Mulching an Ultisol in Southern Nigeria: Effects on Physical Properties and Yields of Maize and Cowpea[1]

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ABSTRACT

A study was carried out over two cropping seasons at Nsukka, southeastern Nigeria, to determine the minimum rate of straw mulch for optimizing the physical conditions of a fragile Ultisol and maize and cowpea yields, soil-water sorptivity, transmissivity, steady-state infiltration rate, cumulative infiltration after 90 mins, and time to attain steady-state infiltration. These proved to be optimum at the 2.0 Mg·ha^{-1} mulch rate. Water retention and percent water-stable aggregates >0.5 mm were maximum at this rate, whereas soil compaction (measured by dry bulk density) was minimum. Evaporative moisture losses were 138%, 30%, 27% and 26% respectively, on the control 0, and 2.0, 4.0 and 8.0 Mg·ha^{-1} mulched plots. Supra-optimal soil temperatures (>30°C) were observed only on the bare plots, whereas no significant differences in maximum soil temperature among the mulched plots were noticed. Maize and cowpea yields were optimum at the 4.0 Mg·ha^{-1} rate, with respective increases over the bare plots of 80% and 67% at the same rate.

COMPENDIO

Se llevó a cabo un estudio durante dos períodos de cultivo en Nsukka, en el Sureste de Nigeria, con el fin de determinar la tasa mínima necesaria de residuos vegetales secos (mantillo de paja) para optimizar las condiciones físicas de un Ultisol frágil y los rendimientos de maíz y caupí; la capacidad de retención y de transmisión de agua del suelo; su velocidad de infiltración y de infiltración acumulativa después de 90 min. y el tiempo para alcanzar la infiltración uniforme. Estos fueron óptimos con una dosis de mantillo de 2.0 Mg·ha^{-1}, punto en el que la retención de agua y el porcentaje de agregados estables en agua (>0.5 mm) fueron máximos, mientras que la compactación (medida por densidad de masa seca) fue mínima. Las pérdidas de humedad por evaporación fueron de 138% en el testigo sin mantillo (0 Mg·ha^{-1}), y de 30%, 27% y 26% correspondientes a 2.0, 4.0 y 8.0 Mg·ha^{-1} en las parcelas con tratamiento. Sólo se midieron temperaturas de suelo arriba de las óptimas (>30°C) en las parcelas sin tratamiento, mientras que no se observaron diferencias significativas en la temperatura máxima del suelo en las parcelas tratadas. Los rendimientos de maíz y caupí fueron óptimos con dosis de 4.0 Mg·ha-1 que mostraron incrementos del 80% y 67% respecto de las parcelas sin tratamiento.

INTRODUCTION

In the tropics with distinct wet and dry seasons, clearing operations which leave the land surface bare predispose the topsoil to high evaporative rates and supra-optimal temperatures (>30°C) during the dry periods, and high rates of sheet and rill erosion during the wet periods. Mulching the soil surface has been shown to reduce soil erosion (6), increase infiltration rates (10), minimise evaporation (1) and reduce soil temperature (9). The overall effect of these changes is increased yields of cereal and legume crops (8, 11). For root crops like cassava however mulching was reported not to have any effects on root yield (3).

These studies utilized high rates of straw mulches (>6 Mg·ha^{-1}). In practical terms straw mulches are not readily available and where they are entail high transportation costs. There is therefore a need to further investigate the optimum mulch rate needed for

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soils in the tropics. The objective of this study was to determine the minimum amount of mulch material needed for optimizing the physical conditions of an ultisol in southern Nigeria as well as improving grain yields of maize and cowpea.

MATERIALS AND METHODS

This experiment was conducted in 1985 on the University of Nigeria Nsukka, Teaching and Research Farm, located at latitude 06°52'N and longitude 07°24'E with an elevation of 400 m above sea level. The location is within the forest-savanna transition vegetation zone and has an average annual rainfall of 1600 mm. The distribution of rainfall is bimodal with peaks in July and September. The soil is classified as an Ultisol (Oxic paleustult) with an isohyperthermic temperature regime. It is formed over false-bedded sandstone parent material and belongs to the Nsukka series.

In March 1985 the site was cleared, residues allowed to dry and then burnt in situ. The experimental layout was a randomized complete block design (RCBD). The treatments were four rates of mulch (0, 2, 4 and 8 $Mg \cdot ha^{-1}$) with dried elephant grass *(Pennisetum purpureum)*.

Separate trials were carried out with maize (var. TZBR, yellow) and cowpea (var. 355) as the test crops. Each crop was grown twice in the year with first planting on April 15 and the second planting on August 20. Each plot received a blanket application of 30 $kg \cdot ha^{-1}$ P (as single superphosphate), 120 $kg \cdot ha^{-1}$ K (as muriate of potash) and 20 $kg \cdot ha^{-1}$ Mg (as hydrated magnesium sulphate). Nitrogen at 120 $kg \cdot ha^{-1}$ and 60 $kg \cdot ha^{-1}$ was applied on the maize and cowpea plots respectively, one third at planting and two thirds four weeks after germination. A spacing of 25 cm x 75 cm was used on each of the 2.5 m x 2.25 m plots. Planting was two per hill and later thinned down to one per hill two weeks after emergence, thus giving a planting population of 5 ha^{-1} x 10^4 ha^{-1}. Small plot sizes were deliberately used to ensure uniform application of the mulch materials, so the number of replications was large (six). The grain and seed yields were measured at maturity and reported at 10 per cent moisture content.

Yield on the mulched plots was compared with the unmulched (control) by computing a mulch factor 95,

$$M = \left[\frac{Ym}{Yc} - 1 \right] \cdot 100 \tag{1}$$

where M = mulch factor, that is the fractional increase in yield over the control due to mulch material; Ym = yield on the mulched plot and Yc = yield on the control plot.

At the end of the second planting season the following soil parameters were measured on the maize plots only: in situ moisture content two and ten days after saturation by Gardner's (2) method, dry bulk density with cores of 300 cm^3 volume, water-stable aggregates >0.5 mm by the wet-seiving technique (5), organic matter by the dichromate oxidation method (4), and infiltration rate by the double ring infiltrometer technique. During the second season, soil temperature measurements were also taken at the flowering stage using a mercury-in-glass, bent-stem soil thermometer. The infiltration data were applied to Philip's (13) and Kostiakov's (7) models and analysed to estimate the sorptivity and transmissivity parameters thus:

Philip's Model

$$I = At + St^{1/2} \tag{2}$$

where I = cumulative infiltration (cm); S = soil water sorptivity; A = soil water transmissivity; and t = time elapsed (mins). To estimate A and S parameters, both sides of equation (2) were divided by $t^{1/2}$ giving

$$I/t^{1/2} = At^{1/2} + S. \tag{3}$$

A plot of $I/t^{1/2}$ against $t^{1/2}$ gives S as the intercept and A as the slope.

Kostiakov's Model

$$I = Kt^a \tag{4}$$

where K = a soil-dependent parameter closely related to the transmission characteristics of the soil, and "a" is another soil-dependent parameter whose value varies between 0 and 1. To estimate these parameters, equation (4) was linearized thus,

$$Log_{10}I = log_{10}K + alog_{10}t \tag{5}$$

A plot of $\log_{10}I$ against $\log_{10}t$ gives $\log_{10}K$ as the intercept and "a" as the slope from where the actual value of K can be obtained from the antilog.

The cumulative infiltration was obtained after 90 minutes. By differentiating equation (2) we obtain

$$\frac{dI}{dt} = i = A + \tfrac{1}{2}St^{1/2} \qquad (6)$$

where i = instantaneous infiltration rate at time, t. The lowest value of "i" is the equilibrium infiltration rate which has practical implications for water management studies.

Table 1. Some physico-chemical properties of the 0-30 cm depth Ultisol.

Parameter		Value
Coarse sand (%)	–	44
Fine sand (%)	–	28
Silt (%)	–	4
Clay (%)	–	24
pH (H_2O)	–	5 6
Organic Matter (%)	–	1 40
Total N (%)	–	0 081
Exch. bases (mEq/100 g)		
Na	–	0 11
K	–	0 12
Ca	–	2 40
Mg	–	0 90
CEC (mEq/100 g)	–	4 00
Aval P (Bray-1) mg/kg^{-1}	–	6 0
Moisture retention at		
0.01 MPa (%)	–	20
1 50 MPa (%)	–	6

RESULTS AND DISCUSSION

Water retention, bulk density, aggregate stability and organic matter content

Table 2 shows that beyond a mulch rate of 2.0 Mg·ha^{-1} no significant changes in water retention, bulk density and percent water-stable aggregates >0.5 mm due to mulching occurred. As for the residual organic matter content, the highest relative increase over the control (76 %) was also obtained at the 2.0 Mg·ha^{-1} mulch rate. Between the second and tenth day of soil moisture measurement, the percent water loss was 138, 30, 27 and 26 respectively on the control, 2.0, 4.0 and 8.0 Mg·ha^{-1} mulched plots. As two days after saturation water percolation due to gravity is deemed to have stopped, the moisture content then represents the field capacity, or for this sandy soil, the moisture held at 0.01 MPa tension. Hence between the two measurements most of the water loss is due to evaporation from the soil surface. The data therefore show, that beyond the mulch rate of 2.0 Mg·ha^{-1}, again there is no significant change in evaporative moisture loss due to mulch, whereas this rate of mulch was able to reduce moisture loss by about 100 per cent in comparison with the bare plots.

The mechanisms governing evaporative moisture loss, compaction and aggregate breakdown in soils are fairly well understood. Mulches reduce the intensity of radiation and wind velocity on the soil surface with attendant reduction in the net amount of heat entering the soil. This reduction in the heat flux density into the soil lowers soil temperature (as will be shown later) and therefore the amount and rate of evaporation from the soil. Also by reducing the kinetic energy of the impacting raindrops on the soil surface, mulches reduce soil compaction and aggregate disintegration. This explains the lower values of bulk density and higher values of percent aggregates >0.5 mm obtained on the mulched plots, and confirms earlier observations on this soil (2).

Infiltration characteristics

Data in Table 3 indicate that soil water sorptivity, transmissivity, steady-state infiltration rate, cumulative infiltration after 90 min. and time to attain steady-state infiltration, increased with mulch rate. The general trend shows, however, that the optimum mulch rate for attaining the highest values is between 2.0 Mg·ha^{-1} and 4.0 Mg·ha^{-1}. At the 2.0 Mg·ha^{-1} mulch rate the relative percentage increments over the control are 32, 450, 155, 225, 174 and 131 respectively for soil water sorptivity, Philip's soil water transmissivity, Kostiakov's soil water transmissivity, steady state infiltration rate, cumulative infiltration rate, cumulative infiltration and time to attain steady state infiltration, respectively. Such increases would generally imply less runoff, soil loss and flooding and increased aeration within the root zone.

Table 2. Effects of mulch rate on water retention (2 and 10 days after saturation), bulk density, water-table aggregates (> 0.5 mm) and organic matter content (maize plots).

Mulch rate (Mg/ha^{-1})	Volumetric water retained (%) 2 days after saturation	10 days after saturation	Bulk density (Mg/m^{-3})	Water-stable aggregates (> 0.5 mm)	Organic matter (%)
0	19a	8a	1.48a	20.3a	1.05a
2	26b	20b	1.26b	46.5b	1.85b
4	28b	22b	1.22b	50.9b	1.92bc
8	29b	23b	1.20b	51.2b	2.03c

Within the same row, figures followed by the same letters are not significant at P ≤ 0.05 using Duncan's range test.

Soil temperature

It can again be noticed from the soil temperature data in Fig. 1 that no significant differences in daily temperature variation were noticed among the 2.0, 4.0 and 8.0 $Mg \cdot ha^{-1}$ treatments, whereas differences between the control and any of the mulch treatments were significant especially between 12:00 h and 18:00 h. It is obvious therefore, that an application of just 2.0 $Mg \cdot ha^{-1}$ grass mulch is enough to reduce soil temperature within the 0 - 5 cm depth below the supra-optimal (>30°C) level. The difference in maximum daily soil temperature between the control and the 2.0 $Mg \cdot ha^{-1}$ treatment was 12°C. Supra-optimal temperatures, as observed on the bare plots, can reduce yields of some crops through reduction in the rate of root elongation (8).

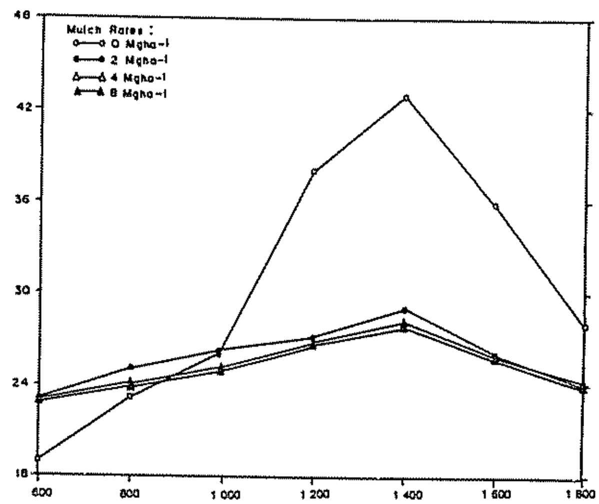

Fig. 1. Daily soil temperature variation under different mulch rates on an Ultisol in Nigeria.

Table 3. Effects of mulch rate on the water transmission characteristics of an Ultisol in Southern Nigeria (maize plots).

Mulch rate (Mg/ha^{-1})	Sorptivity (S)	Transmissivity[1] (A)	Transmissivity[1] (K)	Equilibrium infiltration rate ($cMnr^{-1}$)	Cumulative infiltration (cm)	Time to attain equilibrium infiltration (min)
0	3.66a	0.06a	1.32a	25.4a	47a	26a
2	8.50b	0.33b	3.06b	82.5b	129b	60b
4	9.08c	0.48c	5.01c	85.3b	143bc	62b
8	9.39c	0.52c	5.46c	90.8b	156c	67b

1 The sorptivity (S) and transmissivity (A) are obtained by analysis of Philip's (13) infiltration model whereas the transmissivity (K) was obtained by analysis of Kostiakov's (7) infiltration model.

Within the same row, figures followed by the same letters are not significant at P ≤ 0.05 using Duncan's multiple range test.

Crop performance

In the first season of 1985 plant height differed significantly between the control and the 2.0 Mg·ha^{-1} mulched plots, but it was only during the second (drier) season that height differences among the mulch rate were significant (Table 4). In both seasons maize and cowpea yields also differed significantly among the 0, 2.0 and 4.0 Mg·ha^{-1} mulch rate after which differences were not significant.

From the mulch factor values shown in Fig. 2 it can be observed that the fractional increase in the yield of each crop at the 2.0 Mg·ha^{-1} mulch rate was higher in the second (relatively drier) than the first (relatively wetter) seasons. Considering both seasons however, it is noticed that for maize of the 80 per cent increase in yield (over the control at the 4.0 Mg·ha^{-1} mulch rate), 40 per cent was due to the 2.0 Mg·ha^{-1} rate. For cowpea of the 67 per cent yield increase at the 4.0 Mg·ha^{-1} mulch rate, 45 per cent

Table 4. Effect of mulch rate on yield of maize and cowpea on an Ultisol in Southern Nigeria (1985).

	First Season			Second Season		
Mulch rate (Mg/ha^{-1})	Maize height (cm)	Maize yield (Mg/ha^{-1})	Cowpea yield (kg/ha^{-1})	Maize height (cm)	Maize yield (Mg/ha^{-1})	Cowpea yield (Mg/ha^{-1})
0	179a	2.86a	152.9a	85a	1.64a	739.4a
2	204b	3.70b	213.3b	103b	2.47b	1 108.6b
4	206b	5.16c	242.7c	166c	2.96c	1 298.3c
8	212b	5.43c	267.2c	176d	2.98c	1 342.0c

Within each row figures followed by the same letters are not significant at $P \leq 0.05$ using the Duncan's multiple range test.

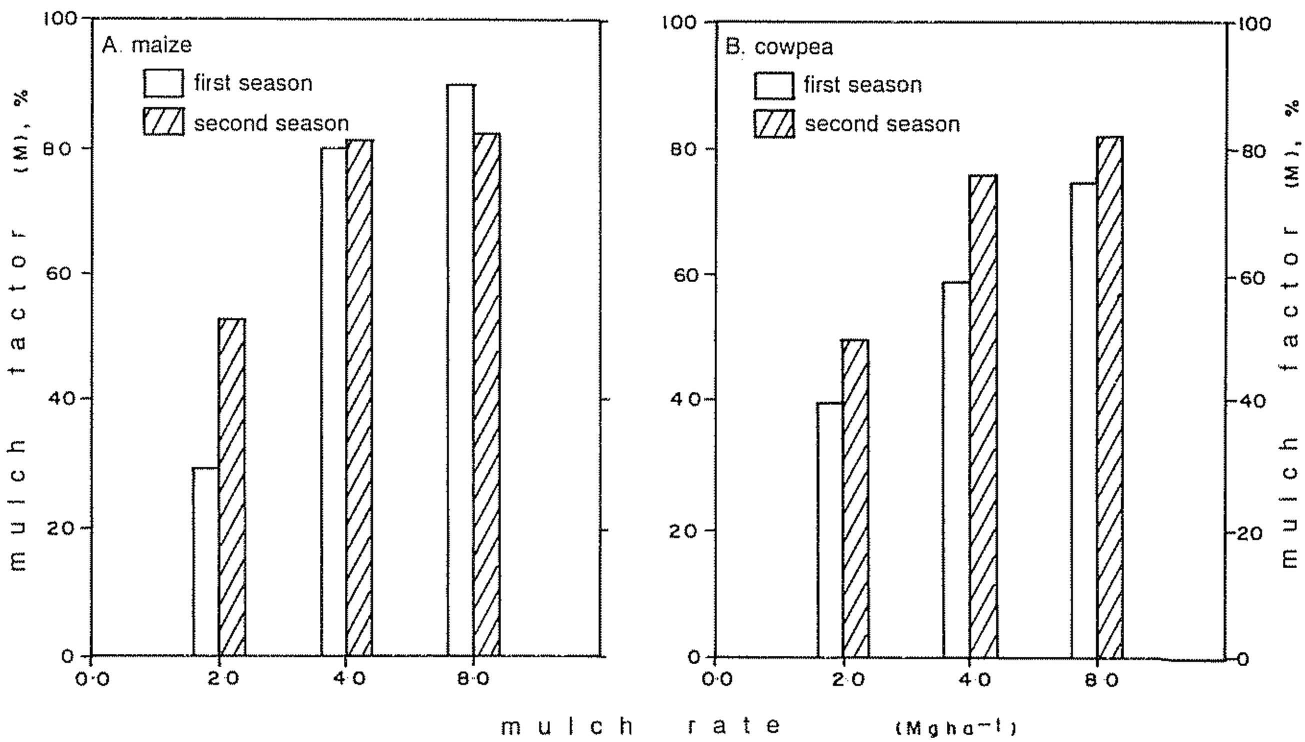

Fig. 2. Influence of mulch rate on mulch factor of maize and cowpea on an Ultisol in Nigeria. Mulch factor = [(ym/yc)-1] 100 where Ym = yield on mulched plot and Yc = yield on bare plot.

was due to the 2.0 $Mg \cdot ha^{-1}$ rate. In practical terms therefore, the 4.0 $Mg \cdot ha^{-1}$ mulch rate appears to be the ideal rate for optimizing the yields of these two crops on this soil.

CONCLUSIONS

The results of this study show that for optimizing the physical conditions and productivity of the Ultisol studied, a straw mulch rate of between 2.0 $Mg \cdot ha^{-1}$ and 4.0 $Mg \cdot ha^{-1}$ is ideal. Higher rates appear superfluous. Increases in yields of maize and cowpea observed at these mulch rates were accompanied by increased moisture retention within the root zone, organic matter content and soil water transmissivity; and reduced compaction, soil temperature and evaporative moisture losses.

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