THE MODIFICATION OF SOIL TEMPERATURE

AND

MOISTURE REGIMES

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MOISTURE REGIMES

by

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SCOPE AND CONTENT:

During the spring and summer months of 1967, measurements of the temperature and moisture regimes under a control, and lamp black, white talc, and straw mulch surface treatments, on a fine sandy loam, and a sandy clay loam, were undertaken. The sites were the McMaster University campus, and the Arboretum of the Royal Botanical Gardens in Hamilton, Ontario.

A description of the experimental procedures is presented in Chapter II. Chapter III discusses the regimes of soil temperature and moisture - content; and also the effects of clear and cloudy skies, and rain on soil temperatures.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

(1) The nature of the problem

This study is concerned with the effects of ground surface modification upon the temperature and moisture regimes of two contrasting soil-types: a fine sandy loam, and a sandy clay loam.

The temperatures in the upper soil layers are determined firstly by the quantity of heat which flows into and out of the soil, and secondly by the physical properties of the soil. Consequently, there are two approaches in a study of the effects of ground surface modification upon the natural soil temperature and moisture content. Attempts can be made either to regulate the in-coming or the out-going energy; or to alter the physical properties of the soil so that different rates of energy consumption by the soil can be achieved. Either approach entails an adjustment of the energy balance within the soil.

This study attempts to regulate the in-coming energy to the surface. Both insulating material and artificial colouring were applied to the surface.

(2) The energy balance at the earth-atmosphere boundary

According to the principle of conservation of energy, all gains and losses of energy at the earth's surface must balance. The basic components include short-wave radiation from the sun, long-wave radiation from the sky and earth, soil heat flow, turbulent transfer of heat through the air, and the latent heat of evaporation or condensation.

In mathematical form, the energy balance is defined by:

$$\left(Q_T - Q_R\right) + \left(Q_L\downarrow - Q_L\uparrow\right) = \pm\ Q_N = \pm\ Q_G \pm Q_H \pm Q_E$$

Where Q_T is the short-wave radiation from the sky and sun; Q_R is the short-wave radiation reflected from the earth; $Q_L\downarrow$ is the long-wave radiation received by the earth's surface from the atmosphere; $Q_L\uparrow$ is the long-wave radiation emitted by the earth's surface; Q_N is the net all-wave radiation; Q_G is the flow of heat into the soil; Q_H is the turbulent transfer of sensible heat to the atmosphere; and Q_E is the latent heat of evaporation and evapotranspiration.

During the day there usually is a gain of radiant energy by the earth's surface. During the night there usually is a net loss of radiant energy by the earth's surface. But this is balanced by upward heat flows from within the soil, downward heat flows from the air layers above, and occasionally by condensational heating.

(3) Review of the literature

Very little work on this subject has been reported. Schübler (Wollny (1878)) was the first to investigate the influence of colour on soil temperature. He noticed a difference of about 8°C existing between white- and black-surfaced soils. Wollny (1878) recognized as early as 1878 that the colour of the surface has a significant influence on the warming of dry soils provided that the mineral content is so slight that the specific heat and the conductivity of the soil play no important rôle. Lang (1878) concluded that the influence of soil colour is of the greatest importance in the 'thermal economy' of soils.

Quite a few studies have shown that a mulch is very effective in conserving soil moisture, and keeping the soil both cool and at an even temperature. Shaw (1926) experimenting with non-perforated paper, impregnated and coated on both sides with asphaltic material, determined that in the surface 18 inches of soil, under the paper mulch, there was from 0.5 to 4.0 per cent more moisture than in the bare plots. Stewart et al. (1926) discovered that, at a depth of 4 inches below the surface, the greatest difference between paper-mulched and bare soil varied from 4° or 5°F during the night to as high as 12° to 15°F during the afternoon. These workers also discovered that in the surface 12 inches of soil, the moisture-content was greater under the paper mulch than in the bare plots. Flint (1928) experimenting with paper mulch, found that the moisture conservation due to paper mulching did not extend beyond the depth of 4 inches. From paper-mulch experiments, Smith (1931) showed that during the dry season of the year, under un-irrigated conditions, a non-perforated black paper was the most effective in conserving moisture. This effect, however, was only confined to the surface 4 inches of the soil, and was due to condensation of water beneath the paper. Krantz (1949) found that the average soil temperature at the 1/2 - inch depth on two sunny afternoons was 118°F in unmulched soil and 81°F in soil covered with a mulch of 3 tons of straw per acre. Ramdas (1957) showed that the mean daily maximum temperature of dark-coloured Poona soil was lowered by as much as 7°C at a depth of 5 cm just by applying a thin layer of French cahlk on the soil surface. In addition, he was able to show, quantitatively, the suppression of evaporation by the presence of this thin layer of chalk. Everson and Weaver (1959) reported that the maximum daily temperatures of a carbon-treated soil surface were on the average 2°F warmer than the untreated soil surface. At a depth of 2 inches the carbon-treated soil had an average daily maximum of 3.4°F higher than the untreated plot. Oke and Hannell (1966) studied the effects of changing the albedo of the soil surface, and reported that beneath a white-coloured plot the maximum temperature at the 1 cm depth was 15°F lower than the corresponding value beneath the control plot; whereas that beneath a black-coloured plot was 11°F higher.

(4) The purpose of the study

This study aims firstly, to describe an approach to the problem of modifying the microclimate within a soil and secondly, to provide quantitative data on the extent to which the natural soil temperature and moisture-content could be modified by the application of simple surface-treatments.

CHAPTER II

EXPERIMENTAL PROCEDURES

(1) The location and nature of the experimental sites

Map 1 shows the location of the two experimental sites utilized in this study. Site A is an area of fine sandy loam soil, located on the McMaster University campus. Site B is an area of sandy clay loam soil, located at the Royal Botanical Gardens Arboretum, a few miles north-east of the campus.

Both sites have a covering of short grass, and occupy a flat topographic position. Although the sites were cordoned off to keep them free of any human interference which might affect the observations, they were, however, freely exposed to external meterological elements.

(2) The layout and design of the experimental plots

The layout of the experimental plots is shown in Fig. 1. At each site, there are four plots, each 90 cm square, separated by 120 cm wide gaps. The covering of short grass on the plots was removed by the application of a strong herbicide which renders the soil infertile for a few years. Any remaining clumps of grass were carefully removed by hand. Every effort was made to present a flat and level soil surface. A careful preparation of the plots was considered essential since it made it possible to colour the surface using only a very thin layer of colouring material. Much more coloured dressing would have been needed on a rough grassy surface, and such an excess of loose powder would act as a mulch. Moreover, the presence of the grass cover would lead to a damping of the temperatures within the soil; and it was felt that the full effects of the surface-treatments would not then be adequately measured.

(3) Determination of soil temperatures

Thermocouples were used at Site A. They were made out of 24-gauge copper-constantan wire sheathed in a durable polyvinyl insulating cover. The thermocouple leads from beneath the plots ran to a centrally located junction box (See Photograph B), containing a 20-point switch, a portable potentiometer, and a reference flask containing a mixture of crushed ice and water at 0°C.

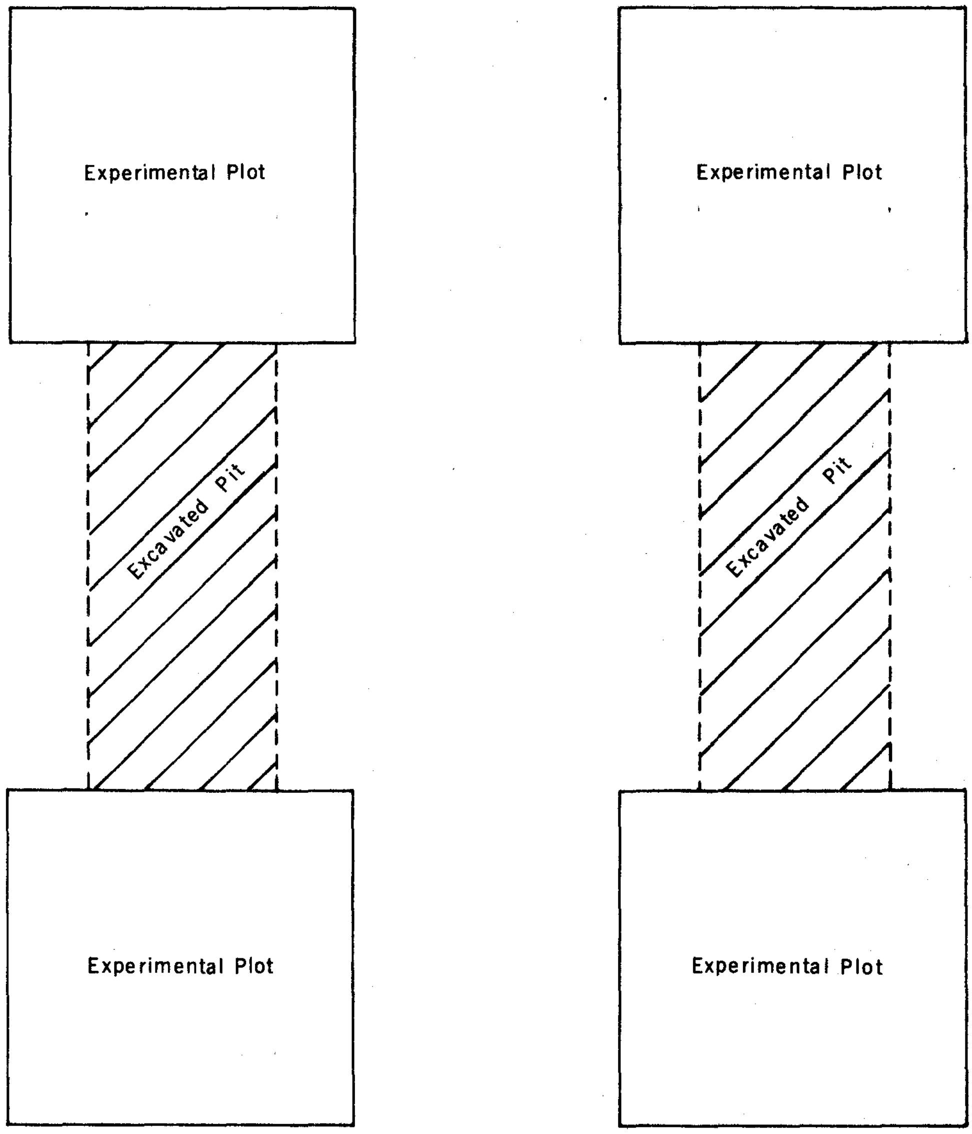
In order to determine an emf/temperature relation in which the temperature could be expressed on a consistent and reproducible scale, the 'comparison method' of thermocouple calibration was adopted. A linear regression analysis of temperature and emf was computed using the University's high-speed IBM 7040 computer, and a table showing emf and the corresponding temperature in °C was drawn up.

Platinum resistance 'bulbs' or thermometers were used at Site B. The 'resistance thermometer' utilizes the direct variation of the electrical resistance of metals with temperature. The thermometers consist of fine platinum wires wound on mica frames and enclosed in thin-walled silver tubes for protection. Copper wires lead from the thermometer units to an automatic 50-point temperature recorder (Thermo-Electric, Brampton, Ontario), housed in a small hut located about 15 metres away from the plots (See Photograph C).

Temperatures were recorded, in chart form, in °F. Conversion of temperatures in °C was performed using specially prepared tables.

Fig. 1

LAYOUT OF EXPERIMENTAL PLOTS



Scale: 0.5 cm to 10 cm

Photograph A. Site conditions (Site A).

Photograph B. Experimental plots at Site A.

Photograph C. Site conditions (Site B).

Photograph D. Experimental plots at Site B.

(4) Insertion of the temperature measuring devices

It was necessary to insert the temperature measuring devices horizontally such that they lay beneath the central point of the respective plots at depths of 1, 5, 10, 20, and 40 cm, without disturbing the 'natural' condition of the ground. In order to facilitate emplacement, a pit about 60 cm deep was excavated. The soil of the various horizons were carefully laid aside. At the required depths below the soil surface, the temperature measuring devices were inserted in the undisturbed soil so that they were 45 cm from the excavation. Care was taken to ensure that the element was in close physical contact with the soil at the depth required, for air pockets within the soil can give unrepresentative temperatures.

The pit was then filled, the soil layers being carefully put back in proper order and lightly tamped so as to attain almost the same degree of compactness as existed originally.

(5) Ground-surface modifications and albedo values

At each site, the following surface-treatments were used:

(a) a 20 cm layer of straw mulch

(b) a thin layer of lamp black

(c) a thin layer of white talcum powder

Just sufficient quantities of colouring material were applied to give a uniform colouring to the plots. Additional treatments were applied when wear was apparent, especially after rains. The control plot was left untreated throughout the course of the experiment. It represented the natural soil temperature and moisture regimes against which the effects of the ground-surface modifications could be compared.

Albedo determinations were made from near simultaneous measurements of incoming and reflected solar radiation using a 'Rothamsted' (Monteith 1959) solarimeter. Table 1 below gives values for the various surfaces.

TABLE 1

Albedo values for experimental plots

Surface	Albedo value	% of solar radiation absorbed
Surface covered with white talc powder	0.47	53
Surface covered with straw mulch	0.21	79
Sandy clay loam soil	0.18	82
Fine sandy loam soil	0.16	84
Surface covered with lamp black	0.06	94

These show that the sandy clay loam and fine sandy loam soils have very similar reflection coefficients and absorb just over 80% of the incident solar radiation, which is 10% lower than for the blackened surface and about 30% greater than the whitened surface. The straw mulch reflects only about 20% of the incoming solar radiation back to the atmosphere.

(6) Mechanical analysis of soils

In this investigation, a mechanical soil analysis was carried out to determine the soil properties. The hydrometer method[1] was used. The results are given in Table 2 below.

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[1]See Appendix III.

TABLE 2

Mechanical analysis of soils

Site	% Sand	% clay	% silt	Texture
A	67	17	13	(fine) sandy loam
B	58	28	12	sandy clay loam

These results show that the fine sandy loam is coarser than the sandy clay loam.

(7) Determination of soil moisture-content

Soil moisture-content was determined in the surface 5 cm of the soil, since this zone comprises part of the agronomically most important superficial soil layers. The direct gravimetric sampling method was employed. This method involves the repeated removal of soil samples by auger at a number of points within the experimental plots.

It was necessary to take triplicate samples to reduce the error due to soil variability. During the sampling operations, care was exercised to minimize soil compression.

A sample of moist soil of known weight was placed in an oven and heated at 100°C to 110°C for 24-48 hours. It was then cooled in a desiccator and weighed. The loss in weight is the moisture-content. Gravimetric water content was calculated as loss of weight on drying divided by dry weight, and expressed as a percentage.

(8) Determination of the upper limit of available-water

'Field capacity' is normally regarded as the upper limit of available-water in soils. Veihmeyer and Hendrickson (1931) have defined the field capacity of a soil as "the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased".

Veihmeyer and Hendrickson (1931, 1949), and Salter and Haworth (1961) have shown that field capacity can be determined by soil sampling a few days after rain. Marshall (1959) suggests that field capacity should be measured by sampling the soil 1-2 days after it has been thoroughly wetted, covering it meanwhile to minimize losses due to evaporation.

In this study, the upper limit of available-water was determined by field sampling 48 hours after a heavy rain in early Spring 1967. The sample-area was covered after the rainfall ceased in order to prevent evaporation. Auger samples of soil were subsequently taken. The moisture-content of each of these samples was determined by drying to constant weight at 105°C. In using this method, reproducible measurements of field capacity were obtained. Table 3 below gives the values for the upper limit of available moisture for the two soil-types.

TABLE 3

Upper limit of available-water

soil-type	per cent dry weight
fine sandy loam	26.0
sandy clay loam	33.0

The value for the fine sandy loam is probably significantly lower than that for the sandy clay loam, since water-holding capacity decreases as texture increases.

(9) Verification of identical temperatures

Before applying any treatments, comparative observations were made at each experimental site, to check that the temperatures at corresponding depths in all the plots were 'identical'.

Observations were made daily, in the morning, afternoon, and evening from March 10 to April 15, 1967. Comparing the temperatures at each depth, small constant discrepancies were noted for the 5, 10, 20, and 40 cm levels. The discrepancies were only significant (greater than twice the error of the measuring system) at the 1 cm depth.

It is probable that these large differences were caused by errors in the depth at which the sensors were emplaced, and by soil heterogeneity. Since no satisfactory method of correction could be applied to the recorded readings, it was decided to re-instrument the 1 cm depth using thermocouples connected in series at Site A only.

Five junctions were constructed to run in a semi-circle. Each junction was separated from the next by 0.5 cm. Four plots each 60 cm square were laid out at Site A such that each was at least 90 cm away from the adjacent plots. Preparation of the soil surface was essentially the same as in the main experiment. The thermocouples, made out of 24-gauge copper-constantan wire, were inserted horizontally such that they lay beneath the central point of each plot.

Soil temperatures in all four plots were found to be very similar. Surface treatments were then applied.

(10) Frequency and types of observations

The daily 'mean' temperatures were obtained from readings taken at 1400 hours daily, except for instrumental repairs and other unavoidable circumstances. According to Oke (1964), 1400 hours is a time when differences in temperature between plots show up very conspicuously. These daily readings were then averaged into 17 weekly 'means' between April 16 and August 19, 1967. Intensive short period observations were also carried out. These lasted for 18 hours, with readings taken every hour.

Soil moisture-content was measured at weekly intervals.

(11) Analysis of experimental error

According to Young (1962), "experimental observations always have inaccuracies. In using numbers which result from experimental observations, it is almost always necessary to know the extent of these inaccuracies".[1]

For the thermocouples (Site A), the experimental error was obtained from the laboratory calibration of the thermocouple wire using the field potentiometer. From the calculated line of best fit to the temperature-emf data, the standard error (SE) was obtained.

$$SE = \sqrt{\frac{\sum (Y - Y_1)^2}{N}}$$

Where Y is an actual temperature, Y_1 is the predicted temperature from the temperature-emf relation, and N is the number of observations.

The value for SE is 0.15°C. This means that 68.3 per cent of all temperature values are likely to lie within $\pm$ 0.15°C of the line of best fit. This is analogous to the standard deviation of a Gaussian distribution or Normal Error Function.

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[1]Young, H.D. (1962) Statistical Treatment of Experimental Data, McGraw-Hill Book Co. Inc., New York, p. 1.

It is usual to use twice the standard error since this includes 95.45 per cent of likely occurrences. Hence, the maximum probable error of the thermocouple temperature measurement will be $\pm$ 0.3°C. In practice, most values will lie well within these "confidence limits".

In the case of the platinum resistance sensors and recorder at Site B, the manufacturer's calibration specifications were accepted. The sensor error is $\pm$ 0.01°C and the recorder error is $\pm$ 0.28°C. The total error, therefore, is $\pm$ 0.28°C. Hence, readings at both sites are accurate to within $\pm$ 0.3°C.

CHAPTER III

RESULTS AND DISCUSSION

(1) The arrangement of data

After the conversion of the field data from millivolts and degrees Fahrenheit, into degrees Centigrade, mean weekly temperatures were calculated for all depths within all the experimental plots. As a measure of the scatter of values, the variance was also computed.

The temperature record is not complete. Temperature observations at the 1 cm depth within the sandy clay loam are not available because of instrumental problems. Temperature observations at the 1 cm depth within the fine sandy loam (using thermocouples connected in series) were made for only eight weeks, commencing from the eleventh week after the start of the experiment. It was not possible to obtain any temperature values at the 40 cm level under the white plot on the sandy clay loam, because of a mal-functioning sensor. Instrumental repairs and other unavoidable circumstances prevented measurement during the third week.

For the comparison of moisture-content within the two soil-types, soil moisture is expressed both as a percentage of dry soil, and as a percentage of the upper limit of available-water.

(2) Weekly means and variances at the 1 cm level

TABLE 4

Weekly means and variances at the 1 cm level within a fine sandy loam

	Control Plot		Black Plot		White Plot		Mulch Plot	
Week	mean	var.	mean	var.	mean	var.	mean	var.
1	30.9	8.7	32.9	7.8	25.9	5.1	20.3	0.3
2	28.6	13.8	31.5	17.9	22.7	13.1	20.2	0.9
3	26.5	26.4	28.8	30.8	23.4	16.3	20.9	1.1
4	31.7	14.0	34.7	16.1	25.8	5.4	20.0	0.8
5	31.7	11.7	34.5	12.3	26.6	8.8	21.7	0.3
6	32.2	13.0	34.9	14.1	25.3	5.2	20.8	0.2
7	30.1	12.1	32.6	13.0	23.5	7.3	20.5	0.4
8	30.4	43.4	32.7	61.0	22.3	2.6	20.3	0.5

The data in Table 4 show that, throughout the experimental period, the black plot maintained a higher temperature than the control plot. The addition of carbon black to the fine sandy loam surface clearly promoted absorption of solar energy and thereby increased the soil temperature.

In contrast to the black plot, the white plot shows significantly lower temperatures than the control plot. This effect can be attributed to the much higher reflection coefficient for solar radiation. Therefore, less solar energy is absorbed.

The lowest temperatures lie beneath the mulch plot. Although the mulch was a good absorber of solar energy (with a low reflection coefficient of 0.21), its low thermal conductivity allowed little energy to enter or leave the soil. Most of the solar energy was used to heat the surface of the mulch itself and the overlying layers of air. Thus, the energy available for heating the soil was strongly reduced.

Values for the weekly variance of temperature, ranked in descending order are: black plot, control plot, white plot, and mulch plot. The variance reflects the temperature range and is, therefore, an indirect index of the thermal properties of the surface. For example, since the black plot is the most efficient absorber and radiator, the best approximation to a black body, it would gain and lose the greatest amount of energy: hence the variance should be the greatest. On the other hand, the mulch plot is the least efficient absorber and radiator and would gain and lose the least amount of energy. As a result, the variance should be the least.

(3) Temperature variations at the 5 cm, 10 cm, 20 cm, and 40 cm levels

TABLE 5

Means and variances of the mean weekly temperatures within a fine sandy loam

	Control Plot		Black Plot		White Plot		Mulch Plot	
Depth	mean	var.	mean	var.	mean	var.	mean	var.
5 cm	23.5	42.3	25.6	47.6	17.9	26.0	14.7	21.2
10 cm	18.1	28.1	19.5	33.6	15.2	25.0	14.7	20.3
20 cm	16.5	27.0	17.4	30.1	14.5	24.6	14.7	20.3
40 cm	15.5	24.0	15.8	26.0	14.2	21.2	14.5	20.3

TABLE 6

Means and variances of the mean weekly temperatures within a sandy clay loam

	Control Plot		Black Plot		White Plot		Mulch Plot	
Depth	mean	var.	mean	var.	mean	var.	mean	var.
5 cm	22.2	43.6	25.3	56.3	18.3	33.8	16.0	31.4
10 cm	19.9	38.4	21.6	46.2	17.1	32.5	16.0	31.4
20 cm	17.8	34.8	18.6	39.7	16.0	31.1	16.0	30.9
40 cm	16.7	31.4	17.4	34.8	--	--	15.5	29.2

Means and variances of the mean weekly temperatures for the fine sandy loam and the sandy clay loam have also been computed (Tables 5 and 6). These emphasize the temperature effects of the treatments. In particular, the effect of the mulch is very marked since temperatures were virtually the same at all depths.

Advantages of applying black treatments have been noted previously. Brooks (1955) reported an advance in cotton ripening in Russia due to the application of coal dust. Van Allen (1961) reported that carbon black is more effective than explosives in destroying dangerous icebergs.

Tables 5 and 6 also show that the variances decrease with depth, similar to the temperature trends. At every depth, the variances of temperature are greater in the sandy clay loam than in the fine sandy loam. This effect may be due to the greater fluctuations in the moisture-content of the sandy clay loam.

The effects of the various treatments on soil temperatures can be seen from graphs of the weekly data (Figs. 2-9); and by determining regression relationships between treated plots and the control (Figs. 10-17). The results of the regression analysis are presented in Tables 7 and 8.

Figs. 2-9 all show similar trends. The effects of the white and the black treatments decrease with depth. While these become more or less insignificant beneath the black plots at a depth of 40 cm, they were still discernible beneath the white plot. The mulch was more efficient than the white talc powder in reducing soil temperatures near the surface, but below 10 cm these two treatments produced similar results.

The differences in temperatures between the black and the control plots appear to be greater in the sandy clay loam than in the fine sandy loam. The higher temperatures in the case of the sandy clay loam could be attributed to the penetration of insolation into cracks in the soil (a common feature of this soil-type) and partly by the very low soil moisture-content.

The large amount of rain during the early spring hindered the rapid warming up of the soil, since the high specific heat of water meant that surface heat did not penetrate deeply into the soil profile under water-logged conditions. According to Chang (1958), there is a peak temperature belt at 5 cm in spring. This is well illustrated in Figs. 2-9. The spring heating of the soil, during the first two weeks of the experiment, was more effective in the fine sandy loam than in the sandy clay loam. In the latter where the soil moisture-content is greater, the temperatures are lower. Because of the lower heat capacity and thermal conductivity, and less evaporational cooling, the fine sandy loam warmed up more rapidly in the first two weeks than did the sandy clay loam.

The following points emerge from Tables 7 and 8:

(i) There is a high and significant correlation between the control and treated plots.

(ii) The correlation coefficients in the case of the fine sandy loam are slightly lower.

(iii) The standard error of the black plot, for both soil-types, is much smaller than for the other plots.

(iv) The standard error, in all cases, becomes smaller with depth.

In Figs. 10-17 the temperatures in the treated plots are shown to be linearly dependent upon those in the control plots.

The regression intercepts will be ignored in this discussion since very little can be said about them. Because they lie so far to the left of the scatter, they can only be regarded as hypothetical projections to where the temperature of the control plot (T) = 0°C.

The existence of a linear relationship confirms the fact that the soil differences within each soil-type have no major effect on the temperature differences but that the main effect is due to differences in the available energy.

The slope of the regression relationship can be interpreted as a measure of the heating or cooling effect of a treatment. The black plots possess the greatest capacity for absorbing solar energy, hence they have the greatest slopes. The mulch plots have the least capacity for absorbing solar energy. As a result, they have the least slopes.

Fig. 2

WEEKLY REGIMES OF TEMPERATURE AT 5 CM DEPTH WITHIN A FINE SANDY LOAM

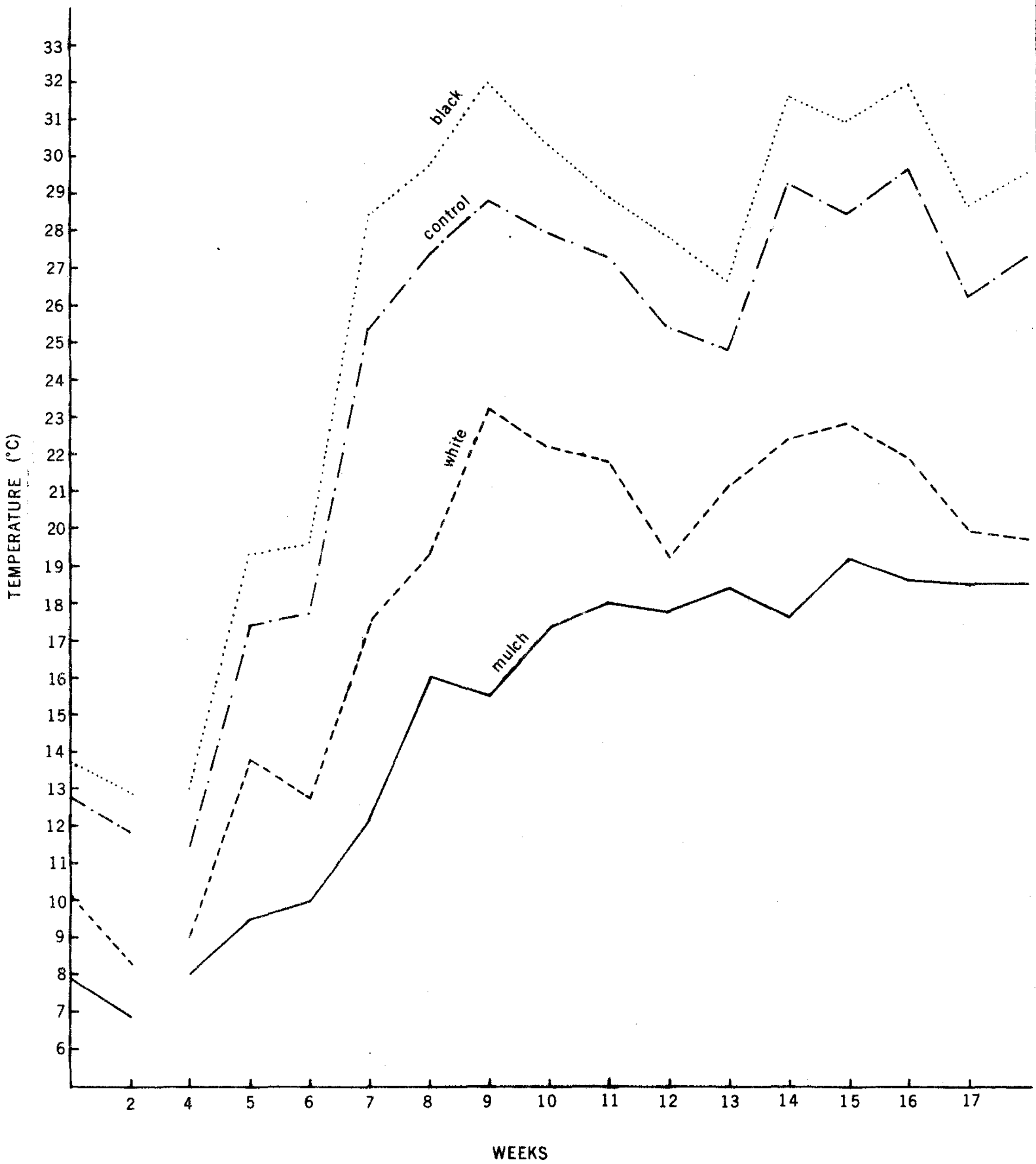


Fig. 3

WEEKLY REGIMES OF TEMPERATURE AT 10 CM DEPTH

WITHIN A FINE SANDY LOAM

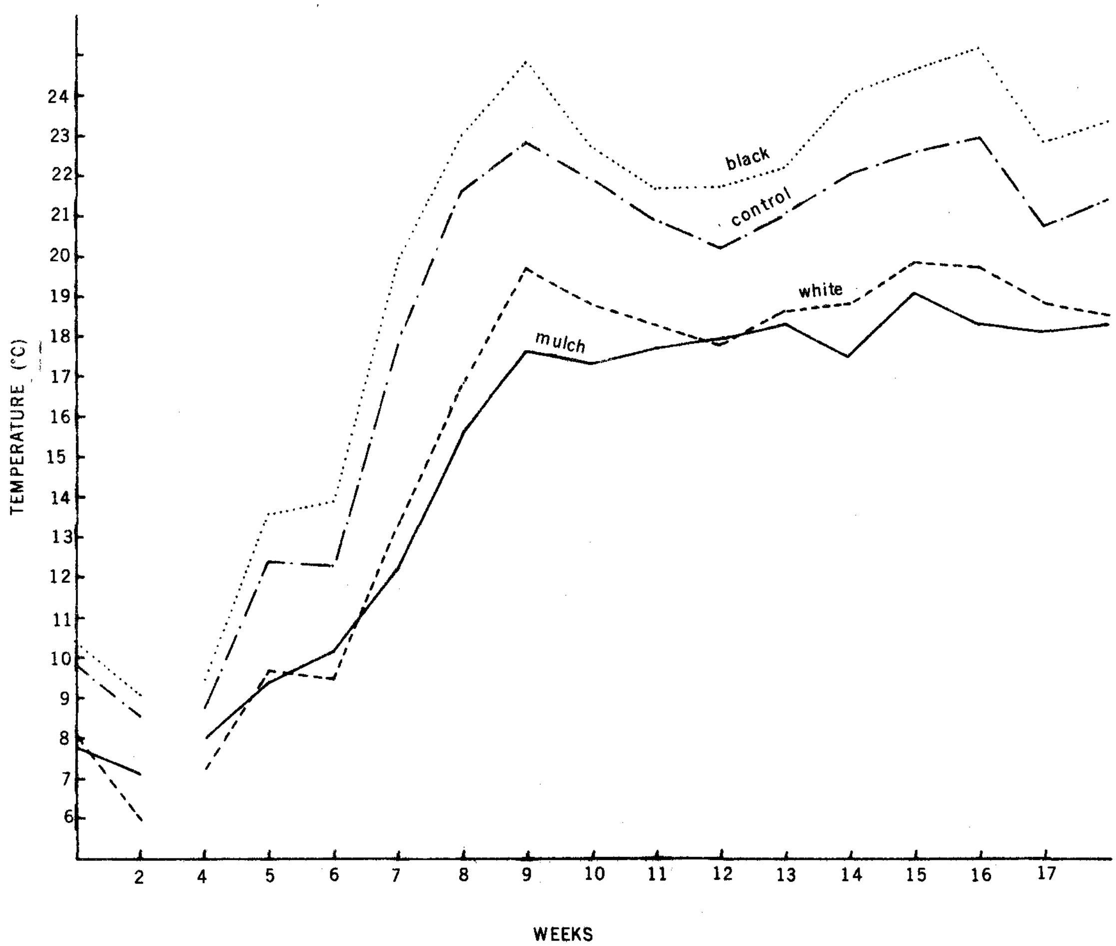


Fig. 4

WEEKLY REGIMES OF TEMPERATURE AT 20 CM DEPTH

WITHIN A FINE SANDY LOAM

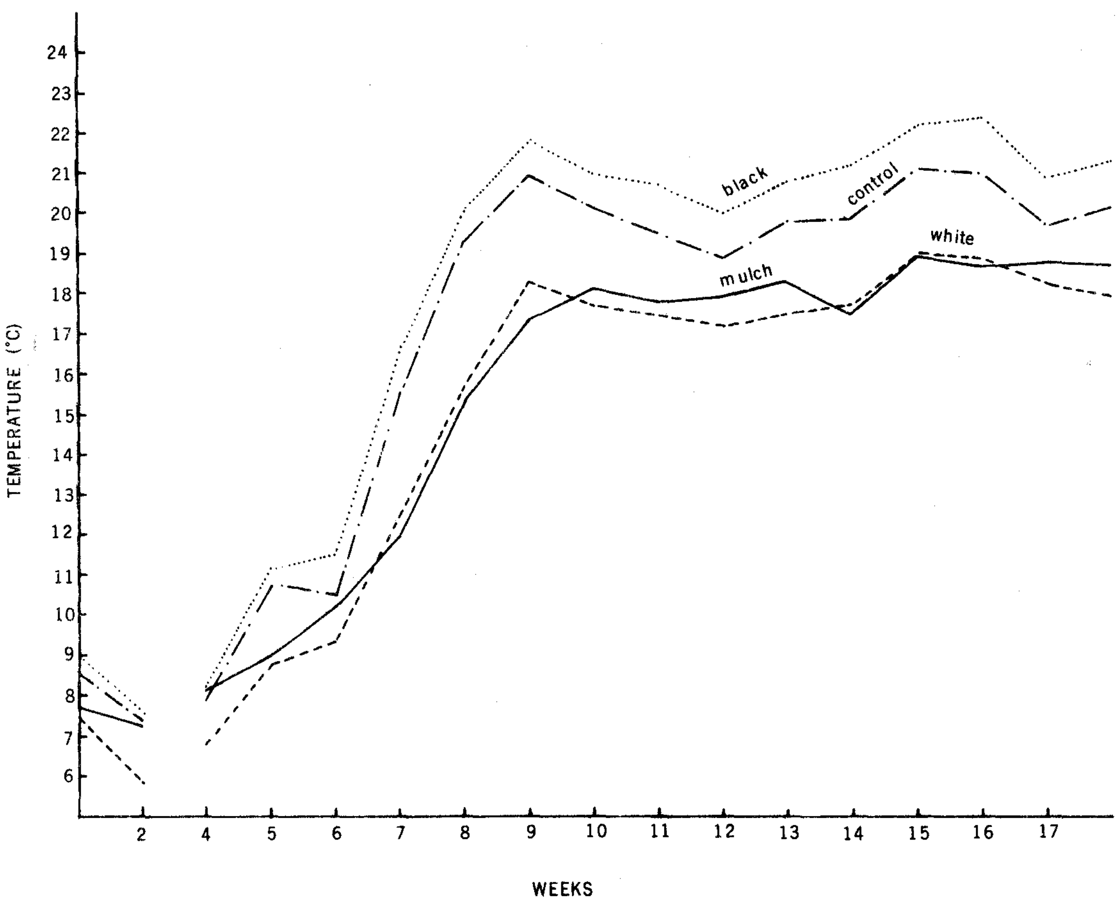


Fig. 5

WEEKLY REGIMES OF TEMPERATURE AT 40 CM DEPTH

WITHIN A FINE SANDY LOAM

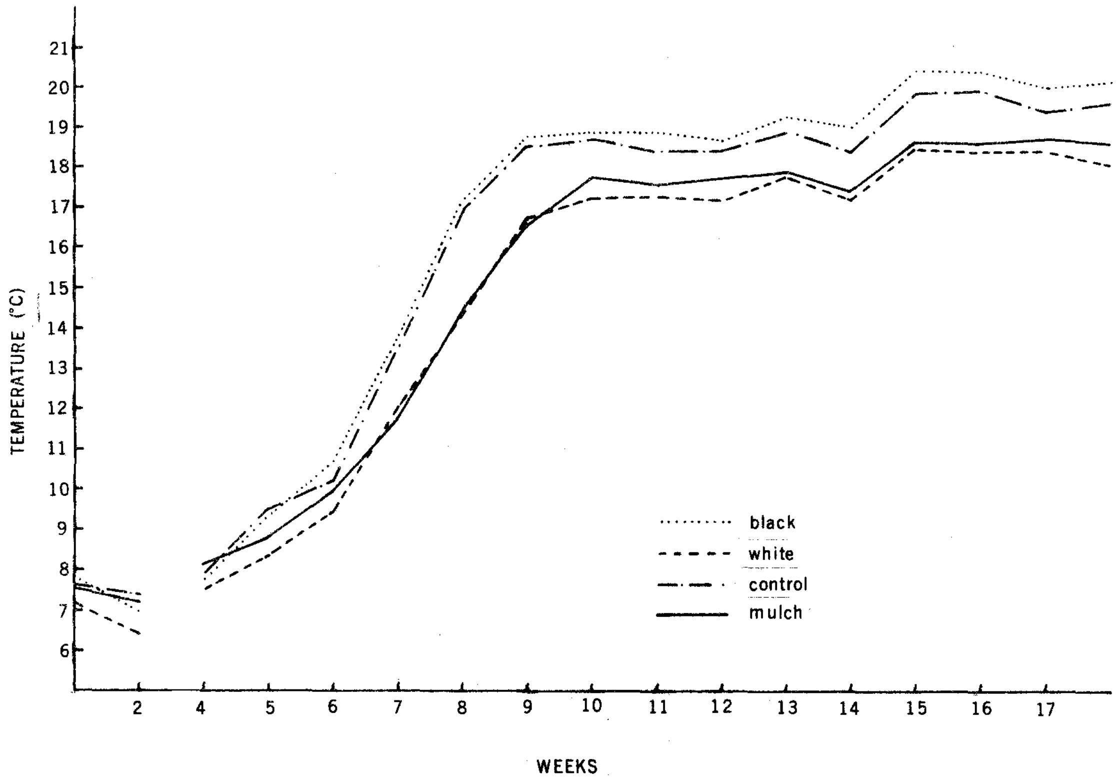


Fig. 6

WEEKLY REGIMES OF TEMPERATURE AT 5 CM DEPTH WITHIN A SANDY CLAY LOAM

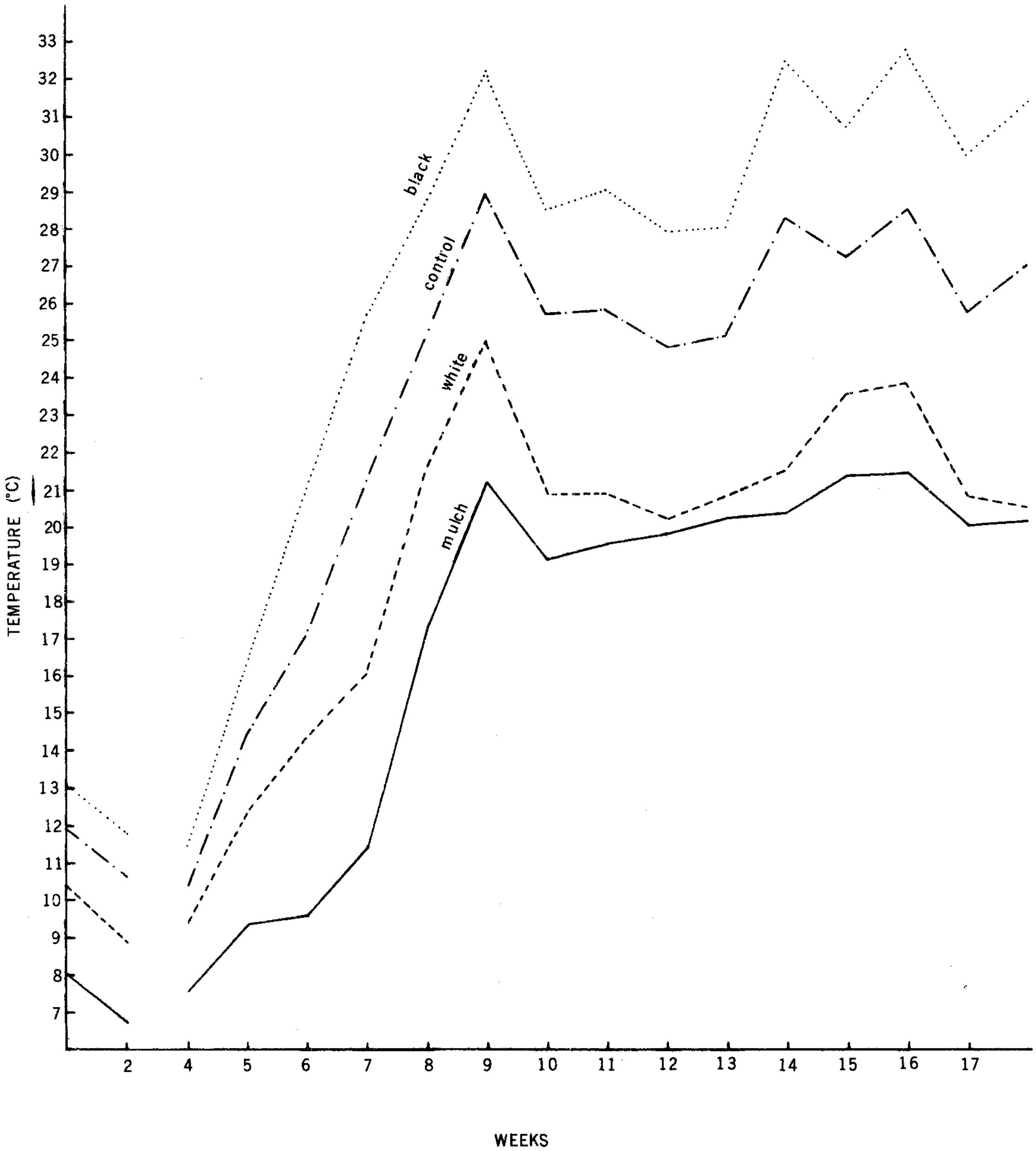


Fig. 7

WEEKLY REGIMES OF TEMPERTURE AT 10 CM DEPTH WITHIN A SANDY CLAY LOAM

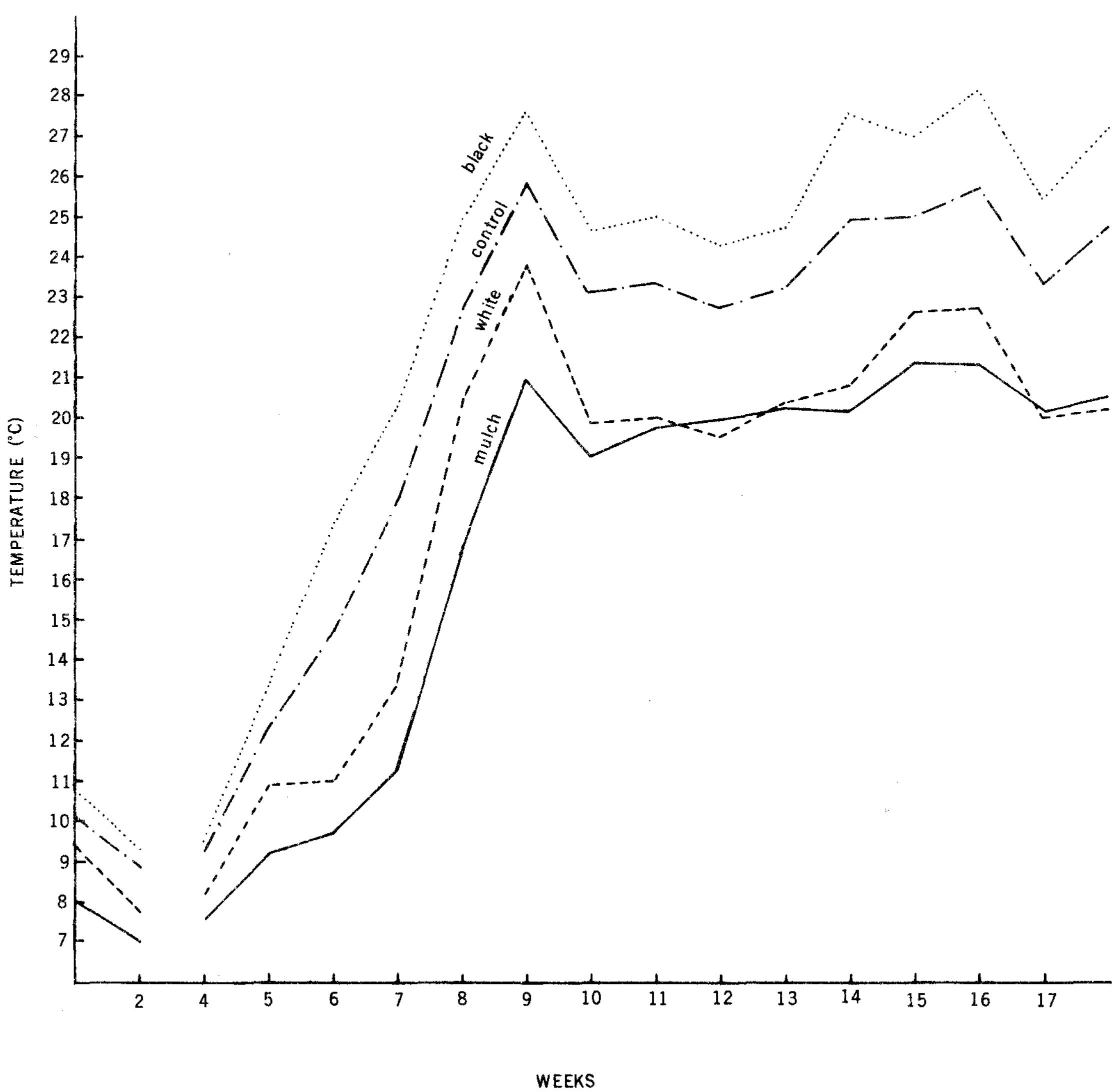


Fig. 8

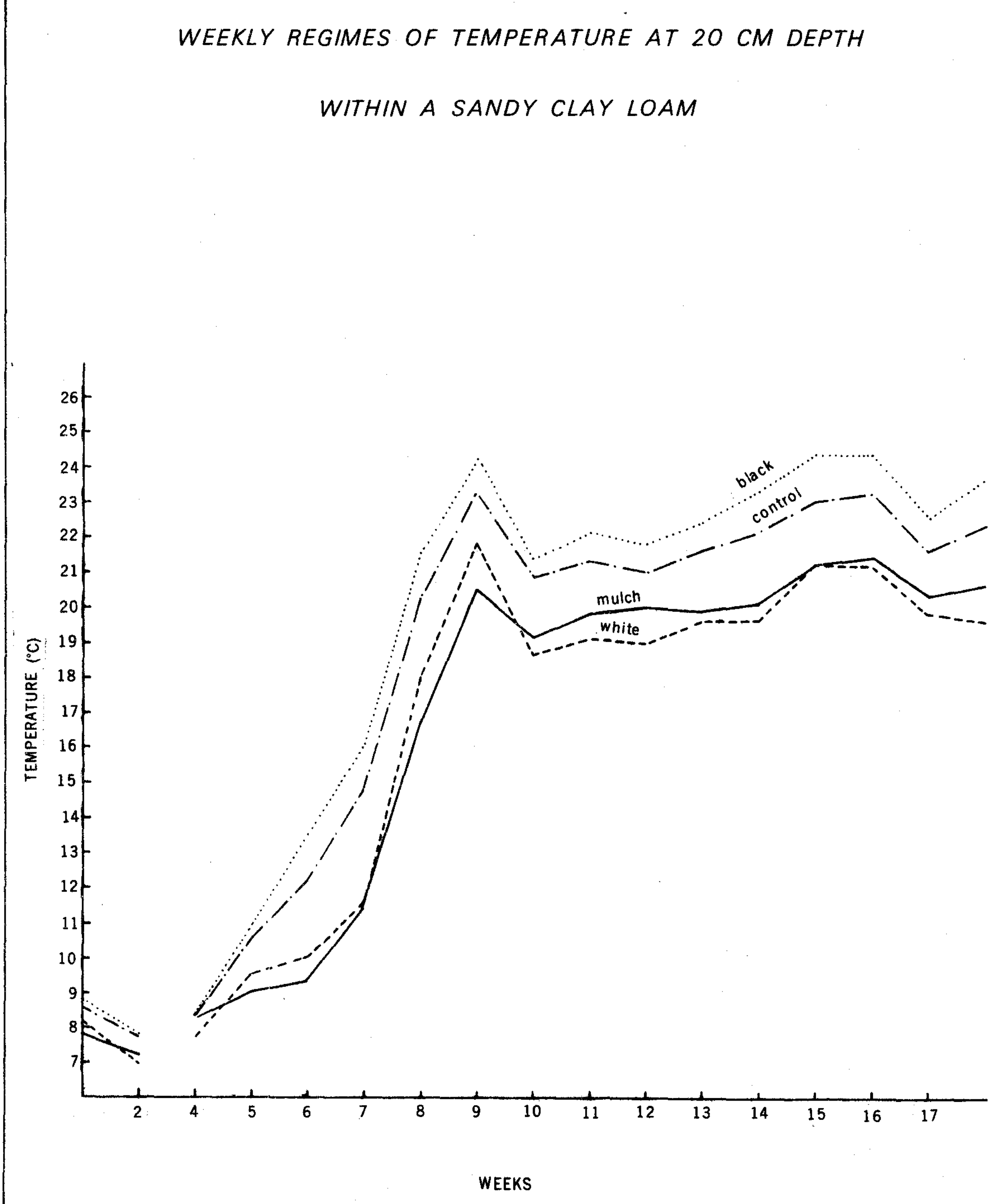
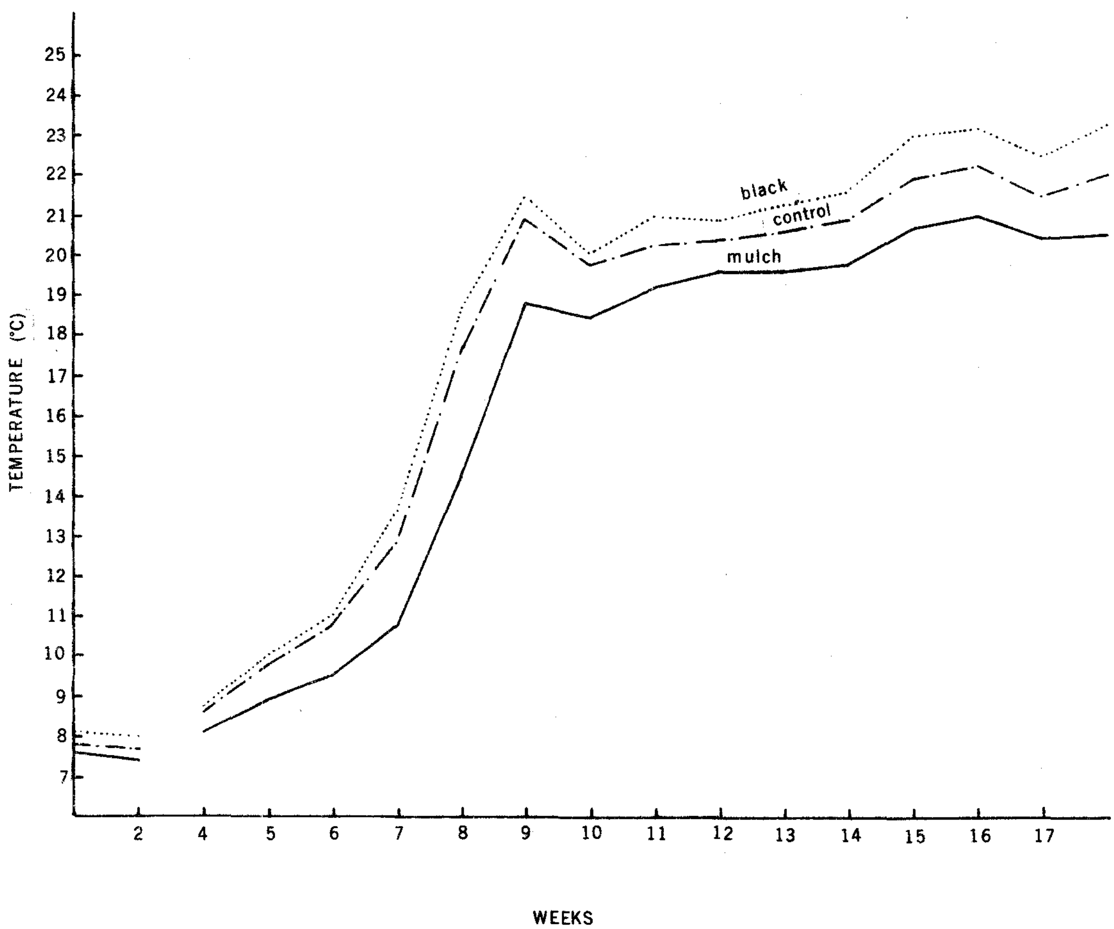

WEEKLY REGIMES OF TEMPERATURE AT 20 CM DEPTH
WITHIN A SANDY CLAY LOAM
TEMPERATURE (°C)
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
black
control
mulch
white
2
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEKS

Fig. 9

WEEKLY REGIMES OF TEMPERATURE AT 40 CM DEPTH

WITHIN A SANDY CLAY LOAM



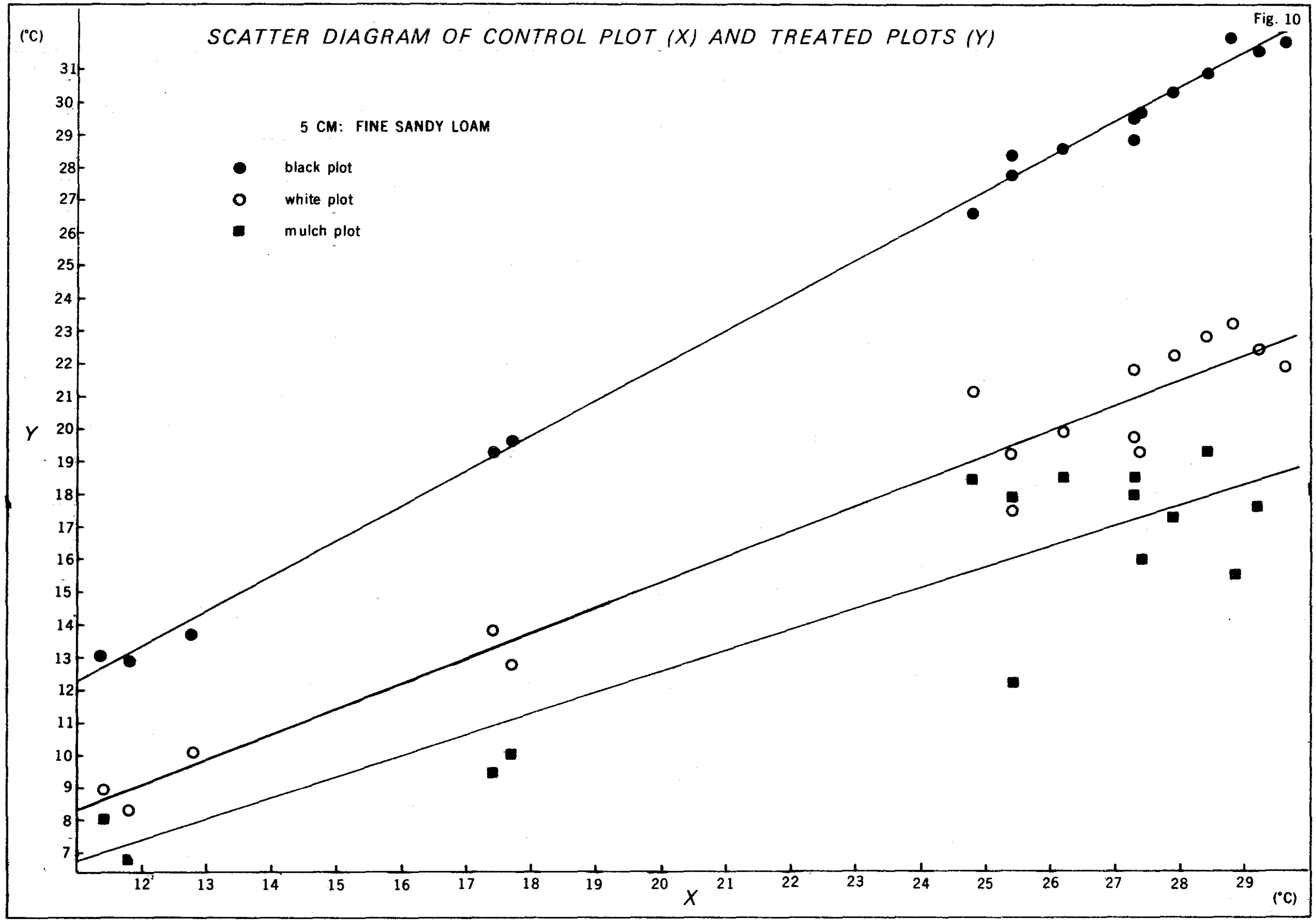


Fig. 10
SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)
5 CM: FINE SANDY LOAM
black plot
white plot
mulch plot
(°C)
Y
X
(°C)
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

Fig. 11

SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)

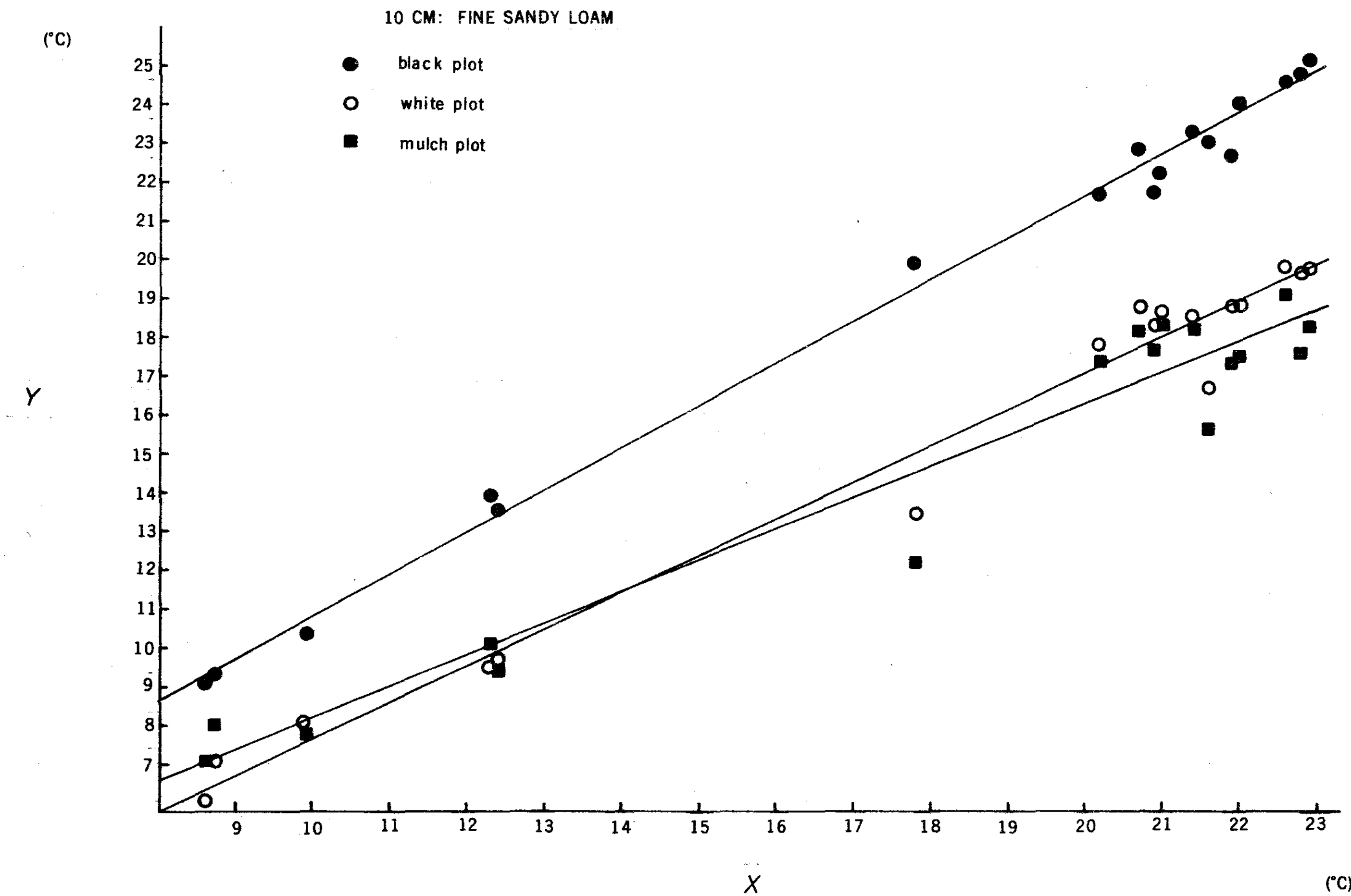


Fig. 12

SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)

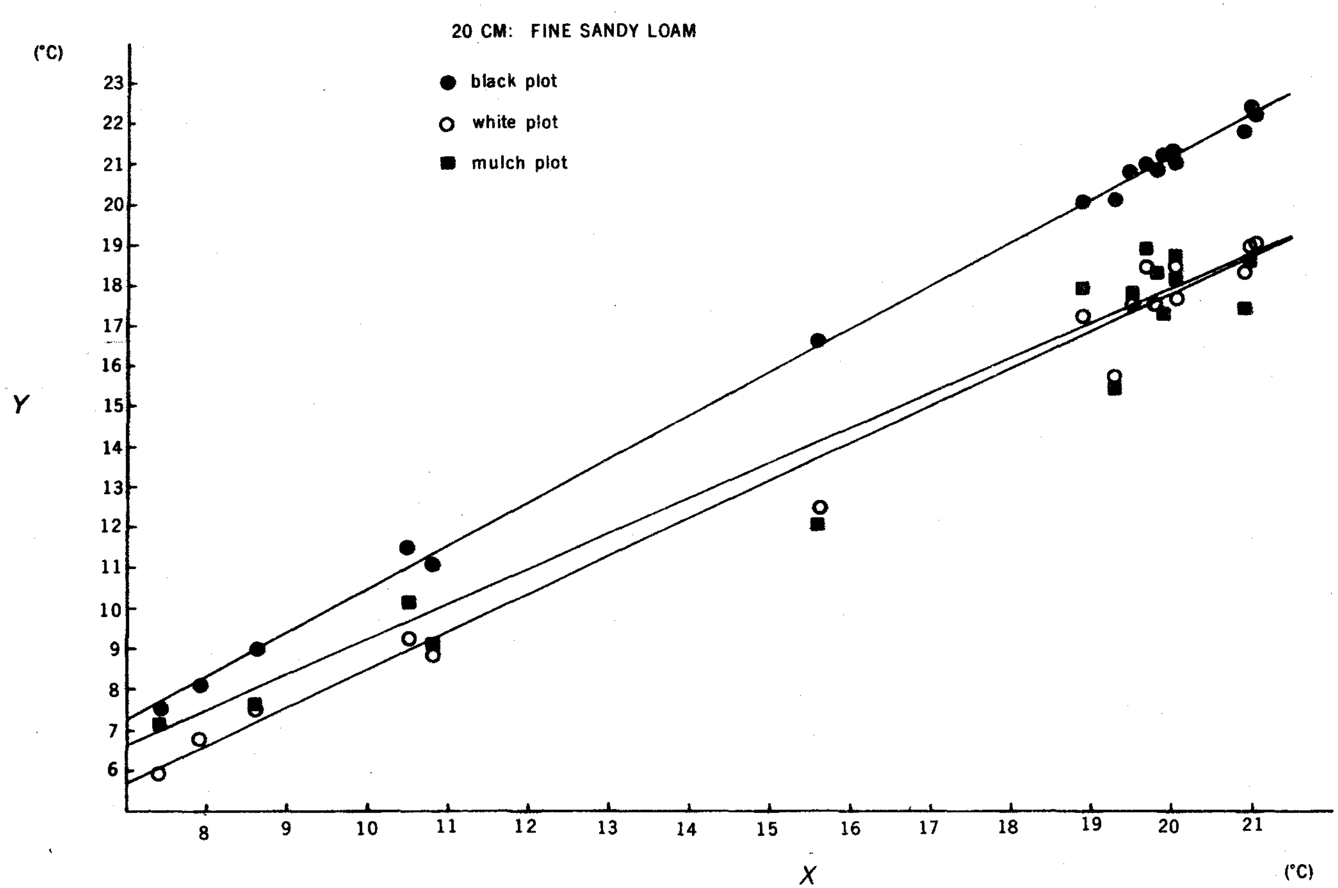
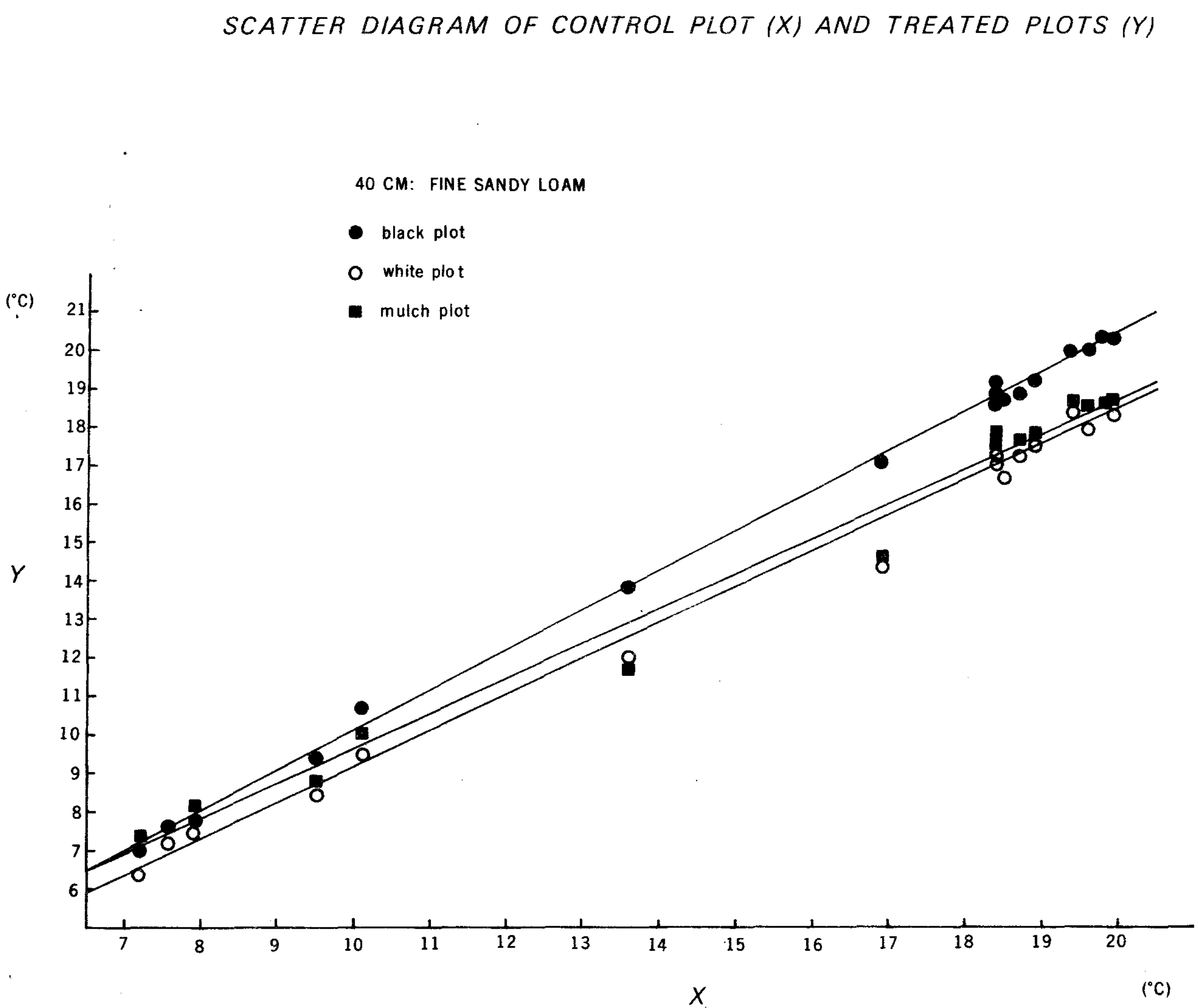


Fig. 13


SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)
40 CM: FINE SANDY LOAM
black plot
white plot
mulch plot
(°C)
Y
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
X
(°C)

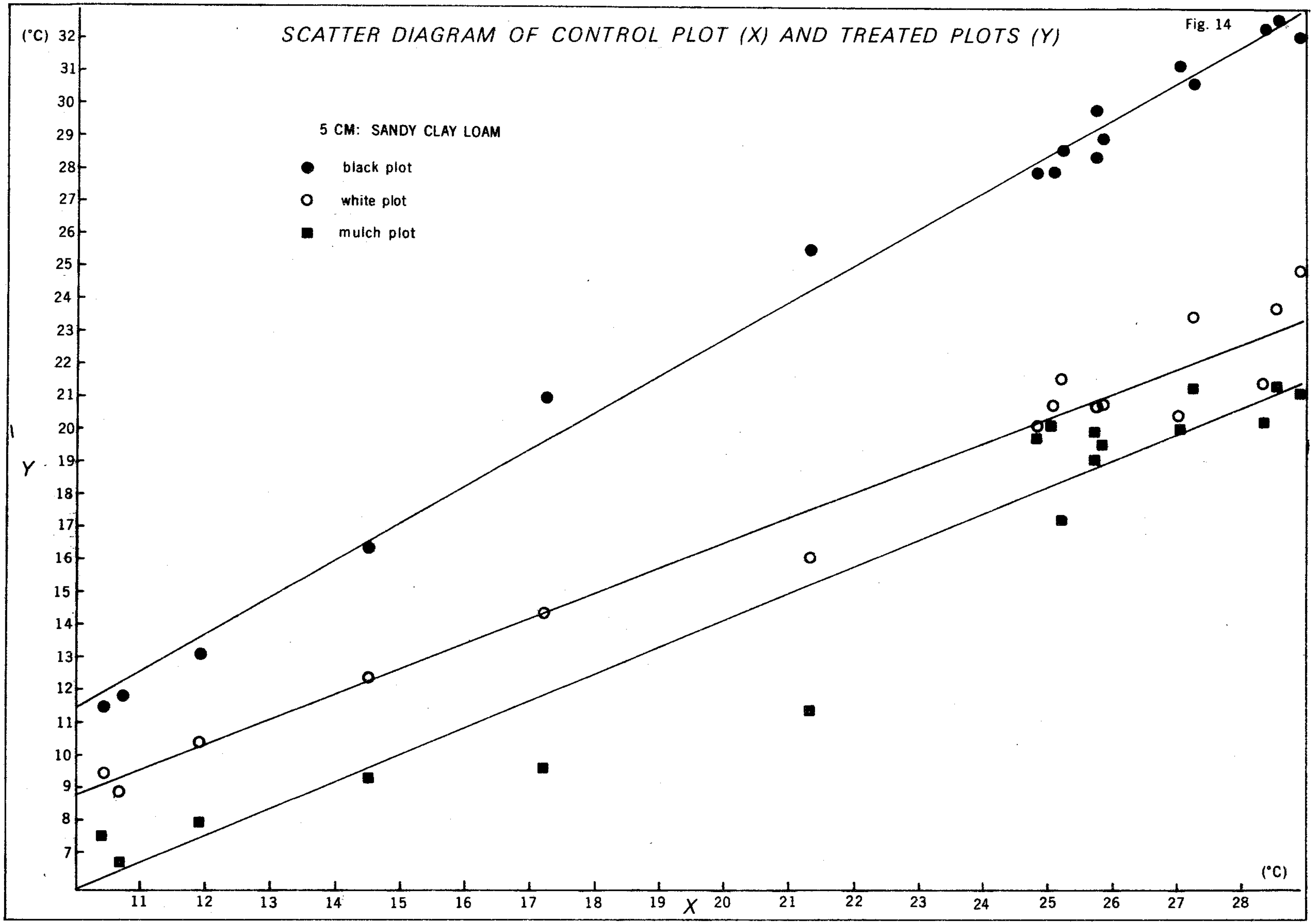
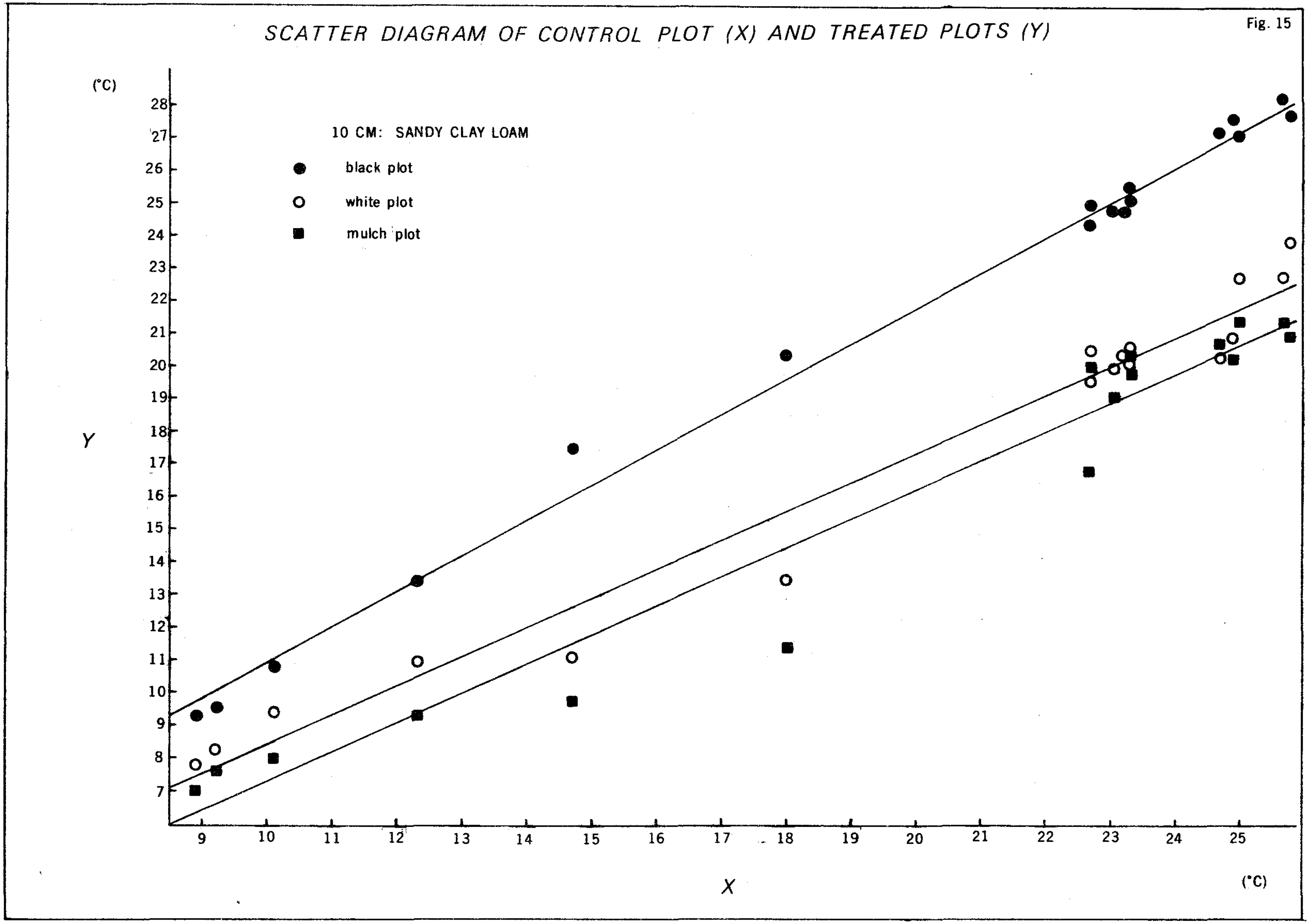


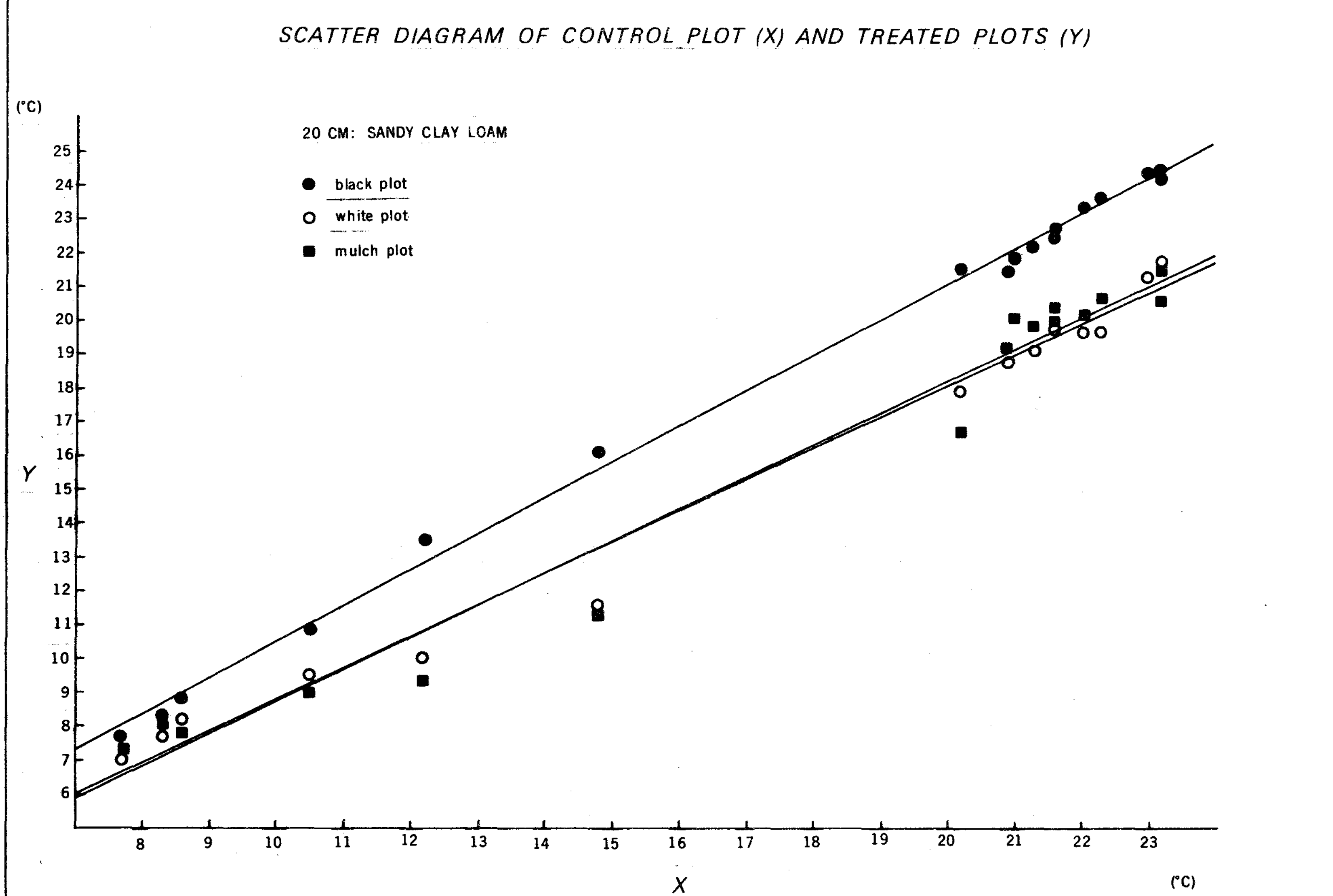
Fig. 14

SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)



SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)
Fig. 15
(°C)
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
Y
10 CM: SANDY CLAY LOAM
black plot
white plot
mulch plot
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
X
(°C)

Fig. 16



SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)
(°C)
20 CM: SANDY CLAY LOAM
black plot
white plot
mulch plot
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Y
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
X
(°C)

37

Fig. 17

SCATTER DIAGRAM OF CONTROL PLOT (X) AND TREATED PLOTS (Y)

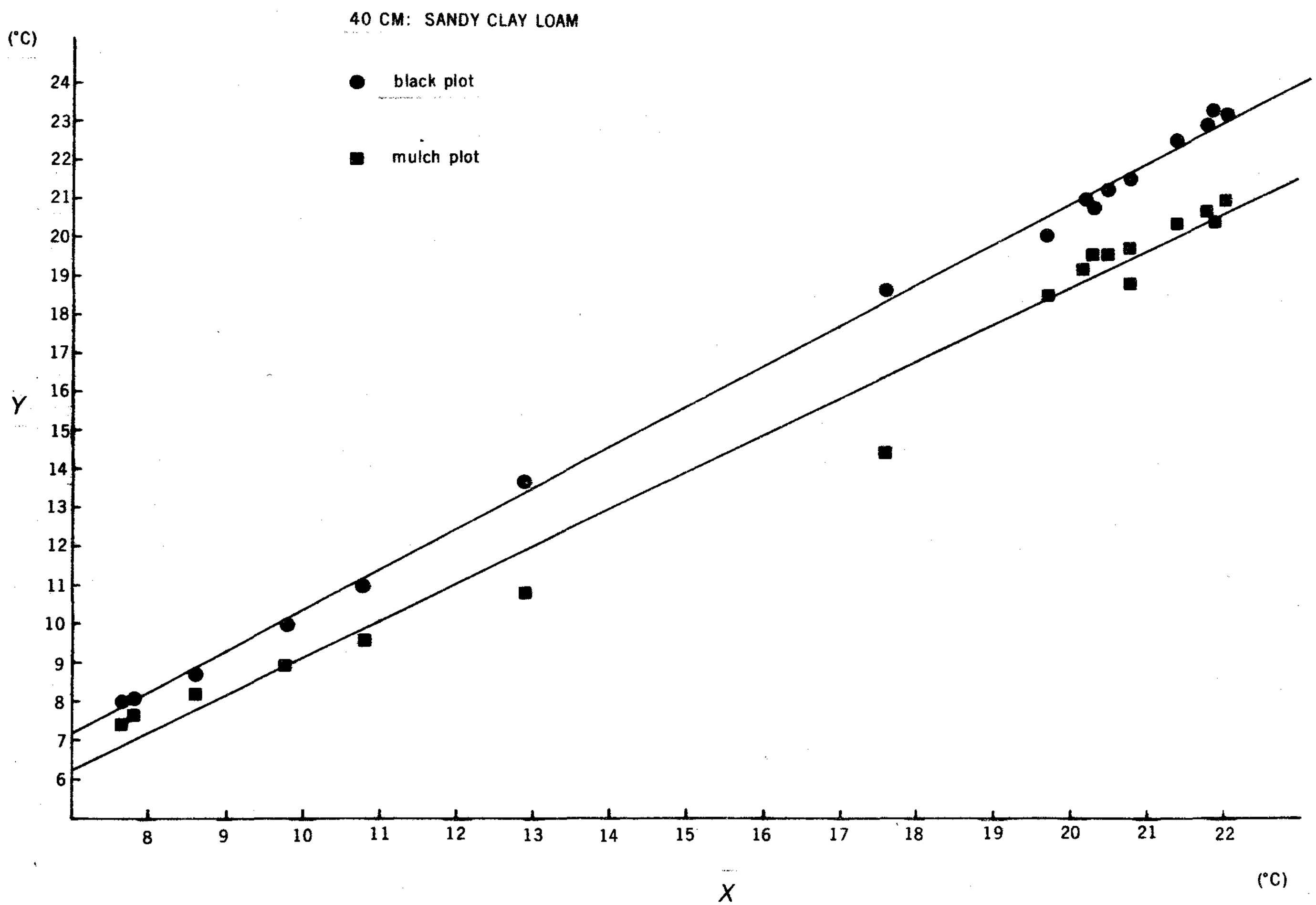


TABLE 7

Regression and correlation results of the mean weekly relationships (of temperature) between control and treated plots on fine sandy loam.

Legend	Regression intercept (a)	Regression coefficient (b)	Heating coefficient (θ)	Correlation coefficient (r)	Fraction of variability accounted for	Standard Error (°C) (SE)
black plot						
5 cm	0.467	1.070	-0.065	0.998	0.997	0.481
10 cm	0.060	1.076	-0.071	0.997	0.993	0.404
20 cm	-0.187	1.065	-0.061	0.999	0.999	0.219
40 cm	-0.336	1.041	-0.039	0.999	0.999	0.191
white plot						
5 cm	-0.178	0.772	0.295	0.978	0.956	1.113
10 cm	-1.637	0.933	0.072	0.989	0.978	0.779
20 cm	-0.791	0.925	0.081	0.993	0.987	0.577
40 cm	-0.208	0.935	0.070	0.996	0.992	0.428
mulch plot						
5 cm	-0.368	0.642	0.558	0.925	0.855	1.769
10 cm	0.077	0.809	0.236	0.970	0.941	1.123
20 cm	0.536	0.863	0.159	0.978	0.957	0.984
40 cm	0.444	0.912	0.097	0.993	0.985	0.566

TABLE 8

Regression and correlation results of the mean weekly relationships (of temperature) between control and treated plots on sandy clay loam.

Legend	Regression intercept (a)	Regression coefficient (b)	Heating coefficient (θ)	Correlation coefficient (r)	Fraction of variability accounted for	Standard Error (°C) (SE)
black plot						
5 cm	-0.057	1.141	-0.124	0.996	0.992	0.680
10 cm	0.043	1.085	-0.078	0.997	0.994	0.531
20 cm	-0.114	1.054	-0.051	0.999	0.997	0.349
40 cm	-0.179	1.048	-0.046	0.999	0.998	0.246
white plot						
5 cm	0.790	0.787	0.271	0.986	0.971	0.966
10 cm	-0.359	0.880	0.136	0.986	0.972	0.917
20 cm	-0.369	0.918	0.089	0.994	0.988	0.628
40 cm	--	--	--	--	--	--
mulch plot						
5 cm	-2.614	0.839	0.192	0.968	0.937	1.481
10 cm	-1.595	0.887	0.127	0.977	0.954	1.252
20 cm	-0.712	0.940	0.064	0.988	0.975	0.914
40 cm	-0.421	0.952	0.050	0.992	0.985	0.690

This interpretation of the slope as an indicator of the heating or cooling effect of the treatment could be shown in mathematical terms as follows:

If $T_t = T_c$,

(Where T_t is the temperature under treatment, and T_c is the temperature under control),

the relationship would be

1 : 1 and therefore b = 1.

If $T_t > T_c$,

then $b > 1$.

Therefore instead of $b = \frac{1}{1}$,

$$b = \frac{1}{(1 + \theta)}$$

where θ is a "heating coefficient",[1] analogous to the β parameter defined by Monteith and Szeicz (1961), with a value less than zero (i.e. negative value).

If $T_t < T_c$,

$b < 1$

and $b = \frac{1}{(1 + \theta)}$ (where $\theta > 0$).

In other words, the parameter θ indicates "heating" when negative or "cooling" when positive.

θ can be evaluated simply.

If $b = \frac{1}{(1 + \theta)}$

$$\theta = \frac{(1 - b)}{b}$$

Values of θ were computed from the b value columns in Tables 7 and 8. For all treatments, the fine sandy loam has, generally, larger

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[1] Monteith, J.L., and G. Szeicz (1961), Quarterly Journal of the Royal Meteorological Society, Vol. 87, No. 372, p. 159.

values than the sandy clay loam. These differences are probably due to soil factors such as thermal conductivity. The fine sandy loam should have a lower thermal conductivity and hence a higher heating coefficient. The opposite should apply to the sandy clay loam. Thermal conductivity therefore could be said to be inversely related to the heating coefficient. In the absence of conductivity data, θ might prove to be a useful proxy-variable in studies of this type.

It is significant that values of b are fairly constant with depth under the black plots. In contrast, b increases with depth under the other treatments. The author is unable to offer any explanation for this phenomenon.

These linear relationships may be used to predict the effect of treatments from a knowledge of control plot temperatures as follows:

$$T_t = b\,(T_c) + a \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$T_t = \left(\frac{T_c}{1 + \theta}\right) + a \quad \ldots\ldots\ldots\ldots \quad (2)$$

The standard errors in Tables 7 and 8 indicate the 68.3 per cent confidence limits of such predictions - equations (1) and (2). Since the black plots have the least standard error, their temperatures could be predicted with the least error. For the other treatments the error is substantially larger. In each case the error in estimating the temperature becomes smaller with depth.

(4) Diurnal temperature variations under clear skies (August 23, 1967).

Ramdas states that, "solar radiation is the main source of heat for the ground surface."[1] The direct and diffuse-sky radiation incident

[1]Ramdas, L.A. (1957), "Natural and artificial modification of microclimate". Weather, Vol. 12, No. 8, p. 237.

at the ground's surface by day represents the most important factor in heating the soil. According to Slatyer and McIlroy (1961) under clear sky conditions the direct beam component is of 80 to 90 per cent intensity.

Figs. 18, 19, and 20 show small temperature differences between plots in the early morning hours. This is the result of nocturnal cooling which began after sunset, and persisted throughout the night. Incoming short-wave radiation is cut off at night, and cooling of the air and the superficial soil layers result from the net long-wave radiation loss from the ground. The abrupt rise in temperature from about 1000 hours is the result of the intense day-time heating of the soil by solar radiation, accentuated by the clear skies. The rapid rise in temperature continues until the diurnal maxima are reached. Temperatures then start to fall as incoming radiation becomes less than outgoing radiation. Nocturnal cooling sets in and lasts until sunrise.

The diagrams show that there is a rapid rise in temperature for both the control and black plots from about 1000 hours, with the black plots showing the higher temperatures. The white plots show a much smaller increase in temperature. The mulch plots maintain a remarkably uniform, although low, temperature. The diurnal temperature ranges are highest in the black plots and lowest in the mulch plots. The mulch cover, because of its poor thermal conductivity, has changed the times of the movement of the diurnal heat waves into and out of the soil. The times of the diurnal minimum and maximum have been delayed by over one hour.

Small-scale differences between the diurnal temperature patterns within the two soil-types can be explained in terms of the physical properties of the soils. The fine sandy loam, because of its smaller heat capacity, and poorer thermal conductivity, compared with the sandy clay loam, heats up and cools down more quickly. Consequently, the day-time rise in temperature is more rapid, the diurnal maximum temperature is higher, and nocturnal cooling is faster within the fine sandy loam.

(5) Diurnal temperature variations under cloudy skies (June 23, 1967).

A cloud cover exerts a profound influence on the amount of short-wave radiation received at the earth's surface. Dense cumulus clouds reflect a considerable fraction of the direct solar radiation. According to van Wijk, "dense clouds can reflect more than 70 per cent of the incident solar radiation".[1] This interception of solar radiation by clouds is very significant in so far as soil temperatures are concerned.

Figs. 21, 22, and 23 show some similarities with Figs. 18, 19, and 20: for example,

(i) The times of maximum and minimum temperatures are delayed for at least one hour under the mulch plots.

(ii) The black plots show higher temperatures than the control plot.

(iii) The white plots show lower temperatures than the control plots

(iv) The mulch plots show relatively low and fairly even temperatures.

Figs. 18-23 indicate that cloud reduced both the diurnal temperature range and the differences between the plots.

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[1]van Wijk, W.R. (1963) Physics of Plant Environment, John Wiley & Sons, Inc., New York, p. 80.

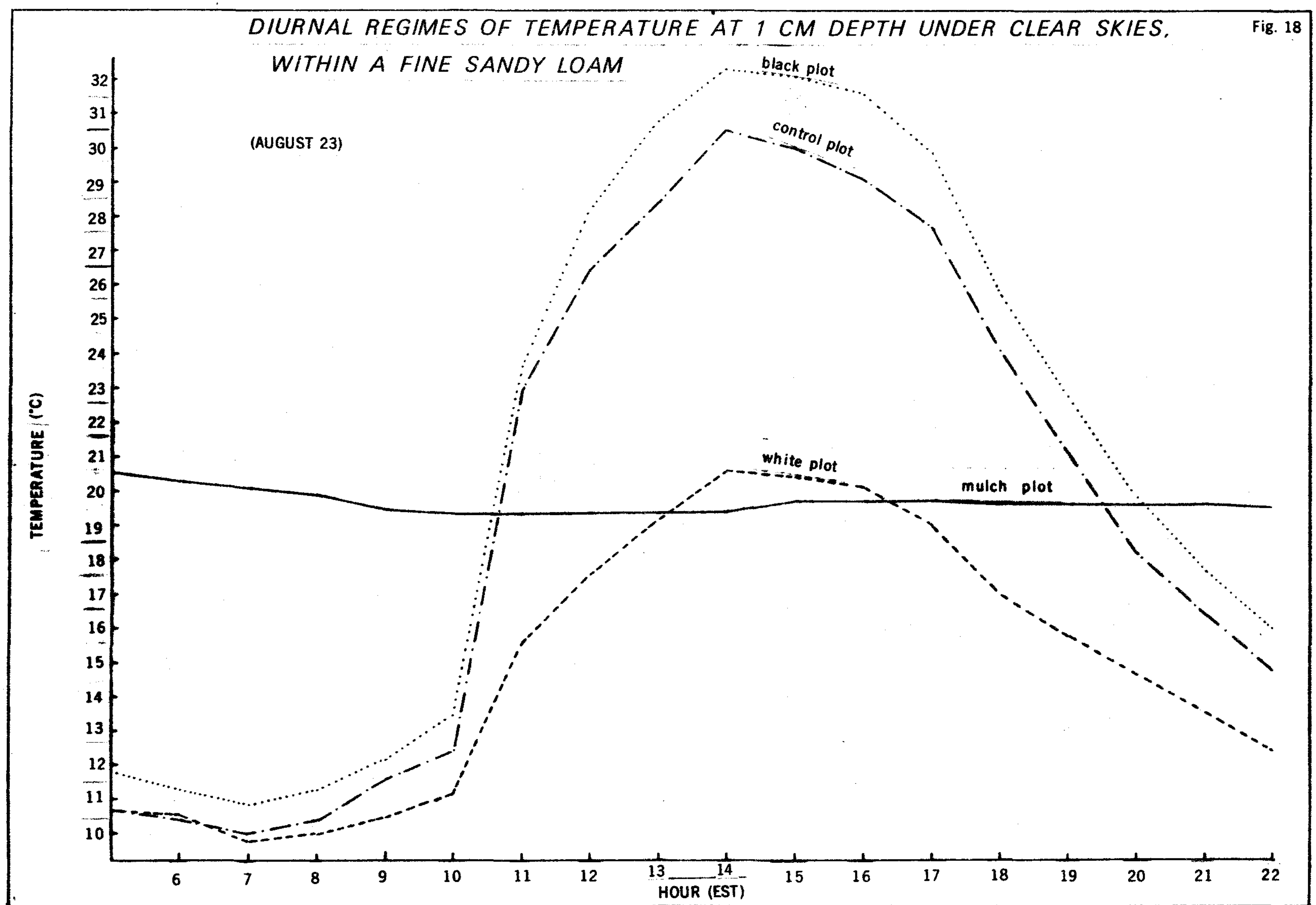

DIURNAL REGIMES OF TEMPERATURE AT 1 CM DEPTH UNDER CLEAR SKIES,
WITHIN A FINE SANDY LOAM
Fig. 18
(AUGUST 23)
black plot
control plot
white plot
mulch plot
TEMPERATURE (°C)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
HOUR (EST)

Fig. 19

DIURNAL REGIMES OF TEMPERATURE AT 5 CM DEPTH UNDER CLEAR SKIES, WITHIN A FINE SANDY LOAM

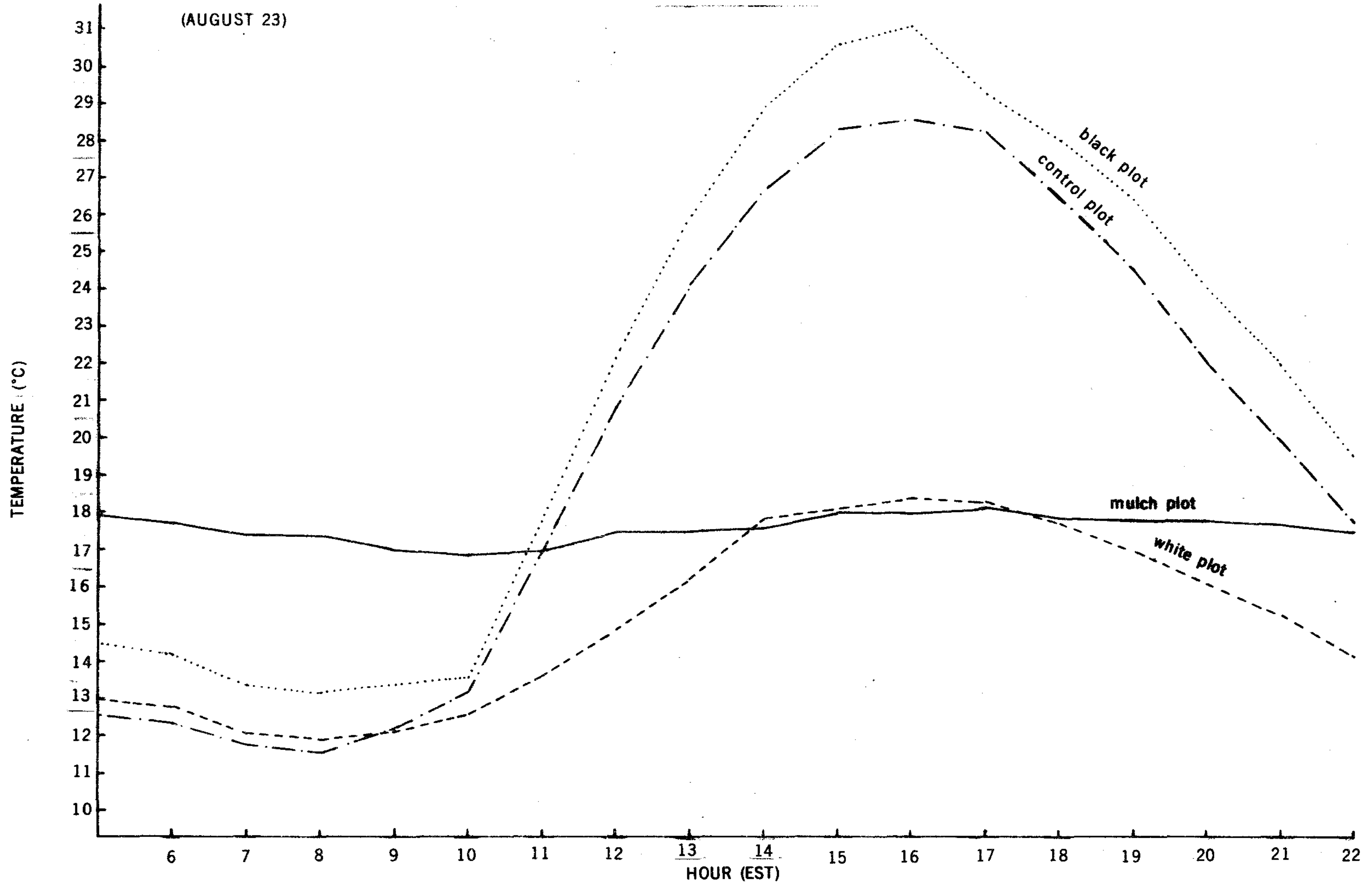


Fig. 20

DIURNAL REGIMES OF TEMPERATURE AT 5 CM DEPTH UNDER CLEAR SKIES, WITHIN A SANDY CLAY LOAM

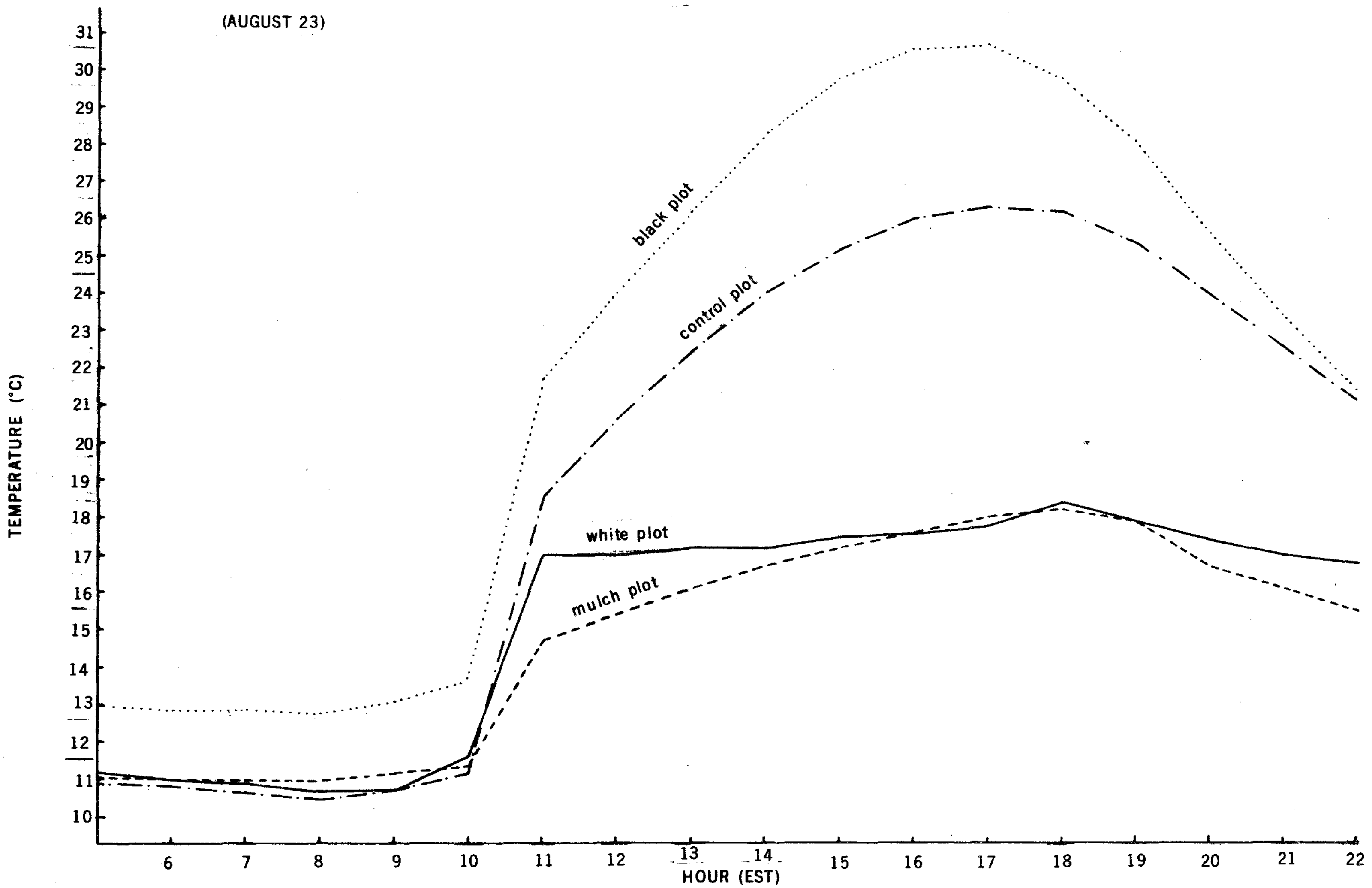


Fig. 21

DIURNAL REGIMES OF TEMPERATURE AT 1 CM DEPTH UNDER CLOUDY SKIES, WITHIN FINE SANDY LOAM

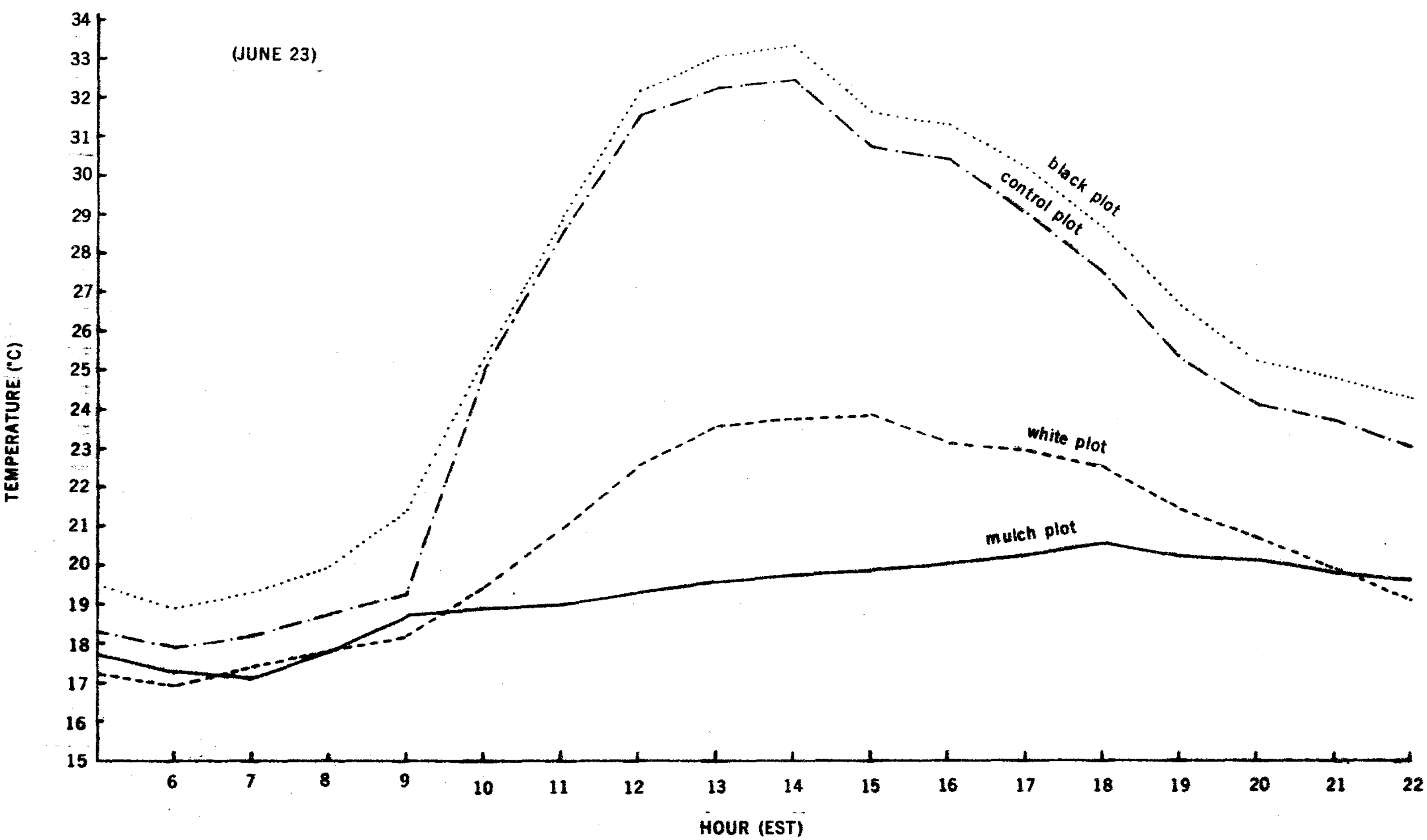


Fig. 22

DIURNAL REGIMES OF TEMPERATURE AT 5 CM DEPTH UNDER CLOUDY SKIES, WITHIN A FINE SANDY LOAM

(JUNE 23)

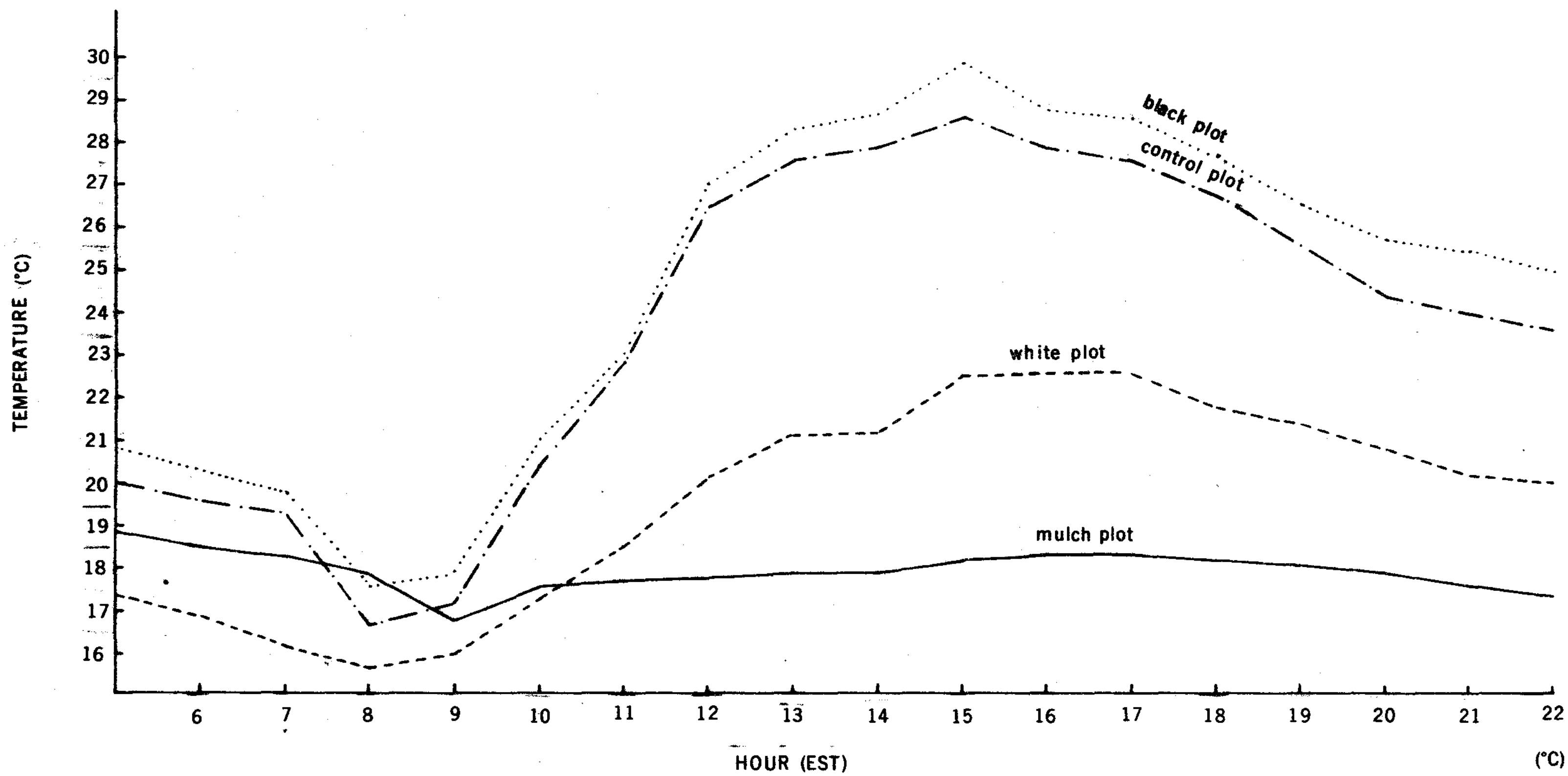
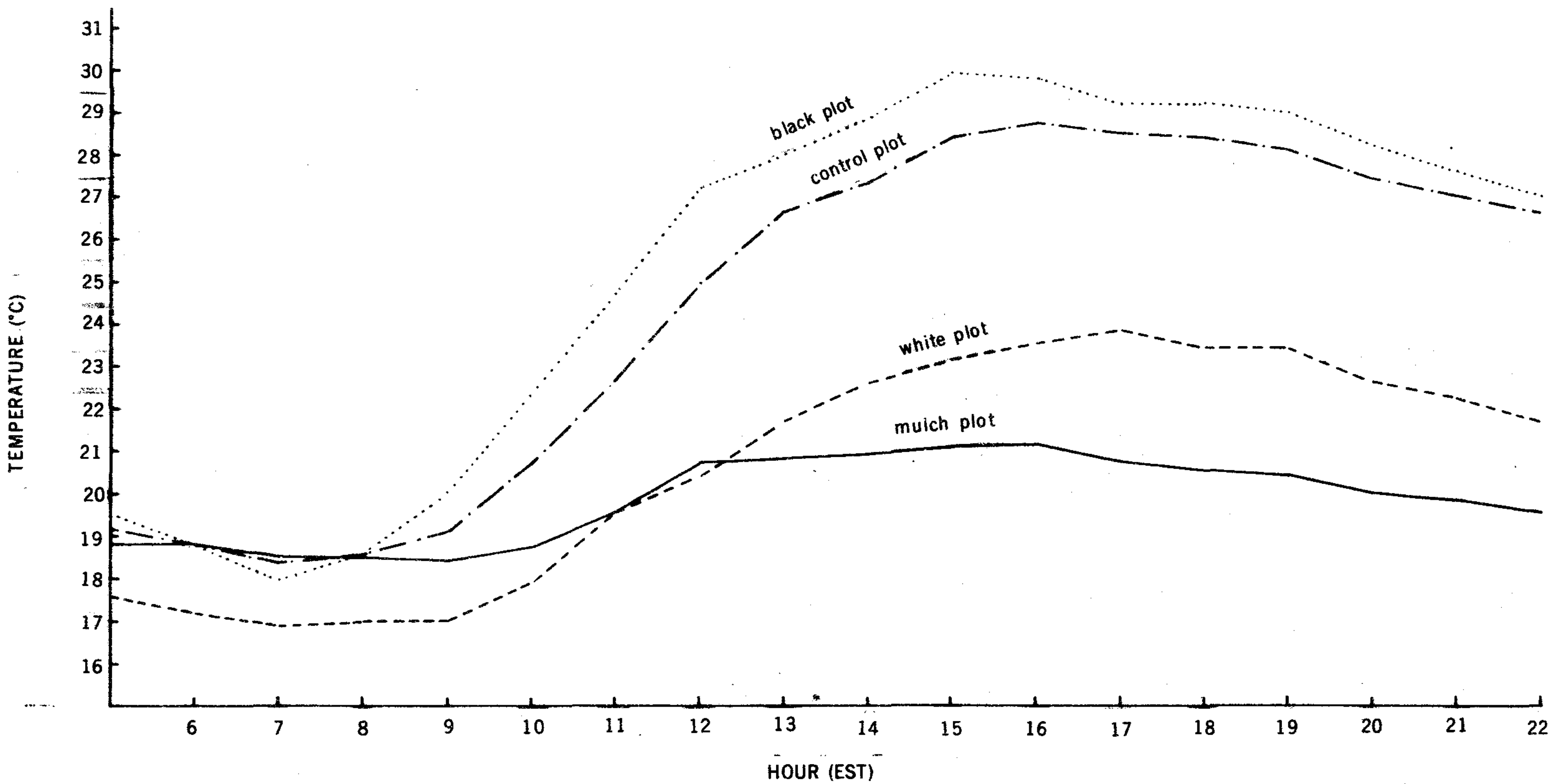


Fig. 23

DIURNAL REGIMES OF TEMPERATURE AT 5 CM DEPTH UNDER CLOUDY SKIES, WITHIN A SANDY CLAY LOAM

(JUNE 23)



(6) Effect of rain on temperatures

In general, rain usually exerts a cooling action on the soil because most rains are of a lower temperature than the soil itself. The penetration of rainwater into the soil profile will probably cause rapid cooling within the profile. It is generally agreed that the primary effect of rain is to modify the responses of the soil to radiant energy. After a rain, the absorptivity of the soil is increased. Much of the heat gained from radiation may be lost by evaporation of water from the surface. Russell and Russell (1950) quote English experiments, which indicate that when the surface soil is wet, about half the absorbed energy is used in evaporating water.

According to Munn, "although soil temperatures normally change only slowly with time, percolation can cause sudden rises or falls of as much as 5°C shortly after heavy rain has begun".[1]

At about 1900 hours on the 16th of June 1967, there was a very heavy downpour of rain which lasted for only a few minutes. Tables 9 and 10 below show recorded hourly temperatures before and after the storm.

TABLE 9

The effect of rain on temperatures at 5 cm depth within a fine sandy loam

Time (EST)	Control plot	black plot	white plot	mulch plot
1800	35.8	39.2	29.4	25.0
1900	34.8	37.0	28.6	24.1
2000	31.2	31.1	27.2	23.3
2100	28.7	29.2	25.8	23.0
2200	27.1	26.9	23.3	21.2
2300	25.8	25.0	22.4	21.0

[1]Munn, R.E. (1966) Descriptive Micrometeorology, Academic Press, New York and London, p. 28.

TABLE 10

The effect of rain on temperatures at 5 cm depth within a sandy clay loam

Time (EST)	control plot	black plot	white plot	mulch plot
1800	35.1	38.6	28.7	24.8
1900	33.9	36.6	27.7	23.4
2000	30.7	31.0	26.5	22.7
2100	28.5	29.4	25.1	22.6
2200	27.1	27.4	22.8	20.8
2300	26.1	26.4	22.5	20.6

Rapid cooling occurred in all plots. Since the black plots absorbed the most heat, they consequently lost the most heat through the evaporation of moisture, and as a result they showed the most rapid fall in temperature. The low thermal conductivity of the mulch plots resulted in relatively slight fall in temperature.

At the end of the observation, a more rapid fall in temperature was noted in the fine sandy loam. This was probably due to the different infiltration rates of the two soils. While rain percolates very rapidly into the fine sandy loam, the sandy clay loam absorbs water so slowly that a large proportion of it runs off. The effect of rainfall on soil temperatures is therefore greater in the fine sandy loam.

(7) Weekly regimes of soil moisture-content.

TABLE 11

Means and variances of the mean weekly moisture-content within a fine sandy loam and a sandy clay loam

	Means			
Legend	control plot	black plot	white plot	mulch plot
fine sandy loam	27.8	25.7	30.4	34.4
sandy clay loam	30.8	26.2	33.3	44.6

Table 11 - cont'd

	Variances			
Legend	control plot	black plot	white plot	mulch plot
fine sandy loam	16.0	17.6	9.6	5.8
sandy clay loam	47.6	65.6	44.9	6.8

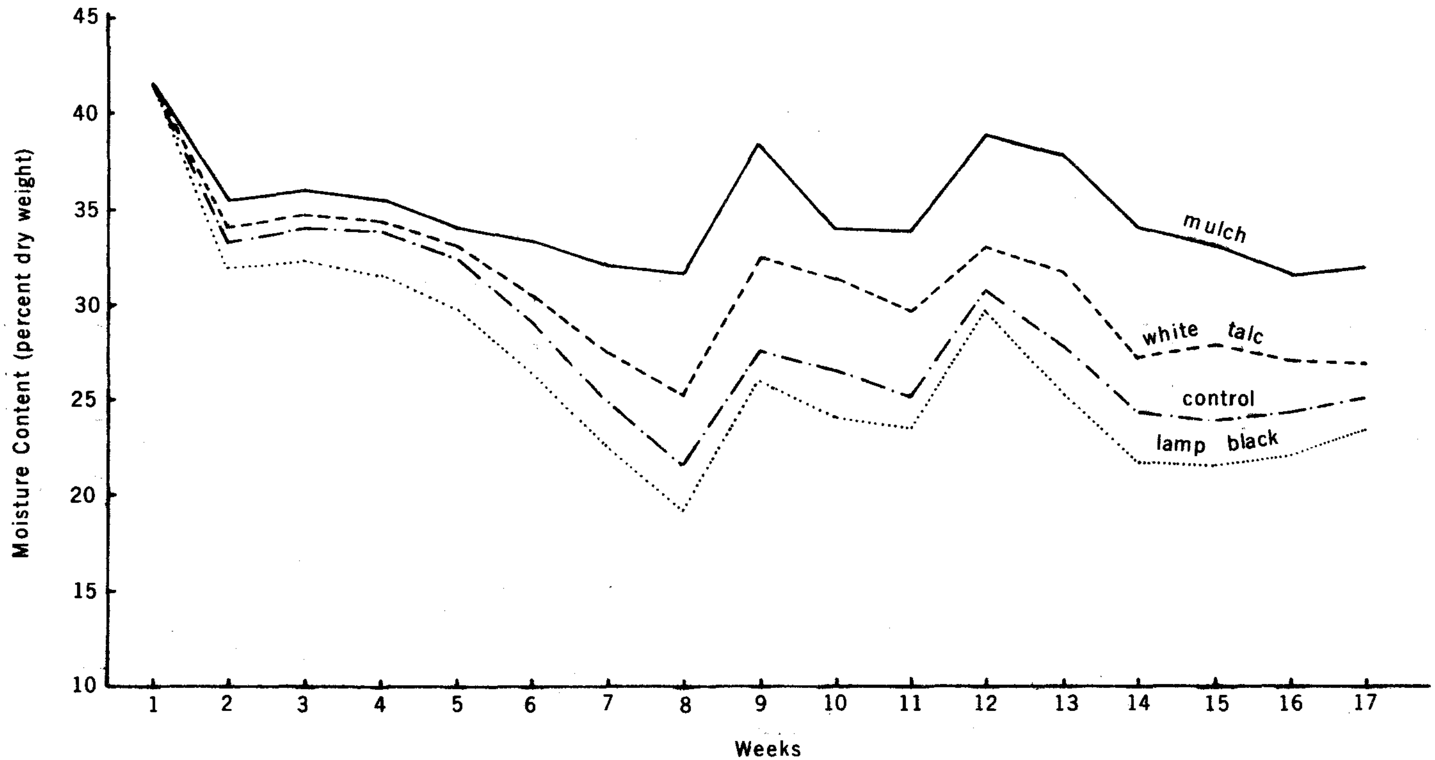
The means and variances of the mean weekly moisture-content for both soils are presented in Table 11 above. These emphasize the effects of the various treatments on soil moisture-content. It is significant to note the high moisture-content in the mulch plots, and the low moisture-content in the black plots. Also, the effect of the black and mulch treatments are more marked on the sandy clay loam.

Poorly drained soils warm up slowly in the spring. The early-season coldness of poorly drained soils is one of the limiting factors in their use for crop production. The high moisture-content of these soils also delays planting in them. Under such water-logged and cold conditions the use of straw mulch would be undesirable. The application of the lamp black powder would be much more effective and useful.

Water that falls as rain is held primarily in the upper part of the soil, which is the zone from which plants withdraw water most rapidly if the water is available. Evaporation from the surface of the soil is a vitally important factor in crop production. Surface evaporation affects water that might otherwise be used readily by the crop. The conservation of soil moisture is clearly important. The straw mulch, with its high capacity for conserving soil moisture, by decreasing moisture losses, would be of practical significance under dry conditions. But the straw mulch, while highly effective in checking evaporation, could not be applied to field crops which require inter-tillage during the growing season.

WEEKLY VARIATIONS OF MOISTURE-CONTENT WITHIN A FINE SANDY LOAM

Fig. 24



WEEKLY VARIATIONS OF MOISTURE CONTENT WITHIN A SANDY CLAY LOAM

Fig. 25

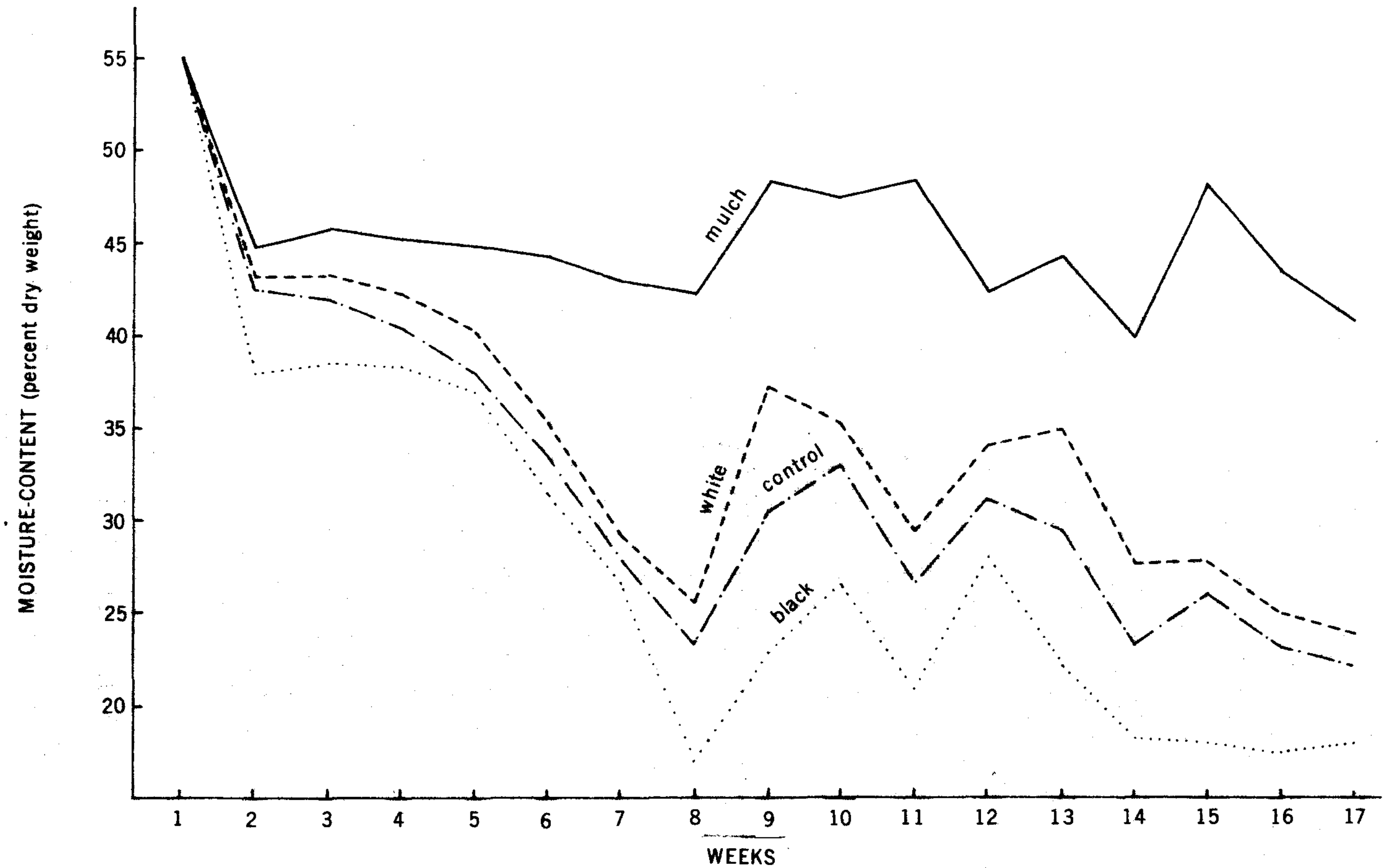
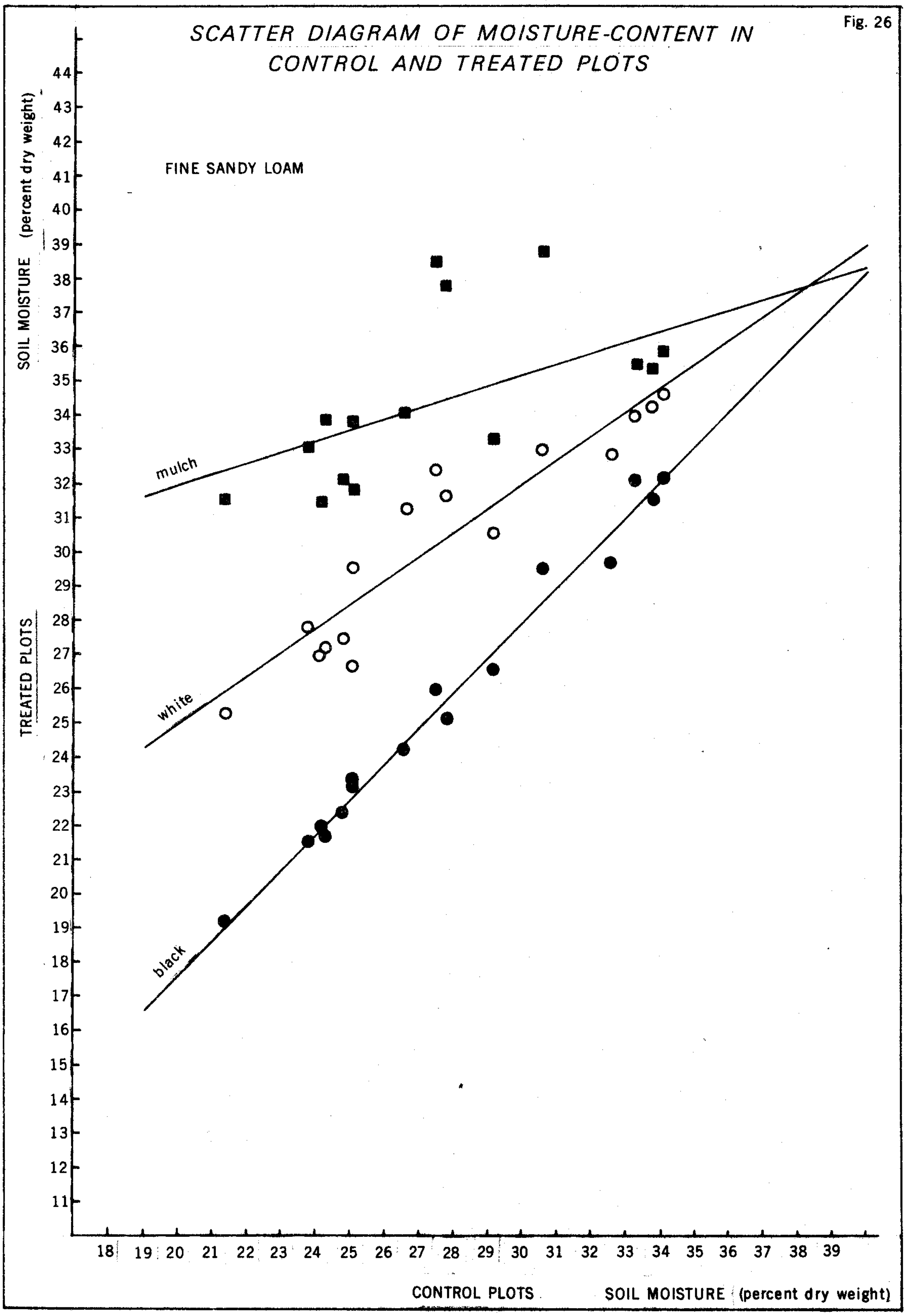
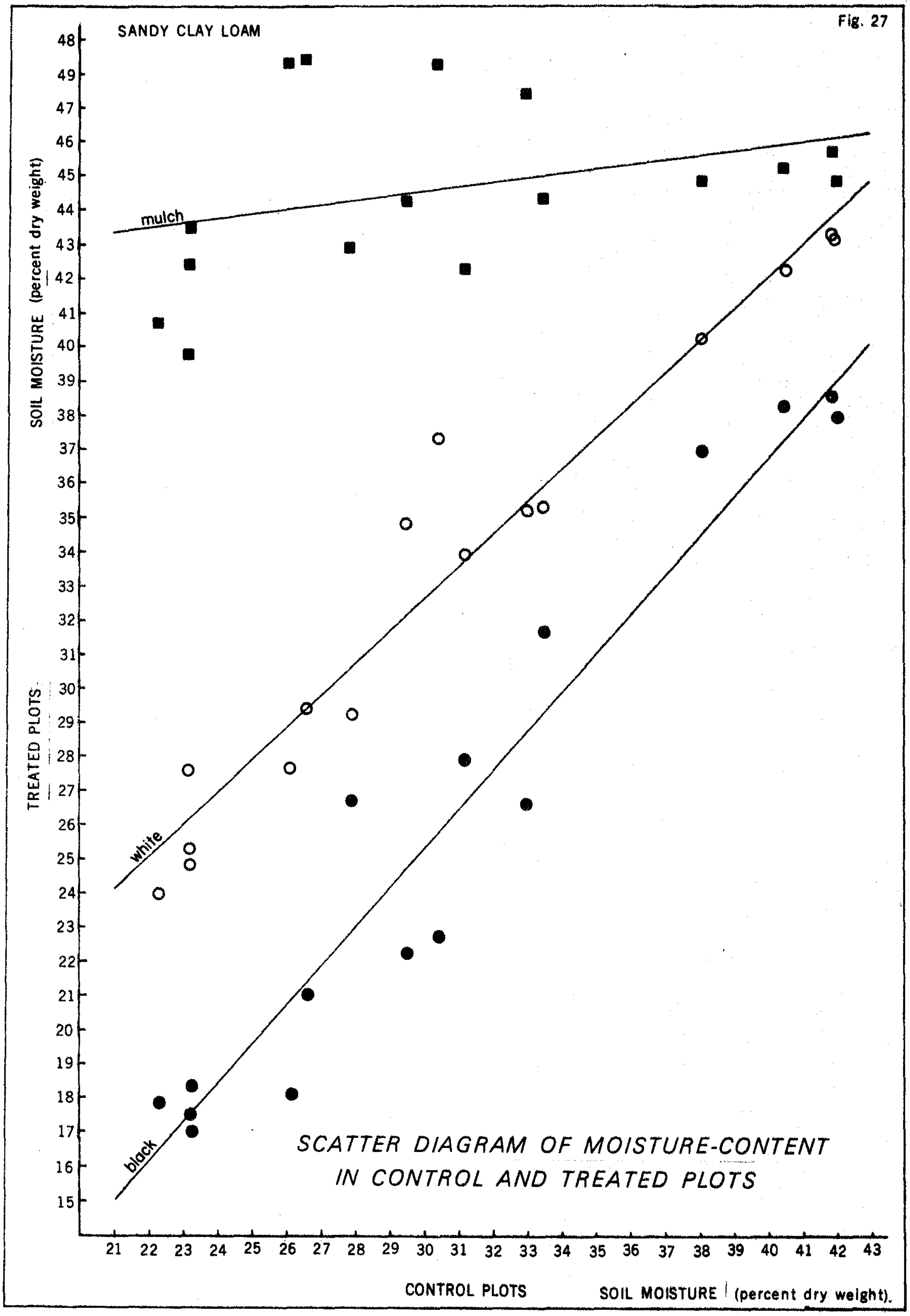


Fig. 26


SCATTER DIAGRAM OF MOISTURE-CONTENT IN CONTROL AND TREATED PLOTS
FINE SANDY LOAM
TREATED PLOTS SOIL MOISTURE (percent dry weight)
mulch
white
black
CONTROL PLOTS SOIL MOISTURE (percent dry weight)



SCATTER DIAGRAM OF MOISTURE-CONTENT IN CONTROL AND TREATED PLOTS

TABLE 12

Soil moisture-content, expressed as a percentage of the upper limit of available-water in a fine sandy loam.

Week	Control plot	Black plot	White plot	Mulch plot
1	159.2	159.2	159.2	159.2
2	128.1	123.5	130.8	136.5
3	131.2	124.2	133.1	138.1
4	130.0	121.5	131.9	136.2
5	125.4	114.6	126.5	130.0
6	112.3	102.3	117.7	128.1
7	95.4	86.2	105.8	123.4
8	82.3	73.8	97.3	121.5
9	105.8	100.0	124.6	148.1
10	102.3	93.1	120.4	131.2
11	96.5	90.0	113.8	130.0
12	117.7	113.8	126.9	149.2
13	106.9	96.9	121.9	145.4
14	93.5	83.5	104.6	130.4
15	91.5	83.1	106.9	127.3
16	93.1	84.6	103.8	121.2
17	96.5	89.6	102.7	122.7

TABLE 13

Soil moisture-content, expressed as a percentage of the upper limit of available-water in a sandy clay loam

Week	Control plot	Black plot	White plot	Mulch plot
1	166.7	166.7	166.7	166.7
2	128.5	114.8	130.6	135.8
3	127.0	116.7	130.9	138.5
4	122.7	115.8	127.9	137.0
5	115.5	111.8	121.8	135.8
6	101.5	95.8	107.0	134.2
7	84.5	80.9	88.5	130.0
8	70.3	51.5	73.6	128.5
9	92.1	68.8	113.0	146.4
10	100.0	80.6	106.7	143.6
11	80.6	63.6	89.1	146,7
12	94.5	84.5	102.7	128.2
13	89.4	67.3	105.5	134.2
14	70.3	55.5	83.6	120.6
15	79.1	54.8	83.9	146.4
16	70.3	53.0	75.2	131.8
17	67.6	54.2	72.7	123.3

The black plots have the greatest variances, (for the reasons stated in considering the temperature regimes), followed by the control, white and mulch plots. The variances of moisture are greater in the sandy clay loam than in the fine sandy loam. This is partly the result of the higher thermal conductivity, and the finer texture of the former.

The effects of the various treatments on the moisture-content can be shown in several ways. Graphs, using weekly means expressed as percentage of dry weight, are shown in Figs. 24 and 25. Tables 12 and 13 show weekly means, expressed as a percentage of the upper limit of available water. Finally, Figs. 26 and 27 show regression relationships between treated and control plots. The results of the regression analysis are presented in Table 14.

The outstanding feature of the soil moisture results presented in Figures 24 and 25, is the strong divergence of the individual curves with time, from the date of treatment applications. Soil moisture declines sharply at first, and thereafter more gradually. The values for the control plots decreased partly as a result of the removal of the grass cover, and partly as a result of the progressive fall in soil moisture-content from early spring to late summer. The values of the soil moisture-content from the tables and figures, are in descending order: mulch plots, white plots, control plots, and black plots. The beneficial effect of a mulch in retaining water is very apparent. The moisture-content under the mulch plots were never less than the upper limit of available-water in the soil.

The reduced absorption of solar radiation by the white plots lead to reduced soil moisture losses by evaporation, whereas the increased absorption of solar energy by the black plots lead to a greater desiccation of the upper soil layers. Since the thermal conductivity of the mulch is probably much lower than that of the soil, the heat gained or lost is less under the mulch. This effect on soil temperatures is one of the basic reasons why evaporation is less and soil moisture-content is correspondingly more.

The mulch also increases the distance through which the water vapour must diffuse between the soil water and the free atmosphere above the soil. This reduces the vapour-pressure gradient and therefore the evaporation loss is reduced. During rains, the mulch also increases the infiltration of water into the soil, and consequently the moisture-content in the soil.

The mulch plot on the sandy clay loam shows a higher moisture-content than the mulch plot on the fine sandy loam (Figs. 24 and 25). This could be explained by the fact that the water-holding capacity increases as the texture becomes finer. According to Sellers, "the ability of a given soil to retain water, that is, its moisture tension, increases as the average pore size decreases and as the surface area per unit mass of soil, the specific surface, increases".[1] The fine sandy loam probably has larger pores and a relatively low specific surface. The sandy clay loam is probably favoured with smaller pores and a high specific surface, hence it holds the greater amount of moisture. It also swells as the moisture-content increases. The cracks formed when the soil dries out later show that swelling has occurred. Cracking will permit more capillary movement of moisture to the surface, and therefore lead to

[1]Sellers, W.D. (1965) Physical Climatology. The University of Chicago Press, Chigago, p. 133.

greater evaporation loss. Also the penetration of solar radiation into these cracks will accentuate the rate of evaporation of moisture from the upper soil layers.

The lamp black powder had a greater desiccating effect on the sandy clay loam than on the fine sandy loam, most probably because of the cracking characteristic of the former when dry. This feature has probably caused the much larger difference between the moisture-contents of the control and the black plots on the sandy clay loam, compared to the corresponding plots on the fine sandy loam. Tables 9 and 10 show these differences in soil moisture-contents clearly. Soil moisture-content was reduced to as low as 50 per cent of the upper limit of available-water in the black plot on the sandy clay loam, whereas at no instance was soil moisture-content lowered to less than 70 per cent of the upper limit of available-water in the fine sandy loam, by the lamp black powder.

The differences in moisture-contents between the black and the control plots on the fine sandy loam are smaller than those between the corresponding plots on the sandy clay loam. This explains the large differences in temperatures between the black and the control plots of the sandy clay loam compared with the corresponding plots on the fine sandy loam.

The general effect of blackening the soil surface is to deplete the moisture reservoir, and this will inhibit plant growth. Clearly, the optimum moisture-content should be such that it secures on the one hand a satisfactory aeration of the root zone and on the other hand, a sufficient storage of water in this zone. Although the mulch conserves moisture better than the other treatments, and keeps the soil damper and more permeable to water, the excess moisture over the upper-limit of available-water in the soil may cause aeration problems for plants' roots.

TABLE 14

Regression and correlation results of the mean weekly relationships (of soil moisture-content) between control and treated plots.

Legend	Regression intercept (a)	Regression coefficient (b)	Correlation coefficient (r)	Fraction of variability accounted for	Standard Error (per cent dry weight) (SE)
fine sandy loam					
black plot	-2.934	1.031	0.993	0.985	0.530
white plot	10.639	0.711	0.933	0.871	1.146
mulch plot	25.508	0.322	0.551	0.303	2.044
sandy clay loam					
black plot	-9.017	1.143	0.969	0.939	2.086
white plot	4.417	0.938	0.971	0.943	1.650
mulch plot	40.617	0.128	0.336	0.113	2.567

The high and significant correlation coefficients of the black and white plots, (Table 14), contrast quite markedly with the low correlation coefficients of the mulch plots. The standard error of the black and white plots, for both soil-tyoes, and smaller than for the mulch plots.

In Figs. 26 and 27 the mean moisture-content beneath the treatments are shown to be linearly related to the control plots. It is significant that the slopes of the lines are in descending order: black plots, white plots, and mulch plots. The slope differences are (as in the case of temperatures) a function mainly of available energy. This interpretation of the slope as an indicator of the drying or wetting effect of the treatment is problematic because of the large intercept values (Table 14). For this reason no attempt has been made to define a slope parameter analogous to the θ parameter in the temperature analysis. A greater range of soil moisture values is apparent for the sandy clay loam than for the fine sandy loam. Hence there is little difference in the correlation and standard errors of the black and white plots. The results for the mulch plots are poor.

Differences in the moisture-content of the black and white treated plots are predictable from the control, but the considerable scatter in the mulch-control plot relationship does not suggest a meaningful or predictable relationship.

Although there is insufficient data to be conclusive, it should be noted that for both soils the regression lines indicate a point of convergence beyond the scatters. Here presumably moisture values under the three treatments have a similar effect. It must be remembered that these plots are small - 90 cm square separated by 120 cm wide gaps - and that as soil moisture levels rise, the likelihood of lateral flow and consequently uniformity over the whole site increases.

CHAPTER IV

CONCLUSIONS

The results of this work show that it is possible to modify the temperature and moisture regimes of a soil in a predictable linear manner by altering its surface albedo, and thereby altering the proportion of the solar radiation that is absorbed.

Blackening the surface, however, not only warmed both soils but depleted the moisture-content considerably, especially in the case of the sandy clay loam. Whitening the surface cooled the soils and kept them more moist than both the blackened and control plots. Mulching kept the soils at a remarkably uniform, although relatively low, temperature, and increased the moisture-content well above the upper limit of available-water. In addition the mulch delayed the diurnal maximum and minimum temperatures for at least one hour.

Greater differences between treatments were produced when skies were clear. Under cloudy skies, the differences were smaller. The effect of rain in lowering soil temperatures was greater in the coarser textured soil.

From this isolated case study it has been shown that the soil temperature and moisture regimes of treated plots are linearly related to those of a control plot. But further work is needed on other soil-types, with greater emphasis on the soil thermal properties, and radiation balance of the surface. These are required since the soundest prediction is most likely to ensue from a thorough understanding of the important physical processes.

APPENDIX Ia

Soil site description (Site A)

Profile Reference:		Site A
Map Reference:		43°16' N, 79°55' W.
Taxonomic Unit:		Grey-Brown Podzolic
Locality:		McMaster University Campus, Hamilton
Local Relief:		flat ground with short grass
Elevation:		326 ft. A S L.
Exposure:		moderately exposed
Slope:		None
Drainage:	Regional:	moderately good to good
	Surface:	moderately good
	Profile:	moderately good to good
Parent Material:		Glacio-fluvio-lacustrine stratified sediments of Lake Iroquois age
Vegetation and Land Use:		Short grass and Recreational
Climate:		Sub-humid

APPENDIX Ib

Soil site description (Site B)

Profile Reference:		Site B
Map Reference:		43° 17' N, 79° 56' W.
Taxonomic Unit:		Grey-Brown Podzolic
Locality:		Royal Botanical Gardens Arboretum, Hamilton
Local Relief:		gently undulating with short grass
Elevation:		350 ft. A S L.
Exposure:		moderately exposed
Slope:		Dipping W to E at about 3°
Drainage:	Regional:	moderately good to good
	Surface:	moderately good to good
	Profile:	moderately good but may be slow, especially after rains
Parent Material:		Fluvio-glacial materials
Vegetation and Land-use:		Short grass and recreational
Climate:		Sub-humid

APPENDIX IIa

Soil profile description (Site A)

A_1 0-13 cm; dark brown (7.5 YR 4/2) when moist; brown (10 YR 5/3) when dry; sandy loam; crumb structure; friable; moderately porous; clear boundary.

A_2 13-25 cm; dark brown (7.5 YR 4/2) when moist; brown (10 YR 5/3) when dry; sandy loam; crumb to blocky structure; friable, moderately porous, clear boundary.

B_{21} 25-35 cm; brown (7.5 YR 5/4) when moist; pale brown (10 YR 6/3) when dry; sandy clay loam; sub-angular blocky structure; compact; moderately porous; merging boundary.

B_{22} 35-63 cm; dark brown (7.5 YR 4/4) when moist, light yellowish brown (2.5 YR 6/4) when dry; sandy clay loam; angular blocky structure; compact; porous; merging boundary.

C 63 cm - ; strong brown (7.5 YR 5/6) when moist; yellowish brown (10 YR 5/8) when dry; loamy sand; angular blocky structure; compact; porous; clear boundary.

APPENDIX IIb

Soil profile description (Site B)

A_{1-2} 0-15 cm; dark brown (7.5 YR 4/2) when moist; yellowish brown (10 YR 5/4) when dry; sandy clay loam; sub-angular blocky structure; friable; fissured; merging to clear boundary.

B_{21} 15-38 cm; dark reddish-brown (5 YR 3/3) when moist; light yellowish brown (10 YR 6/4) when dry; sandy clay loam; angular blocky structure; compact; porous and fissured; merging boundary.

B_{22} 38-68 cm; reddish brown (5 YR 4/3) when moist; yellowish red (5 YR 4/8) when dry; sandy clay loam; angular prismatic structure; compact; porous and fissured; merging boundary.

C 68 cm - ; dark reddish-brown (5 yr 3/4) when moist; reddish brown (2.5 YR 4/4) when dry; sandy clay loam; massive structure; hard; porous; merging boundary.

APPENDIX III

Procedure of mechanical analysis

50 gm of soil was weighed into a 600 ml beaker. 200 ml of distilled water and 10 ml of N. NaOH were added, and the whole mixture slakes for about 24 hours. Occasionally, the mixture was stirred to ensure that all the soil came in contact with the solution.

The suspension was then washed into the metal cup of the turbo-agitator which was filled to within one inch of the top with distilled water and then mounted on the dispersion machine and stirred for 30 minutes.

After dispersion, the mixture was then transferred to a litre cylinder, the hydrometer inserted and the volume made up to the mark with distilled water. The hydrometer was withdrawn and the suspension thoroughly shaken manually for 60 seconds. It was necessary when inserting and removing the hydrometer to exercise especial care so as not to unduly disturb the suspension.

At the end of 60 seconds the cylinder was carefully placed on the bench and the time noted. Froth above the suspension were broken up by adding a few drops of amyl acetate. After standing for 4 min., the hydrometer was very carefully inserted into the suspension and the reading taken at 4 min. 48 sec. The hydrometer was withdrawn and the temperature of the suspension taken immediately. The suspension was then left for two hours when the hydrometer and temperature readings were again taken.

In analyzing the results, the readings at 4 min. 48 sec. was first corrected for temperature. The corrected reading was then divided by the weight of oven dry soil equivalent to 50 gm air dry soil, and multiplied by 100. The result is the amount of silt and clay still in the suspension. The percentage of sand is found by substracting that result from 100.

The reading at 2 hours was also corrected for temperature. The percentage clay was found directly by dividing the corrected hydrometer reading by the weight of oven dry soil equivalent to 50 gm. air dry soil, and multiplying by 100. The percentage silt was found by difference.

Finally an arbitrary correction was made to the sand value in order to allow for organic matter content.

APPENDIX IV

Temperature - EMF relation

EMF (millivolts)	Temperature (°C)
0.0000	0.0
0.0851	2.0
0.1698	4.0
0.2542	6.0
0.3382	8.0
0.4219	10.0
0.5051	12.0
0.5880	14.0
0.6706	16.0
0.7528	18.0
0.8346	20.0
0.9161	22.0
0.9971	24.0
1.0779	26.0
1.1582	28.0
1.2382	30.0
1.3179	32.0
1.3971	34.0
1.4760	36.0
1.5546	38.0
1.6328	40.0

$$\text{Temperature} = -0.190 + 2.436\ (\text{EMF}).$$

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LOCATION OF EXPERIMENTAL SITES