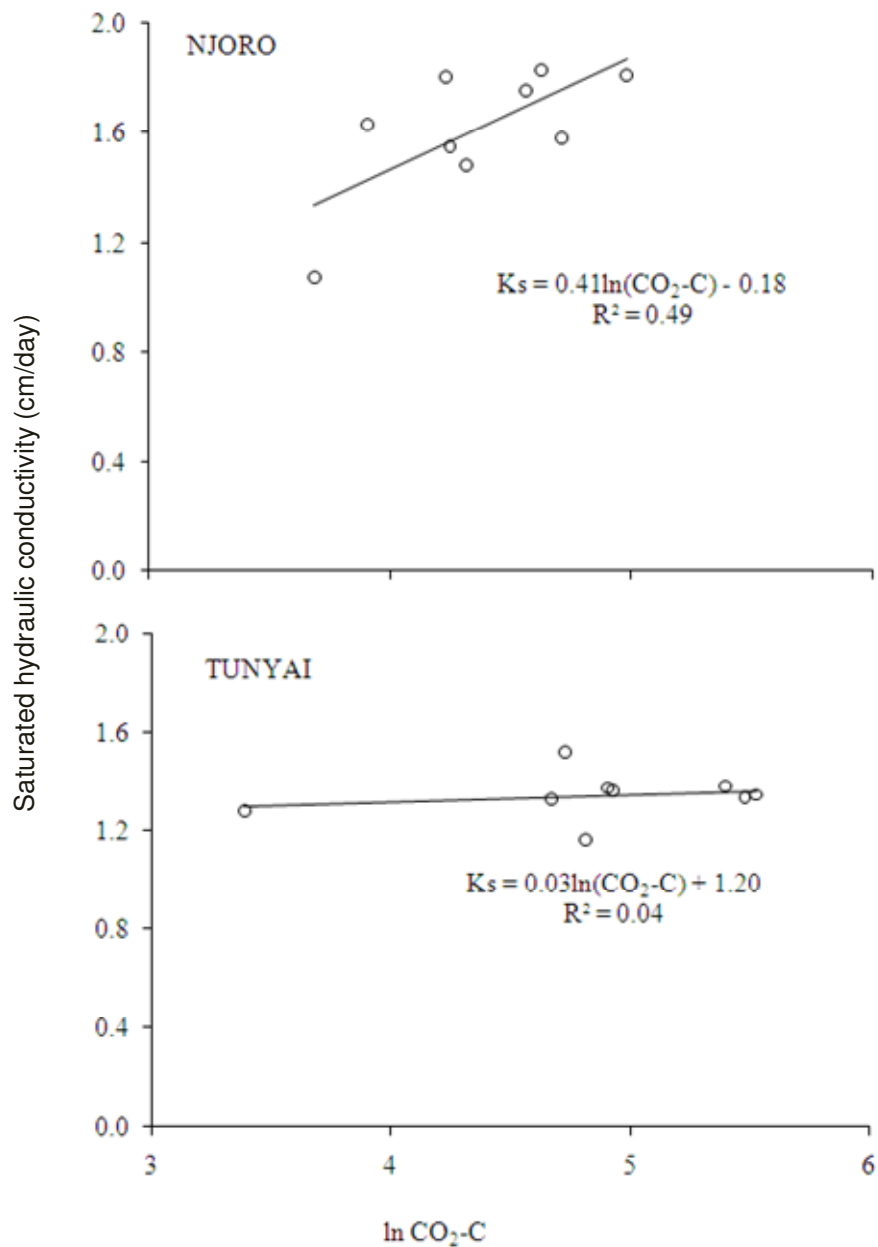
**Table 3.** Contd.

7	Green	1.35c	251.4a
7	Mature	1.16f	122.8b
30	None	1.52a	112.7b
30	Green	1.36bc	137.6b
30	Mature	1.38b	221.0a

In each soil, values followed by different letters were significantly different.



**Figure 3.** Mean weight diameter (MWD) as a function of  $CO_2-C$  evolution for the soils from the two locations.



**Figure 4.** Saturated hydraulic conductivity (Ksat) as a function of  $\text{CO}_2\text{-C}$  evolution for the soils from the two locations.

Incorporating manure significantly increased aggregate stability on day 7 relative to day 3 and 30 in clay loam soil but there was a slight increase in aggregate stability in clay soil regardless of intensity of decomposition in clay soil. Martens (2002) reported increased MWD values in a silty clay loam soil after only nine days under laboratory conditions. Decomposition intensity enhanced Ksat in clay loam soil on day 7 compared to day 3 and 30 in all the treatments but not in clay soil (Table 3). The significant ( $R^2 = 0.86$ ) relationship between the MWD and the  $\text{CO}_2$  that was being evolved in the clay loam soil (Figure 3) suggested that aggregate stability was strongly

affected by the intensity of decomposition. The higher the decomposition intensity the higher was the MWD. However in clay soil higher decomposition intensity led to slightly lower aggregate stability.

The products of OM decomposition bound the primary particles in the aggregates physically and chemically, and this in turn, increases stability of the aggregates limiting their breakdown during wetting process (Le Bissonnais, 1996) since the soils had low exchangeable sodium percentage (Golchin et al., 1995) (Table 1). Conversely when decomposition intensity was low in day 30 there was aggregate breakdown (Figure 2). The higher the OM

contents of a soil the higher the Ksat (Wuddivira et al., 2009; Lado et al., 2004). Moreover, Wuddivira et al. (2009) mixed soils of different texture and mineralogy with farm yard manure and observed up to 27% increase in water stable aggregates and 700% increase in Ksat after 56 d of incubation. In our experiment the soils had similar OM content and the increases in aggregate stability and Ksat related to the intensity of decomposition, mostly in clay loam soil. However, this relationship was weak in clay soil (Figure 4).

Clay loam and clay soil had low ESP and EC but different clay content (Table 1). Therefore the effects of the intensity of decomposition were more evident in the lower clay content soil than the higher clay content soil. CO<sub>2</sub> which is a simple product of decomposition may be used as a rapid indicator of soil aggregate stability and water movement in agricultural soils.

## ACKNOWLEDGEMENTS

We acknowledge the international crop research institute for semi-arid tropics (ICRISAT) in Nairobi for providing chickpea seeds and Dr Meni Ben-Hur the Institute of Soils, Water and Environmental Sciences at Volcani Centre, Bet Dagan in Israel for donating the equipment for the hydraulic conductivity study.

## REFERENCES

- Danga BO, Wakindiki IIC (2009). Effect of placement of straw mulch on soil conservation, nutrient accumulation, and wheat yield in a humid Kenyan highland. *J. Trop. Agric.*, 47: 30-36.
- Danga BO, Ouma JP, Wakindiki IIC, Bar-Tal A (2010). Chickpea - wheat rotation for higher production in a humid tropical region. *Agron. J.*, 102: 363-371.
- Danga BO, Ouma JP, Wakindiki IIC, Bar-Tal A (2009). Legume-wheat rotation effects on residual soil moisture, nitrogen and wheat yield in tropical regions. *Adv. Agron.*, 101: 315-349.
- Golchin A, Oades JM, Skjemstad JO, Clarke P (1995). Study of free and occluded particulate organic matter in soils by solid-state C P/MAS NMR spectroscopy and scanning electron microscopy. *Aus. J. Soil Res.*, 32: 285-309.
- JPM<sup>®</sup> Version 8 (2008). SAS institute Inc., Cary NC.
- Jones JB, Case VW (1990). Soil testing and plant analysis. p 389-427 In: R.L Westerman (Ed). Soil Science Society of America book series; no 3. Madison, Wisconsin USA.
- Lado M, Paz A, Ben-Hur M (2004). Organic matter and Aggregate size interactions in saturated hydraulic conductivity. *Soil Sci. Soc. Am. J.*, 68: 234 - 242.
- Le Bissonnais Y (1996). Aggregate stability and assessment of soil crust ability and erodibility: I. Theory and methodology. *Euro. J. Soil Sci.*, 47: 425 - 437.
- Lefroy RDB, Konboom Y, Blair GJ (1995). An in vitro perfusion method to estimate rates of plant residue breakdown and associated nutrient release. *Aus. J. Agric. Res.*, 46: 1467-1476.
- Martens DA (2002). Relationship between plant phenolic acids released during soil mineralization and aggregate stability. *Soil Sci. Soc. Am. J.*, 66: 1857-1867.
- Oades JM, Waters AG (1991). Aggregate hierarchy in soils. *Aus. J. Soil Res.*, 41: 979-989.
- Onwonga RM (1997). The effects of incorporating chickpea residue on soil nutrient status, Nitrogen availability and wheat yield in a chickpea-wheat rotation. Unpublished Msc. Thesis. Egerton University, Kenya.
- Rowell DL (1994). Soil science: Methods and applications. Longman. UK.
- Smith JJ, Papendick RI, Bezdicke DF, Lynch JM (1993). Soil organic matter dynamics and crop residue management. In Metting, F.B. Jr (ed). Soil microbial ecology: Application in agricultural and environmental management. Marcel Decker Inc. New York, pp. 65-94.
- Tisdall JM, Oades JM (1982). Organic matter and water stable aggregates in soils. *J. Soil Sci.*, 33: 141-163.
- Villegas-Pangga G, Blair GJ, Lefroy RDB (2000). Measurement of decomposition and associated nutrient release from barrel medic (*Medicago trunculata*) hay and Chickpea (*Cicer arietinum*) straw using an in vitro perfusion system. *Aust. J. Agric. Res.*, 51: 563-568.
- Wakindiki IIC, Ben-Hur M (2002). Soil mineralogy and texture effects on crust micromorphology, infiltration and erosion. *Soil Sci. Soc. Am. J.*, 66: 897-905.
- Wuddivira MN, Stone RJ, Ekwue EI (2009). Structural stability of humid tropical soils as influenced by manure incorporation and incubation duration. *Soil Sci. Soc. Am. J.*, 73: 1353-1361.