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SOIL TEMPERATURE, SOIL MOISTURE AND MAIZE YIELD FROM MULCHED AND UNMULCHED TROPICAL SOILS

by RATAN LAL

International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria

SUMMARY

The effect of mulching on maize yield was investigated for luvisol and cambisol tropical soils during 1970–72. The increase in grain yield by mulching was 46, 52 and 22 per cent respectively, for 1970, 1971 and 1972. Mulched plants had higher growth rate and vigour and chlorotic symptoms of nutritional disorders were observed only for unmulched plants. Mulching significantly decreased the maximum soil temperature measured at 5, 10 and 20 cm depths. In the initial stages of crop growth, temperature differences of as much as 8°C were observed between mulched and unmulched plots at a 5-cm depth. Mulched plots also had a higher soil moisture content. Increase in grain yield by mulching was attributed primarily to a decrease in soil temperature and partly to improved soil moisture regime.

The sensitivity of maize to high soil temperature at the seedling stage was demonstrated by Grobbelaar [7] and Walker [15]. During early vegetative growth the root activity of maize is confined to the upper few cm of soil and the growing point of maize remains below the soil surface until about the fourth week of growth. Though the culm development is largely embryonic, the number of ovules on the embryonic ear shoots are determined during this period of growth. Soil conditions at the early stage of growth may, therefore, determine the theoretical potential of the maize plant. The optimal range of soil temperature for maize has been found to be from 25 to 34°C [8 15].

Soil temperature is significantly influenced by mulching and tillage practices [1 2 8 17]. Considering its agricultural importance the work done on the influence of mulches on soil and water management and

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crop growth in humid tropical West Africa is rather scanty. Lawes (1962) showed that water conservation in the loess plain soils in Northern Nigeria was improved by mulching. Similarly, Chinwuba[6] reported that soil moisture for a maize crop in Western Nigeria was increased by mulching. In a lysimetric investigation carried out by Federal Department of Agricultural Research, Nigeria, (1966), mulching significantly reduced evapo-transpiration of upland rice. Lal [8] showed that mulching lowered the surface temperature of soil. The beneficial effect of mulching on the growth and production of yam in tropical soils has also been demonstrated [10].

The effectiveness of mulch on moisture conservation and evaporation control has long been a controversial issue. This may be because the influence of mulch in controlling evaporation depends not only on the water retention and transmitting characteristics of the soil but also on the prevailing evaporative demand of the atmosphere and the frequency of rains [4 5 12].

The objective of this report is to describe the effect of mulching on soil temperature, soil moisture and maize growth at the International Institute of Tropical Agriculture (IITA).

MATERIAL AND METHODS

Mulching experiments were conducted at IITA, which is located about 30 km south of the northern limit of the lowland rain forest. The bimodal character of rainfall distribution in western Nigeria results in two distinct growing seasons, one from April to July and the other from August to November. The total annual rainfall varies from 900 to 1700 mm. The experiments were conducted during 1970–72 on soils of Egbeda association derived from basement complex rocks and characterized by a deep, red, clayey profile with a sandy surface soil and a layer of angular and sub-angular quartz gravels in the horizon immediately below the surface horizon [14]

General physical properties of the soil are described in Table 1. The organic carbon content of the surface soil is about 1.5 per cent, which decreases abruptly in the third horizon. The overall bulk density of the various horizons is about 1.5 cm^{-3}, though the bulk density of the fine material within the quartz stones is low. The clay content increases progressively with depth in the profile. The gravelly horizon is believed to offer mechanical resistance to root penetration, particularly to those of cereals such as maize and rice.

The moisture retention characteristics obtained on the disturbed soil samples indicate that the available water holding capacity of the surface soil (1–5 cm depth) is 0.4 cm while that of the second horizon (5–15 cm depth) is

TABLE 1

General physical properties of the soil profile

Horizon Depth (cm)	Organic C %	Bulk density g cm^{-3}	Mechanical analysis (%)			
			Gravels	Sand	Silt	Clay
0– 5	1.54	1.47	25.0	50.1	8.9	16.0
5– 15	1.50	1.46	20.0	46.3	13.4	20.3
15– 45	0.76	1.55	45.0	26.8	7.6	22.6
45– 65	0.28	1.61	40.0	17.9	8.3	33.8
65– 95	0.26	1.51	40.0	17.8	3.6	38.6
95–110	0.18	1.52	33.0	13.5	9.6	43.9

TABLE 2

Soil moisture characteristics

Horizon depth (cm)	Soil moisture (gg^{-1}) at various suction (bars)							
	0	0.1	0.3	0.5	1	2	3	15
0– 5	0.397	0.199	0.119	0.110	0.105	0.100	0.09	0.069
5– 15	0.361	0.181	0.178	0.166	0.121	0.116	0.084	0.071
15– 45	0.433	0.289	0.194	0.186	0.153	0.138	0.128	0.124
45– 65	0.480	0.291	0.266	0.264	0.244	0.229	0.220	0.219
65– 95	0.525	0.313	0.290	0.289	0.271	0.261	0.245	0.210
95–110	0.570	0.330	0.311	0.310	0.288	0.247	0.260	0.191

TABLE 3

List of the treatments imposed

Treatments	1970	1971	1972	
			1st season	2nd season
Time of planting	Sept. 11, 1970	April 15, 1971	April 12, 1972	Sept. 5, 1972
Variety	NS-5	Comp AxComp B	Comp AxComp B	Comp AxComp B
Rice straw mulch	2 tons/ha	2 tons/ha	2 tons/ha	2 tons/ha
Forest litter mulch	—	—	2 tons/ha	2 tons/ha
Termite control with Dieldrex-20	—	—	0.5 kg/ha	0.5 kg/ha

1.6 cm. The majority of the pores drain at a suction of about 100 cm of water (Table 2).

Mulching experiments in 1970 and 1971 involved only the use of rice straw, whereas forest litter was used as an alternate source of mulch for the 1972 trials (Table 3). Mulching was done immediately after planting at the rate of about 4 tons of rice straw or forest litter per hectare. This material covered the inter-row soil surface to a depth of about 1 cm.

Maize seeds were planted in a disced field at a distance of 75 cm between and 25 cm within the rows. Fertilizer application at planting was made at the rate of 100 kg of ammonium sulphate-nitrate, 500 kg of single superphosphate and 120 kg of muriate of potash per hectare. A top dressing at the rate of 360 kg of ammonium sulphate-nitrate was applied 3 weeks after planting. This fertilizer application was equivalent to a total of 120 kg N, 100 kg P_2O_5 and 60 kg of K_2O per hectare. The crop was regularly sprayed to control stalk borer with carbaryl (Vetox 85) at the rate of 2 kg per hectare. Termite control treatment in 1972 consisted of spraying with Dieldrex-20 at 0.5 kg per hectare one week before planting. The chemical was thoroughly incorporated in 5 to 10 cm of the soil surface.

The experiments were conducted on plots of (10×2) m^2 size and with a 2-m wide buffer zone. The treatments were replicated 3 times and a completely randomized design was used. The data were analysed statistically.

Weekly measurements of soil moisture contents were made gravimetrically at 0–10 and 10–20 cm depths. Accumulative soil moisture content was calculated by sequential integration of volumetric moisture content over time. Soil temperature measurements were made at 7:30 a.m. and 3 p.m. using bent-stem soil thermometers installed at 5, 10 (for 1971 only) and 20 cm depths. Soil temperature and moisture measurements were not made for 1970 trials. Weekly measurement of plant height were recorded as an index of plant vigour and growth.

RESULTS AND DISCUSSIONS

Soil temperature

Mulching significantly decreased the maximum soil temperature for all the soil depths investigated (Figures 1, 2 and 3). In the initial stages of crop growth, temperature differences of as much as 8°C were observed between mulched and unmulched plots at a 5-cm depth. The maximum recorded temperature for unmulched plots were as high as 42°C at a 5-cm depth (Fig. 1). The minimum soil temperature was, in general, lower for unmulched plots, and hence the diurnal fluctuations were higher. The observation made on soil temperature at one hour intervals indicated that there were phase differences of daily temperature fluctuations due to mulching. The maxima for unmulched plots at 5 cm depth occurred at about 3 p.m. followed by a sharp decline while the maxima for the mulched plots was around 4 p.m. with a gradual decline in the temperature. The temperature differences of mulched plots at 3 and 4 p.m. were of the order of 0.2 to 0.3°C.

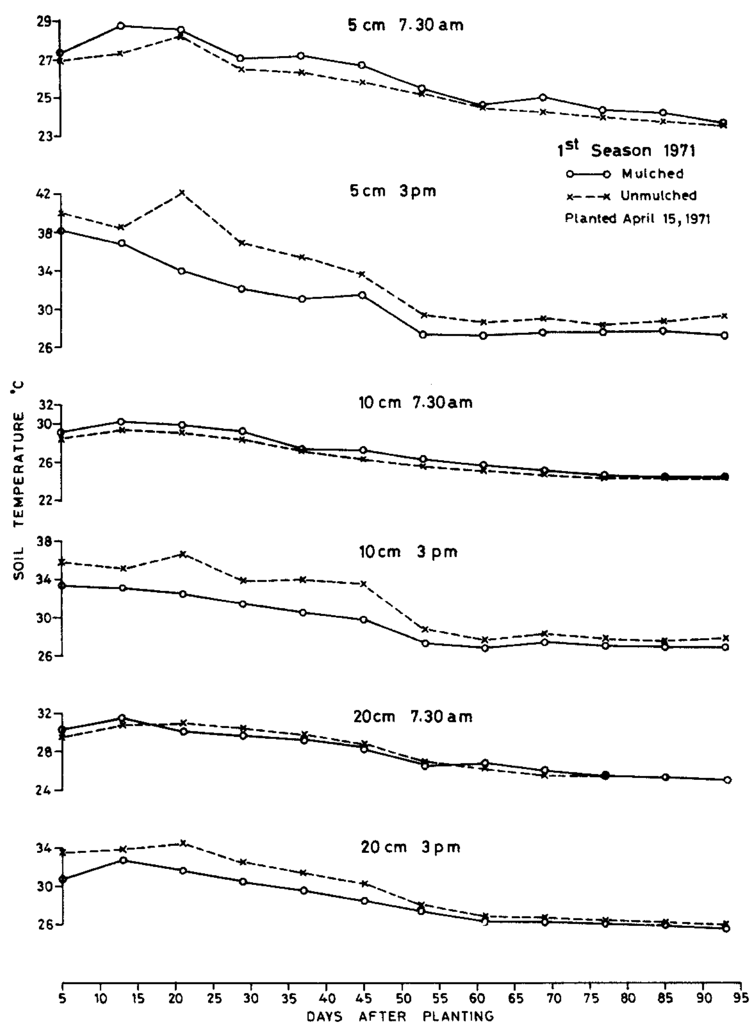

Fig. 1. Effect of mulching on soil temperature for the first season, 1971.

At 20 days after planting the differences between the maximum temperature for the mulched and unmulched plots of 1971 were 7.2, 3.6. and 2.6°C for the 5, 10 and 20-cm depths, respectively. For the first season of 1972 these differences were 6.1 and 1.5°C, at the 5 and 20 cm depth respectively. Maximum soil temperature in unmulched plots even at the 20 cm depth, was generally above the optimum level for maize growth. For instance, soil temperature at this depth,

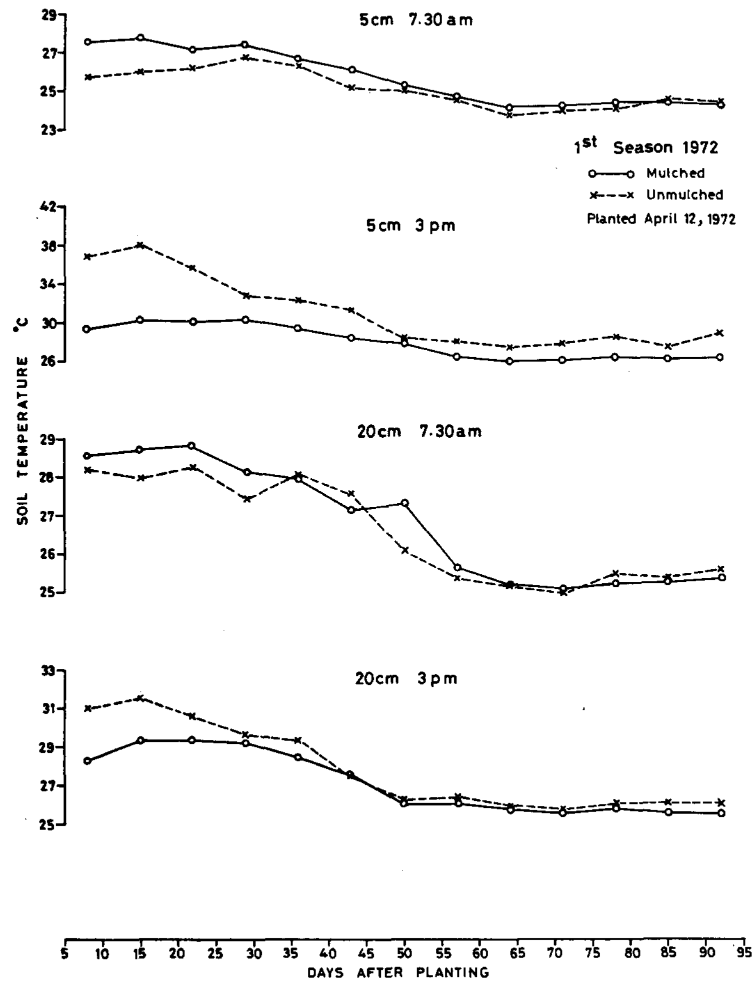

Fig. 2. Effect of mulching on soil temperature for the first season, 1972.

20 days after planting was 32, 29.4 and 27.4°C respectively for 1971 and the first and the second season of 1972. Soil temperature for unmulched plots at 5-cm depth and 3 p.m. was above 30°C until 52, 41 and 37 days after planting respectively for 1971 and the first and second crop of 1972.

The soil temperature for the second season of 1972 decreased until about 45 days after planting and then increased with the start of the dry season in mid-October (Fig. 3). The maximum soil temperature

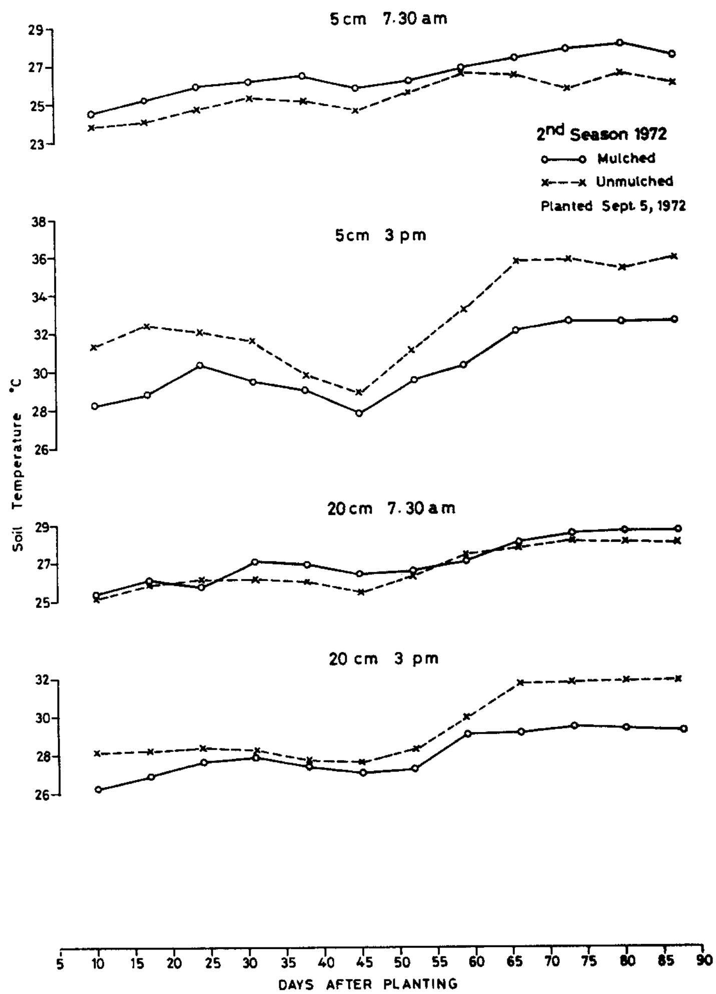

Fig. 3. Effect of mulching on soil temperature for the second season, 1972.

at the silking stage was 35.6°C for unmulched and 32.3°C for mulched plots at 5-cm depth.

Soil moisture

Mulched plots had a higher soil moisture content throughout the growing season than the unmulched plots for both 0–10 and 10–20 cm depths (Figs. 4, 5 and 6). Soil moisture content is generally higher for 0–10 than for 10–20 cm depths for all the experiments

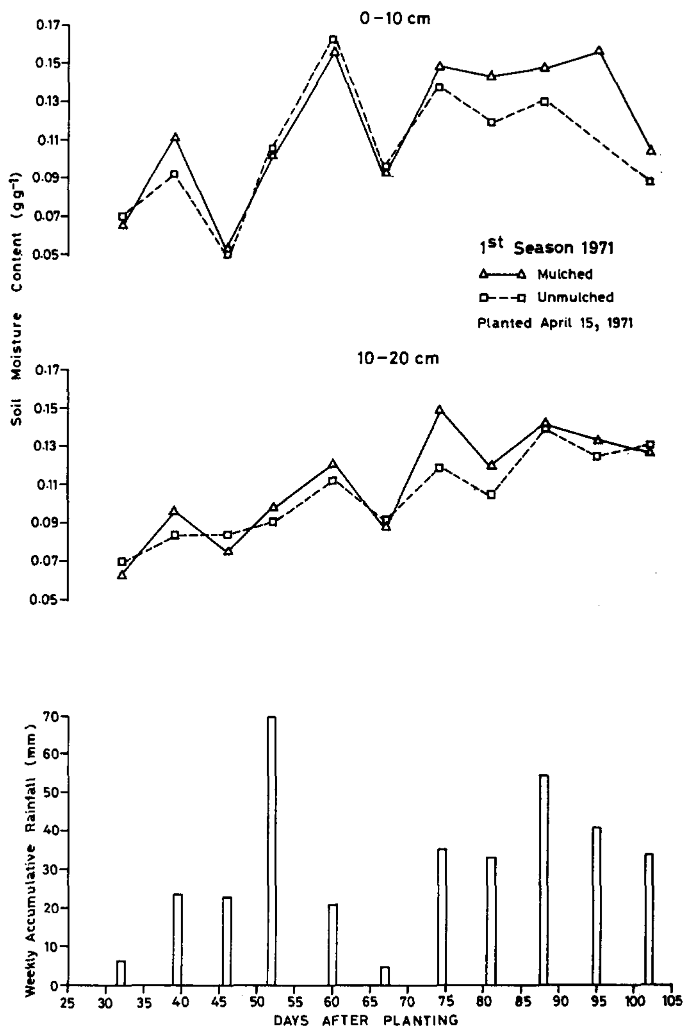

Fig. 4. Effect of mulching on soil moisture storage for the first season, 1971.

conducted. Increase in soil moisture storage for the entire growing period for the mulched over unmulched plots is given in Table 4. This increase in soil moisture is equivalent to 12.2, 7.2, and 8.3 per cent of the rains received during 1971 and during the first and second season of 1972, respectively. The absolute quantity of moisture stored however, was the highest for the first and the lowest for the second season of 1972 (Table 4). Mulching improved soil moisture stor-

TABLE 4

Increased in soil moisture of mulched over unmulched plots

Depth (cm)	Cm of water		
	1st Season 1971	1st Season 1972	2nd Season 1972
0–10	2.26	3.24	1.12
10–20	2.11	1.22	0.70
Total	4.37	4.46	1.82

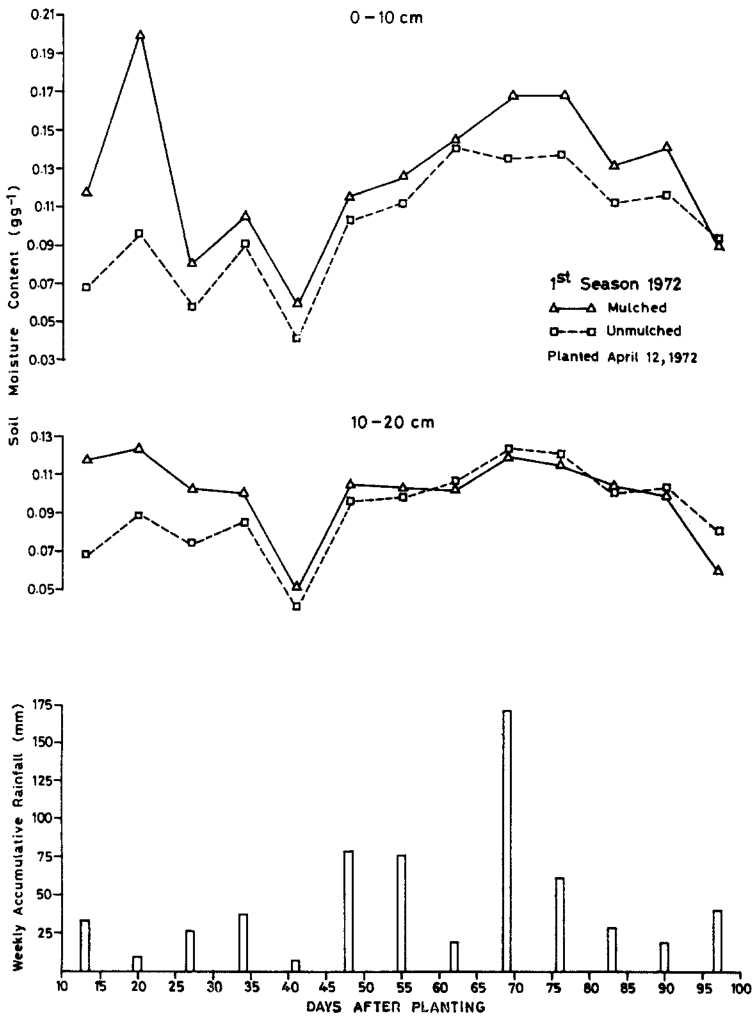

Fig. 5. Effect of mulching on soil moisture storage for the first season, 1972.

age more in the first than in the second season of 1972, indicating thereby the correlation between the soil moisture storage by mulching and the frequency and the quantity of rainfall received. This implies that mulching improves soil moisture storage for short periods rather than long periods of drought. These results agree with the findings of Lemon [12] that mulching decreases evaporation losses only when the soil is at the first stage of the drying cycle. When at

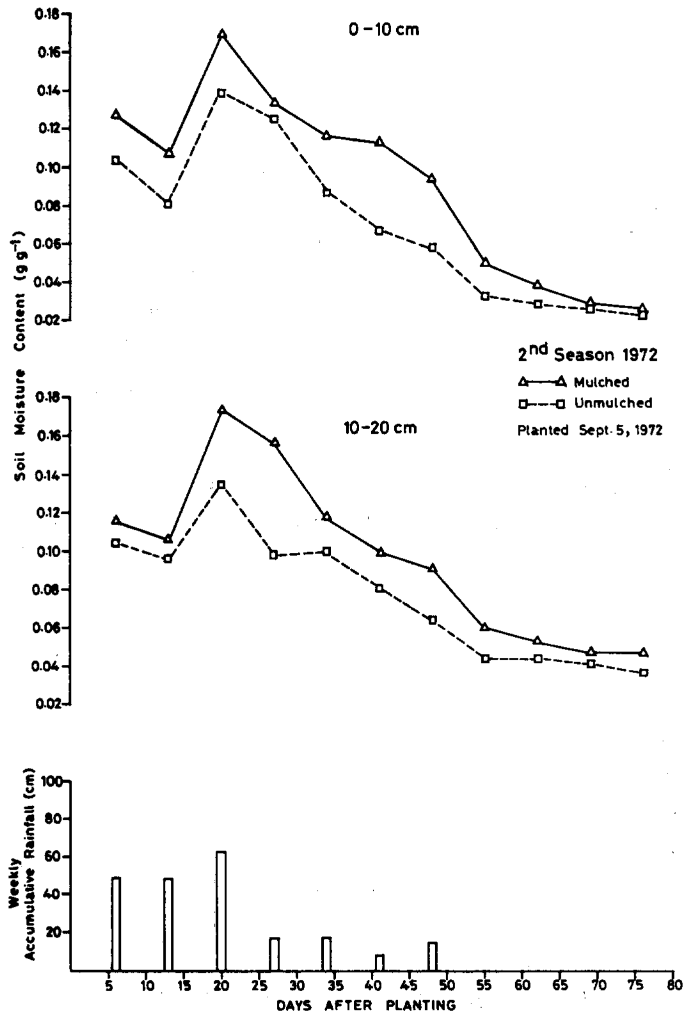

Fig. 6. Effect of mulching on soil moisture storage for the second season, 1972.

the second or third stage of drying, the evaporative demand of the atmosphere is not a limiting factor for soil moisture retention.

The lesser increase in percent of the rain stored by mulching in the first as compared to the second season of 1972 indicates the importance of soil properties in moisture retention under mulching. Only a fraction of the high rainfall received in the first season was stored in the 0 to 20-cm layer because of the low moisture holding capacity of the sandy surface soil. The efficiency of mulching in moisture storage is higher for soils of heavy texture with higher available water holding capacity.

Mulching indirectly influenced the moisture holding capacity and moisture release characteristics of the soil. Since the unmulched plots eroded severely, the loss of the surface soil over a period of three years decreased the moisture holding capacity of the soil (Fig. 5).

Weed growth

Mulching significantly suppressed weed growth. Weight of fresh weeds harvested eight weeks after planting in the second season of 1972 was significantly higher in the unmulched than in the mulched plots (Table 5). Lower soil moisture content in the unmulched plots could also be partly due to more weed growth.

TABLE 5

Effect of mulching on weed control

Treatment	Weed growth (kg/plot)
Rice straw mulch	14.96
Forest litter mulch	12.96
Control	45.97
LSD (.05)	8.77

Plant growth and vigour

Mulched plots had more vigorous growth than the unmulched ones (Fig. 7). Greater differences in plant heights for 1971 crops may be attributed to high temperature for the unmulched plots in the seedling stage (Fig. 1). In addition, the young leaves of unmulched maize seedlings showed chlorotic symptoms. This may be partly due to restricted root growth and therefore poor fertilizer efficiency of the

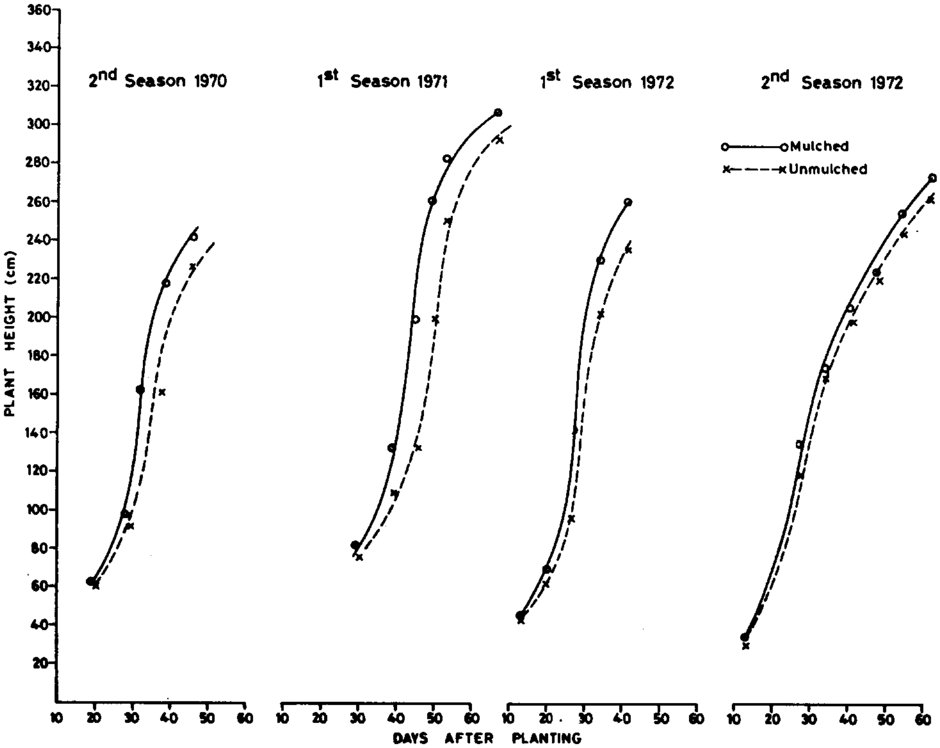

Fig. 7. Effect of mulching on plant height.

unmulched plots. These symptoms of high-temperature-induced nutrient deficiency in maize seedlings were also demonstrated by Walker[14].

Grain yield

The grain yield for 1970 and 1971 is shown in Table 6. Though the increase in yield was 46 and 52 per cent for 1970 and 1971, respectively, the yield level was low for the 1970 crop. This was primarily due to a short rainy season in 1970.

The experiments conducted in 1972 showed that the grain yield for the first season was significantly influenced by mulching, irrespective of mulching material (Table 7). Termite control was not significant, since the surrounding forest had been cleared and the experimental land had been under cultivation for three years. There

TABLE 6

Effect of mulching on grain yield (1970–1971)

Treatment	Grain yield (tons/ha)	
	1970	1971
Mulched	0.78	5.4
Unmulched	0.53	3.6
LSD (.05)	0.32	0.7

TABLE 7

Effect of mulching on grain yield (1972)

Treatment	Grain yield (tons/ha)	
	With termite control	With termite control
Rice straw mulch	4.5	4.4
Forest litter mulch	4.4	4.3
Control	3.6	3.6
LSD (.05)	0.7	0.7

was no grain yield for the second season crop due to a drought at the silking stage.

The increase in grain yield by mulching may be attributed to a decrease in soil temperature (Arndt[3], Walker[14], improved soil moisture conditions and a variety of resultant chemical and biochemical factors associated with mulching. The absence of grain formation in the second season of 1972 crop and lower yield for 1970 crop may entirely be due to high soil temperature at silking stage of growth (Fig. 3) and low availability of soil moisture (Fig. 6).

CONCLUSIONS

The results emphasize the beneficial effects of mulching as measured by the integrated effect of all parameters in terms of grain yield. The agronomic importance of yield increase by mulching is significant. It is, however, difficult to attribute the components of yield increase to various parameters, such as soil temperature and soil moisture. Model studies on the influence of mulching on thermal properties, *e.g.* thermal conductivity and thermal capacity of soil in relation to crop growth, should be conducted to clarify the effect of thermal regime.

The thermal regime of tropical soils under rainforest is significantly altered by clearing the land. Unless proper cultural practices are adopted, high soil temperature in the surface layers can be a limiting factor in crop production in the tropics. Mulching is one approach to overcome this limitation. The other is to manage crop residue with tillage techniques such as minimum tillage and the use of herbicides to control weeds. These cultural practices will not only decrease soil temperature hazards and improve soil moisture conditions but also reduce soil erosion.

In the light of these results, the choice of suitable varieties is important. A maize variety with a vigorous growth in the initial stages and with a strong root system to penetrate quickly through the upper 20 cm of the soil should be more able to tolerate the adverse effects of high soil temperature.

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