RESPONSE OF CROP PLANTS TO HIGH SOIL TEMPERATURE WITH PARTICULAR REFERENCE TO MAIZE

by

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Field investigations carried out at IITA, Ibadan, Nigeria, have indicated that high soil temperature may be a major factor causing yield reduction of maize (Zea mays L.) and yam (Dioscorea rotundata) planted on heaps or ridges (Lal, 1973, Lal and Hahn, 1973). The positive response of maize to straw mulching on flat seed beds (Chinwuba,1965; Agboola and Udom, 1967; Lal,1974) may also be due to reduction of soil temperature. These results were obtained on upland soils with shallow coarse-textured surface horizon overlying a stone line, a common feature of West Africa soils derived from basement complex rocks. Ibadan lies in the zone of transition between the humid and subhumid tropics with a mean soil temperature of 26.3°C and rainfall of 1250 mm. From this work, it was difficult to estimate the portion of yield reduction on unmulched plot attributed directly to high soil temperature as compared with that due to increased moisture stress. The other effects of mulching which may be involved are lack of surface crustation, minimal nutrient loss in surface water runoff, and release and/or fixation of some nutrient elements.

Investigations relating crop response to soil temperature are mostly conducted with constant temperature throughout the root zone. It has been shown that maize growth rate declines very rapidly when grown at a root zone temperature of above 30°C. (Brouwer, 1962; Grobellnar,1963; Walker, 1969, Lal, 1974). The growth rate of maize at soil temperature above 36°C is negligible. At Ibadan, the maximum temperature at 5cm depth frequently exceeds 36°C for part of the day during the early stages of growth of maize crops. However, it is clear from a few investigations of the response to soil temperature fluctuating on a diurnal basis (Walker, 1970; Lal, 1974), that such short periods of high temperature do not have the same effect as continuous exposure to the same temperature. It is possible that in the field the lower temperature of the deeper soil is also an important factor in the amelioration of the effect of high temperature near the surface.

This report describes field experiments designed to partially separate the individual factors that are modified by straw mulching in order to determine the importance of soil temperature relative to the other factors, and also a new approach to work with controlled soil temperature in artificial environments.

Field Response of Maize to High Soil Temperature

Plastic mulches have been extensively used in the temperate regions to increase soil temperature at the same time increasing the average soil moisture content. (Hanks et al, 1961). Field investigations at IITA have shown that a selection of various mulching materials can be used to create a range of soil temperatures with negligible differences in the average soil moisture content. The effect of mulching with clear polythene, black polythene and rice straw on the soil temperature and soil moisture content during selected periods of 1974 and 1975 first seasons is shown in Table 1 and 2 respectively. The magnitude of the soil temperature differences depends, amongst other factors, on soil type and the flux density of global radiation reaching the ground surface, but the ranking order of the treatments only changes in exceptional circumstances. For example, the maximum temperature is in the order Clear Polythene > Black Polythene > Unmulched > Straw; while for the minimum temperature, the order becomes Clear Polythene > Black Polythene > Straw > Unmulched because the straw mulch reduces head loss at night as well as heat gain during the day.

Table 1. The effect of different mulching material on soil temperature (C) and soil moisture (1st Season, 1974).

	Unmulched	Clear Polythene	Black Polythene	Straw
Soil Temperature[3] 0700 hr	24.4	29.2	27.7	25.6
1500	36.9	42.7	38.6	33.0
Soil Moisture[4] (%, w/w)	12.6	17.3	17.2	16.4

[3]Mean of measurements at 5 cm depth during the 3rd week after planting

[4]Mean of 14 measurements made at weekly interval, 0-10 cm depth.

Table 2. Effect of different mulches on soil temperature[5] (C) and soil moisture[6] (1st Season 1975).

	Unmulched	Clear Polythene	Black Polythene	Straw
0700 hr	27.0	30.4	30.0	28.5
1500 hr	40.2	43.2	40.7	33.5
Soil Moisture (%, w/w)	14.53	16.09	16.49	16.20

[5]Mean of 20 daily measurements at 5 cm depth during the first 23 days after planting.

[6]Mean of 9 measurements made at regular intervals over the first 23 days after planting 0-10 cm depth.

The soil moisture content records from both seasons indicate that the only major difference is between the unmulched and the mulched treatments, the various mulches being virtually identical.

The plant height data at 5 weeks after planting for 1974 and 1975 is shown in Table 3. The plant height at this stage of growth was significantly lower under clear polythene, with the highest maximum and minimum soil temperature, than in any of the other treatments. Since the soil moisture conditions under different mulches are approximately the same, the suppression of plant growth under clear polythene can therefore be attributed to the detrimental effect of high soil temperature. The difference in plant height between the straw mulched and unmulched treatments is likely to be due partly to the difference in soil moisture and partly to the difference in soil temperature between the two treatments. This interpretation is based on the intermediate plant height observed under black polythene, where the soil temperature is comparable with that of bare ground while the soil moisture content is comparable to that under straw mulch.

Table 3. Effect of different mulches on plant height (cm) in 1974 and 1975.

Mulching Material	1974	1975
Unmulched	123.4	163.5
Clear Polythene	118.7	139.2
Black Polythene	136.3	172.6
Straw	144.9	175.5

The relative grain yields from the 1974 crop shown in Table 4, reveals the predominating influence of water stress due to an extended drought from the 3rd to the 7th week after planting. The detrimental effect of high temperature under relatively favourable soil moisture condition is evident in the 10% yield difference between clear polythene and black polythene. Since the maximum temperature without any mulch is very similar to that under black polythene, the slightly higher yield obtained under black polythene compared with straw suggest that in this season high soil temperature was not the major factor responsible for the yield reduction that occurred in the unmulched treatments. This conclusion may not be valid if the response to high temperature is greatly modified by water stress. Unfortunately, these experiments cannot yield any information concerning such an interaction. Therefore, as regards the effect of soil temperature, the important conclusion to be drawn from this experiment is that with a moderate soil moisture stress, a yield reduction of about 10% can result from a treatment that increased the soil temperature at 5cm depth by a maximum of about 5°C. If moisture stress were not a limiting factor, the temperature difference of 5°C might result in greater yield reduction.

Table 4. Relative grain yield and yield parameter as affected by different mulches (1st Season, 1974).

	Unmulched	Clear Polythene	Black Polythene	Straw
Grain Yield	100	113	124	120
Dry stower weight	100	107	132	122

Response to constant versus fluctuating soil temperature

Interpretation of controlled environment experiments involving constant root zone temperature in terms of prediction of the response to the soil temperature regime of the field is clearly impossible.

An attempt is, therefore, being made to develop apparatus whereby reproducibly controlled diurnal and spacial variation in soil temperature regime can be achieved in a container of soil fitted with transparent sides to permit measurement of root growth as well as shoot growth. This approach to understanding the significance of the variable nature of soil temperature in the field appears to offer great potential. Specifically, some of the questions which may be answered are:

(i) How does the plant respond to a short period of exposure to high soil temperature near the surface when the mean soil temperature is constant over all depths and treatments (i.e. to the amplitude of the diurnal cycle independently of the mean temperature)?

(ii) How is the response to the amplitude of the diurnal temperature cycle affected by the mean temperature?

(iii) How does the growth rate response of the shoot correlate with the growth rate response of the root system?

(iv) How is the plant response modified by the depth to which root has penetrated when the high temperature is imposed?

(v) To what extent can plants recover (a) as their root tips penetrate deeper and are thus exposed to lower maximum temperatures and (b) if the high temperature stress is removed after a few days exposure?

(vi) Which part of the plant is primarily responsible for the observed morphological and growth rate response?

(vii) How does high temperature stress interact with the availability of water and nutrients, mechanical impedance to root penetration and other factors of the soil environment?

viii) What varietal differences are there in response to a high soil temperature stress similar to that which occurs in the field and how do the differences correlate with those from simpler experimental situations that could be used for screening purposes?

Inter-Specie Differences in Response to High Soil Temperature

In general, one would expect tropical crop plants to be more tolerant to high soil temperature than the temperature species. Some of the constant root zone experiments conducted at IITA have shown that maize and soybeans have the optimum soil temperature range from 25 to 30°C. Soybeans, however, can withstand extremes of temperature better than maize. Cowpeas and pigeonpeas have much higher optimum range than maize and soybeans (Lal, 1974 C). The optimum range for cowpeas and pigeonpeas lies between 30 and 35°C. Rice also has a much higher optimum as compared to other cereals such as maize (Takeshima, 1964). Though the optimum soil temperature range for cassava is also 30 to 35°C, this plant can withstand extremely high soil temperature.

Conclusions

1. Under climate and soil conditions similar to those at IITA, growth of maize planted on unmulched flat seedbeds can be reduced by high soil temperature during the early stages of crop growth. The early growth inhibition due to high soil temperature can also cause reduction in grain yield.

2. If soil temperature is much above that of an unmulched flat seedbed, as may occur on ridges or heaps, then high soil temperature can certainly reduce maize yield as much as 10% or more depending on the time of planting, soil and climatic conditions during the growth.

3. There are significant interspecific differences in response to high soil temperature. There may be intervarietal differences as well.

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COMMENTS

In discussing temperature effects, it was realised that at dffferent developmental stages the meristem of maize was below, at, and above the soil surface, and it was questioned whether root temperature optima changed with age and whether seminal and adventitous roots had separate characteristics.

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