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Full Length Research Paper

Mulching an Arenic Hapludult at Umudike: Effects on saturated hydraulic conductivity and rhizome yield of turmeric

Nwokocha, C. C.[1*], Olojede, A. O.[1], Ano, A. O.[1] and Mbagwu, J. S. C.[2]

[1]National Root Crops Research Institute Umudike, Abia State, Nigeria.
[2]Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka, Enugu State, Nigeria.

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A study was carried out over two cropping seasons on an Arenic Hapludult at Umudike, southeastern Nigeria, to investigate and determine the quantity and type of mulch material that would optimize the rhizome yield of turmeric (*Curcuma longa* Linn) and improve the saturated hydraulic conductivity of the soil. The turmeric was planted at two depths; 5 and 10 cm. Two types of mulch, straw (elephant grass) and wood shavings were evaluated at 3 rates (0, 4 and 8 t/ha). Results showed that the effect of mulching on rhizome yield was significant. Yields increased significantly with the rate of mulch. Rhizome yield of turmeric was significantly influenced by the depth of planting and mulch type used. The 10 cm planting depth out-yielded 5 cm depth, and straw mulch out-yielded wood shavings. Optimum values of Ksat occurred at the 4 t/ha mulch rate. Bulk density, macro porosity and micro porosity were the most important physical properties influencing K_{sat} of the soil. Total porosity (P_t), and void ratio (V_e) were not good indicators of K_{sat} even though they positively explained between 98 and 96% of its variations, respectively.

Key words: Turmeric, mulching, saturated hydraulic conductivity, bulk density, porosity, Arenic Hapludult.

INTRODUCTION

Turmeric (*Curcuma longa* Linn), a shallow-rooted crop, is a relative of ginger and is indigenous to India. It is a spice used extensively by all classes of people in India. India exports 20 different spices, among which turmeric ranks fourth in terms of foreign exchange earnings (Naidu and Murthy, 1989). The soil and agro-climatic conditions at Umudike are favorable for successful cultivation of turmeric (Olojede et al., 2003).

Soil conditions at the rooting depth of a crop influence the full exploitation of its genetic potentials. Mulching affects the conditions in the surface layer of the soil, and in consequence, on the crops with shallow root systems. However, the magnitude of mulch effects on nutrient supply and improvement on soil physical properties depends on the quantity and quality of mulch, soil properties and environment (Lal, 1995). Lal (2000) reported for an Alfisol high variability in the data on K_{sat} with no consistent trends with regards to mulch rate or depth. Mulch rate had no significant effect on K_{sat} for any of the layers (0 to 50 cm depth). However, K_{sat}, changed significantly with depth (Lal, 2000). It therefore becomes necessary to: (1) determine the quantity and type of mulch material that will optimize the saturated hydraulic conductivity of an Ultisol at Umudike; and (2) evaluate their effects on rhizome yield of turmeric.

*Corresponding author. E-mail: chystova@yahoo.co.uk. Tel: +234 805 5846 329.

MATERIALS AND METHODS

Site characteristics

This study was carried out for two consecutive cropping seasons (2004/05 and 2005/06) on the National Root Crops Research Institute (NRCRI) Umudike Research Farm (latitude 05° 29′ N; longitude 07° 33′ E) in southeastern Nigeria. Soil of the expermental site was characterized as loamy sand (Arenic Hapludult), with acidic soil reaction [pH (H_2O) 5.42]. Total N (0.084%), exchangeable K (0.102 mg/kg), ECEC (3.98 cmol/kg), and OC (0.75%), were very low. The rainfall distribution as recorded at Umudike, followed the bi-modal pattern, typical of the tropical rain-

Table 1. Rhizome yield of turmeric as influenced by planting depth, mulch type and rate at Umudike.

Treatment	Rhizome yield (t/ha)		
	2004	2005	Means
Planting depth* (cm)			
5	8.03	6.15	7.09
10	9.59	10.31	9.95
Mulch type**			
Straw	10.23	10.51	10.37
Wood shavings	7.38	5.95	6.67
Mulch rate (t/ha)**			
0	4.06	3.52	3.79
4	10.60	8.66	9.63
8	11.76	12.51	12.14

*, ** = Significant at 5% and 1% alpha levels, respectively.

forest with peaks in July and September. Total annual rainfall amount within the period of study, was 1911.4 in 2004 and 2054.8 mm in 2005. Chemical characteristics of the mulch materials used showed that percent OM was high (5.10 %) in straw, but low (1.31%) in wood shavings.

Experimental design and soil sampling

A factorial combination of two planting depths, two mulch types and thee mulch rates with thee replications was arranged in a split-split plot format using a randomized complete block design. The main plot treatments were two depths of planting (5 and 10 cm). The sub-plot treatments were two mulch types (straw and wood shavings). The sub-sub-plot treatments comprised thee mulch rates (0, 4, and 8 t/ha). The dimensions of each sub-sub-plot were 3 m x 2 m. Planting was done in June each year. Mulch treatments (dry) were applied immediately after planting. Fertilizer (N. P. K. 15:15:15) was applied 8 weeks after planting (WAP) at the rate of 400 kg/ha. Primextra and Gramazone herbicides were applied, as pre-emergence, at the recommended concentrations, while supportive rouging was done at regular intervals to keep the plots weed free. Harvesting was done at 28 WAP and data collected on rhizome yield. Two undisturbed core samples were collected from each plot at 0 – 5 cm and 5 – 10 cm depths for saturated hydraulic conductivity and bulk density determinations.

Laboratory analysis

Measurements were taken on saturated hydraulic conductivity using the constant head method as described by Klute (1986), using the equation:

$$Ksat = \theta / At \times L / \Delta H \times 60$$

where θ volume of water per unit time; A = area of core sampler; t = unit time in min/h; L = length of core; and ΔH = hydraulic head difference. Bulk density (BD) was determined according to Blake and Hartge (1986). Total porosity (P_t), and macro-porosity (P_e), were obtained from BD values with assumed particle density (d_p) of 2.65 g/cm^3, as follows:

$$P_t = 100\,(1 - BD / d_p) \quad (1)$$

$$P_e = P_t - \theta \text{ (60 cm tension)} \quad (2)$$

where θ is the volumetric water content. Particle size distribution in calgon was measured by the hydrometer method (Day, 1965). Percent organic carbon (%O.C.) was determined by the dichromate oxidation method of Walkley and Black (Nelson and Sommers, 1982), organic matter (O.M) was determined by multiplying %O.C with the conventional Van Bernmeller factor of 1.724.

Data analysis

Statistical method of analysis of variance for a split-split plot design as outlined by Steel and Torrie (1980) was used for the analysis. Mean separation for significant effects ($P < 0.05$) was carried out using F-LSD, as described by Obi (1986). Correlation coefficients, coefficients of determination and regression equations, were used to explain relationships between yield and soil properties, and soil properties and soil indices.

RESULTS AND DISCUSSION

Effect of treatments on rhizome yield of turmeric

Effects of planting depth, mulch type and rate on rhizome yield of turmeric are shown in Table 1. Planting depths significantly influenced ($P < 0.05$) rhizome yield (t/ha) in both years. Planting at 10 cm depth consistently gave higher total rhizome yield in 2004 (9.59 t/ha), and in 2005 (10.31 t/ha) than at 5 cm depth (8.03 and 6.15 t/ha respectively). Mulching with straw significantly increased ($P < 0.05$), the total rhizome yield per hectare over wood shavings by 38.62% in 2004 and by 76.64% in 2005. Rhizome yield increased significantly ($P < 0.05$) with increase in mulch rate in both cropping seasons. Maximum rhizome yield of 11.76 and 12.51 t/ha in 2004 and 2005 respectively, were obtained at 8 t/ha mulch rate. Higher yield recorded at 10 cm planting depth may be due to the improvement of Ksat and macro-porosity, and reductions in micro-porosity and bulk density at the 5 cm depth, which subsequently, enriched the soil moisture content and aeration status of the soil at the 10 cm depth. Nwokocha et al. (2006) reported that straw mulch contains higher percent OM and improved soil structure better than wood shavings. These may have implications for the higher rhizome yield observed with straw mulch. Lower micro-porosity and BD, and higher Ksat and macro-porosity observed in mulched plots, and as mulch rate increased may be responsible for the increased yield due to mulch rate, and may have resulted from the beneficial effects of a mulch cover to breakdown the kinetic energy of the rain drops. Thus, reducing their impact pressure on the soil, and consequently, reducing soil compaction and aggregate disintegration and crusting. Also, according to Nwokocha et al. (2006) the decomposition of the mulch materials provide SOM which

Table 2. Effects of mulch types, rates and sampling depth on selected physical properties of an arenic hapludult.

Treatment	K_{sat} (cm/h)	P_t (%)	P_e (%)	P_m (%)	BD (g/cm^3)
Mulch type					
Straw	43.9	50.13	21.33	28.81	1.56
Wood shavings	44.8	51.91	18.92	32.94	1.55
LSD (0.05)	NS	NS	0.21**	NS	NS
Mulch rate (t/ha)					
0	18.3	49.71	11.55	38.16	1.57
4	54.9	49.29	22.26	26.94	1.58
8	60.0	54.08	26.55	27.53	1.51
LSD (0.05)	6.00**	2.08**	0.64**	2.08**	0.03*
Sampling depth (cm)					
5	54.4	51.26	21.73	29.53	1.51
10	34.4	50.79	18.52	32.22	1.59
LSD (0.05)	3.6**	NS	0.48**	1.39**	0.03**

*, ** = Significant at 5% and 1% alpha levels, respectively; NS = not significant at 5% alpha level.

Table 3. Percent increase in saturated hydraulic conductivity due to sampling depth and mulch application on an arenic hapludult.

Sampling depth (cm)	Mulch material	Ksat (cm/h)				% increase
		0	4	8	Mean	
0-5	Straw	15.4	60.9	79.2	51.8	414.3
	Wood shavings	29.0	78.4	63.3	56.9	118.3
5-10	Straw	10.0	40.5	57.2	35.9	472.0
	Wood shavings	18.3	39.8	40.1	32.7	119.1
Mulch type x rates	LSD (0.05)	12.0**				
Mulch type x depth	LSD (0.05)	12.9*				
Mulch rate x depth	LSD (0.05)	7.0**				
Mulch type x rates x depth	LSD (0.05)	NS				

*, ** = Significant at 5% and 1% alpha levels, respectively; NS = not significant at 5% alpha level.
% increase = [(Ksat value at 8 t/ha / Ksat control value) -1] x100.

helps to stabilize soil aggregates, thus making the soil conducive for rhizome development (Table 1).

Effect of treatments on saturated hydraulic conductivity, total porosity, macro and micro porosities and bulk density

Effects of mulch type, rate and sampling depth on saturated hydraulic conductivity are shown in Table 2. Mulch rate and sampling depth significantly influenced K_{sat}. Mulching at 4 t/ha rate was found to be optimum for K_{sat}. However, increase in K_{sat} due to mulch rate was more pronounced in straw than in wood shavings at both sampling depths (Table 3). Nwokocha et al. (2006) reported that straw (elephant grass) has higher organic matter content (5.10%) than wood shavings (1.31%). This may have been responsible for the pronounced percent increase in K_{sat} recorded by straw (443.2%) as against that by wood shavings (118.7%). More percent increase in Ksat occurred within the 10 cm soil depth than within the 5 cm soil depth. Increase in macro-porosity and decreases in micro-porosity and bulk density recorded at 5 cm depth may have facilitated the higher Ksat value (54.4 cm/h) obtained within the 5 cm soil depth (Table 2). Significant interaction was also obtained between mulch rates and sampling depths (Table 3). Optimum value of Ksat (69.7 cm/h) was obtained in the 4 t/ha x 5 cm depth interaction. The order was 8 t/ha x 5 cm depth (71.2 cm/h) = 4 t/ha x 5 cm depth (69.7 cm/h) > 8 t/ha x 10 cm depth (48.7 cm/h) > 4 t/ha x 10 cm depth (40.2 cm/ha) > 0 t/ha x 5 cm depth (22.2 cm/h) > 0 t/ha x 10 cm depth (14.2 cm/h). Higher Ksat, and P_e and lower BD observed in mulched plots, and as mulch rate increased may be

Table 4. Coefficients of determination and regression analysis between saturated hydraulic conductivity and physical properties of an arenic hapludult following mulch application (N = 72).

Independent variable	R^2	Regression models
Macro porosity ($P_{e,}$ %)	0.88**	K_{sat} = -13.44 + 2.87(P_e)
Micro porosity (P_m %)	0.94**	K_{sat} = 110.82 - 2.15(P_m)
Total porosity (P_t %)	NS	K_{sat} = -5.1 + 0.97(P_t)
Bulk density (BD g/cm^3)	0.98**	K_{sat} = 281.7 – 152.9 (BD)
Void ratio (V_e)	NS	K_{sat} = 23.3 + 19.8(V_e)

** and NS = significant at 1% and not significant at 5% alpha levels respectively.

Table 5. Simple linear correlation between saturated hydraulic conductivity and physical properties of an arenic hapludult at two sampling depths following mulch application (N = 36).

Physical property	Sampling depths	
	5 cm	10 cm
Macro porosity ($P_{e,}$ %)	0.85***	0.86***
Micro porosity (P_m %)	-0.76***	-0.49*
Total porosity (P_t %)	0.06NS	0.41*
Bulk density (BD g/cm^3)	-0.56**	-0.21NS

*,** and NS = Significant at 5%, 1% and not significant at 5% alpha levels, respectively.

responsible for the increased yield due to mulch rate. Lack of crusts and high earthworm activities observed on the mulched plots may have contributed more to their having higher K_{sat} rates, compared to the unmulched plots. The reduction in saturated hydraulic conductivity as sampling depth increased from 5 cm to 10 cm could be due to increased BD and reduced macro-porosity, with increasing soil depth. This is in agreement with the findings of Mbagwu (1995) who reported that K_{sat} and macro-porosity decreased with increase in soil depth. Lal (2000) also observed that K_{sat} changed significantly with soil depth.

Saturated hydraulic conductivity and soil physical properties

The correlation and regression analyses given in Table 4 showed that bulk density, macro porosity and micro porosity were the most important physical properties influencing K_{sat} of the soil. The negative linear regression relationship between K_{sat} and bulk density indicated that as bulk density increased to 1.84 g/cm^3, K_{sat} decreased and approached zero. This linear regression explained 98% of variation in K_{sat}. Linear relationship between K_{sat} and P_e explained 88% of the variation in $K_{sat.}$ This predicted negative K_{sat} for P_e below 4.58%; an unrealistic regression relationship. Similar result was reported by Mbagwu (1995), where he used an exponential model with P_e as the independent variable to explain the variation in K_{sat} and to produce a relationship having acceptable physical interpretations over the range of measured P_e values. Table 5 showed that macro porosity was the more consistent property that explained most of the variations in K_{sat} at either of the two sampling depths. Total porosity (P_t) and void ratio (V_e) were not good indicators of K_{sat} even though they positively explained between 98 and 96% of its variations, respectively. By definition, P_t is the sum of P_e and P_m and therefore, the overall contribution of P_t to K_{sat} is the sum of the individual contributions of P_e and P_m. The positive effect of P_e on K_{sat} (r = 0.94) was more than the negative effect of P_m (r = -0.97) implying that the overall contribution of P_t to K_{sat} was positive, though not significant at $P < 0.05$. This is consistent with the findings of Rasse et al. (2000) who reported that saturated hydraulic conductivities were significantly and positively correlated with macro porosity.

Conclusions

From these results, mulching increased the rhizome yield of turmeric with yield increasing with increase in mulch rates. Planting depth of 10 cm, out-yielded 5 cm depth. Straw proved a better mulch material than wood shavings. There was no significant difference between effects due to straw mulch and wood shavings on Ksat of the soil. Optimum values of Ksat occurred at the 4 t/ha mulch rate. Bulk density, macro porosity and micro porosity were the most important physical properties influencing K_{sat} of the soil. Linear relationship between K_{sat} and P_e was unrealistic. Total porosity (P_t) and void ratio (V_e) were not good indicators of K_{sat} even though they positively explained between 98 and 96% of its variations, respectively.

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