Color as a soil amendment.

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by

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INTRODUCTION

Temperature influences the rate of most chemical, physical, and biological processes. The soil temperature under field conditions is determined by factors affecting the balance between heat gain and loss.

Many crops would be benefitted by increasing soil temperature in the spring. It is within man's power to modify certain factors in order to hasten the rise of temperature of a given soil. When a soil is blackened, a higher soil temperature results due to increased radiant absorption. Blackening materials such as soot, charcoal, and boneblack have been used. All of these contain essential plant nutrients. No effort has been made to separate the effect of color from that due to nutrients.

The problem of this thesis is to determine the direct effect of color on soil temperatures. For the present study, inert carbon black was used to color the soil.

REVIEW OF LITERATURE

The soil temperature obtained under field conditions is the resultant of many factors. It is influenced not only by quality, quantity and direction of the sun's rays which fall upon it, but by the temperature and amount of air, rain, and ground-water with which it comes in contact. It is influenced by heat developed within it through oxidation of organic or oxidizable substances which it contains, by loss of heat through evaporation of water, and by the capacity of soil itself for absorbing and retaining, or for radiating and reflecting heat.

The Color Factor in Soils

Bouyoucos (4) reports temperature differences found by staining white sand black. Temperatures in sunshine were 6.3°C. higher in July and 5.9°C. higher in August on the black sand at 2 and 2:30 p.m. respectively.

Sands, stained with aniline dyes, show different temperatures in sunlight, (Table 1). The darker the color of the sand the greater the temperature. Minimum temperatures of the different colored sands are about the same due to the fact that all have reached the temperature of the surrounding air.

Wollny (39) writes that the principal mineral ingredients of a soil are clay, lime, and quartz which are white. When soil is any other color it is usually made so by humus or iron. In sands 0.2 to 0.3 percent of humus or 1 percent of ferric oxide is required to produce the same coloring effect. In clays however, 5 to 10 percent of ferric oxide and 2 to 5 percent humus is required.

As shown in Table 2, the darker colored soils have wider daily variation of temperature than the lighter colored soils. Both surface and subsoil of darker colored soils are warmer than the lighter ones. This indicates that there is more energy going into the darker soil. As the 6 a.m. temperature is higher in the dark soil it appears that more heat is retained from the previous day.

Oemler (34) found that darker colored soil absorbs more heat than lighter colored soil, (Table 3).

Wollny (39) found that the greatest differences exist when temperatures of soils are highest. At times when the earth attains a daily maximum of temperature, in summer sunshine, a soil will be warmer in proportion as its color is darker. But during different seasons the differences in temperature between dark and light colored soils may be less noticeable. These differences that are observed are less noticeable below the surface.

Absorptive power of a soil is effectively changed by changing the surface color. A thin cover of charcoal on the surface is not as effective in raising the temperature as chalk is in lowering it, (Table 4).

Mosier and Gustafson (23) compared germination of seeds on a light and a dark soil. They found that more seeds germinated on the dark soil and germination time was shortened, (Table 5).

Germination interval of rutabagas was reported by Irwin (17) as not being affected. For winter oats and barley he observed the germination interval to be 1.5 to 2 days shorter for each 1°F. of soil temperature increase; in spring oats and barley, 1 day per 1°F.

Girardin (34) found that the times at which potatoes ripened varied from 8 to 14 days according to the character of the soil. At a given date, August 25th, he found 26 varieties of potatoes ripe in a very dark soil high in organic matter, while upon sandy soil there were about 20 varieties ripe. In clay 19 varieties were ripe and on a white limestone only 16.

Hilgard (16) states that the red tint of soil is probably the chief cause of higher quality of wines from grapes grown on red hillsides in middle and northern wine districts of Europe. Here, everything that adds to earlier maturity is of greatest importance.

In England, Hall (13) reports a deeper color of roses and apples on red sandstones and loams.

O'Neal (25) indicates that soils high in organic matter show great variations in color with changing moisture conditions. However, there is very little change in color up to 30 percent of the waterholding capacity.

The Radiation of Soils

Substances differ in their ability to absorb heat from the sun. Radiation rate is often unrelated to absorption as a poor absorber may be a good radiator.

Newton (24) seems to be the first to perform experiments on soil radiation. From data obtained he formulated the law that the quantity of heat lost or gained by a body in a second is proportional to the difference between its temperature and that of the surrounding medium. Dulong and Petit (8) proved that this law is not general but applies only with differences of temperature which do not exceed 15° to 20°C. In 1879, Stefan (33) showed, from his own researches and from recalculating his predecessors' data, that the rate of radiation of a body is proportional to the fourth power of its absolute temperature.

Lang (21) determined the radiation of a white substance and then after mixing this with a colored substance, such as soot, determined the radiation of the mixture. He concluded from his results that color affects radiation and absorption equally well.

Ahr (1) employed a slightly different arrangement in apparatus but used practically the identical material of Lang. His results were much the same as his predecessor's but he did not deduce the same conclusions. Difference in radiation he thought was due to the composition of the various colored substances rather than to the color.

To obtain radiation readings, Bouyoucos devised a method whereby two Beckman thermometers were used. One was placed near a container of the radiating material and the other in the air. The two readings were taken simultaneously and when the reading of the first thermometer was divided by that of the second, a ratio was obtained which he designated as the radiating power of any particular soil. Using this apparatus he carried out a series of experiments to determine the effect of texture and moisture content on the relative rates of radiation of soils.

In samples taken from the field, the radiation ratio, as he determined it, was the same in all soils tested (Table 6). These same soils covered with a dry surface had much less radiation, (Table 7). Mineral soils radiated from 7 to 9 percent and the peat nearly 14 percent less when covered with a dry layer of soil.

A dry sand has a heat conductivity of 0.00093 compared to 0.00131 for water (12). Where water content is high the transfer of heat to the surface might be as much as 40 percent greater than through a dry material.

Water loses its heat slowly. This is not because of low radiating power, but because of its low heat conduction and its high heat capacity.

The data of Bouyoucos indicate that soils in general possess approximately the same radiating power when moistened. When these soils have a thin layer of dry mulch this power varies only slightly. This means then that these soils, under field conditions, will cool at the same rate as far as their property of radiation is concerned. The different rates of cooling and warming that are observed with soils is due mostly to their different moisture contents and hence to their different specific heats.

Increasing the Heat Absorption of Soils

It has been rumored that the Russians have successfully moved their spring wheat belt farther north by spraying 100 pounds of powdered coal per acre over the surface of snow (3). Three other substances used to darken a soil are soot, charcoal, and carbon black. Carbon black seems to be more feasible as a material to be used on a wide scale. It is a by-product of the petroleum industry and is produced in large quantities.

There are several different types of carbon black on the market. The type used in this work was the least active of those listed in Table 8. This carbon black has been peletized to make it easier to handle. These larger particles break up quickly in the soil. Results obtained with the "SS" type of carbon black might differ somewhat from results obtained with other types due to the difference in pH and particle size. Also the results may not be identical to those found using soot or charcoal. These substances differ in composition but they are all black.

Soot and Its Uses

It is felt by many that "Scotch Soot" will give deeper color to both flowers and foliage. As early as 1775 it was known that soot applied to the soil would produce a deeper color in dahlia flowers (5).

Perotti and Ruso (26) report that the crop-producing power of a soil is improved by the use of about 400 pounds of finely divided carbon per acre. This they say is due first, to the water retaining power of the carbon, second, easy absorption of ammonium salts, and third, to less dispersion of nitrates. (They were probably speaking of charcoal rather than soot.)

Clevenger (6) states that soot from the air may injure plants. This is chiefly due to the accompanying ash, tar, and gases.

Soot contains a certain amount of substances that supply a plant with nutrients (Table 9).

Johnston and Cameron (11) report oats and wheat production increased by 12 and 22 percent respectively, by the use of soot as a top dressing.

Threinen (36) reports the use of soot or carbon black on shallow lakes in Wisconsin to prevent winter killing of fish due to a lack of oxygen. Thirty pounds of carbon black or 300 pounds of soot per acre supplies a uniform dark surface to the snow cover. In bright sunlight, with little wind, this dark surface caused snow to melt with an air temperature below freezing.

Hall (13) suggests the use of soot to discourage slugs and small snails.

Charcoal and Its Uses

Tryon (37) states that the influence of charcoal is thought to be due to changes in physical and chemical properties of the soil and to changes which may occur in the population of competing organisms.

Verona and Ciriotti (40) found that the ash content of charcoal was not entirely responsible for the changes produced in the increased rate of growth and improved quality of beans and corn.

Charcoal at the rate of 0.5 to 0.75 percent showed beneficial results but over 0.75 percent caused a decrease in the growth of micro-organisms (17). The differences found were very small and there was no statistical proof that the differences were enough to be significant.

At the Mont Alto Nursery in Pennsylvania, the production of conifer seedlings had been a failure on heavy clay soil. Charcoal residue from old pits was applied to the seed beds by Retan (30). Two-year-old seedlings on the treated beds were as large as average three-year-old seedlings on the untreated beds. This appeared to be due to the increased water and air content of the soil. Damping-off of seedlings seemed to be decreased by the charcoal.

In Minnesota, Hartley and Pierce (15) were unsuccessful in controlling damping-off by use of charcoal.

Johnson (19) used charcoal successfully in control of brown root rot of tobacco.

Alderfer and Merkle (2) used charcoal as a mulching material and compared it to peat, manure and leaves. The charcoal had no advantages over the other materials.

Isaac (18) found temperatures on charcoal covered soil surfaces to be higher by 7° to 18° F. than those on a yellow soil surface. This temperature difference accounted, in one instance, for the difference between a 100 percent loss of Douglas fir seedlings on a black soil and a 32 percent loss on an adjoining yellow soil. Dying of seedlings began at a soil temperature of 125° F. (which may occur at an air temperature of 85° F.). The highest surface soil temperature recorded for black soil was 165° F.

EXPERIMENTAL

Determination of Carbon Black Placement for Maximum Radiant Energy Absorption

To make the experiment as simple as possible a light colored sand was used. What little organic matter was present was effectively removed by washing with water. There was no apparent color change when the sand was wetted. Hence, any color change would be due only to the added carbon black.

Containers for the sand were six one-gallon crocks placed on a flat table. The experiment room chosen was one that contained no steam radiators and was opened for only a few minutes during the day. For a light source a 300-Watt Mazda bulb was used. A circle of five 100-Watt bulbs was later used. This was necessary because the temperature of the sand on the open filament side of the bulb was as much as five degrees cooler than the other side. The light was placed at such a distance as to produce a temperature approximately equal to that found on a bare soil surface in full summer sunlight.

Carbon black in each crock was applied at the rate of two tons per acre by weight. Each crock contained 6,000 grams of sand. Placement of carbon black was as follows:

1. Carbon black on surface.
2. Carbon black and sand mixed.
3. Carbon black mixed with top one-third.
4. Carbon black mixed with middle one-third.
5. Carbon black mixed with bottom one-third.
6. Pure sand as control.

Using the Hilgard method (16) for waterholding capacity it was found that the sand would hold approximately 25 percent of water. An amount of water equal to 5 percent of the waterholding capacity was added to the sand. Crocks were put under the lights and after a given period of time were weighed to determine the amount of water lost per crock. This was repeated for 10, 20, 30, 40, and 50 percent waterholding capacity, (Table 10).

A second series was run starting with a water saturated sand. After an evaporational run which caused the loss of about 20 percent of the water present, water was added to bring each sample up to 87 percent of its waterholding capacity. Two more adjustments were also made at the 70 and 56 percent levels. From the latter percentage there were no further additions of water. Water losses were noted for several days at 24 hour intervals.

As shown in Table 10 and Table 11, the mixture of carbon black and sand appears to be most effective in causing water loss. Surface application was also quite effective.

The Effect of Different Rates of Application of Carbon Black on the Evaporation Rate of Water from a Soil.

A mechanical mixture of carbon black and a soil is different in texture from that of the original soil. Although carbon black will blacken the soil to a certain extent, much of the carbon black simply lodges in the pore spaces. In order that the internal structure should be uniform, surface application of carbon black was tried.

Ten calorimeter cans were filled with sand and packed as uniformly as possible. Each can contained a glass tube through which water was added to the bottom of the can so that the surface would not be disturbed. It took approximately 91 grams of water to completely saturate each of these soils. This amount was added and the ten cans placed in the outer calorimeter cans which had been evenly spaced below a circle of five 100-Watt bulbs, (Figure 1). The lights were left on for 18 hours and then shut off to let the cans cool to room temperature. When the cans were weighed the evaporation losses were found to be somewhat different. The cans were therefore paired, and divided into two groups which had about the same rates of evaporation. To one of the groups carbon black was added to the surface. Each of the cans was replaced to its original position and the light source was kept in the same relative position at all times.

The first surface application was at the rate of 25

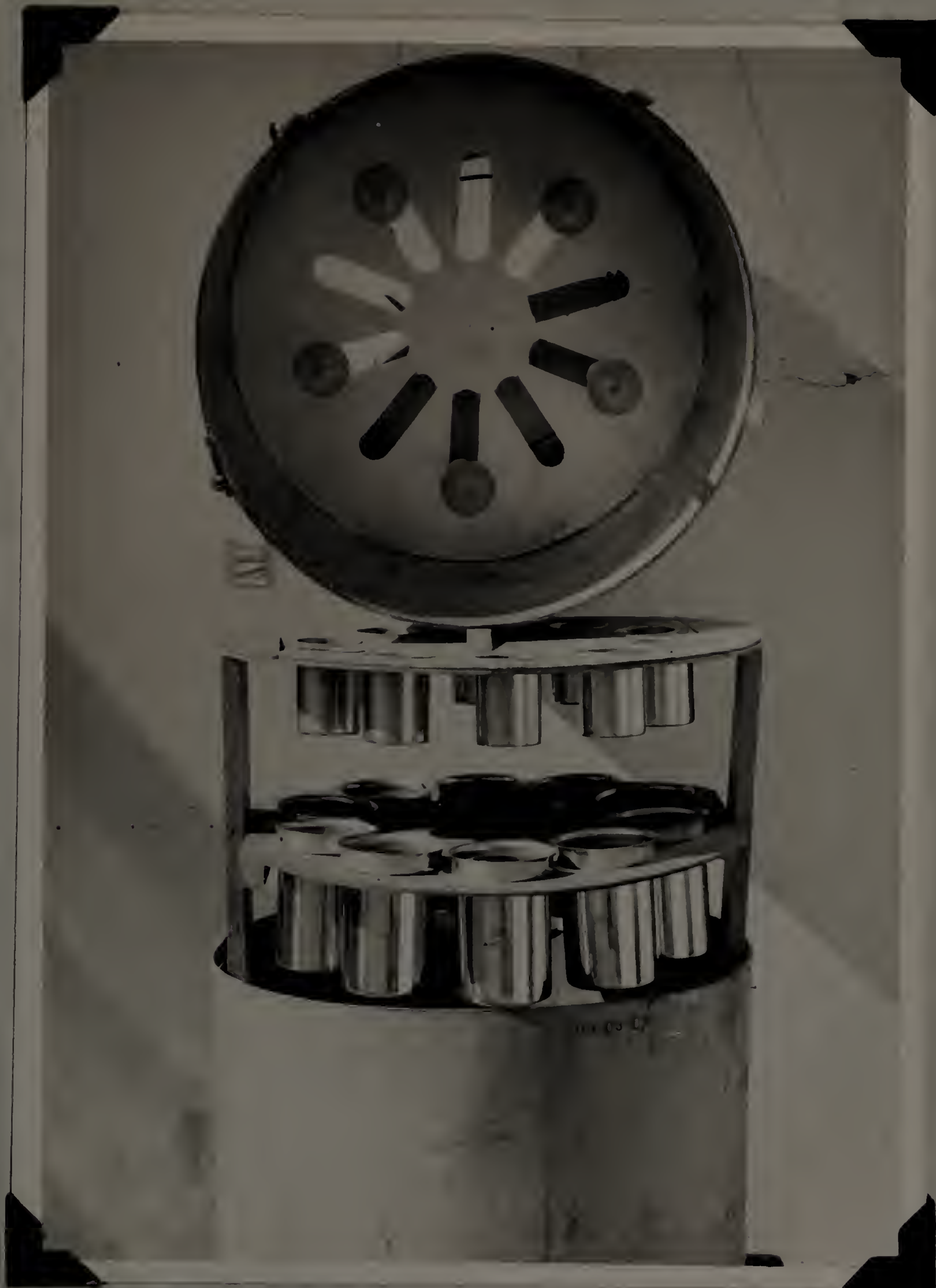

Figure 1. Breakdown view showing use of calorimeter cans and light source as used in moisture evaporation experiment.

pounds carbon black per acre. After the carbon black was added each of the cans had water added in order to bring it back to the original water content. The cans were left under the lights for twelve hours and then allowed to cool to room temperature. Weighings were then made and more carbon black and water added. The application rate of carbon black was doubled each time until a point was reached where the added carbon black caused less evaporation than the previous addition. This point was reached at 800 pounds per acre. Results are shown in Table 12.

Table 13 shows the results of mixing carbon black with the sand. The ton per acre rate was as effective as eight tons per acre. With finer textured soils this rate of application may need to be higher to obtain a maximum rate of water evaporation, (Table 13 and Table 14). A ton per acre may darken a sand considerably but have little effect on color in a clay soil.

Two tons of carbon black per acre had very little effect on evaporation from a loam. Averages of four replicates for eight successive 12-hour periods are shown in Table 14.

Effect of Carbon Black on Evaporation Rate of Water from Sand with a Constant Supply of Water.

Evaporation rate may vary with moisture content. To keep the moisture content constant a system was devised whereby water could be replaced as evaporated. Two methods used are shown in Figure 2.

The first method employed a reservoir connected to a porous cup in the bottom of the container holding the soil. The suction force of the soil is sufficient to pull water from the porous cup. The amount of water evaporated can be found by filling the reservoir to an original mark. The level of water in the reservoir was kept below the level of the bottom of the soil container.

A second method was tried using the same porous cup attached to a small reservoir. Water was replenished in the small reservoir by use of an automatic level gravity feed. There was one main objection to this method. If the air over the water in the large reservoir became heated it would expand and force water out into the smaller reservoir.

For the evaporation run six separate containers were used with six water sources. One control and one treatment were run at the same time with three replications of each. For a source of light, three 100-Watt bulbs were placed over the soil surface. The temperature of the surface was about 44° C. The six reservoirs were so placed

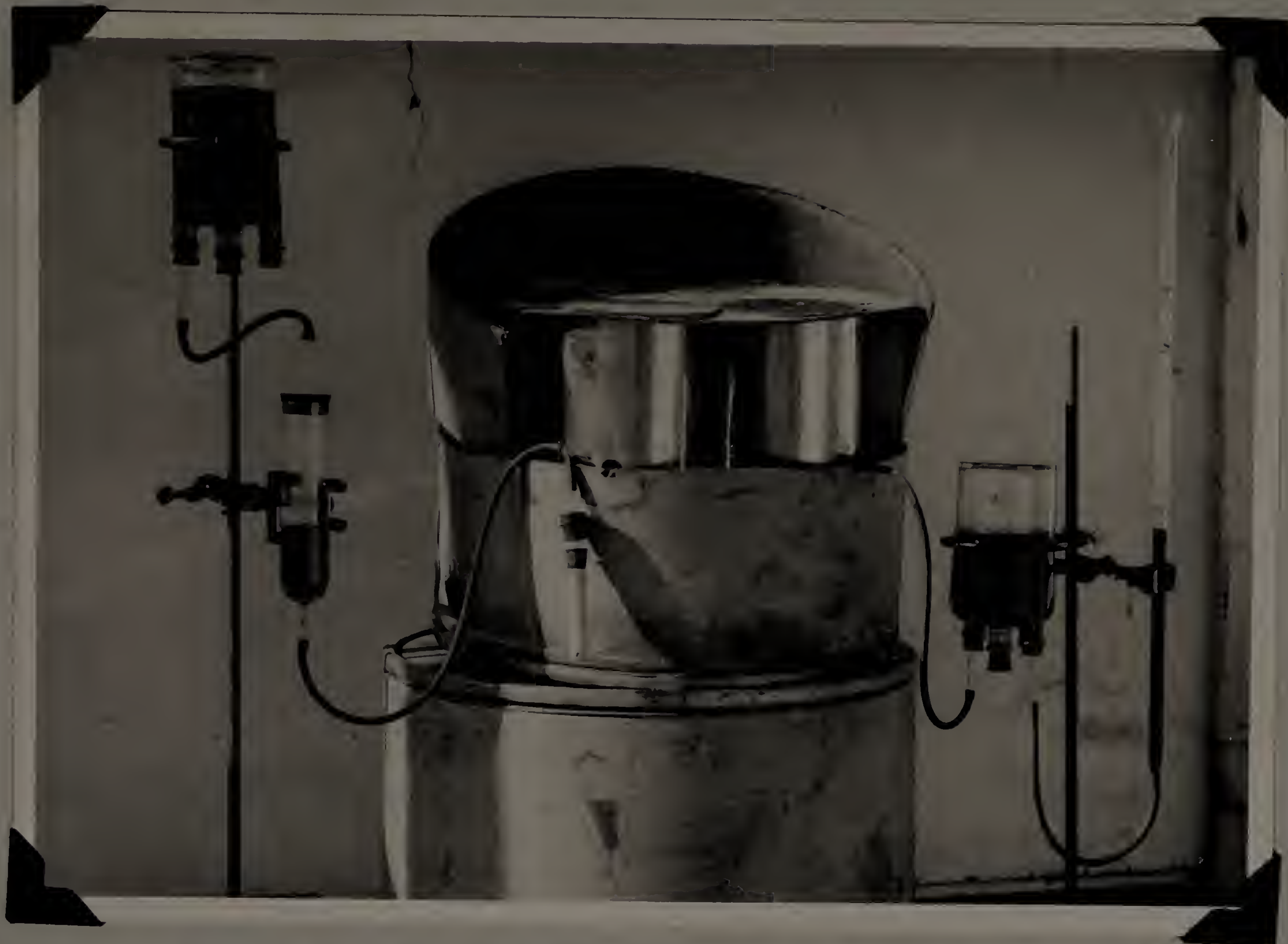

Figure 2. Two methods of supplying water used in the constant moisture experiment. Porous cup at left center.

that when filled to a given mark they would all be on a common level. They were kept filled to this mark for about a week and then records were kept to determine how much water was evaporating from each soil surface. When constant rates were in evidence the cans were divided into two groups of equal evaporation rates. To one group carbon black was applied to the surface. Records of water evaporation were kept for two days and more carbon black was added to the surface.

The method described was satisfactory when a sand was used. However, when a loam was added to the cans, the moisture in the loam would concentrate in the interior of the can allowing the edges to dry. Miller (22) suggests the use of a double walled container for this type of experiment. The inner wall next to the soil would be porous nearly to the level of the soil. This would not dry out around the edges as was found to be the case when the water was supplied at the bottom.

Greater evaporation due to surface application of carbon black ranged from 10 percent greater with 25 to 50 pounds per acre up to near 20 percent greater evaporation when 400 pounds were applied, (Table 15).

A short experiment was carried out in the greenhouse using much the same procedure except that the sun was the light source. Evaporation rates were quite uniform during a week of exceptionally clear weather. It was found that a 200 pound per acre rate would evaporate about 9 percent more water than the control. Double this amount doubled the evaporation rate increase over that of the control. Data are given in Table 16.

Effect of Color on Heat Wave Absorption as Measured by Water Evaporation Rates.

Energy waves absorbed by a body in an oven are much different from those received from the sun. It is possible that a dark body might not absorb any more of these energy waves than a lighter colored body.

A light colored quartz sand and the same sand darkened with carbon black were used to determine energy absorption by amounts of water evaporated. Containers held 500 grams of sand saturated with 125 grans of water. Carbon black rates varied from 4000 pounds to 128,000 pounds per acre, (0.2 to 6.4 percent by weight). Triplicates were run of each treatment. Weighings were made when the sand was saturated and after the containers had been in the oven long enough to evaporate about half of the water. A second weighing was made after the containers had been in the oven three more hours without any addition of water. A third set of readings was taken after the sand was again saturated and left in the oven for twelve hours.

The rates of evaporation follow a general pattern, (Table 17). The smallest application of carbon black resulted in an increase in evaporation, but larger amounts caused a decrease below even the control. The next to the highest application rate caused another peak in evaporation. Double this amount lowered the evaporation rates below the control. This was probably because pore space was being blocked and free movement of water vapor hindered.

The Effect of Carbon Black on Capillarity and Waterholding Capacity of Soils.

Addition of carbon black to a sand increases energy absorption, but may also have other effects on moisture movement. To check the possible effect on capillarity a quantity of carbon black was mixed with some sand and placed in a glass tube. This tube and another one filled with pure sand were placed in a shallow dish of water. Water rose more slowly in the carbon black-sand mixture but rose to a greater height; twelve cms. in pure sand and fifteen in carbon treated sand. This might in part explain why more water was being evaporated from the black sand. Increased capillarity would move water to the surface at a faster rate.

A series of sand-carbon black mixtures was prepared using the equivalent of 4,000 to 32,000 pounds carbon black per acre. The lowest rate of carbon black caused a decrease in capillary rise over the control. Eight thousand pounds per acre, about equaled the capillary rise in pure sand. The 16,000 pound rate further increased the capillary rise,(Table 18).

This indicates that there might have been an effect on waterholding capacity. To check this four soils were used; a clay loam, a silt loam, a sandy loam, and a sand. The Hilgard method (16) was used with three replicates of the eight different treatments for each soil. Carbon black rates varied from 1,000 to 40,000 pounds per acre by weight.

To be sure that the samples were thoroughly wetted they were allowed to stand in contact with the water for several hours. The cups were then placed on wet paper and allowed to drain under an inverted glass cover for half an hour. After weighings were made the soils were dried in an oven at 110° C. for 24 hours, and weighed again to give dry weights. Waterholding capacity was calculated on dry weight basis.

In the loams it was found that the waterholding capacity was increased by the application of 1,000 pounds of carbon black per acre (Table 19). The effect was most pronounced in the clay loam, less so in the silty loam. In the sandy loam there was a slight increase and in the pure sand there was a slight decrease in waterholding capacity. Added increments up to 20,000 pounds per acre, first decreased and then increased the waterholding capacity. The capillarity experiment indicated that this might be expected. With the exception of sand at low amounts of carbon black and the sandy loam at high amounts, the general effect of the carbon black addition at different levels was similar for the four soils tested.

Cooling of a Soil and Moisture Absorption

> "The importance of condensation directly into the soil is particularly great in summer on black soils, which have high rates of cooling owing to nocturnal radiation. When moisture concentration is high and radiation at a maximum as much as 0.05 of an inch of water may be added to the soil by condensation during a single night."

The following experiment was performed in an attempt to prove or disprove the preceding statement by Thornthwaite and Holzman (35). An attempt was made to show a relationship between color and rate of condensation. Soils of varying textures were used in two types of containers. A coarse white sand was stained black by mixing a quantity of carbon black in water and adding the sand to this mixture. This and the white sand to be used as control were dried in the oven at 60° C. for 24 hours. Late in the afternoon these samples were weighed and put into a humidity chamber. The next morning they were weighed again before the heat of the morning had evaporated any moisture. In the small surface area containers there was very little moisture condensed. The average was about 4 mg. per container. In the larger containers (Petri dishes) about 10 mg. condensed per container. This was in no way comparable to the respective areas. The Petri dish has about 30 times the area of the small vial.

The coarse sand presented very little surface on which moisture could condense. Therefore a silt loam, and two different sandy loams were used. Where 20 mg. of moisture condensed in the sand, 500 mg. condensed in the finer textured soils. The carbon treated soil condensed a greater quantity of moisture in nearly all cases. It was found that the finer textured soil gained as much as 1 to 2 percent of moisture when cooling in the humidity chamber. Those that contained carbon black absorbed from 5 to 13 percent more than those with no carbon black added.

An effort was made to determine if there was any difference due to color alone or if greater absorption was due to a change in texture. Samples were placed in sunlight until about 4 p.m.; then covered and weighed. They were placed in sunlight again before being placed in the humidity chamber over night. These same uncovered soils were placed in a 60° C. oven for about 8 hours. After cooling, the containers were weighed and placed in the humidity chamber over night. The amount of moisture absorbed differed little from that absorbed after the samples had been in the sunlight, (Table 20).

The results of this experiment are substantiated by the work of Ramdas and Katti (28, 29) in India. (Their papers were not available until after the present experiment had been concluded.) Their results are shown in Table 21. They also measured the hourly variations of moisture content and found that moisture content of the soil was in phase with variation of air temperature and humidity percentage rather than soil surface temperature.

To further correlate their results with soil conditions, surface samples were taken from a bare field at sunset and sunrise, (Table 22). Results obtained are comparable to those obtained with samples in soil cups, (Table 21).

Ramdas and Katti (29) determined moisture variations in natural soils that varied in color from black to gray. The darker colored soils underwent the maximum daily variation in moisture content. The light colored alluvial soils showed variations about one-fifth that of the black soil. It would appear that color might affect the absorption rates in some way. It is more likely that the greater effect of color was on evaporation rates. The darker soils would warm to a higher temperature in sunlight and lose more water.

Many writers have stressed the importance of condensation of water into soil at night. This increased moisture in the soil may be especially valuable in arid regions or during dry periods. Evidence cited indicates that such condensation takes place under favorable conditions.

Local Temperature Differences Produced in the Field by 4,000 Pounds of Carbon Black Per Acre.

Starting in July 1944, an experiment on soil temperatures was carried out for a period of a year by Everson (10). He mixed 4,000 pounds of carbon black per acre with the top two inches of soil. Thermocouples were placed on the surface and two inches in the soil. The carbon black treated soil and the control soil were kept bare. Temperatures were recorded by a micromax recorder at 15 minute intervals. The readings as received by the writer were hourly readings. Due to mechanical and electrical difficulties there were periods when records were unavailable. Unless 24 hourly readings were recorded per day, the day's readings were discarded. This data was furnished the writer and all the interpretations are his own.

There were complete readings for 268 days or a total of 6432 hourly readings. Using only the complete readings, four sets of comparisons were made. The first two comparisons were made between the temperatures recorded at the surface and the two inch level of control and treated soil. The second group of comparisons was made of the difference found between the surface and two inch level of each of the two soils. The procedure was as follows: On a daily basis the number of hours of identical temperatures for the two reference points were set down. Then the number of hours per day that each exceeded the other in temperature and the total hourly degrees of excess. This made five separate figures for each day for each set of comparisons. These readings were grouped by months and added to make monthly totals.

The comparisons of temperatures at the surface and two inch depth of the two soils are shown in Table 23 A. In both cases the darker soil is at a higher temperature 58 percent of the time. The control soil is warmer 10 percent of the time. This indicates that the darker soil may have cooled more rapidly due to faster radiation.

A second indication of a more rapid loss of heat from the darker surface is shown in Table 23 B. The control surface is identical to or exceeds the two inch temperature an average of 58 percent of the time. For the darker soil this figure is 50 percent.

Table 24 gives the summaries of three periods of clear weather. In April the darker soil is at a higher temperature for all but a few hours. In August and October there are more identical temperatures and the control soil is higher in temperature more of the time.

In comparing the surface temperature with the two inch depth there is little difference between light and dark soil, (Table 24). There is a difference in the degree of temperature but the hours are about the same. This indicates that the increased temperature found with the dark soil is not confined to the surface alone.

Over the period of a month the hourly average temperature increase on the dark soil is less than two degrees Fahrenheit. In terms of the annual mean temperature of Massachusetts this temperature difference is approximately equivalent to 150 miles of latitude or about 600 feet in altitude.

DISCUSSION AND CONCLUSIONS

The presence of a black material in a light colored soil tends to raise the average temperature of that soil. This increased temperature is not confined to the surface, but heat is conducted to the lower soil levels. The maximum and mean daily temperatures have been increased without an increase in minimum temperature. As a result the thermoperiodic effect has been intensified.

There is some effect on the texture of the soil by the addition of carbon black. This is indicated by the effect on capillarity and waterholding capacity. This is indicated also where carbon black, 2 to 4 inches beneath the surface, causes a greater evaporation of water than the control.

Soils darkened by organic matter content are usually more productive than light colored soils. There is little evidence proving that color is in any way responsible for increased plant growth. A soil high in organic matter darkens when wet. A blackening material has little effect on the energy intake of such a soil.

In this work the attempt has been to produce an increase of energy intake in soils, and to study in a limited way any other physical effect that the material might have on the soil. There seems to be no reason why the physical effect produced could not be produced by any other wettable material such as colloidal clay or colloidal organic matter. There is no reason to believe that carbon black has special properties that could not be duplicated in color produced by organic material.

SUMMARY

1. Addition of carbon black to a soil causes a greater absorption of energy from sunlight and artifical light.

   a. Greatest effect produced on a quartz sand.
   b. Little effect evident on soil high in organic matter.
   c. Surface application quite effective at low application rates.
   d. Soils that naturally darken when wetted are little affected.

2. As little as 50 pounds of carbon black on the surface of quartz sand gave a significant difference over the control in regard to water evaporation under artificial light.

3. There is an apparent blanketing effect or a blocking of pore space when 800 pounds per acre of carbon black is applied to the surface. When this amount is applied to the surface the rate of water evaporation is less than with smaller amounts of carbon black.

4. Where carbon black is mixed with a soil there appears to be an optimum amount for greatest evaporation of water. This amount seems to be about 10,000 pounds per acre or 0.05 percent by weight for sand.

5. A mixture of 4,000 pounds per acre of carbon black in the top two inches of a fine sandy loam increased the mean annual temperature by less than two degrees Fahrenheit over that of the untreated soil.

6. Air dried soil treated with carbon black absorbs more moisture when cooling in a humidity chamber than does untreated soil.

7. Varying the amounts of carbon black in a sand apparently changed the evaporation rates of water in an oven. This seemed to be due to texture more than color. However, in this case the effect of color could not be entirely separated from the effect of texture.

8. Carbon black slightly affects waterholding capacity.

   a. Amounts up to 1,000 pounds per acre increase waterholding capacity of loams but have no effect on a coarse sand.
   b. Larger amounts up to and including about 10,000 pounds per acre decrease waterholding capacity.
   c. Waterholding capacity is increased by amounts over 10,000 pounds per acre.

9. Carbon black affects capillarity.

   a. Ten tons per acre (1 percent by weight) depresses capillary rise of water.
   b. Two to eight percent by weight progressively increases capillarity.

10. A possible added advantage of organic matter in a soil may be the darker color that is produced.

Table 1. Effect of Color on Raising and Lowering of Temperature. (Data of Bouyoucos, 4.)

Name of colored sand	July 27-28 Max. 2:oo p.m.	July 27-28 Min. 4:00 a.m.	August 5-6 Max. 1:30 p.m.	August 5-6 Min. 4:30 a.m.
Black	40.9°C.	16.6°C.	37.6°C.	12.45°C.
Blue	40.0	16.65	36.7	12.4
Red	38.55	16.65	35.9	12.4
Green	37.10	16.60	34.7	12.3
Yellow	35.8	16.60	32.65	12.25
White	34.6	16.44	31.7	12.2

Table 2. Effect of Color of Soil on Absorption of Heat. (Data of Mosier and Gustafson, 23.)

Time	Depth below surface of soil (Degrees Fahrenheit) 1 inch Light	1 inch Dark	2 inch Light	2 inch Dark	3 inch Light	3 inch Dark
6 a.m.	48.8	50.0	47.5	49.0	48.5	50.5
Maximum reached	71.5	82.0	70.8	78.5	71.3	78.4
Rise in temperature	22.7	32.0	23.3	29.5	22.8	27.9
Gain for dark surface	----	9.3	----	6.2	----	5.1
6 p.m.	66.5	71.5	70.0	74.5	71.0	77.0

Table 3. Heat Absorptive Power of Air-dried Soils. (Data of Oemler, 34.)

Type of soil	Percentage absorption	Relative absorption
Moor earth	24.40	100.0
Fine dark brown humus	23.25	95.29
Sandy humus (50% humus)	22.75	93.24
Dark Reddish brown sand	22.65	92.87
Loam rich in humus (20% humus)	22.10	90.57
Clay rich in humus (20% humus)	21.40	87.70
Reddish yellow loam	21.00	86.07
Light gray clay	20.00	81.97
Coarse sand	20.50	84.02
Pure chalk	19.77	77.90

Table 4. Effect of a Thin Cover of Charcoal and Chalk Powder on Soil Temperatures in C^{o}. at 6 a.m. and 2 p.m. Figures are averages for a week. (Data of Ramdas and Katti, 29.)

Depth	Control		Chalk Powder	
cms.	6 a.m.	2 p.m.	6 a.m.	2 p.m.
0	12.1	50.1	10.9	31.9
5	18.9	31.3	16.4	24.1
10	21.8	26.1	19.3	21.4
20	24.3	23.7	22.0	21.4

Depth	Control		Charcoal Powder	
cms.	6 a.m.	2 p.m.	6 a.m.	2 p.m.
0	14.1	55.7	14.5	57.4
5	21.2	38.2	21.4	39.5
10	24.5	30.4	25.0	30.5
20	26.6	26.0	27.2	27.0

Table 5. Effect of Color of Soil on the Number of Plants That came up and the Length of Time Required. One Hundred Seeds of Each Crop Planted. (Data of Mosier and Gustafson, 23.)

Days after	Wheat		Oats		Corn		Barley	
planting	Light	Dark	Light	Dark	Light	Dark	Light	Dark
7	--	4	--	6				
8	8	75	--	80				
9	29	86	27	100	--	6		
10	51	86	70	100	1	84	--	21
11	58	86	75	100	66	95	1	60
12	62	86	75	100	72	95	32	86
13	65	86	75	100	72	95	57	86

Table 6. Radiation from Field Samples. (Data of Bouyoucos, 4.)

Name of Soil	Radiation ratio	Percent radiation	Percent moisture
Sand	1.697	100.0	4.24
Loam	1.694	99.82	39.20
Clay	1.682	99.01	27.6
Peat	1.690	99.59	234.0
Water	1.946	114.70	----

Table 7. Radiation from Moist Soils with a Dry and Moist Surface. (Data of Bouyoucos, 4.)

Name of Soil	Radiation ratio, Moist surface	Radiation ratio, Dry surface	Percent radiation Moist surface	Percent radiation Dry surface	Percent moisture
Gravel	1.668	1.542	100	92.44	4.76
Sand	1.668	1.553	100	93.10	5.32
Loam	1.678	1.524	100	90.89	25.85
Clay	1.670	1.530	100	91.06	17.25
Peat	1.502	1.293	100	86.09	84.94
Water	1.946				

Table 8. Characteristics of Carbon Blacks. (Data of Everson, 10.)

Type	SS	E3	Mogul
Surface area in square meters per gram	20	150	370
Average particle diameter	600 Å	250 Å	250 Å
pH	9.0	4.5	3.0

Table 9. Analysis of Soot. (Data of Griffiths, 11.)

Substance	Percent
Moisture	7.39
Organic matter	43.09
Ammonia equivalent of nitrogen	0.21
Sulfate of Ammonia	12.72
Ammonia equivalent of nitrogen	3.29
Ferric oxide and alumina	6.51
Calcium carbonate	10.63
Magnesium carbonate	1.84
Alkalies	2.70
Insoluble silicous matter	15.12

Table 10. Relative Evaporation Rates of Water from a Sand as Affected by Carbon Black Placement and Moisture Content.

Placement of carbon black *	Percentage of waterholding capacity **				
	5	10	20	40	50
None ***	100	100	100	100	100
Surface	86	131	212	107	201
Mixed all through	107	146	226	159	251
Top third	88	95	158	164	226
Middle third	95	121	156	117	176
Bottom third	102	132	164	110	176

* Carbon black added at the rate of two tons per acre by weight.

** Water was added to top of sand just before placing crocks under 300-Watt light bulb.

*** Each gallon crock contained 6,000 grams of sand.

Table 11. Evaporation of Water From a Saturated Sand as Affected by the Placement of Carbon Black.* Figures Give the Number of Grams of Water Left in Each Crock After a Given Period Under the Lights.

Series	Pure** sand	Placement of Carbon Black: Surface only	All through	Top third	Middle third	Bottom third
1.***	1213	1249	1247	1269	1266	1299
2.***	1017	853	796	970	937	902
3.***	768	737	692	670	746	830
4.***	696	621	585	645	647	666
5.	570	563	530	594	600	621
6.	520	405	338	441	420	451
7.	497	375	323	407	390	420
8.	396	300	270	274	308	284
9.	324	259	233	221	271	232
10.	286	238	207	187	250	209
11.	263	222	182	170	234	190
12.	240	203	163	155	213	168

* Carbon black at rate of 2 tons per acre, 0.2 percent.
** Containers were gallon crocks holding 6000 grams of sand.
*** Number 1 was completely saturated with water. Number 2 adjusted to 86.7 percent of waterholding capacity, number 3 to 70 percent, and number 4 to 56.7 percent. For others through 12 there were no further additions of water.

Table 12. Effect on Evaporation of Varying the Amount of Carbon Black Added to the Surface of Quartz Sand.

Grams of Water Evaporated

Check	25lb.*	Check	50lb.	Check	100lb.
51.85	53.60	57.95	60.90	53.25	58.85
51.85	54.15	58.80	60.80	55.05	58.75
53.65	54.30	58.90	63.80	54.85	60.90
55.25	55.90	60.80	64.85	55.95	61.10
53.25	54.90	59.15	63.50	54.70	61.05
Averages					
53.1 7	54.57	59.12	62.77	54.76	60.13
Difference					
1.40	grams	3.65	grams	4.37	grams
2.6	percent	6.2	percent	7.6	percent

Check	200lb.	Check	400lb.	Check	800lb.
54.10	60.05	52.85	60.05	53.75	60.15
53.80	60.15	55.80	61.80	56.05	60.50
55.70	62.40	54.20	63.10	57.00	63.45
55.70	63.30	55.50	62.70	57.20	63.00
54.45	62.15	55.30	62.60	55.15	61.85
Averages					
54.75	61.61	54.73	62.05	55.83	61.79
Difference					
6.86	grams	7.32	grams	5.96	grams
12.5	percent	13.5	percent	10.7	percent

* 25 pounds of carbon black per acre. Each container contained 500 grams of sand and 91 grams of water when saturated. Figures above show evaporational loss of water per day. Light source provided by five 100-Watt light bulbs. See Figure 1.

Table 13. Relative Evaporation Rates from a Sand and from Carbon Black-Sand Mixtures.

Carbon black lbs/acre/6 in.	1st day	2nd day	3rd day	4th day
0	100	100	100	100
500	90	74	68	69
1000	94	84	88	91
2000	128	123	118	70
4000	123	129	148	81
8000	134	136	139	72
16000	130	130	112	82
Free water surface	117	106	95	89

Note: Equipment used is shown in Figure 1. Sand contained 125 grams of water when saturated. No water was added after the series was started.

Table 14. Average* Evaporation Loss in Grams from Saturated Loam and Loam-Carbon Black Mixtures.**

	Hours under lights							
Soil	12	24	36	48	60	72	84	96
Loam	32.6	18.6	8.8	6.2	5.0	4.1	3.1	4.1
Loam-carbon black mixture	34.6	16.2	8.9	6.7	5.1	4.9	3.5	3.4

* Average of four replicates.

** Carbon black at rate of two tons per acre (o.2 percent by weight). Equipment used is shown in Figure 1.

Table 15. Evaporation of Water As Changed by the Addition of Carbon Black to the Surface of a sand.

Grams of water evaporated

Carbon rate	25lb.*		50lb.		100lb.		200lb.		400lb.	
Carbon	172	150	148	134	168	168	170	189	154	175
black on	167	144	155	147	167	175	170	175	143	178
surface	175	156	155	150	178	155	180	200	160	182
Totals	514	450	458	431	313	498	520	564	457	535
Control	157	137	146	140	163	160	150	168	133	152
sand	145	129	135	117	141	150	147	150	125	140
	160	136	138	130	155	154	150	165	130	153
Totals	462	402	419	387	459	464	447	483	388	445

Totals per treatment

	25lb.	50lb.	100lb.	200lb.	400lb.
Carbon black	964	889	1011	1084	992
Control	864	806	923	930	833
Difference in grams	100	83	88	154	159
Difference in percent	11.6	10.3	9.5	16.6	19.1

* Pounds of Carbon Black per acre applied to surface.

Note: Water replaced in sand as evaporated by auto-irrigator and water reservoir. Container holds 6000 grams of sand. Light source, three 100-Watt bulbs. Evaporation period between recording of amount evaporated was 24 hours. The experiment ran for ten successive days.

Table 16. Evaporation of Water As Changed by the Addition of Carbon Black to the Surface of a Sand.

Loss of water in grams

Date	Pure sand A	Pure sand B	Pure sand C	200# carbon black per acre on surface A	B	C
July 4	122	122	115	124	124	124
" 5	136	128	125	137	135	143
" 6	89	81	85	93	98	94
" 7	88	82	79	92	93	95
" 8	116	107	109	126	126	125
Totals	551	520	513	572	576	581

Total water loss from carbon black 1725 grams
Total water loss from untreated 1584 "
Difference 141 grams
or
8.9% greater for carbon black.

Loss of water in grams

Date	Pure sand A	Pure sand B	Pure sand C	400# carbon black per acre on surface A	B	C
July 9	131	129	127	148	150	170
" 10	81	80	86	93	100	96
Totals	212	209	213	241	250	266

Total water loss from carbon black 757 grams
Total water loss from untreated 635 "
Difference 122 grams
or
19.2% greater for carbon black.

Note: Containers were gallon cans with water reservoirs attached so that water is supplied as it is evaporated. Containers were placed in an unshaded greenhouse. There was free air circulation and bright sunshine over the greater part of each day. See Figure 2.

Table 17. Percentage of Water Evaporated from Saturated Sand-Carbon Black Mixtures.

Carbon black in pounds per acre	Total percentage evaporated Trial 1	Trial 2	Trial 3
0	47.2	62.0	28.2
4,000	48.2	63.8	31.3
8,000	45.5	60.9	28.7
16,000	45.1	59.4	29.2
32,000	44.9	59.6	32.3
64,000	47.3	62.0	30.6
128,000	40.2	56.3	26.9

Table 18. Capillarity as Affected by Added Increments of Carbon Black.

% Carbon black	Trial A 5 min.	30 min.	24 hours
	(in.)	(in.)	(in.)
0	6 3/8	7 3/4	8 1/2
1	4 1/2	5 3/4	7
2	4 1/8	5 3/8	7 7/8
4	4 1/4	5 7/8	8 3/4
8'	3 3/4	5 1/4	8 3/4
% Carbon black	**Trial B 3 min.**	**4 min.**	**24 hours**
0	2 5/8	4 3/8	7 1/2
1	2 1/4	3	6 3/8
2	1 7/8	2 3/4	7
4	1 5/8	2 1/2	7 3/4
8	1 3/8	2 1/8	8 1/4

Table 19. Waterholding Capacity as Affected by Additions of Added Increments of Carbon Black.

Waterholding capacity in percent

Soil	Percent of carbon black mixed with soil 0	0,05	0.1	0.2	0.4	0.8	1.0	2.0
Sand	25.30	24.37	24.21	23.10	23.58	24.25	24.75	26.64
Sandy loam	42.57	43.70	43.18	40.45	42.73	40.42	39.01	36.96
Silty loam	53.88	56.84	54.49	53.54	52.27	53.77	53.01	54.69
Clay loam	87.37	98.59	88.59	87.36	85.33	87.06	85.27	87.68

Table 20. Changes in Moisture Content of a Dry Soil Placed in a Humidity Chamber. Untreated Soil Compared to a Carbon Black Treated Soil.

Soil	Trial	Replications	Gain in moisture: Untreated soil	Gain in moisture: Carbon black treated	Carbon black greater than untreated
			grams	grams	percent
Sand*	1	6	0.0158	0.0167	5.0
Sandy loam*	1	5	0.634	0.666	5.0
	2	5	0.586	0.622	6.1
	3***	5	0.512	0.566	10.5
Fine sandy loam*	1	3	0.800	0.893	11.7
	2	3	0.890	1.020	14.6
	3***	3	0.690	0.783	14.0
Silty loam*	1	5	0.652	0.742	13.7
	2	5	0.652	0.704	7.9
	3***	5	0.542	0.580	9.4
Sand**	1	6	0.0040	0.0048	20.0
	2	6	0.0046	0.0054	17.4
	3***	6	0.0037	0.0045	21.5
Silty loam**	1	6	0.0753	0.0798	3.6
	2	6	0.0758	0.0756	-0.3

* Petri dish as container. Surface area-77 sq. cm. 40 grams of soil.

** Glass vials as container. Surface area-2 sq. cm. 25 grams of soil.

*** These samples warmed in sunlight; others in 60° C. oven.

Table 21. Daily Changes in Moisture Due to Evaporation and Absorption. Samples Weighed at Sunrise and Sunset. (Data of Ramdas and Katti, 29.)

Date March 1934	Absorption Gain in grams	Absorption Percentage	Evaporation Loss in grams	Evaporation Percentage
9	0.651	4.3	0.630	4.1
10	0.685	4.5	0.764	5.2
11	0.684	4.3	0.645	4.2
12	0.655	4.3	0.557	3.7

Table 22. Percentage of Moisture in Surface Soil Samples Taken at Sunrise and Sunset. (Data of Ramdas and Katti, 29.)

Date March 1934	Mean percentage Moisture Sunrise	Sunset	Loss by evaporation	Gain by absorption
9	4.7	1.7	3.0	2.2
10	4.8	3.4	1.4	3.1
11	6.8	2.5	4.3	3.4
12	5.8	3.5	2.3	3.3

<u>Table 23.</u> Relationship of Temperatures of a Light Colored Loam and This Same Loam Darkened by Carbon Black. Temperatures Taken ar Surface and Two Inch Depth. Figures Give Percent of Total Readings by Months. (Unpublished Data of Everson, 10.)

A.

Month	Hours	Surface: Control Higher	Surface: Identical Temp.	Surface: Carbon black higher	Two inches deep: Control higher	Two inches deep: Identical Temp.	Two inches deep: Carbon black higher
		percent	percent	percent	percent	percent	percent
Aug.*	768	16.7	47.0	36.3	21.2	46.6	32.2
Sep.	552	33.3	21.0	45.7	25.2	33.9	40.9
Oct.	648	19.8	13.7	66.5	15.9	15.7	68.4
Nov.	528	11.7	42.2	46.4	7.4	21.6	71.0
Dec.	576	1.4	13.9	84.7	0.4	2.8	96.8
Jan.	96	0.0	5.2	94.8	0.0	1.1	98.9
Feb.	504	1.8	46.4	51.8	0.6	24.8	74.6
Mar.	456	7.7	19.1	73.2	7.1	25.4	67.5
Apr.	672	6.1	29.0	64.9	2.8	40.6	56.6
May	672	10.0	55.3	34.7	8.2	71.1	20.7
Jun.	600	10.2	44.3	45.5	17.8	60.7	21.5
Jul.	360	10.0	34.7	55.3	3.3	51.7	45.0
Averages		10.7	31.0	58.3	9.2	33.0	57.8

B.

Month	Hours	Surface higher	Identical Temp.	2 inch depth higher	Surface higher	Identical Temp.	2 inch depth higher
		percent	percent	percent	percent	percent	percent
Aug.*	768	33.6	15.7	50.7	35.6	17.9	46.5
Sep.	552	31.5	21.6	46.9	26.1	31.3	42.6
Oct.	648	23.9	17.6	58.5	17.5	18.2	64.4
Nov.	528	18.2	45.4	36.4	9.5	20.1	70.4
Dec.	576	2.8	30.2	67.0	1.1	15.1	83.8
Jan.	96	1.0	41.7	57.3	1.1	3.1	95.8
Feb.	504	2.6	82.3	15.1	0.6	35.5	63.9
Mar.	456	20.4	26.3	53.3	21.7	25.0	53.3
Apr.	672	25.6	30.9	43.5	26.5	32.3	41.2
May	672	18.0	66.5	15.1	20.1	72.9	7.0
Jun.	600	23.7	49.5	26.8	26.5	64.3	9.2
Jul.	360	26.1	37.2	36.7	23.6	56.7	19.7
Averages		20.0	38.7	42.3	17.5	32.7	49.8

* Includes a few days of July.

Note: Data as received showed temperature for each hour. Those readings that did not include 24 hours per day were discarded. Carbon black rate, 4,000 pounds per acre, mixed with top two inches of soil.

Table 24. Summaries of Temperature Conditions During Three Periods of Clear Weather on Untreated and Carbon Black Treated Soil.

A. Surface and 2 inch temperature of control soil compared to that of the dark soil.*

Date	Surface			2 inch		
Apr. 6-10	Control higher	Identical	Black higher	Control higher	Identical	Black higher
Hours	4	10	106	1	29	90
Degrees	6		252	1		152
Aug. 8-13						
Hours	22	62	60	27	69	48
Degrees	51		79	38		58
Oct. 26-31						
Hours	28	31	85	19	20	105
Degrees	46		138	25		238

B. Surface temperature compared to the 2 inch temperature in control soil and carbon black treated soil.*

Date						
Apr. 6-10	Control higher	Identical	Black higher	Control higher	Identical	Black higher
Hours	39	16	65	40	13	67
Degrees	176		144	269		171
Aug. 8-13						
Hours	64	5	75	61	14	69
Degrees	449		166	476		173
Oct. 26-31						
Hours	32	27	85	30	15	103
Degrees	122		196	92		285

* Carbon black rate was 4,000 pounds per acre. This was mixed with the top two inches of soil.

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