1970

Effect of soil surface treatments on soil temperature and growth and development of early sweet corn, Zea mays, L. cv Early Golden Giant.

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EFFECT OF SOIL SURFACE TREATMENTS ON SOIL TEMPERATURE AND GROWTH AND DEVELOPMENT OF EARLY SWEET CORN, *Zea mays, L.* cv EARLY GOLDEN GIANT

A Thesis Presented

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D.I.C.T.A. - U.W.I.

Submitted to the Graduate School of the
University of Massachusetts in
partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Plant and Soil Science
University of Massachusetts
AUGUST 1970

ACKNOWLEDGEMENTS

It would be difficult to adequately express my sincerest gratitude to all who have in one way or another contributed to the successful completion of this work. However special thanks are due to: Professor C. L. Thomson, who proposed the problem and whose excellent guidance, patient help and personal encouragement throughout the project were invaluable; to Dr. Mack Drake for his helpful suggestions and technical assistance; and to Dr. G. L. Stewart for his helpful ideas and constructive corrections. Appreciation is extended to Dr. G. T. Goddard for his help with the photomicrographs and Professor H. T. Yegian for his help with the statistical analyses.

I am also greatly indebted to the many other people in the university community who made this possible through their technical help, advice, and guidance.

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INTRODUCTION

It has been known for centuries that increasing temperatures increase the rate of growth and maturity of plants (39). By the turn of this century, it was recognized that soil temperature may be important since it can confer a controlling effect on root development (50,100,101). During the last few years researchers (5,16,31,66,113,175) have come to recognize that increasing soil temperature in the early stages of corn growth may result in earlier maturity and greater yields.

For soil temperature to increase, heat must be applied to the soil. This heat is obtained from the sun, biological activity, chemical reactions (when the sun is the main source), or artificially from electric heaters, steam pipes, etc. (13). As the latter is expensive under field conditions many techniques have been devised to use the natural sources. These include mechanically altering soil surface slope angles (3) or altering the soil surface reflectivity and absorptivity by mulches (71,99,165).

Soil mulches of various materials have been used to regulate soil temperatures, to control weed growth and to conserve moisture with varied success. These mulches are of two broad groups—natural materials (usually organic in nature) and synthetic materials. The natural materials are usually bulky and expensive to apply. They may improve soil tilth (84,135) and reduce run-off water (31,84), but because they usually reduce soil temperature (84,135,142), they may not contribute to early production. Synthetic materials range from paper, plastic, and foils to various emulsions. These materials have been used with increasing success since 1914 when asphalt coated paper was found to stimulate growth and control weeds in Hawaii (45,149).

During the 1920's and 1930's several kinds of paper mulches were tested with vegetables (58,142,149). The "warm season" vegetables of the Cucurbitaceae and Solanaceae families such as cucumbers and melons, tomatoes and egg-plants, consistently increased in yields and growth rate because of mulching. But paper mulch was never widely used commercially, for it deteriorated quickly in wet areas and was relatively costly and difficult to lay out in the field (45,111,158).

The development of low-cost polyethylene films has increased interest in mulching vegetable crops. Several crops such as strawberries, melons, and corn give earlier and greater yields when grown in soil mulched with plastic[1/] as compared to plants grown on bare soil (125,147). Although both black and clear plastic mulch increase soil temperature,

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[1/] "Plastic" and "polyethylene" are used synonymously throughout this dissertation.

clear or translucent film is preferred when weeds are controlled by selective herbicides, because the black film although controlling weeds does not cause comparatively large increases in soil temperatures.

Resinous emulsions have been used experimentally as mulches (94,156). These materials are sprayed as bands directly over the row after planting. There are reports that they may increase soil temperature, promote early germination of seeded vegetables (74,94,156) and may increase the moisture content in the early rooting zone (94,104,156). However problems of formulation, application, weed control and rapid surface breakdown with rainfall have limited their use.

There is current interest in aluminum and steel foil for mulching (45,165). But as they reflect light and keep the soil surface cool, they may not be important in the production of early vegetable crops.

From the foregoing, it is obvious that mulches change the environment in which plants grow. Those changes must influence plant development and growth especially under plant stress, when conditions are not optimal. In the field, plant stresses may be caused by abnormal weather conditions such as temperature and moisture extremes, and by soil physical and chemical properties, weed growth, and microbiological activity, etc. Although these environmental factors are interrelated, changes in soil moisture and soil temperature under mulches usually give the greatest crop response (45,96,97).

With this in mind, this study was designed to study the response of sweet corn to different mulches. Corn was chosen for two main reasons: 1) because early fresh sweet corn locally produced can demand a premium price in Northern States, and 2) because of its known sensitivity to mulching in general and soil temperature in particular (14,15,175). Soil temperature in the early spring has a particularly large effect on seedling growth and development since the roots as well as the shoot apex are located in the soil (14,15).

The main objectives of this study were to determine if modifying the soil micro-environment by mulches has a significant influence on the development and yield of sweet corn in the field, and to determine some of the associated physiological and morphological changes in corn.

LITERATURE REVIEW

The History of Corn

Corn, Indian Corn, or Maize refers to the same plant type or product. "Maize" is an Arawak word encountered in many forms in South America and the Caribbean e.g. ma-hiz, marisi, mariky, marichi, mazy, maysi, etc. "Maize" has been adopted in many languages and is used much more generally than "corn". The Saxon word "corn", Teutonic: "korn", Afrikaans: "koren", is the general term for any cereal (24,33,129). It was not until early colonization of America that the name "corn" was accepted legally in its present form, when a Judge in a Pennsylvania county ruled that "corn" rather than "maize" or "Indian Corn" will be used.

The Botany of Corn

Corn, *Zea mays*. L., belongs to the family Gramineae or Poaceae, which includes the grasses and cereals such as wheat, oats, barley, sorghum, and rice (167). Corn is classified under the sub-family Panicoideae and the tribe Maydeae or Tripsaceae. It is normally a monoecious plant with its functional staminate flowers borne in the tassels which terminate the stems, and its functional pistillate flowers borne in the ears on shoots in the leaf axils at all but the basal branches or tillers (19,92,167).

Corn has ten pairs of chromosomes; sweet corn has a recessive gene that prevents the conversion of sugars to starches.

The corn kernel or "seed" is not merely a seed but a one-seeded fruit, in which the seed, consisting of embryo, endosperm, and remnants of the seed coats and nucellus are permanently enclosed in the adhering pericarp. The embryo is embedded near one face of the endosperm at the base of the kernel or caryopsis. It has a central axis terminated at the basal end by the primary root and at the other end by the stem tip (92). The stem comprises five or six short internodes and bears a leaf at each node. The first leaf, known as the scutellum, never functions as a true leaf. It serves to digest and absorb food stored in the endosperm during growth. The second leaf, the coleoptile, is modified as a protective covering for the plumule or first bud of the plant during germination; in general, the dormant organs of the embryo formed during kernel development resume their growth and development (1,2,76,83,92).

Developmental Morphology

In a study of the developmental morphology of the caryopsis, according to Bonnett (20), Randolph found no significant differences among dent, flint and sweet corn; likewise no essential differences were noted in the morphological characteristic of the inflorescences of dent and sweet corn. It seems reasonable to expect that whatever is found regarding the ontogeny of corn should apply to sweet corn.

Huelsen (83) divided the germination process into three parts: (1) Water imbibition by the seed accompanied by no marked enlargement of the cells, (2) Cell enlargement by cell walls stretching, (3) Formation and enlargement of new cells in the embryonic regions. The first internode of the stem between the scutellar and coleoptilar nodes lengthens during germination, by intercalary growth at the upper end, and serves to elevate the coleoptile to the surface (11). By this time, the primary root is in the soil and two or more adventitious seminal roots have arisen at the base of the first internode. Both the first and second internodes are transitional and therefore stem-like to root-like in structure. Soon afterwards, the first crown roots appear immediately above the coleoptilar node and later an additional whorl of roots forms at the base of each of the succeeding six to ten internodes of the stem (92). These crown roots soon form the major part of the plant's root system. Brace roots do not appear until tasseling or later. The stem length and size may vary according to cultivar and environmental conditions. Detailed descriptions of the anatomy of stems and leaves of corn have been given by several investigators and will not be described here. In his later publication, Bonnett (20) stated that the shoot of corn passed through two stages in its development from germination to the dehiscence of the anthers. During the first stage, leaf fundaments, leaves, and axillary shoots were produced and the internodes of the stem remained short. During the second stage, the internodes of the stem elongated; the tassel began to differentiate and develop; and the axillary shoot or shoots (ear or sucker) passed through their several stages of development (20).

The first stage was basically a preparation for the second stage. In the latter, two processes occurred simultaneously indicating the beginning of that stage of development: (1) the internodes of the stem began to elongate and, (2) the shoot apex elongated in preparation for tassel differentiation.

It is not entirely clear when the ear begins to differentiate. Bonnett (20) suggested that " . . . in the early stage of stem development a shoot was produced in the axil of each leaf, but at a later stage of development axillary shoots were no longer produced." The cessation of axillary shoot development seemed to be associated with stem internode elongation and tassel differentiation. This agrees with observations reported for wheat and barley. Recent work by Seimer *et al.* (141) studying inbred lines and their Fl hybrids over a three year period, found that tassel initiation consistently was the first reproductive event observed about one month after planting. But this seemed to depend on genotype, environment and/or criteria for determining initiation. It was usually followed by initiation of the top ear in about ten days.

Normally ears develop from the upper one or more axillary shoots of the stem. Those shoots at the base of the stem remain non-functional or develop into suckers (tillers). When the topmost shoots are producing ear primordia, the lowermost shoots are producing leaf primordia. At this time axillary shoots develop in acropetal succession, with the largest shoots at the base. But when ear initiation occurs the size sequence (development) changed. Thus the topmost axillary shoots became the marketable ear or ears; those shoots in some of the lower axils may develop into tillers. The number of tillers, degree of development of rudimentary ear shoots, and number of ears developed, depend partly on inherited characteristics of the corn and partly on environmental conditions (20).

Some time before ear initiation and tassel differentiation, initials have been laid down for all the nodes and internodes of the stem, all the leaves, tillers, ear branches, and the primary and adventitious root system. Martin and Hershey (112) observed that 90% of the final number of vascular bundles had been laid down in the lower internodes. Kiesselbach (92), and Shaw and Loomis (146) stated that the entire stem surmounted by the differentiating tassel was visible below or at the soil surface. It was therefore possible for soil temperature to directly influence these preceding changes.

Temperature Effects on Morphological Development and Growth

Germination, emergence and early growth are intimately related to soil temperature (83,132). Low soil temperature at seedling time often produce a poor stand. This can be attributed to the direct effect of low temperature on the reduced metabolic and water absorption capacity of the seed or to an indirect effect caused by unfavorable soil conditions associated with low soil temperature.

Hagan (68), quoting Dr. P. A. Minges, has shown that the minimum and optimum temperature range for germination and emergence of sweet corn in the field is 11-18°C (50-62°F), and 25-30°C (78-86°F) respectively. Shaw and Thom (144) referred to Newhall's unpublished M.S. thesis (122) in which he found length of emergence period closely followed an exponential function of soil temperature for specific locations within a field. Huelsen (83) found that seeds absorbed water in an inverse exponential function to soil temperature and that the rate of water absorbed at 50°C (122°F) was slightly more than eight times greater than at 5°C (41°F). If the data has followed the Van't Hoff's Q_{10} rule it would be about 32 times as rapid. The temperature effect on water absorption may, therefore, be controlling germination especially in sweet corn.

In addition to a direct temperature effect, Richards et al. (132) have shown that low temperature can affect the physical and chemical properties of soil by reducing the kinetic energy of molecular systems and their interactions and by reducing microbial activity. In addition Huelsen (83) stated that below 10°C (50°F), many fungi, especially Pythium spp and Gibberella sp., were responsible for heavy seed decay.

According to Loomis (109), temperature may also modify the growth pattern of seedlings at emergence thus determining whether shoot growth or root growth may be initiated first. Many workers have made studies on developmental correlations of corn seedlings. They found that seedling internodal growth must stop before rapid growth of the plumule and first whorl of nodal roots will begin (11). This was affected by light (100 ft-candles for 24 hours) or heat (50°C for one hour) acting on growth chemicals such as auxins. Friend (60,61) has shown that during early vegetative development failure of chlorophyll accumulation limits growth at air temperature below 15°C (59°F).

Studies directly relating soil temperature to corn seedling morphological development are scarce but soil temperature has been shown to affect the morphology of wheat and sorghum seedlings. Dickson (50) reported that for wheat, high soil temperature greatly stimulated the elongation of the subcrown internodes (the region between the seed and the first internode). At 8°C (46°F) there was very little elongation, and the first node and secondary roots developed immediately above the seed. At 24°C (75°F) and above, the secondary roots developed at or above the soil surface. At high soil temperatures sorghum seedlings formed most of their crown roots above the surface, he suggested this may affect yields at harvest time. Dickson (50) also observed that at temperatures above 20°C (68°F) the wheat culm always broke through the coleoptile before emerging from the soil. This can be important in conditions favoring plant disease build up.

Grobelaar (67) used a South African single cross corn hybrid K64r x E184 seedlings pre-treated at 20°C (68°F) for ten days in water culture and demonstrated that (root) soil temperature affects growth during the vegetative stage. Rate of leaf initiation has been noted to increase with temperature by a Q_{10} of 1.3 when the whole plant was exposed to the same temperature. Grobelaar found maximum leaf initiation occurred at 40°C (104°F) which has been confirmed by other workers.

Although Whaley *et al*. (172) suggested that a break in time occurred between the development of embryo leaves and post-embryo leaves, this was not revealed by Grobelaar's study. On the contrary, rate of leaf development normally increases continuously. Grobelaar's work confirmed that of Abbe and Phinney (1,2) who found that with field corn, the sixth plastochron (i.e. the period between leaf primordia initiation) was 4.7 days and that the successive periods became progressively shorter so that plastochron 13 (about two plastochrons before tassel initiation) was only 0.5 of a day. The total period from plastochron six to 16 was about 16 days. Temperature was kept the same throughout. In the field, the phyllochron (the period for successive leaf appearance) is much longer (32,117).

Because leaf development involved, leaf differentiation and leaf growth, Higgins *et al*. (78) proposed that leaf development was a valid index for estimating plant response to environmental conditions. Accordingly, Beauchamp and Lathwell (14,15), studying an eastern hybrid NE310, found that root-zone (soil) temperature almost entirely regulated rate of plant development even though aerial temperature was high enough to allow rapid development. Thus the number of days required for any one growth stage interval (phyllochron), increased with decreasing soil temperature.

Beauchamp and Lathwell (14,15) also found that the transition of the shoot apex from vegetative to flowering (tassel) occurred at the six-leaf stage regardless of the imposed root-zone (soil) temperature treatment and that the temperature effect persisted only until the six-leaf stage. This meant that the last leaf was initiated (plastochron 15 or 16) at about the six-leaf stage and that root-zone (soil) temperature regulated corn plant development only during the period of leaf initiation (the "first stage" according to Bonnett, (20). Elongation of the true stem began at the eight-leaf stage. This agrees with work by Seimer et al. (141) who found the same developmental sequence in many hybrids and inbred strains of field corn.

The question, therefore, arises, can temperature effects be related to ear development and, consequently, to yield? Aung et al. (10) in field experiments using sweet corn seedlings pre-treated at soil temperatures varying from 13-30^{o}C (55-85^{o}F) for two weeks in growth chambers, showed the marked effect soil temperature may have on both vegetative and ultimate reproductive development. Temperature not only altered the nodal position at which marketable ears developed but it also increased yields at the higher temperature regime.

Many other workers have shown that soil temperatures early in the plant's life can affect yields (10,118,119). Willis *et al*. (175) finding yield reduction by high soil temperature treatments correctly attributed this to too high soil temperatures. Mederski and Jones (113) using Ohio K-62 field corn grown in rows, found significant increases in yields between check plots and plots heated at 29.5°C (85°F) for their first 60 days. Other workers (10,117) have confirmed this early temperature effect on increasing yields. Recently Pendleton and Egli (127) found that where water and fertility were not limiting grain yields were generally correlated with leaf area index. This may help explain the increased yields in early plantings in the north central states. Friend *et al*. (62) have shown that the total leaf area increases with temperature up to 20-25°C (68-77°F) and then rapidly decreases at higher temperatures.

Temperature Effects on Quantitative Growth

In their review on soil temperature and growth, Richards *et al*. (132) showed the ambiguity of using growth as a basis for physical measurements; because during germination and early development seeds or tubers have a reduced dry weight. With this in mind, quantitative growth and plant part development will be separated (14,15).

Many workers have used different indices for measuring quantitative growth (116,117,132). These include: increases in plant height and diameter, increases in leaf area and leaf length, increases in stem and root length, fresh weight, dry weight and yields of seed or plant parts. They can be divided into two groups: elongation and accumulation.

When corn seedlings were grown in equal air and soil (root) temperatures, Lehenbauer (100) found rates of stem elongation quickly adjusted to new temperatures reaching a maximum elongation rate at 30-31°C (86-89°F). Other workers have confirmed this (50,67). They found that when the soil temperature alone is varied, the optimum temperature for stem elongation is about 27°C (80°F) and even lower for roots alone.

Plant height [leaf extended, Willis et al. (175)], or length of true stem [from first crown root whorl to stem apex, (67)] always increased with increasing temperature up to about 30°C (86°F). But this is in the vegetative stage, for immediately tassel initiation occurs there is rapid elongation of the true stem. Grobelaar (67) suggested that even after the tassel initiation stage, soil temperature may still influence growth although the growing point is at or above the soil surface.

Because leaves are the major photosynthesizing organs of cereals (117), leaf growth (leaf area, leaf length) is of prime importance. Most workers agree that soil temperature influences leaf growth but there are suggestions of interactions with other external conditions such as light (60). Grobelaar (67) studying field corn, by water culture methods, found that the longest leaves occurred at around 15°C (59°F), but that plants grown at higher temperatures had an increased rate of leaf elongation and leaf maturation. Thus the leaves of plants at 40°C (104°F) matured quickest and were smallest. As a result total lengths or leaf area was greatest at 25-35°C (77-95°F)—similar to fresh weight results. Walker (166) using a field corn hybrid in pot experiments found similar results.

Friend (60,62) reported that temperature, light intensity and daylength can affect leaf area. Increasing light intensities (below saturation point) and daylength (up to 16 h.) changed size, number and shape of component cells. An increase in temperature from 10° to 30°C (50°F to 86°F) resulted in narrower and thinner leaves; the increase in leaf thickness at low temperatures was caused by an increased thickness of cell membranes in each of the three rows of mesophyll cells. He suggested a hormonal effect and that at high light intensities a destruction of gibberellins may occur in corn.

In temperature-growth studies, in addition to elongation measurements, both dry weight and fresh weight studies were used. Meyer _et al_. (116) stated that the most generally used indices of quantitative phases of growth were increases in height and fresh weight. According to Beauchamp and Lathwell (14,15) and Grobelaar (67) elongation measurements alone were insufficient a criterion for growth.

Beauchamp and Lathwell (14,15) found the following: (1) Shoot growth rates at a soil temperature of 20°C (68°F) were greatest both at the two-leaf to four-leaf period of growth and at the four-leaf to six-leaf period of growth. However, when soil temperatures of 15°C and 25°C (59°F and 77°F) were compared they found that at 25°C shoot growth rate was greater than at 15°C during the two-leaf to four-leaf period and it was less during the four-leaf to six-leaf period. In contrast, root growth was lowest at 25°C for both periods but greatest at 15°C during the two-leaf to four-leaf stage then becoming greatest at 20°C in the next stage. It may be concluded that dry matter production-temperature responses depend on stage of development and whether roots, shoots or both are measured. It is, therefore, questionable whether many of the general studies using whole plants give a true picture of the dependence of growth on temperature. Although plants may be at the same age on a day-basis from planting, they may be in an entirely different stage of development in their growth cycle.

Dry matter content (per cent) gives a truer picture. Some studies (26,67,123,166) indicate that dry matter content in the early stages of corn growth is higher at low temperatures (5-15^{o}C or 41-59^{o}F). For dry matter to accumulate, carbon assimilation must be above the compensation point. According to Friend (60), this occurred after wheat seedlings had reached the stage where the first and second leaves were fully expanded, and the tip of the third leaf was just extruding from the sheath of the second. This is the same stage as described by Beauchamp and Lathwell (14,15) for corn. Generally, dry matter content has been found to be inversely proportional to (root) soil temperature (26,123,166).

Researchers (109,116)use fresh weight responses to soil temperature to show changes not tested by other indices Grobelaar (67) in his literature review justified this with findings from Lingle and Davis (103) using tomatoes. Beauchamp and Lathwell (14,15) have shown that dry matter production may give a bias for lower soil temperature-growth responses. Generally fresh weight responses are quite similar to growth responses measured as an increase in length (20,29,66). Generally the "optimum" temperature for root fresh weight production is lower than for shoot fresh weight.

Temperature Effects on Corn's Metabolism

As growth and development depend on the nutrition of corn (27,72,107,109,124), it is essential to review available information on the subject. Because soil temperature acts directly on the meristem of roots, and on tassel and ear primordia development during early stages of growth, one can expect soil temperature to affect the mineral nutrition, and carbohydrate and protein metabolism of corn.

Mineral nutrition includes uptake of cations and anions and their accumulation. Uptake normally occurs in the root and is affected both by existing physical and chemical conditions (64) surrounding the plant and by the plant's metabolic activity (29,79,136,139,154). The effect of temperature on physical processes (diffusion, ion exchange and absorption) is relatively less than its effect on active accumulation (132,154).

Prior to 1952, Nelson (121) found only one reference (by Zamfirscu, 177) dealing directly with the effect of soil temperature on the mineral nutrition of corn. Zamfirscu (177) reported that NH_4-N was taken up more rapidly than NO_3-N in the temperature range from 18-40°C (64-104°F). Potassium (K) was taken up more rapidly at 32°C than at 4°C; at 32°C (90°F) uptake of phosphorous (P) was eight times and calcium (Ca) twice as rapidly as at 4°C (39°F). According to Nelson (121), Brouwer and Bramley, found that at low temperatures and in an atmosphere of increased CO_2, Na and P uptake decreased.

According to Löehwing (107), three fairly distinct stages in the metabolism of plants are evident from germination to flowering. These are: a) an initial anabolic phase in which intake of inorganic nutrients and synthesis of proteins is rapid, b) a second phase where accumulation of carbohydrates is accelerated while rate of protein synthesis gradually diminishes, c) a catabolic phase which becomes evident as flowering is approached in which hydrolysis of reserves begins to overbalance synthesis and a general internal redistribution of nutrients is initiated. It is, therefore, possible that plants exposed to optimum temperatures for a long period may have passed the anabolic phase.

Because mineral content is expressed on a dry weight basis, dry matter can influence it. Smith (150) discussing growth as a factor in the mineral composition of tissues stated that the accumulation of dry matter dilutes all elements unless an influx of minerals offsets this effect. A comparison of mineral content on a fresh weight basis eliminates the effect of differences in dry matter percentage to a large extent. Grobelaar (67) studying corn grown in water culture found no differences in the content of N, P, and K in shoots in the temperature range from 20-35°C (68-96°F). Less N, P, and K were accumulated in the shoot at 5°, 10°, 15°, and 40°C. That the N, P and K contents at 5°C (41°F) were equal to that at 10°C (50°F), Grobelaar explained the latter as a dilution effect. Similar trends were found on a dry weight basis although differences were larger at the 20^{o}-35^{o}C (68^{o}-95.5^{o}F) range.

Mederski and Jones (113) could find no major differences in the mineral composition of corn after it had been grown in heated and unheated soils for 60 days. However, at 30 days, plants grown in heated soil had 25% more N and K, and 100% more P and about 25-30% less Ca and magnesium (Mg) than plants grown in the control. It must be realized that much of the difference may be due to increased growth and development. Results of Neilson et al. (123) were similar, but they found that Mg uptake increased with increasing temperature. They did not report on the mineral content in tissues.

Walker (166) using a single cross hybrid WF9-38 x 11 found that except for boron (B) the total uptake of the 16 or 17 elements studied increased with increased soil temperature. Maximum values were found at 26-34^{o}C (79-94^{o}F) depending upon the element. However, the uptake of B was different. Total B present in the shoots did not vary appreciably from 12-20^{o}C (54-68^{o}F) even though shoot dry weight increased seven-fold. Boron uptake then increased from about 190 to 1900 micro-grammes per pot when soil temperature was controlled at 20 and 30^{o}C (68^{o}F-88^{o}F) respectively. Concurrently B concentration(per cent) in the shoots decreased from 91 to 16 ppm between 12°C (54°F) and 20°C (68°F) then increased up to 272 ppm at 35°C (95.5°F). The concentration of K increased over 100% from 12-18°C (54-64°F), then increased again at a temperature of 34°C (94°F). The P content decreased 25% from 12-25°C (54-77°F) and then increased up to 34°C (94°F). Magnesium content increased only slightly from 16-29°C (61-84°F). All other elements decreased from 12°C to between 20°-27°C and then increased.

Walker (166) also found a soil temperature-dependent plant disorder in corn shoots: emerging leaves tended to stick together and remain rolled. The symptoms resembled "calcium deficiency" and were located mainly in the upper half of leaves of plants grown at the optimum soil temperatures of 21°C-35°C (70°F-95.5°F). The top portion of these blades were gummy and discolored. It has been reported that Ca was immobilized in the stem of certain tobacco varieties at 26 to 30°C (79-86°F). Went (171) noted similar symptoms for corn grown in continuous lighting in a phototron.

Because P deficiency symptoms usually show up in corn grown in cold soils, it was usually thought that low soil temperatures may be hindering growth through limiting P metabolism. Ketcheson (91) tested this in the greenhouse using a loam soil. He found that after eight weeks all plants grown at 20°C (68°F) had higher yields and P content than plants grown at 13°C (55°F). However, phosphorus-fertilizer banded near the seed increased the phosphate percentage at 13°C (55°F) and 20°C (68°F). Dormaar and Ketcheson (51) using three soils found increased P uptake with increase in soil temperature from 15°C (59°F) to 27°C (80°F). The fertilizers were, however, mixed throughout the soil. They rightly concluded that banding would have a different effect (52,134).

Earlier Hall _et al_. (70) had reported that seven weeks after field planting, over 40% of the total P in corn had been taken up from the top three inches (7.5 cm) of soil. They suggested that early root growth must depend on conditions in the upper soil layers. Ketcheson (91), using radioactive P^{32} placed at the bottom of one gallon pots containing six lbs of oven-dry soil showed that P^{32} did not enter plants grown at 13°C (55°F). Robinson _et al_. (134) reported that band application of phosphate increased P uptake of clover by 272% at 10°C (50°F) compared with only 34% at 26°C (80°F). He also showed that phosphate alone did not increase root proliferation confirming work by Duncan and Ohlrogge (52) and Wilkinson and Ohlrogge (173) (who had shown marked root concentration only with the combination of N and P placed together).

In another experiment, Robinson (134) showed P-availability was higher in most soils at low soil temperatures due to a reduced rate of phosphate fixation. Eid et al. (53) also had reported that rapid mineralization of organic P occurred only at higher soil temperatures (113).

Neilsen et al. (123), and Mederski and Jones (113) found a decrease in growth and in P uptake by corn at low soil temperature. Grobelaar (67) confirmed this using radioactive rubidium. Zhurbitskii and Shtrausberg (178) found that both uptake and translocation of P^{32} in shoots and roots were lower at $7^{\circ}C$ ($42^{\circ}F$) than at $21^{\circ}C$ ($70^{\circ}F$) root (soil) temperature. It seems, therefore, probable that at low temperatures P mixed with the soil is absorbed slowly resulting in P deficient seedlings that are generally poor in growth.

Brouwer (27,28) and Davis and Lingle (47) have shown that rate of nutrient supply did not limit shoot growth in peas and tomatoes at low root (soil) temperatures in water culture. Temperature was reported to control plant growth directly through its effect on the metabolic activity of cells. Knoll et al. (93) concluded that P content in plant tissue did not govern growth (dry weight) of corn plants.

They also showed that anthocyanin synthesis is stimulated by both low P level in the nutrient and low root zone (soil) temperatures. This has been mentioned also by Grobelaar (67) and Walker (166). However anthocyanin synthesis can also be caused by high light intensities, sugar accumulation and even injuries. According to Straus (152) reduced growth and high sugar (sucrose) content can enhance pigment production.

Brouwer and Leon (26) reported that shoot growth is more sensitive to nitrogen shortage than to photosynthesis. The increased dry matter percentage of shoots at low soil temperature therefore mainly consists of carbohydrates. Loomis (108) reported that starch is not found in the vegetative parts of corn, its nearest equivalent, an amylodextrin, is only a minor constituent. As sucrose was the characteristic carbohydrate of photosynthesis, it would be increased at low temperatures. Arreguin-lozano and Bonner (9), and Meuwse (114) in Holland found that hydrolysis of starch (in potatoes) at low temperatures was correlated with high phosphorylase activity. At high temperatures an inhibitor is formed for this phosphorylase. Thus soil temperature may influence anthocyanin synthesis other than when phosphorus is low.

Because water, carbohydrates, proteins and other minerals combine during growth, and because soluble carbohydrate increases at low soil temperatures when growth and mineral uptake are reduced, soil temperature must be acting on protein synthesis and/or on the physical and chemical properties of water in some instances.

There is conflicting evidence on the role of water in corn. It is known that the physical and chemical properties of water are influenced by temperature. Yet evidence seem to show that the physical effects are not always important (132). Loomis (109) and Thut and Loomis (160) concluded that water was important for short-term growth (day-time) and that the growing region of corn may suffer from a water deficit during the day. Kramer (95,96,97) and other workers suggested that water supply decreases growth at low soil temperatures. Grobelaar (66,67) using fresh weight as a growth index of plants grown in water culture confirmed this. However Davis and Lingle (47) have shown that not only are rates of mineral and water absorption important in shoot growth-(soil) root temperature relationships but also were "endogenous mechanisms" important in tomatoes. Since "endogenous mechanisms" originate at meristems (137) and the shoot and root meristems of young corn plants are under the influence of soil temperature, these "endogenous mechanisms" may be more important in corn. Campbell (35) had shown that neither water stress nor reduced uptake alone could explain poor corn growth.

From literature reviewed one can see that soil temperature may be acting on the plant at a fundamental level. Although not yet proven, it is conceivable that reduced growth (especially root growth) may be connected with protein synthesis and enzyme synthesis.

Growing Degree Days and Heat Sum

A simplified method of relating plant growth and development to environmental conditions is the growing degree day or heat sum method. The degree day concept assumes that growth and development are related to air temperature linearly rather than logarithmically as predicted by the Van't Hoff-Arrhenius Q_{10} Law; and that both growth and development do not occur below a critical or base temperature. The heat sum concept uses soil temperature rather than temperature of the air.

According to Dethier and Vittum (49) and Chang (40), the degree day concept has the following disadvantages: (1) it over-simplifies the complex temperature responses of plants at different developmental stages in the growth cycle; (2) it ignores optimal temperatures and diurnal changes; (3) it ignores many other interrelated environmental factors affecting plant growth. But in spite of its theoretical inaccuracies, its simplicity appeals to research scientists, plant breeders, resource planners, farmers and seed companies. According to Chang (40), the success of this method depends on a close relationship between radiation "per se" and temperature.

The growing degree day or heat sum value for any day is obtained by subtracting the appropriate base or critical temperature for the specific crop from the mean temperature (air or soil). Thus on a day with a maximum of 78°F and a minimum of 44°F the mean temperature would be 61°F. Because sweet corn is generally accepted to have a base temperature of 50°F, the degree day or heat sum for that day would be 61° (the mean) minus 50° (the base) or 61 - 50 = 11. Note, however, that negative values are ignored in summation of growing degree days and heat sum over a growing period.

Many investigations have found that both air and soil temperatures influence early development and growth of plants. The early workers (100,101,105) did not separate soil and air temperature effects, yet, most of their concepts are still true. According to Chang (39), around 1735 René A. F. Réaumur published a quantitative study showing that increasing (air) temperature (degree days) increases plant development in early spring, and that each development stage required a minimum total amount of heat. This was known later as "Réaumur's thermal constant" of phenology which gave rise to the "Heat unit indices" system or "degree days" system of today. It is used commercially for predicting crop maturity in the canning industry, etc. (90,140).

Variations of the heat sum concept include (1) the remainder index method (49,83) where all soil temperatures below 10°C (50°F) are ignored. The formula used is:

$$T_t = \sum_s^h (T - T_c)$$

where: T_t is the total heat sum, T_c is the critical temperature, T is the daily mean temperature, s is the date of sowing and h is the date of harvest (2). The Livingston's Physiological summation index derived from Lehenbauer experiments with field corn (105), the formula used is $\text{Log}_2 U + (T - 40^{\circ}F)/18$ where U is the index of efficiency, T is the soil temperature in °F, 40°F is the threshold temperature and 18°F is the Arrhenius - Van't Hoff temperature constant. Temperatures above 116°F were ignored.

Other variations include temperature interrelationships: (1) Boswell's temperature and daylengths (21), Nuttonson's photothermal unit (PTu) = $\sum_s^h (T - T_c)D$ where D is daylengths (hrs.); (2) Thornthwaite's evapo-transpiration concept (involving moisture, temperature and daylength) $E = 1.6\ (10T/I)^a$ where E is the unadjusted potential evapo-transpiration in centimeters (for 30 days-each a 12 hour day), T is the mean monthly temperature (°C), a is a constant that varies from place to place, and I is the annual heat index [the sum of (i) 12 monthly heat indices, where $i = (T/5)^{1.514}$]; (3) Went's thermoperiodicity where photo-temperature and nycto-temperatures were studied (40).

All these formulae are empirical and should be used with care, they have, however, been helpful in scheduling cultural practices and in estimating harvest times. Cleary and Waring (43) after sub-dividing the growing season into time periods related to stages of development of Douglas fir seedlings, found that temperature and growth are not related linearly. However, the above equations have been useful at a base temperature of $10^{o}C$ ($50^{o}F$) in corn. Gilmore and Rogers (63) using temperatures within a narrower limit found "effective degree days" to be helpful in predicting maturity. Arnold (7,8) and others have met with similar success with sweet corn. Using Lehenbauer's data to develop an exponential curve, which was applied to soil temperatures, Newhall (122) found a correlation of 0.96 between field measured growth rates and computed growth rates for corn seedlings. Hortik and Arnold (82) using Ferguson's method adjusted for sweet corn found a close linear relationship between soil temperature and plant development up to the four-leaf stage.

Soil Temperature and Mulching

Soil temperature studies and measurements are of wide interest and references to literature dealing with this include plant physiology, ecology, pathology, horticulture, agronomy and soils. Because of this, sources of information are scattered and measurements and methods are so diversified that it is virtually impossible to give a true summary. Particular cases will therefore be taken as the need arises (132).

The temperature of the soil depends primarily on the amount of radiant energy received from the sun. Other sources reaching cooler spots by conduction (37,38) from within the earth or from chemical and biological actions are often negligible (13). The atmosphere modifies incoming and outgoing energy (39). The latitude and slope of the land greatly influences the amount of radiation received per unit area (3,99). Thermal properties of the soil such as color, heat absorptivity, specific heat, water content (38), heat conductivity and porosity, influence soil temperature (13,39).

Any material spread over and allowed to remain covering the soil surface is referred to as mulch. Mulches are used because of their influence on both external and internal factors. According to Waggoner _et al_. (165) mulches were known for more than three centuries. In their book on mulching, Jack _et al_. (84) described the diversity in mulches, etc. Many of the early researchers (111,149,158), showed that mulches had little effect on soil temperature, tending to keep the soil cool or just 1-2^{o}C (2-4^{o}F) above normal especially early in the growing seasons (111). In 1955, Emmert (54,55) showed that crops benefit from clear plastic mulches. Recently other workers (12,41,42) showed that clear and black polyethylene mulches, and clear polyethylene covered row-tents (cloches) increase soil temperature and conserve moisture. Other data showed that black polyethylene mulches control weed growth, increase minimum and lower maximum soil termperatures during the spring (57,81), increase minimum, maximum, and mean temperatures during summer (73,80), and conserve moisture (126,145,165). In addition a rise in air temperature of 4.5°C (8°F) over clear plastic mulch and 2.4°C (4.5°F) over black polyethylene at 0.5 inches (1.5 cm) above the surface (165) have been reported. Waggoner et al. (165) showed that clear polyethylene mulches increased soil temperatures at the 3 cm depth from 11.0 to 34.5°C (20-63°F), conserved both soil moisture and soil heat, increased superficial root growth and changed the chemical composition of tobacco plants. The yield of tomatoes, beans and corn were found to increase under mulches (45,46,73,147). Harris (73) reported that row tents covered with clear plastic although advancing maturity of corn and increasing yields, had little effect on soil temperature and moisture.

Later in the season soil temperatures under plastic mulch may exceed the optimum range and be detrimental to crop production (6). Hanks and Bowers (cited from Bowers, 22) have found soil temperatures of 66°C (150°F) at the

1 cm depth and 38°C (100°F) at 16 cm under a clear plastic mulch.

Other mulches have been used with varying success. In 1930, Thompson and Platenius (158) using black paper mulches found 2-3°C (4-5°F) increases in soil temperature at the 12.5 cm (5 inches) depth. Their result with tomatoes, sweet pepper and muskmelon showed yield increase whereas with bean and cabbage yield decrease. Clarkson and Frazier (41) found similar increases in yields with cantaloupe.

Takatori et al. (156) found petroleum mulch placed in bands at 15 cm (6 inches) or more wide gave the same soil temperature increase and soil moisture conservation as clear plastic of similar width. Black plastic maintained more heat than either petroleum mulch or clear plastic during the night. Petroleum mulch hastened initial emergence, and harvesting, in cantaloupe, cucumber, water melon, summer squash, onion, beet and tomato. Other workers (17,74,110) have reported similar findings. Kowsar et al. (94) showed that the maximum soil temperature at a 1 cm depth under petroleum mulch was 5°C (9°F) higher than bare soil. The mulched soil lost water in the upper 1 cm but gained water at depths below this zone while the check lost water in the upper 4 cm.

METHODS AND MATERIALS

Field Experiments

In early spring (April 16th, 1969) a completely randomized block experiment with ten treatments replicated six times was laid out at the "Brook's Farm", University of Massachusetts, Amherst, Massachusetts. The objective of the investigation was to compare mulches, other soil treatments and bare soil as they affect soil temperature and the growth and development of early sweet corn. The cultivar used was Early Golden Giant, a single cross hybrid from two inbred lines of yellow sweet corn Ma CX13 and Ma C5NT (98).

The original soil status of the area was as follows: the soil type was Agawam fine sandy loam--"a brown mellow find sandy loam 20-25 cm (8-10 inches) deep, passing into yellowish brown mellow sandy loam and then grayish yellow soil". Chemical analysis for plough layer of samples collected before fertilizing and liming (untreated) and after they were applied (treated) are shown in Table 1.

Table 1. Soil Test Results[1/]

Treatment	pH	Ca	K	P	Mg	NO_3-N	NH_4-N
Untreated	5.6	1600	120	25	25	5	12 (ppm)
		H[2/]	M	M	M	L	L
Treated	6.6	1600	250	25	25	30	35
		H	H	M	M	H	M

1/ Analysis by University of Mass. Soil Testing Lab.

2/ Symbols: H=high, M=medium, L=low nutrient status.

Plate I

Plate II

Plate III

Plate IV

Plate I. In the forefront are the first seven treatments (plots) in one replicate arranged from left to right as listed in the text; boxes at ends of plots contain thermographs.
Plates II, III, A close up view shows the same treatments separated by single guard rows.
Plate IV. Notice the wax (right row) and asphalt (left row) mulches.

Pre-planting operations included ploughing, discing and fertilizing. Lime and fertilizer were broadcasted and incorporated at the rate of 2230 kg (one ton) per hectare lime, and 112 kg (100 lbs.) N, 223 kg (200 lbs.) P_2O_5 and 223 kg (200 lbs.) K_2O.

Additional increments of N and P at 11 kg (11 lbs.) N and 54 kg (48 lbs.) P_2O_5 per hectare as monoammonium phosphate were placed about 5 cm (two inches) below and 5 cm to the side of the seeds at planting. Atrazine w.p. (2-chloro-4-ethyl-amino-6-isopropyl amono-s-triazine) at the rate of 2.2 kg (2 lbs.) active ingredient per hectare was sparyed on for post-planting weed control. As the soil was still cold, four to five seeds per hill were hand planted with hills and rows 0.9 meter (36 inches) apart, and at a depth of 3.5-5 cm (1.5-2.0 inches).

Clear polyethylene sheets 1.2 meters (4 feet) wide and two mil (0.002 inches) in thickness, black polyethylene sheets 1.2 meters (4 feet) wide and 1.5 mil (0.0015 inches) in thickness were used as mulches. Spray application of white wax at the rate of 390 kg (350 lbs.)/hectare and black asphalt solution at the same rate were sprayed over the rows in 0.3 M (12 inches) strips on the soil surface in appropriate treatments one day after planting. After the polyethylene sheets were placed on the soil surface, their edges were covered with soil to about 15.2 cm (6 inches) to keep them from lifting in the wind (Plates I-IV). Before the corn plants could suffer physical damage, an x-shaped incision about 15 cm (6 inches) long were made in the black and clear polyethylene mulches over each hill; after the six-leaf stage was reached, the row-tents were cut and the clear polyethylene left as a loose mulch.

The plots were 9 meters (30 feet) long with inter-plot guard rows 0.9 meters (36 inches) apart to eliminate border effects. Treatments were: (Plates I-IV)

(1) Flat Bare plots (control).

(2) Black polyethylene mulch on the flat.

(3) Clear polyethylene mulch on the flat.

(4) Clear polyethylene mulch on the flat removed at the 3-leaf stage.

(5) Clear polyethylene row tents [cloches about (9 inches) 23 cm] high.

(6) Clear polyethylene mulch on south slope.

(7) Bare south slope about 31 cm (12 inches) above the surrounding area.

(8) Black asphalt mulch on the flat.

(9) White wax mulch on the flat, and

(10) Clear from treatment No. 4 applied on the flat bare surface at the two-leaf stage. (see description later) . .

The treatments were disturbed on the following occasions: 1) when thermographs and thermistor were installed in one replicate, 2) when both plant and soil samples were collected and, 3) when plants would suffer physical damage if left under mulches (see Recording and Sampling for further explanation).

Recording and Sampling Methods and Materials

Two days after planting, automatic soil temperature recording Moeller Thermograph (Model 7-180) were installed permanently (162) in the following three plots of one replicate: Black, clear polyethylene flat mulch and bare soil. Their soil probes — about 23 cm (9 inches) sensitive area—were inserted horizontally at the 10 cm (4 inches) and 5 cm (2 inches) soil depth and placed at 5 cm (2 inches) above the soil and/or plastic surface. Nine days after planting, individual soil probes (about 0.5 cm sensitive area) for a manual recording thermistor Model No. 401 (Yellow Springs Instrument Co., Inc.) were placed permanently at the same levels in all treatments except treatments four and ten. Before installation, both the thermographs and thermistor with their probes attached were calibrated using the more accurate glass mercury thermometer. After installation previously calibrated Wesson dial thermometers were used to check both the thermograph and thermistors in the fields.

Two types of temperature records were kept: 24-hour continuous records for three plots and daily records at

7.30 a.m. and 3.30 p.m. for eight treatments in the same replicate. The thermograph records were collected weekly.

On two occasions, soil samples were collected 48 hours after rainfall for moisture determination under clear and black plastic mulches and bare soil at 5 cm (2 inches) and 10 cm (4 inches). They were taken from several borings in the row between hills. During the second sampling, soil structure under clear plastic vs. bare soil was measured by a Magness-Taylor pressure tester used for measuring firmness in fruits. Soil samples were collected under clear and black plastic mulch and bare soil plots at 5 cm (2 inches) and 10 cm (4 inches) depths and stored in a refrigerator at 5^{o}C (41^{o}F) for later tests to evaluate the different broad groups of soil microflora.

Growth patterns of stems, leaves and roots were recorded by measurement and by photography (see Plates VIII-XVII). The period taken for each stage of development from emergence to the six-leaf stage; from the six-leaf stage to tassel appearance; to 50% silking and, to harvesting were also noted. Development stages were defined as follows:

1. Emergence: Coleoptile beginning to emerge from the soil. (Plates VIII-IX).
2. One-leaf stage: second leaf tip emerging past margin of the first leaf, etc. (See Plates X-XVII).

Because the method of sampling plants for mineral analyses and for morphological microscopic work were destructive the experiment was divided into two sections based on plant size: Section I: early growth and development stages, when removal of plants reduced plants from 10 to 8 hill plots and Section II: later growth and development stages when plots were 8 hills. At each end of the row one hill was replanted to avoid border effects. A stage of development was recorded when more than 50% of the plants in a treatment reached the same stage of development in the growth cycle.

Specific development stages of corn were chosen. The appearance of the leaf tip out of the leaf whorl of the shoot according to Beauchamp and Lathwell's designation (14,15) was used as a basis for development. This has also been proposed as a valid index for estimating plant response to environmental conditions by Higgins _et al_. (78), since leaf environment involves leaf differentiation and leaf growth "per se". In this way plants from different treatments at the same stages of development could be compared (see Plates X-XVIII).

From the process of thinning during early stages, plant material was stored for chemical and anatomical analyses. In the latter stages the entire hill was carefully removed by digging out a poll of soil containing roots. After preliminary digging with a hand shovel, a screw-driver and an ice pick were used to dislodge soil aggregates. The remaining attached soil was then gently washed with running water. Root excavation and cleaning became increasingly difficult in the latter stages of early development.

Typical whole plants at early development stages were mounted and pictures taken to indicate extent and downward angle of root development. Differences in growth and development were measured as number and types of roots, angle of downward development, root length and root weight. The three types of roots observed were described as primary root, seminal (seed) roots and nodal (crown) roots.

Samples were taken for chemical analyses and for microtome work. Those for chemical analyses were washed thoroughly, oven-dried at about 70°C, weighed and ground in a micro-Wiley mill to pass through a No. 20 mesh sieve. The roots were not saved for analyses, because of contamination by extraneous adhering soil.

Samples for microtome work were washed; the growing point dissected to determine its position in the shoot and only that section was saved for examination. In the four-leaf and later stages, as the true stem had begun to elongate it was cut into sections of about 0.5 cm long. This was to secure both the differentiating tassel and ear shoots at the same time facilitating penetration of the killing and fixing liquids into the tissues.

Laboratory Methods

Moisture content of soil samples was determined according to standard practices. Samples were placed in tared water-tight containers, weighed before oven-drying at 110°C for 24 hours and weighed after cooling in a dessicator, and the percent water by weight was determined on a oven-dry weight basis.

Estimated bacteria, fungi and actinomycetes populations of soil samples were measured by the plating method according to Johnson *et al*. (87) and Pramer and Schmidt (130). Uniform asceptic practices were maintained throughout the experimental period. Population counts were made in duplicate after three, five and seven days.

The oven-dried plant samples were analyzed for phosphorus by Sherman's method (148). Potassium, calcium and magnesium content were determined using a wet digestion method ($HClO_3$ + HNO_3) (65) and spectrophotometer(Perkin Elmer Model 214.)

Plant samples for anatomical studies were uniformly cut and fixed in "Craf" solution (Chromium oxide--formalin mixture) under vacuum to ensure penetration and to remove air bubbles (86). They were then prepared for wax microtome work by displacing plant fluids and Craf using ethyl alcohol, tertiary butyl alcohol, and finally wax. They were then imbedded in wax blocks (131). Sections approximately 12 mu's were made with a rotary microtome. All plant sections of the same development stage, as seen externally in the field, were stained in 1% safranin and fast green before being observed microscopically for differences among treatments.

Harvesting: When most of the ears in the six plots of one treatment had reached marketable quality (the upper portion of the ears had filled out), they were harvested. The diameters and lengths of ears were measured after unhusked and husked weight were taken.

Statistical methods: Analyses of variance and co-variance and Duncan's new multiple range tests were computed according to methods described by Steel and Torrie (151).

RESULTS AND DISCUSSION

Temperature Variations

Temperature data were obtained from two sources: a) the U.S. Dept. of Commerce, Environmental Sciences Data Service (44), and b) from actual measurements at the experimental site. The U.S. meteorological data were recorded at Amherst using 24-hour automatic thermocouples, while temperature measurements at the site were with 24-hour thermographs and with thermistors recorded manually.

Weekly Averages: As shown in Tables 2 and 3, both air and soil temperatures were progressively cooler for the first three weeks of the period beginning April 25. During the first and second weeks, the average air temperatures inside the clear polyethylene row tent at 7.30 a.m. were over 6°C (11°F) and 1.5°C (3°F) greater than air temperatures over the black and clear polyethylene flat mulch treatments respectively (Table 2). At 3.30 p.m. (Table 3), weekly average air temperatures inside the clear polyethylene row tent for the first three weeks were about 12°C (22°F) higher than air temperatures over the clear and black polyethylene flat mulch treatments.

During the first three weeks, the 7.30 a.m. weekly temperature 5 cm below the surface was 4.5°-7°C (8-13°F) greater for plastic row tent than bare soil and 4.5-5.5°C (8-10°F) greater for flat plastic mulch than for bare soil

Table 2 - Temperatures at 7:30 a.m. expressed as weekly averages from April 25 - June 5, 1969 (Amherst, Mass.)

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
	Air Temperature 5 cm above Surface (^{o}F)					
Black plastic mulch	56.7	54.2	50.0	61.1	56.3	64.2
Clear plastic mulch	59.0	52.7	50.4	63.1	57.4	63.1
Clear plastic row tent	67.9	56.1	53.3	59.9	54.2	59.7
	Soil Temperature 5 cm below Surface (^{o}F)					
Bare soil	48.5	46.1	46.6	54.6	54.1	59.0
Black plastic mulch	52.1	53.2	51.0	59.8	59.0	65.9
Clear plastic mulch	58.7	55.9	54.4	63.4	61.6	68.6
Clear plastic row tent	61.7	56.8	54.6	59.6	57.4	64.8
Clear plastic on s. slope	60.6	57.6	55.4	63.3	63.6	70.6
Bare south slope	49.0	44.4	45.4	53.9	51.5	58.6
Asphalt mulch	49.6	45.9	46.4	54.5	54.7	59.9
White wax mulch	48.6	45.4	46.4	54.4	54.7	59.9
	Soil Temperature 10 cm below Surface (^{o}F)					
Bare soil	48.8	47.1	47.5	55.2	55.6	60.0
Black plastic mulch	51.5	53.3	51.7	60.0	59.6	66.7
Clear plastic mulch	57.1	58.6	58.8	64.4	63.4	69.9
Clear plastic row tent	59.2	58.8	56.1	60.7	60.4	66.9
Clear plastic on s. slope	57.9	56.0	53.7	62.3	62.4	69.2
Bare s. slope	51.1	44.7	45.9	53.9	51.9	58.0
Asphalt mulch	49.0	47.1	47.4	55.1	55.4	60.8
White wax mulch	49.5	46.6	47.4	55.3	55.9	71.4

Table 3 - Temperatures at 3:30 p.m. expressed as weekly averages from April 25 - June 5, 1969 (Amherst, Mass.)

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
	Air Temperature 5 cm above Surface (°F)					
Black plastic mulch	72.1	69.3	66.5	76.4	77.3	85.6
Clear plastic mulch	72.3	68.5	69.5	77.8	78.3	86.7
Clear plastic row tent	94.6	89.0	88.4	76.0	72.9	81.5
	Soil Temperature 5 cm below Surface (°F)					
Bare soil	65.7	65.1	63.6	71.8	71.2	77.9
Black plastic mulch	68.4	68.6	64.8	73.4	75.5	82.9
Clear plastic mulch	82.6	79.4	78.4	86.9	81.9	87.8
Clear plastic row tent	89.0	86.9	85.3	80.1	79.2	91.4
Clear plastic on s. slope	75.3	76.3	71.9	80.1	79.6	90.5
Bare s. slope	65.6	66.2	63.8	71.6	71.8	80.6
Asphalt mulch	67.6	66.2	63.1	71.3	66.9	73.9
White wax mulch	64.4	63.2	62.1	71.1	67.7	73.2
	Soil Temperature 10 cm below Surface (°F)					
Bare soil	59.9	60.8	58.0	66.9	65.7	71.9
Black plastic mulch	61.6	62.7	59.4	68.7	68.9	76.6
Clear plastic mulch	72.1	72.5	70.7	79.2	76.2	81.3
Clear plastic row tent	72.7	74.0	69.1	71.9	69.8	77.8
Clear plastic on s. slope	85.1	85.4	82.1	89.9	90.1	99.0
Bare s. slope	64.1	64.6	62.4	70.8	70.4	79.3
Asphalt mulch	60.6	60.4	59.8	66.0	64.4	69.4
White wax mulch	61.7	61.4	60.1	67.6	66.3	71.4

(Table 2). However soil temperature under black plastic mulch was only 2-3.5°C (3.5-6°F) greater than for bare soil.

At 3.30 p.m. (Table 3) for the first three weeks during the period beginning April 25 weekly average soil temperatures at 5 cm below the surface of the clear plastic mulch were over 11°C (20°F) greater than soil temperatures at the same depth in bare soil.

As shown in Table 2, throughout the period April 25 to June 5, at 7.30 a.m. the weekly average soil temperatures at 10 cm under the surface in all polyethylene treated plots were always more than 10°C (50°F). On the other hand, the bare soil, the asphalt mulch and white wax mulch treatments had weekly average soil temperatures that were less than 10°C (50°F) for the first three weeks in the period April 25 to June 5. The average soil temperatures 10 cm under the surface in the row tent and clear polyethylene flat mulch treatments were about 5.5°C (10°F) greater than bare soil at the same depth.

At 3.30 p.m. for the first three weeks (Table 3), the average soil temperature 10 cm under the surface in the row tent and the clear polyethylene flat mulch treatments were about 7°C (13°F) greater than the average soil temperature of bare soil at the same depth but for the last three weeks the difference was only 3°C (6°F) greater for clear plastic.

Table 4 - Typical morning and afternoon air temperatures 5 cm above the surface—thermistor readings, Amherst, Mass. 1969

	PLASTIC TREATMENTS TEMPERATURE (°F)					
Date	Black mulch		Clear mulch		Row-tents	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
May - 1	49.0	73.0	52.5	72.0	59.0	102.0
" - 2	56.0	75.0	53.5	74.0	52.0	102.0
" - 3	54.5	74.5	56.0	75.0	59.0	87.5
" - 4	58.0	82.0	56.5	76.5	60.0	105.+
" - 15	56.0	75.0	54.5	96.5	55.5	105.+
" - 16 1/	58.0	78.0	58.0	82.5	57.0	81.0
" - 17	63.0	89.0	64.5	90.0	63.5	90.0
" - 18	65.0	80.5	72.0	80.0	63.0	79.0

1/ The Row-tent was cut forming a loose clear plastic mulch.
+Greater than 105°F

Table 5 - Typical 5 cm and 10 cm soil temperatures taken at 3:30 p.m. (thermistor readings at Amherst, Mass. 1969)

	Soil Temperature (^{o}F)							
Treatment	May 1st		May 2nd		May 3rd		May 4th	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
Bare soil	69.0	61.0	68.0	61.5	67.0	61.5	75.0	68.5
Black plastic mulch	72.0	63.0	72.5	65.0	71.0	64.0	77.5	67.5
Clear plastic mulch	89.5	76.5	90.0	73.5	77.5	74.5	90.0	74.5
Clear plastic row tent	95.0	75.0	95.5	77.0	89.0	75.0	100.0	80.0
Clear plastic on s. slope	74.5	93.0	81.0	94.0	77.0	86.5	84.0	97.5
Bare south slope	69.0	67.5	66.5	65.5	68.5	66.5	74.0	72.5
Asphalt mulch	71.0	61.5	69.5	61.5	68.0	61.5	76.5	68.5
White wax mulch	66.0	62.5	65.5	62.5	65.0	62.5	72.0	69.0
	May 15		May 16		May 17		May 18	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
Bare soil	73.0	69.5	70.0	64.0	74.0	67.5	75.5	69.5
Black plastic mulch	75.5	65.5	74.5	67.5	79.0	70.0	80.0	71.5
Clear plastic mulch	91.5	78.5	91.0	80.0	96.0	84.5	96.5	85.0
Clear plastic row tent	93.5	72.5	85.0	74.5	84.5	74.0	87.0	76.0
Clear plastic on s. slope	82.5	97.5	81.0	92.0	84.5	96.0	81.0	97.0
Bare south slope	75.0	72.0	69.0	68.0	75.0	74.0	75.5	75.0
Asphalt mulch	72.5	69.0	78.0	65.0	74.0	67.0	76.5	69.0
White wax	73.0	70.0	69.5	63.5	71.5	68.5	74.0	71.0

Table 6 - Typical 5 cm and 10 cm soil temperatures taken at 7:30 a.m. (thermistor readings, Amherst, Mass. 1969)

Treatment	Soil Temperatures (°F)							
	May 1		May 2		May 3		May 4	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
Bare soil	43.0	44.5	44.0	45.0	49.0	50.0	50.0	50.0
Black plastic mulch	49.0	50.5	51.5	52.5	55.5	50.0	56.5	56.0
Clear plastic mulch	52.5	53.0	55.5	58.0	59.5	61.0	59.0	60.0
Clear plastic row tent	57.5	60.0	49.5	51.5	59.5	61.0	60.0	61.0
Clear plastic on s. slope	59.0	56.0	50.5	53.0	60.5	59.0	60.0	58.0
Bare south slope	40.5	45.0	42.0	43.0	49.0	49.0	49.5	49.5
Asphalt mulch	43.0	44.5	43.5	45.0	49.5	50.0	50.0	50.0
White wax mulch	43.0	43.5	42.5	44.5	49.0	49.5	49.0	49.5

Treatment	May 15		May 16		May 17		May 18	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
Bare soil	44.0	46.0	48.0	49.0	50.5	51.0	56.5	56.5
Black plastic mulch	49.5	51.0	55.0	55.0	57.5	57.5	62.5	62.0
Clear plastic mulch	53.0	54.5	58.0	60.0	62.0	62.5	71.5	72.0
Clear plastic row tent	54.5	55.5	58.0	60.0	59.5	57.0	63.0	62.0
Clear plastic on s. slope	55.0	52.0	60.0	58.5	61.5	60.0	66.0	65.5
Bare south slope	41.5	43.0	46.0	46.0	50.5	50.5	57.0	56.0
Asphalt mulch	44.0	46.0	47.5	49.0	50.5	51.0	56.0	56.5
White wax mulch	44.5	45.5	47.5	48.5	50.5	51.0	56.5	56.5

Typical air temperatures: During the period May 1 - 4, at 7.30 a.m., typical air temperature inside the clear polyethylene row tent were 1.5-5°C (3-9°F) greater than air temperature 5 cm over the black and clear polyethylene flat mulch treatments (Table 4). At 3.30 p.m., air temperatures within the row tent were 7°-17°C (13°-30°F) greater than air temperature 5 cm above the black and clear polyethylene flat mulch treatments. There were several days when the air temperature inside the row tent exceeded 38°C (100°F). On May 16, the row tent was cut transforming it to a treatment similar to the clear polyethylene flat mulch; Table 4 also shows this effect.

Soil temperatures: As shown in Table 5, the 3.30 p.m. soil temperature at 5 cm under the surface were in decreasing order: row tent, clear polyethylene flat mulch, clear polyethylene mulch on the south slope, black polyethylene flat mulch, black asphalt mulch, bare south slope, bare soil, and the white wax mulch treatments. Soil temperatures under the row tent were 11° to 14°C (20°-26°F) greater than soil temperatures under bare soil and 11° to 16.5°C (20-30°F) greater than soil temperatures under white wax mulched treatments at the same depths. Soil temperature effects at 10 cm. followed the same trend but differences were smaller.

As shown in Table 6, soil temperatures for 7.30 a.m. at 5 cm below the surface were as follows in decreasing order:

clear polyethylene on south slope, row tent, clear polyethylene flat mulch, black polyethylene flat mulch, bare soil, bare south slope, asphalt mulch, and white wax mulch. Soil temperatures under the row tent ranged from 5.5° to 9°C (10°-16°F) greater than bare soil, asphalt mulch or white wax mulch treatments. Soil temperature at the 10 cm depth was in the same order.

Time Course Study

Because the major source of heat is from the sun, a study of heat gain during the daylight hours was carried out on May 1st and May 8th, when the soil was relatively cold. The temperature changes above and under both black and clear polyethylene mulches and inside the row tent during a sunny and cloudy day were observed. However, as soil temperatures during the cloudy day were almost the same in all treatments, they were not shown in Figs. 2 and 3.

Air temperature: Changes in air temperatures inside the polyethylene row tent and 5 cm above the clear and black polyethylene flat mulch did not exceed 4°C (7.5°F) on the cloudy day (Fig. 1). However, on the sunny day, air temperature inside the row tent increased by about 8°C (14°F) from 7.30 a.m. to 9.30 a.m. and by about 24.5°C (44°F) from 7.30 a.m. to 3.30 p.m. Air temperature at 5 cm above the clear and black polyethylene flat mulch only rose

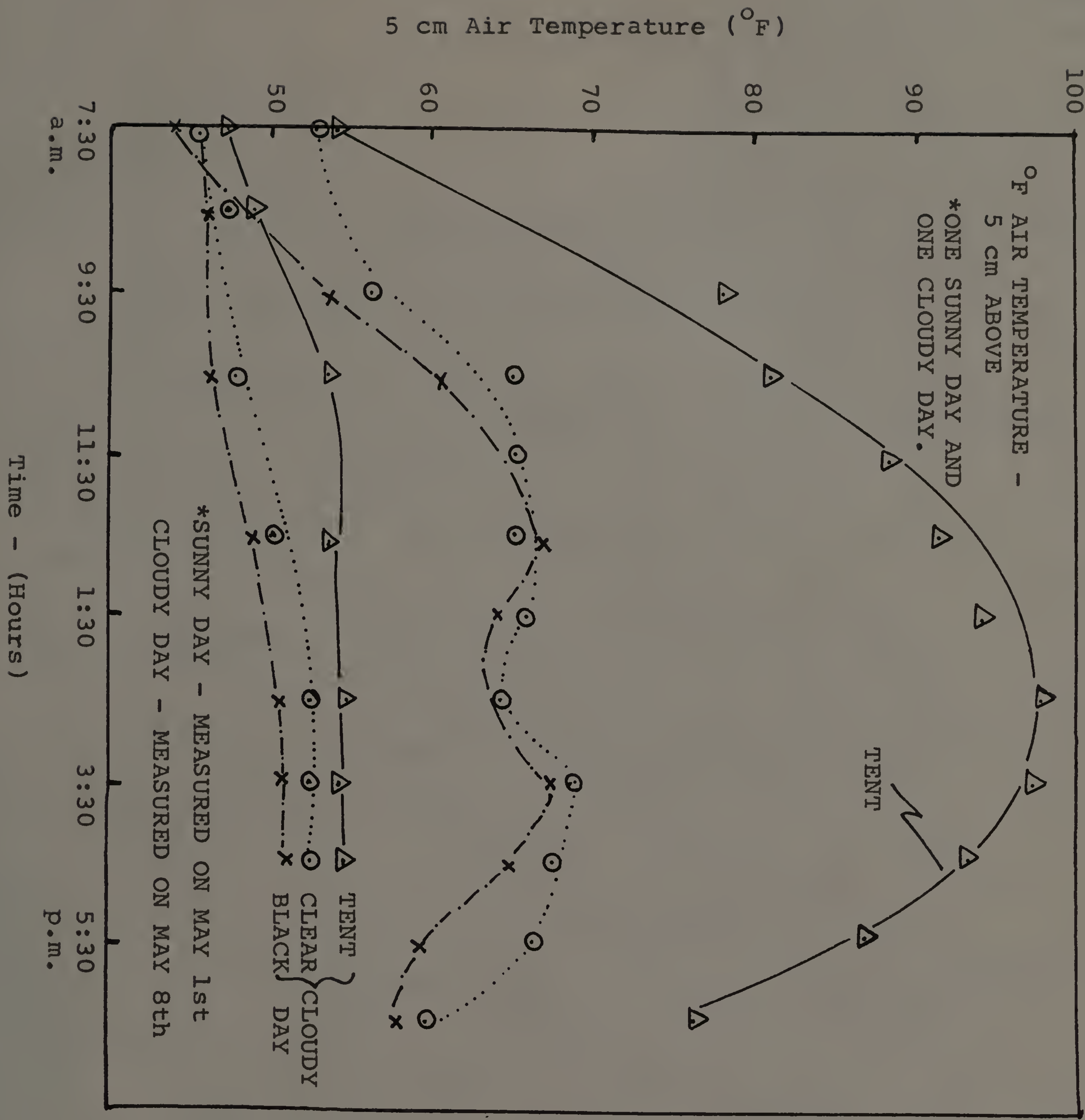


Figure 1. Time course.
Study of heat gain during a sunny
and a cloudy day.

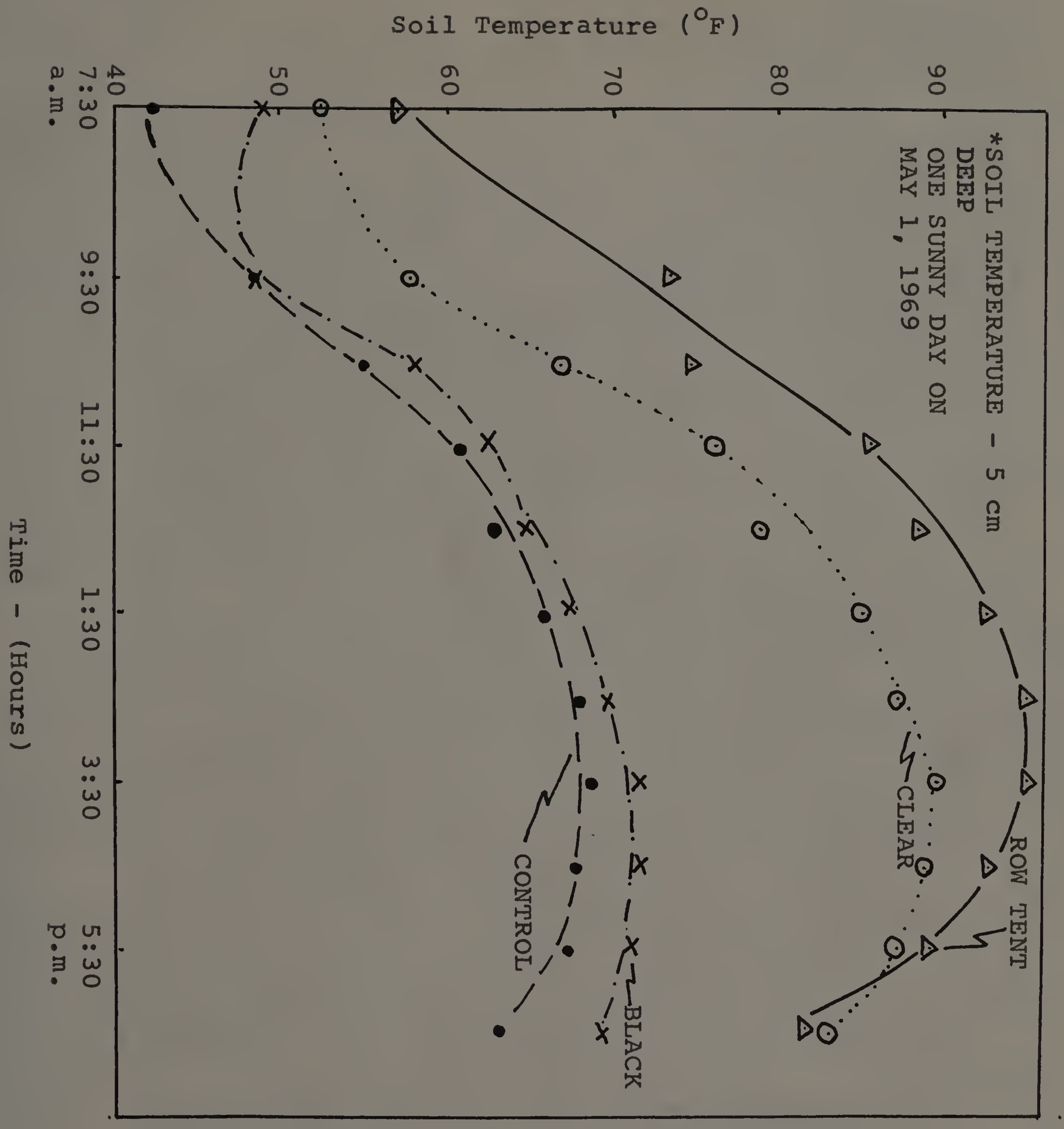


Figure 2. Time course.
Study of heat gain during the day.

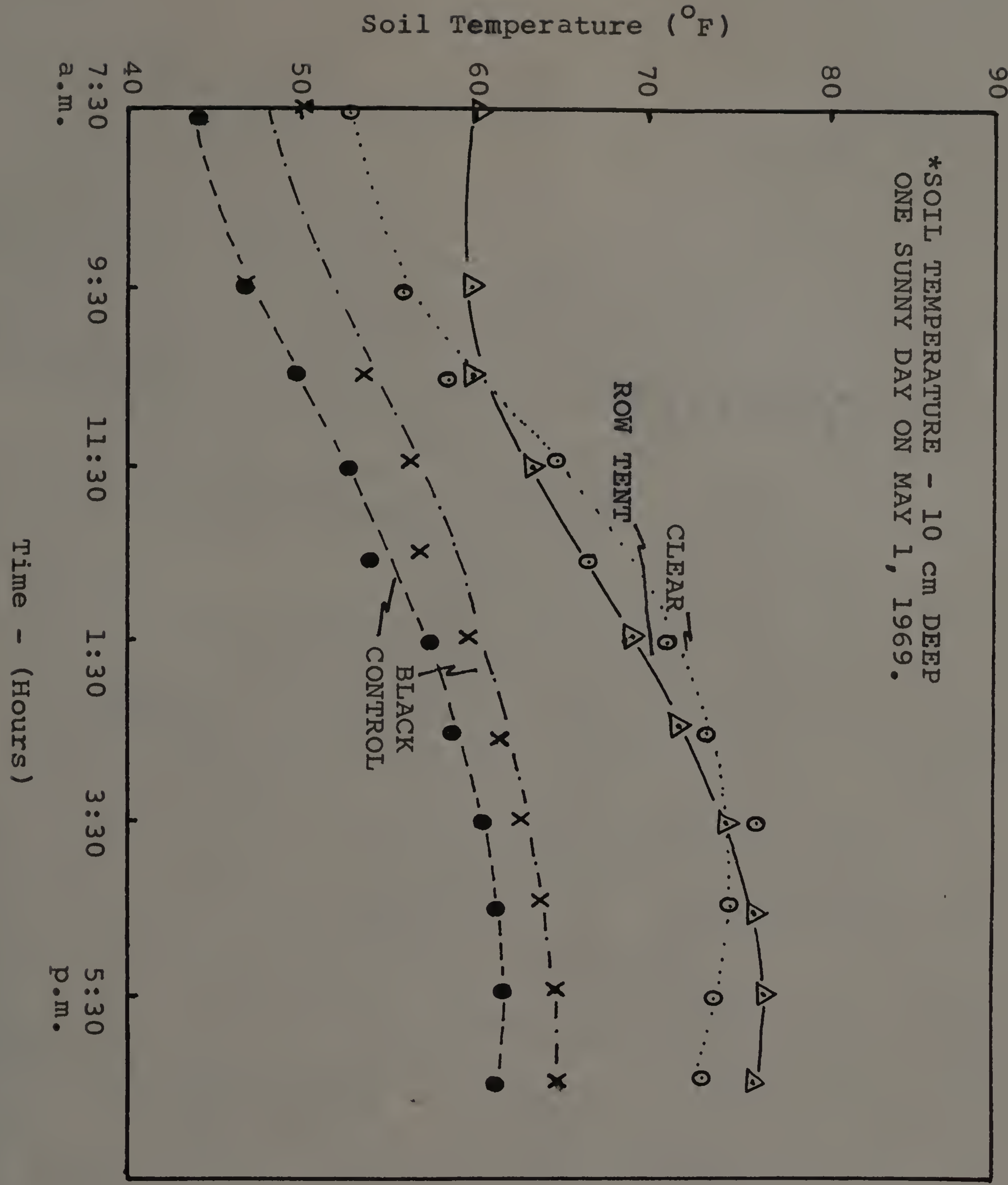


Figure 3. Time course.

Study of heat gain during the day.

by about 11°C (20°F) throughout the day. From 7.30 a.m. to 11.00 a.m. and again from 3.30 p.m. to 5.00 p.m., air temperatures above the clear polyethylene flat mulch were as much as 4°C (7°F) higher than the air temperature above the black polyethylene mulch.

Soil temperature: On the sunny day, from 7.30 a.m. to 3.30 p.m. soil temperature 5 cm below the surface (Fig. 2) under the row tent was about 3-4°C (5-7°F) higher than soil temperature at the same depth under clear polyethylene mulch. After 3.30 p.m., the row tent cooled off much more quickly than did the clear polyethylene flat mulch; thus by 6.30 p.m., the soil temperature under the row tent was less than that of the clear polyethylene mulch. During most of the day, the black polyethylene mulch treatment and bare soil had quite similar soil temperatures at the 5 cm depth: with the black polyethylene mulch about 1°C (2°F) higher than it was for bare soil.

It is interesting to note, that the soil temperature 5 cm below the surface in the clear polyethylene flat mulch (Fig. 2) exceeded the air temperature (Fig. 1) by about 11°C (20°F) during the day. However in the case of the black polyethylene flat mulch, soil temperature 5 cm under the surface exceeded its air temperature by only 1°C (2°F) during the day.

At 10 cm under the surface (Fig. 3) soil temperature

Plate V

Plate VI

Plate V. The white areas show the air pockets creating a "green-house effect" under the clear plastic mulched flat. Note the plants growing in the X-shaped incision.

Plate VI. Moisture condenses under the plastic drops to the soil and recycles.

Plate VIIa

Plate VIIb

Plates VIIa and VIIb. The white wax mulch tended to prevent corn seedling emergence. The emerging seedlings were often damaged as they lift up the almost impenetrable surface layer, notice a damaged seedling (Plate VIIb).

of the clear polyethylene mulch and row tent treatments were almost the same. However, soil temperatures under clear polyethylene flat mulch increased during the day to a maximum that was about two hours earlier than in the row tent. Throughout the day, soil temperatures 10 cm under the row tent and clear polyethylene flat mulch were 5.5^{o}-8^{o}C (10^{o}-14^{o}F) greater than soil temperature at the same depth under the bare soil; however, the soil temperature 10 cm under the black polyethylene mulch was 1^{o}-1.5^{o}C (2^{o}-3^{o}F) greater than the temperature under bare soil.

The relatively higher temperatures observed under the plastic mulches as compared with unmulched soil is probably due to the thermal characteristics of the mulch, the so-called "green house effect", the insulating effect of air between the plastic and the soil, the result of greater evaporative cooling in the bare soil, and increased biological activity in the rooting zone.

Emmert (55), and Clarkson and Frazier (41), had noted the rapid rise in air temperature inside row tents and in "plastic caps"—individual hill tents. Waggoner *et al.* (165) have shown that where air pockets existed between the soil surface and clear plastic mulch (as observed in Plates V and VI), a "green house effect" may exist. The condensing water vapour droplets on the clear plastic seem to be transparent to the sun's energy but opaque to the thermal radiation, so that much of the heat lost to space from a bare soil due to infra-red radiation is retained under clear plastic mulches. This occurs on a much larger scale in the row tent, for there were similar recondensation of water. Sheldrake (147) showed that carbon dioxide can be much higher under non-perforated plastic; and carbon dioxide may also act as an infra-red filter.

Observed differences in soil temperature between clear and black plastic mulches must have been mainly due to their color difference. A reasonable explanation is that the clear plastic acts as a "heat trap", allowing heat rays to penetrate the soil but preventing reradiation from the soil by the "green house effect". The black plastic mulch acts as a "heat shield", allowing little long wave radiation into the soil. Army and Hudspeth, Jr. (6) showed that daytime temperatures on the lower surface of black plastic was 46.5°C (116°F) compared to 43°C (110°F) on the lower surface of clear plastic mulch. They suggested that transmission of short wave radiant energy is greater through the clear plastic than through the black plastic. Some conversion of incoming short wave radiation apparently occurred within the black plastic film but with the clear plastic, the change in wave-length occurred in the soil.

Although the higher afternoon temperatures were above the optimum range of 22°-30°C (72°-86°F) for corn, and may have adversely affected the physiological activity of the plant, the "night temperature" may be more important, when, according to Went (169,170), reproductive changes are being influenced. It was noted that minimum temperatures under the row tent and clear plastic mulch were maintained above the critical 10°C (50°F) temperature. This relatively greater minimum (night) temperature obtained under plastic row tents and mulches may therefore have influenced reproductive development in sweet corn (as indicated later). In 1957, describing the work done by Dr. Liverman, Went (171) suggested that the optimum night temperature for ear development in field corn ranged from 17°C to 20°C (61° to 68°F). Plants grown at a daytime temperature of 30°C (86°F) had an optimum night temperature of 20°C (68°F) while those grown at a daytime temperature of 23°C (74°F) had an optimum night temperature of 17°C (61°F). Ears were formed when night temperatures were over 12°C (54°F); at 13°C (55.5°F) and less, female flowers developed in the tassel.

The literature consistently confirms that moisture is conserved under mulches (71,94,104,158). An exception was reported by Sheldrake (147) who has shown that soils under plastic mulches may dry out. He suggested that as the crop removed water, little is replenished under the impermeable plastic cover resulting, therefore, in a net moisture loss. The soil moisture content under plastic

Table 7 - Soil moisture status in bare soil versus plastic mulched soil 48 hours after rain and near the plant versus the center of mulch. Amherst, Mass. 1969.

Treatment	Moisture Content (%)			
	5/28	5/23	Near plant	Mulch Center
Bare soil 5 cm deep	28.0	28.0	-	-
" " 10 cm deep	27.0	30.0	-	-
Black plastic 5 cm deep	29.0	29.0	-	-
" " 10 cm deep	28.5	27.5	32.0	29.0
Clear plastic 5 cm deep	28.0	30.0	-	-
" " 10 cm deep	28.0	29.0	31.0	28.5

Table 8 - Soil penetration on May 23 under clear plastic mulch versus bare soil (taken from 10 measurements).[1/]

Treatment	Pressure Required for Penetration (psi)
Bare soil	10.4
Clear plastic mulched soil	6.6

1/ Measured by the Magness-Taylor Pressure tester.

Table 9 - Soil microflora in different treatments at different depths determined by the plating method. Amherst, Mass. 1969.

Treatment	Actinomycetes	Bacteria	Fungi
After 5 days			
Bare soil 5 cm deep	38×10^4	24×10^5	4×10^4
" " 10 cm deep	50×10^4	12×10^5	4×10^4
Black plastic 5 cm deep	55×10^4	22×10^5	3×10^4
Black plastic 10 cm deep	48×10^4	16×10^5	4×10^4
Clear plastic 5 cm deep	40×10^4	4×10^5	4×10^4
Clear plastic 10 cm deep	30×10^4	12×10^5	3×10^4

mulches was almost the same as it is in bare soil two days after rainfall (Table 7). Samples taken near the plant (where the soil was exposed by an X-shaped slit) had a higher moisture content than samples taken in the middle of the plastic mulch equal distances from any two corn hills. It must, therefore, be assumed that some rain water was funnelled by leaves and by the plastic and entered close to the plants. This agrees with the results of Shaw (145) who found that rain drop interception by corn was 0.13 to 0.19 inches for rains with a total precipitation rate greater than 0.30 inches.

It was observed (Table 8) that the soil surface under clear plastic appeared to be more friable than the surface of bare soil. Using the "Magness-Taylor" pressure tester, penetration measurements were made on flat surfaces between hills. Less penetration pressure was required under soils mulched with clear plastic than under bare soil. These pressure tests were performed on May 23, when their measured moisture content was the same (Table 8). The improved soil structure at the surface layer (0-3 cm) under clear plastic mulches versus bare soil may be caused by factors such as: compaction of the bare soil by raindrops or other physical factors, improved porosity, soil microbes or other biological activity, and chemical reactions (132,136). Of these the only factor measured was soil

Table 10 - Degree days and calendar date for sweet corn early development and harvest for 4 treatments by standard air temperature measurements[1/]. Planted 4/69 (Amherst, Mass.).

	Bare		Black		Clear		Tent	
	Date	^{o}F	Date	^{o}F	Date	^{o}F	Date	^{o}F
Emergence	4/30	94.0	4/29	78.5	4/27	52.0	4/25	49.5
1-leaf	5/2	100.0	4/30	94.0	4/28	62.0	4/26	52.0
2-leaf	5/5	121.0	5/2	100.0	4/30	94.0	4/28	62.0
3-leaf	5//4	140.5	5/7	125.0	5/4	113.0	5/1	100.0
4-leaf	5/20	208.5	5/14	140.5	5/7	125.0	5/4	113.0
5-leaf	5/25	253.5	5/17	154.0	5/13	140.5	5/10	137.0
6-leaf	5/30	302.5	5/21	226.0	5/16	142.0	5/14	140.5
Silking	6/30	863.0	6/27	761.5	6/23	690.5	6/16	581.0
Harvesting	7/22	1272.5	7/18	1196.0	7/14	1093.5	7/8	989.0

1/ Taken from U.S. Environmental Science Service report for Amherst, 1969.

microbial activity which was inconclusive (Table 9).

Visual field observations showed a "green algal bloom" on the soil surface below clear plastic treatments. A laboratory test by the dilution technique and plating method gave no definite indication of increased fungi, bacteria, or actinomycetes under clear plastic mulch (Table 9). No test was made for algae. This does not prove or disprove the observation that there was increased biological activity; because microbiological growth in the laboratory depends on the type of medium used, the dilution technique, and invariably the field conditions are not duplicated in the laboratory.

Degree Days and Heat Sum

Degree days: A total of 1,273 degree days were required over bare soils before Early Golden Giant sweet corn was ready for harvest as fresh corn (Table 10). The row tent, clear polyethylene flat mulch and black polyethylene flat mulch treatments reduced the number of degree days for harvest by 290, 180, and 80 degree days respectively.

Plants growing in bare soil required almost twice as many degree days (Table 10) to reach the development stages from emergence to the six-leaf stage as did those plants grown in the row tent or the clear plastic flat mulch.

Degree days for air temperatures 5 cm above the soil

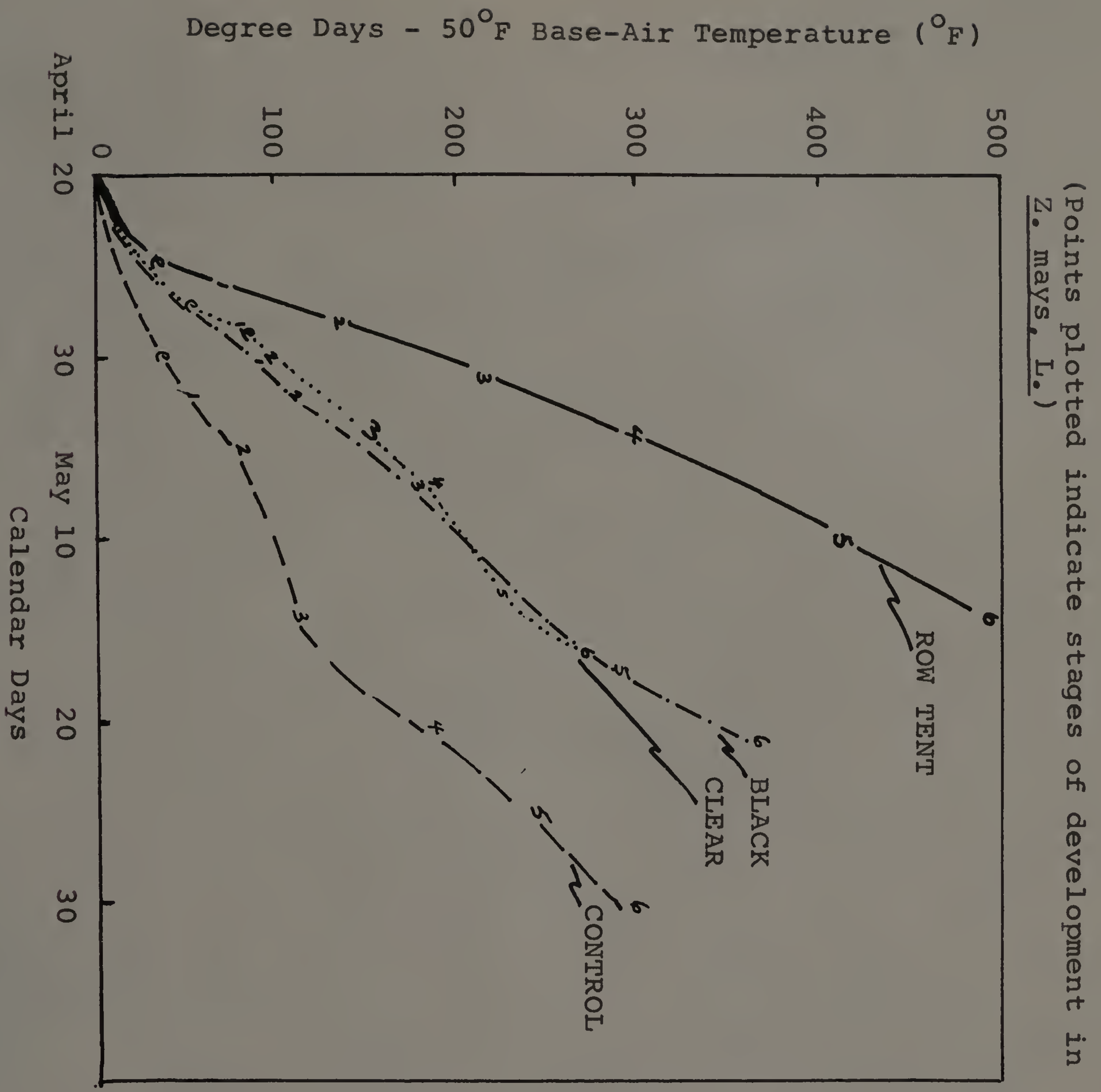


Figure 4. Rate of accumulation of degree days to 6 leaf stage.

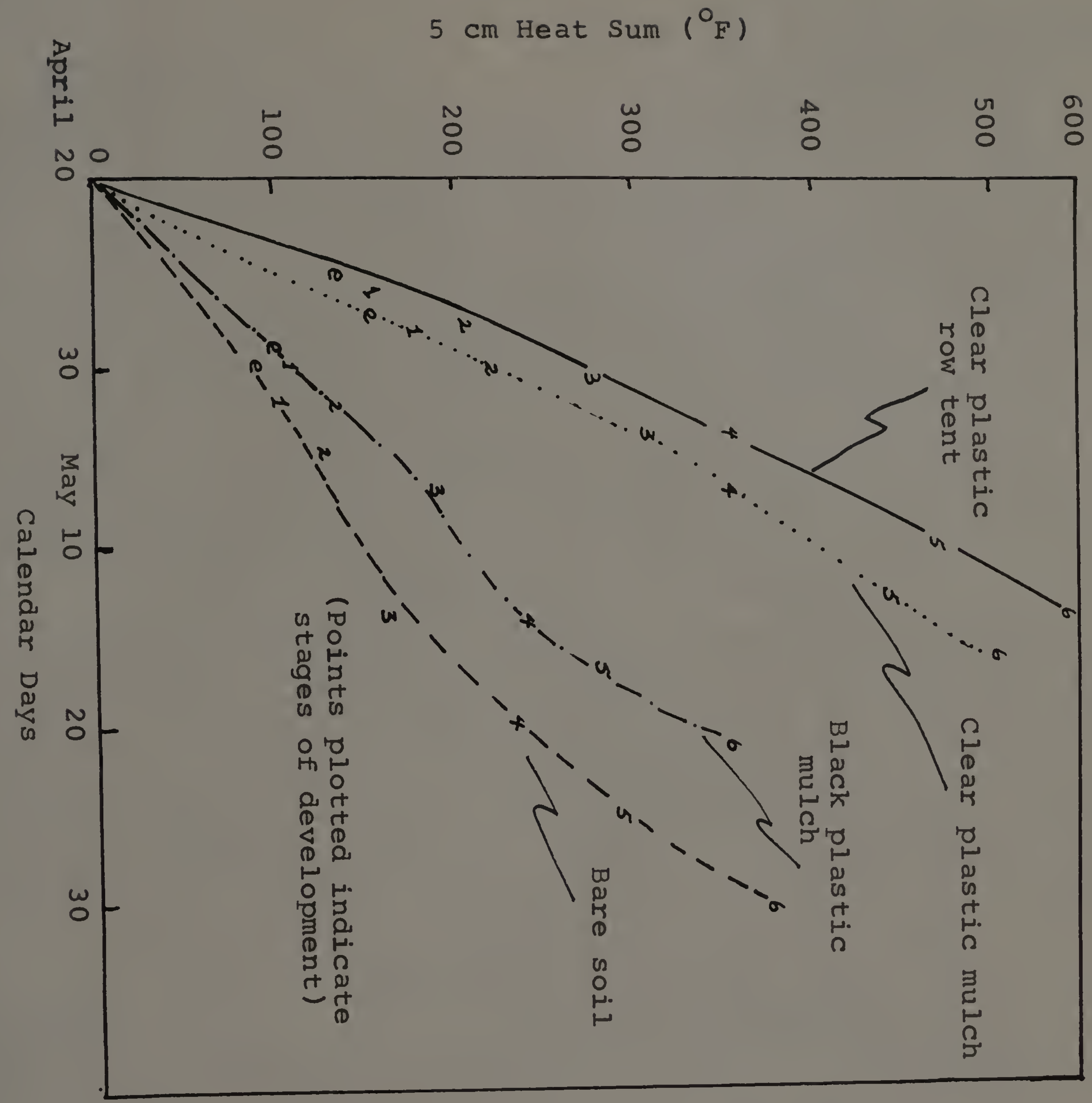


Figure 5. 5-Centimeter soil temperature accumulated up to the 6th leaf stage above 50^{o}F base temperature.

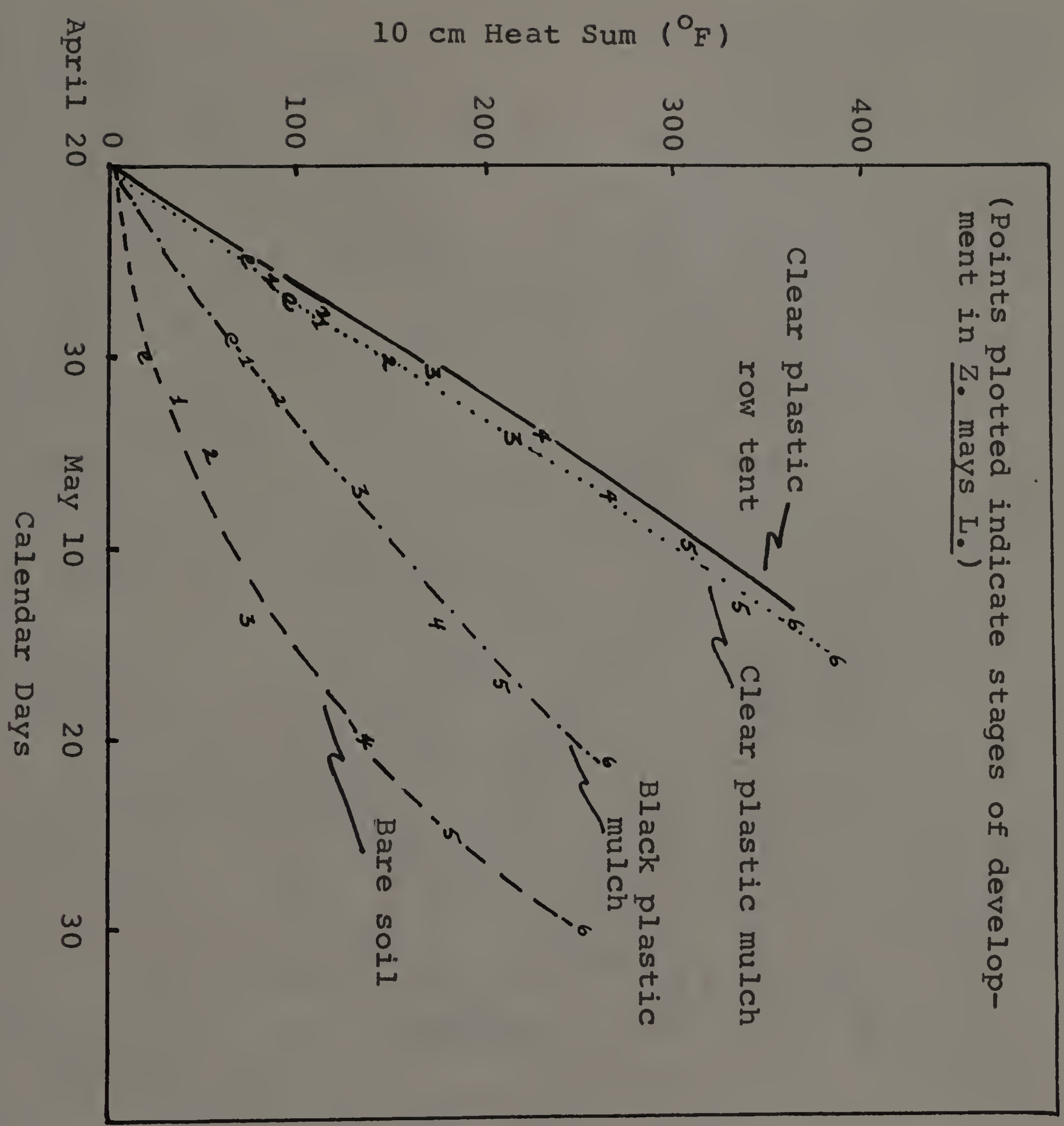


Figure 6. Rate of heat accumulation at 10 cm soil depth up to the 6-leaf stage - (Base temperature = $50^{\circ}F$).

surface (Fig. 4) show that black and clear plastic mulches followed the same pattern of increasing degree days with time. However, plants grown on soil mulched with the black polyethylene required more degree days to reach the same development stage than did plants grown in soil mulches with clear polyethylene. The plants grown with the row tent and polyethylene mulch treatments had higher degree day values than those grown in bare soil during early plant development. However, in the clear polyethylene flat mulch treatment, after the four-leaf stage, the bare soil had more degree days.

Heat sum: Heat sums have been calculated using soil temperatures (Figs. 5 and 6). Rate of corn development (leaf number) was greatly influenced by soil temperature. In comparison with the black plastic mulch and bare soil, the row tent and clear polyethylene flat mulch treatments both had greater rates of heat sum accumulated and total heat sum accumulated at 5 cm under the surface (Fig. 5), at early development stages of sweet corn. Although the total heat sum at 5 cm under the clear polyethylene flat mulch was greater than under the row tent at each stage of sweet corn development up to the four-leaf stage, the rate of heat sum accumulation was slower under the clear polyethylene flat mulch.

The total heat sum at 10 cm (Fig. 6) under the row

Table 11 - Correlation coefficients between soil temperature heat sum and growth paremeters for Z. Mays. L. Amherst, Mass. 1969

GROWTH PARAMETERS	TEMPERATURE 10 cm Heat Sum (28 days) On May 14	10 cm Heat Sum At 6-leaf stage	5 cm Heat Sum On May 14	5 cm Heat Sum At 6-leaf stage
Plant Height	0.87 1/	0.65 2/	0.77 1/	0.73 2/
Period for harvest	-0.87 1/	-0.61 2/	-0.95 1/	-0.83 1/
Period for 6-leaf stage	-0.92 1/	-0.67 2/	0.78 1/	0.95 1/
Ear length	-0.75 2/	-0.56	-0.86 1/	-0.82 1/
Mean ear husked weight	0.31	-.0.17	-0.51	0.58
Mean ear unhusked wt.	0.04	-0.13	-0.33	-0.08
Mean plant dry wt. at 6-leaf stage	0.61 2/	0.47	0.77 1/	0.64 2/
Mean plant Fr. wt. at 6-leaf stage	0.81 1/	0.77 1/	-0.13	0.41
Ca% at 6-leaf stage	-0.86 1/	-0.69 2/	0.81 1/	0.90 1/
P% at 6-leaf stage	0.23	0.66 2/	0.56	0.77 1/
Total number of ears	0.43	0.27	0.67 2/	0.78 1/
Total Fr. wt.	0.32	0.29	0.40	0.50

1/Highly significant difference according to Steele and Torrie.

2/ Significant difference according to Steele and Torrie.

tent and clear polyethylene flat mulch followed the same trend even at the six-leaf stage.

Growth correlations: Correlations computed between growth parameters (Table 11) and heat sum at 5 cm and 10 cm under the ten treatments at their six-leaf stage and on May 14 (about one month after planting) in sweet corn, showed the following:

(1) Total heat sum 10 cm deep on May 14 was highly correlated linearly with maximum plant height and plant fresh weight at the six-leaf stage, and negatively with period for harvest, period to the six-leaf stage and calcium (Ca) content at the six-leaf stage.

(2) Total heat sum 10 cm deep at the six-leaf stage was highly correlated linearly with plant fresh weight at the six-leaf stage, and correlated linearly with maximum plant height and phosphorous content at the six-leaf stage and negatively with period for harvest, period to six-leaf stage, and Ca content at the six-leaf stage.

(3) Total heat sum 5 cm deep on May 14 was highly correlated linearly with maximum plant height, period for six-leaf stage, plant dry weight at six-leaf stage, Ca content at six-leaf stage and negatively with period to harvest, and ear length.

(4) Total heat sum 5 cm deep at the six-leaf stage was highly correlated linearly with period to the six-leaf

Table 12 - Total period to harvesting from planting and from emergence--(Days)--data taken 1969, Amherst, Mass.

Treatment	From Emergence	From Planting
Bare	83[g] [1/]	97[g]
Black plastic	80[d]	93[d]
Clear plastic (C/P)	78[b]	89[b]
No C/P after 3-leaf	82[f]	93[d]
C/P row tent	74[a]	83[a]
C/P on south slope	79[c]	89[b]
South slope bare	81[f]	97[g]
Asphalt mulch	81[f]	95[e]
White wax mulch	81[f]	96[f]
C/P on at 2-leaf stage	78[b]	92[c]

1/Figures followed by the same letters are not significantly different at the 5% level (Duncan's Multiple Range Test).

stage, Ca content and P-content at the six-leaf stage, total number of ears, and negatively with period for harvest and ear length.

Period for Harvest and Maximum Plant Height

The maximum plant height and days to harvesting were closely correlated ($r = -0.96$); generally the treatment with taller plants was harvested earlier (Table 12). The plants associated with row tents were harvested first: six days earlier than those from the continuous clear polyethylene flat mulch treatment or those from clear polyethylene mulch on the south slope, and 14 days earlier than those grown on bare soil or on bare south slopes. The total period from planting to harvest in the row tent was only 83 days compared with 97 days for bare soil (Table 12).

Comparing the total period from emergence to harvest (Table 12), the plants with row tents took the shortest time (74 days), about nine days less than plants grown in bare soil, as compared to 14 days less from planting to harvest. Plants continuously mulched with clear polyethylene or with clear polyethylene mulched after the two-leaf stage, took the same time to harvest.

The row tent produced the tallest plants (Table 14), their height averaged almost 27 cm taller than plants grown in bare soil. Plant height in the treatments was in decreasing order as follows: row tent, clear plastic continuously mulched on the south slope, plastic mulch after the two-leaf stage of development or the clear plastic mulched flat continuously, clear plastic mulch removed after the three-leaf stage, black plastic mulch or black asphalt mulch, bare soil, bare south slope, and white wax mulch treatments.

Reduced times to maturity and increased plant height in sweet corn due to increased temperature has been shown by workers in the midwest and Europe (22,59,73,81,163,164). Perhaps the results obtained by Van Dobben (163) are most instructive. He found that when temperature rises from 16°C to 25°C (61°F to 77°F), growth is accelerated more than development in crops of subtropical origin (such as corn and beans), so that plants finally become larger. This therefore agrees with data when the tallest plants were found under the row tent and that there was a close correlation between maximum plant height and soil temperature.

The two week earlier harvest time measured for the row tent treatment is of special importance in producing early sweet corn in New England. This increase in development rate as compared to bare soil was due to difference in microenvironment and primarily to increased soil temperature as observed in correlation studies (Table 11). In

Table 13 - Yield in fresh weight and in number of ears per hectare for sweet corn. Data from 1969, Amherst, Mass.

	TOTAL UNHUSKED		TOTAL HUSKED
Treatment	Fresh Weight (Kg)	Number of Ears	Fresh Weight (Kg)
Bare Soil	12588.8 b-e 1/	34588 b-d	8131.2 2/
Black plastic	12700.8 b-d	34086 b-d	8444.8
Clear plastic(C/P)	14123.2 ab	37297 a-c	8825.6
No C/P after 3-leaf	11200.0 e	36062 a-d	7683.2
C/P Row tent	13809.6 a-c	39520 a	8680.0
C/P on south slope	12409.6 cd	32851 cd	7873.6
S. slope bare	13193.6 a-d	35568 a-d	8478.4
Asphalt mulch	12947.2 a-d	33098 cd	7963.2
White wax mulch	11782.4 de	32110 cd	7694.4
C/P on at 2-leaf	14291.2 a	38038 ab	8915.2

1/ Figures followed by the same letters are not significantly different at the 5% level (Duncan's Multiple Range test).

2/ Not significantly different by F-test (Steele and Torrie).

Table 14 - Effects of soil treatment on plant height, period to harvest, ear length and ear fresh weight (unhusked and husked) in sweet corn.

Treatment	AVERAGE UNHUSKED Weight (g)	AVERAGE HUSKED Weight(g)	AVERAGE EAR Length(cm)	PLANT Height(cm)	HARVEST Period(days)	AVERAGE EAR (cm) Diameter
Bare Soil	370.1 b[1/]	237.2 bc	16.8 a-c	127.8 f	96.5 f	5.1[2/]
Black plastic	372.9 b	248.6 a	17.0 a	130.8 e	92.5 b	5.0
Clear plastic (C/P)	378.8 b	236.8 cd	16.0 de	140.5 c	88.5 b	5.0
C/P off at 3-leaf	311.8 b	213.7 e	16.2 c-e	136.4 d	92.5 d	4.9
C/P row tent	348.8 c	219.5 d	15.8 e	152.4 a	82.5 a	4.9
C/P on s. slope	378.8 b	239.5 bc	16.3 b-e	141.5 b	88.5 b	5.0
South slope bare	370.6 b	238.1 bc	16.5 a-b	125.7 g	96.5 f	5.0
Asphalt mulch	391.9 a	240.4 b	16.7 a-c	130.8 e	95.3 e	5.1
White wax mulch	366.5 b	239.1 bc	16.9 ab	124.5 h	95.6 e	5.0
C/P on at 2-leaf	375.6 b	234.5 cd	16.5 a-b	140.5 c	91.5 c	5.0

1/Figures followed by the same letters are not significantly different at the 5% level (Duncan's Multiple Range Test).

2/Not significantly different by F-test (Steele and Torrie) addition the apparent high humidity and probable carbon dioxide build up (147) may have contributed to this.

Yield

The treatments produced large differences both in total fresh weight of unhusked ears and in total number of ears (Table 13). Total fresh weights of unhusked ears and number of ears produced by different treatments varied by as much as 3,091.2 kg per hectare and 7,410 ears per hectare respectively. The total weight after husking followed the same trend but varied by only 1,232.0 kg per hectare.

Corn grown with row tents up to the six-leaf stage produced the greatest number of ears, over 5,000 ears per hectare more than the total number produced by plants grown under black polyethylene mulch or in bare soil.

Plants treated with clear polyethylene mulch when the two-leaf stage was reached produced the greatest total unhusked fresh weight of ears per hectare. This weight was over 1,590 kg per hectare greater than the weight produced by plants grown with black plastic mulch, with bare soil or with treatments with no clear polyethylene after the three-leaf stage.

Ear Size (Ear Length, Weight, and Diameter)

The average ear length and ear fresh weight (husked and unhusked) produced by plants grown with different treatments (Table 14), differed by as much as 1.2 cm (among treatments) and 34.9 g (husked) and 80.1 g (unhusked). The average diameter of ears produced among treatments followed the same trend but differed by as little as 0.20 cm.

There was a trend for ears of corn from plants treated with black polyethylene mulch to be the longest. However ear length of corn from black plastic treatments did not differ significantly from those produced on plants grown in bare soil (Table 14). Ears of corn from both the black polyethylene mulch and bare soil treatments were almost one centimeter longer than those produced with row tents, but this was not of economic importance.

The average weight of unhusked ears produced by plants with asphalt mulching was greatest (about 392 g), and was about 21 g more than the weight of unhusked ears produced by plants grown in bare soil, and 43 g more than those of row tents (Table 14). On the average, ears produced by plants grown with black polyethylene mulch had the greatest weight after husking; they were more than 11.4 g and 29 g heavier than those produced in bare soils and row tents respectively.

The results (Table 13) show that plants grown in either bare soil or treated with black polyethylene mulch had less total number of ears and total fresh weight than those with treatments producing the more rapid development, such as in row tents or other clear plastic mulches. It is important to note that plants treated with clear polyethylene mulch at the two-leaf stage had both higher unhusked yields and greater total number of ears; but those plants with clear polyethylene mulch removed after the three-leaf stage had as great total number of ears but their unhusked fresh weight was the lowest. Thus it appears that the effect of clear plastic is critical at the two to three leaf stage for numbers and unhusked ear weight.

Aung *et al*. (10), Harris (73), Miller (119), and others have reported higher yields for clear plastic mulches and row tent treatments. But this literature review found no mention of the effect of clear polyethylene mulches at different stages of development on fresh weight yields of sweet corn. Because clear polyethylene cause increased temperatures and increased growth and development of sweet corn, it is conceivable that clear polyethylene can affect plant part development particularly the reproductive parts: thus influencing final ear size and yields.

Developmental Responses

Many workers have divided the development of corn plants into several stages each with its responses to weather, and its relation to final yield. The development

Table 15 - Mean number of days from planting to certain early developmental stages in corn. Data from 1969, Amherst, Mass.

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	14	16	19	28	34	39	44
Black pl.	13	14	16	21	28	31	35
Clear pl. (C/P)	11	12	14	18	21	27	30
No C/P after 3-leaf	(11)1/	(12)	(14)	18	21	29	37
C/P row tent	9	10	12	15	18	24	28
C/P on south slope	10	11	14	18	21	28	30
S. slope bare	16	17	19	28	34	38	44
Asphalt mulch	14	15	18	26	31	36	43
White wax mulch	15	18	21	30	36	42	46
C/P on at 2-leaf stage	(14)	(16)	19	24	29	31	36

	STAGES OF DEVELOPMENT		
Treatment	Tasseling	Silking	Harvesting
Bare	65	75	97
Black plastic	60	72	93
Clear plastic (C/P)	56	68	89
No C/P after 3-leaf	63	73	93
C/P row tent	50	61	83
C/P on s. slope	55	67	89
South slope bare	65	75	97
Asphalt mulch	63	73	95
White wax mulch	64	74	96
C/P on at 2-leaf stage	58	71	92

1/Figures in parenthesis are from bare soil or clear plastic mulch treatments.

stages studied here (and described earlier) are based on studies by Shaw and Loomis (146), Beauchamp and Lathwell (14,15) with field corn and Bonnett (19,20) with sweet corn. Sweet corn morphological development is divided into early development, tasseling, silking, and harvesting. Differences in early development were measured as the time taken for a new leaf to be visible; the associated morphological and anatomical changes were then noted.

The plastic mulches and their initial higher soil temperatures reduced the period required for each stage of development to occur in corn plants (Table 15). Those with the clear polyethylene flat mulch required about two days (at emergence) and five days (at the six-leaf stage) less than those with the black plastic mulch. The plants grown with row tents emerged five days earlier and required 15 days less by the six-leaf stage than plants with bare soil. Delayed mulching of plants with clear polyethylene at the two-leaf stage reduced the growth period to the six-leaf stage by eight days when compared with bare soil. On the other hand, removing the clear polyethylene mulch at the three-leaf stage increased the growth period to the six-leaf stage by seven days when compared to plants grown in the continuous clear polyethylene mulch treatment.

It was difficult to determine when the coleoptile had emerged above the soil surface under the opaque black polyethylene mulch. As a result some of the plants had reached the one-leaf stage but had no chlorophyll when the black polyethylene was cut for air and light. However black polyethylene treated plants required nine days less time to reach the six-leaf stage than the plants in bare soil.

The general pattern of development continued into tasseling, into silking, and into harvesting; however, about five days advantage were lost by plastic treatment compared to bare soil between the six-leaf stage and harvest (Table 15). Plants grown with the row tent, clear polyethylene flat mulch, black polyethylene, and bare soil took respectively 50, 56, 60, and 65 days from planting to tasseling. Silking occurred 61, 68, 72, and 75 days after planting with the row tent, clear polyethylene mulch flat, black polyethylene flat mulch, and in bare soil respectively. The ears were ready for marketing 20-22 days after silking in all treatments.

The fact that the row tent and clear plastic mulches reduced the period for emergence in sweet corn is very important especially in cold soils where fungi may be prevalent. It is interesting to note, that the increased rate of development carried over into harvesting. This rate of early development, in a large way, determined the time required for tasseling, silking, and harvest. Other workers (5,10,31,82,89,119,175) have implied this but

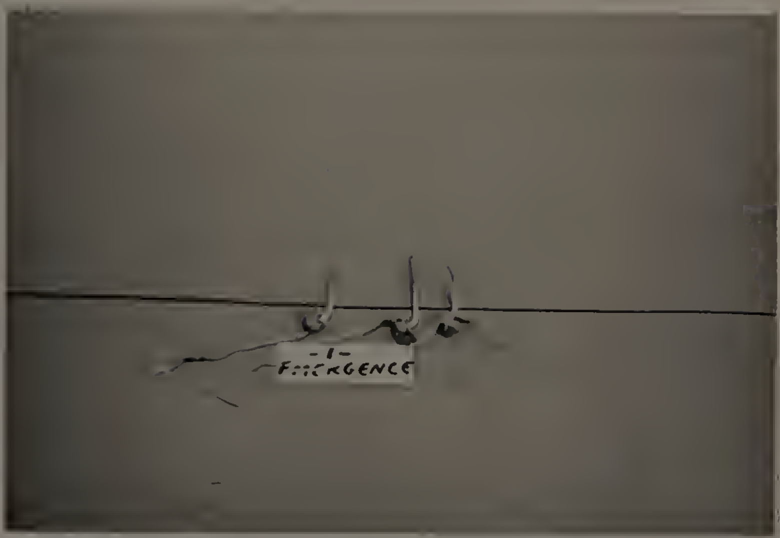


Plate VIII

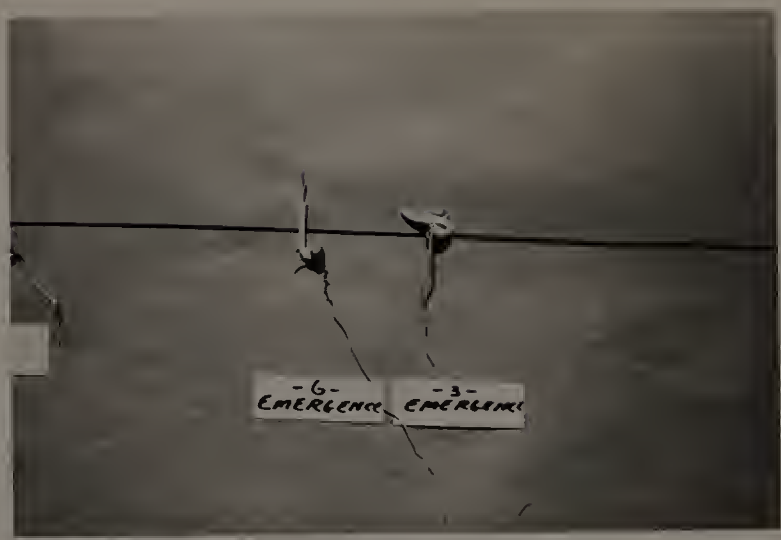


Plate IX

Plate VIII. At emergence, the corn seedlings' primary root in bare soil was growing almost horizontally.

Plate IX. At emergence, seedlings' primary root under clear plastic mulch was growing almost vertically.

Plate X

Plate XI

Plate XII

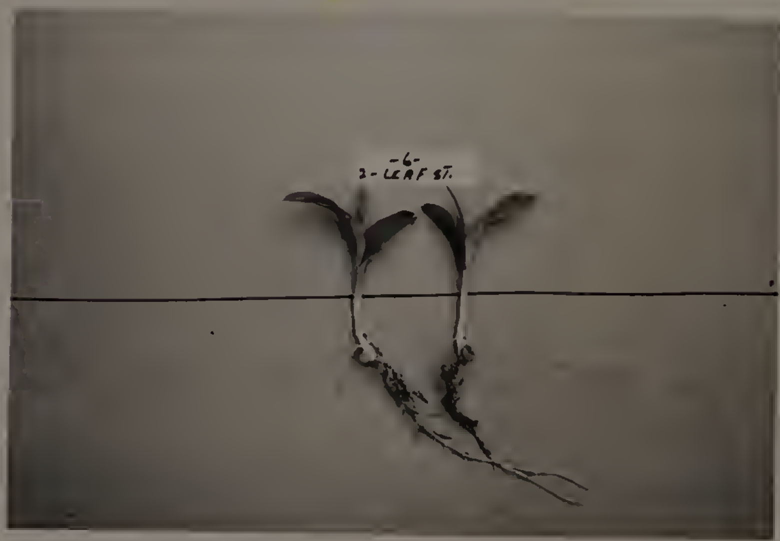


Plate XIII

Plates X to XIII. At the 2-leaf stage, corn seedlings' roots under clear plastic row tents (Plate X), mulched flat (Plate XI) or on south slope (Plate XII) were growing almost vertically and had increased number of secondary roots compared with bare soil (Plate XIII).

Plate XIV

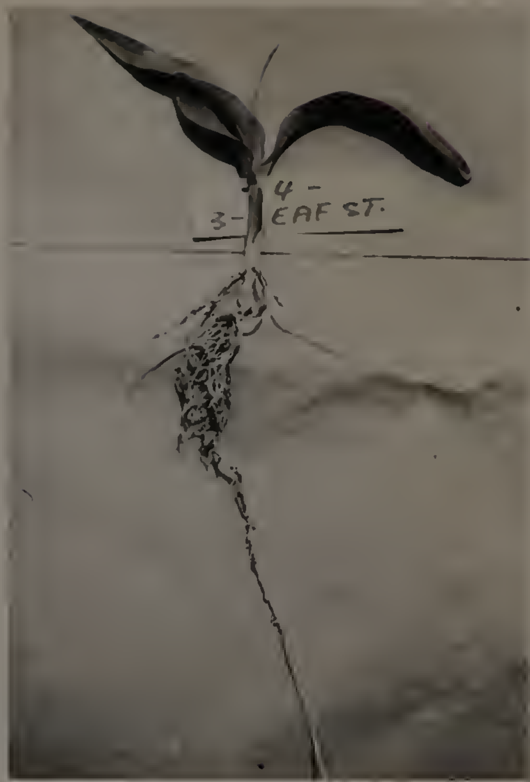


Plate XV

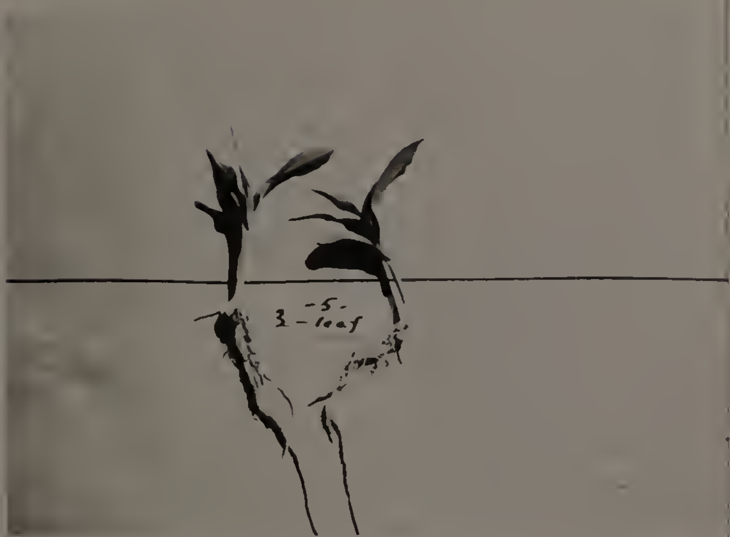


Plate XVI

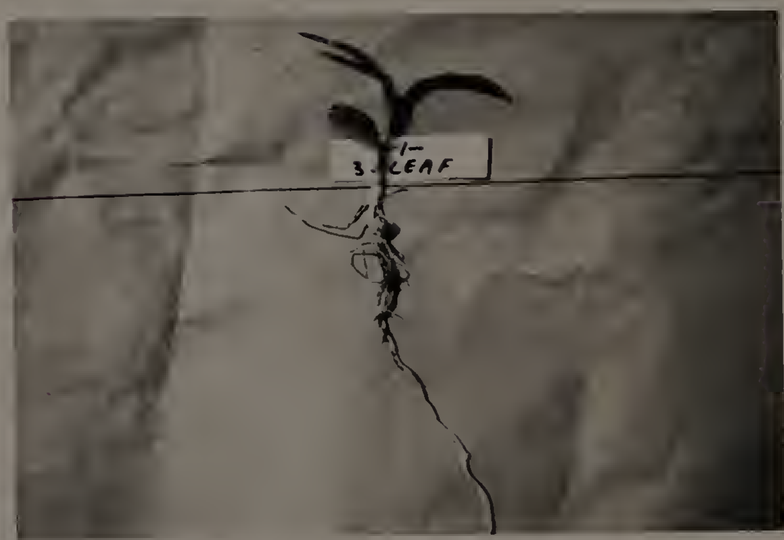


Plate XVII

Plates XIV-XVII. At the 3-leaf stage observe corn seedlings' primary roots elongating and growing vertically in all treatments. Notice the increased number of laterals on the primary root and the development of seminal and nodal roots in clear plastic treatments (Plates XIV to XVI) compared with bare soil (Plate XVII).

Table 16 - Total number of roots emerging from the hypocotyl of sweet corn as affected by soil treatments--(mean of 10-6 plants in 6 replicates.)

	STAGES OF DEVELOPMENT[1]						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	1	1	3	5	6	9	11
Black plastic	1	1	2	7	9	11	12
Clear plastic (C/P)	1	1	2	7	9	9	11
No C/P after 3-leaf	1	1	1	6	8	10	10
C/P row tent	0	1	1	5	11	11	12
C/P south slope	1	2	2	12	12	12	15
S. slope bare	0	3	5	6	8	9	11
Asphalt mulch	1	2	2	6	8	10	11
White wax mulch	1	6	7	9	9	9	12
C/P on at 2-leaf stage	1	1	3	5	7	8	12

1/See Appendix 1 for sampling dates.

Table 17 - Mean number of seminal roots in the early stages of sweet corn as affected by soil treatments[1] (mean of 10-6 plants.)

Treatment	STAGES OF DEVELOPMENT[2] Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	1	1	1	1	1	1	1
Black plastic	0	1	2	3	4	4	4
Clear plastic (C/P)	1	1	2	2	2	2	2
No C/P after 3-leaf	1	1	1	1	1	1	1
C/P on row tent	0	1	1	2	2	2	2
C/P on south slope	1	2	2	(6)	2	2	5
S. slope bare	3	3	3	3	3	3	3
Asphalt mulch	1	2	2	2	2	2	2
White wax mulch	1	3	4	4	4	4	4
C/P on at 2-leaf stage	1	1	1	1	2	2	2

1/See Appendix for sampling dates.

2/According to leaf appearance reference 14, 15.

seminal (seed) roots and, later, the crown roots which form the main fibrous root system (26,29,92). At emergence and the one-leaf stages, the primary and seminal roots were growing almost horizontally at a depth of 5 to 10 cm under the asphalt and white wax mulches and in bare soil (Plate VIII). In some cases the area behind the primary root tip was slightly swollen and curved upwards toward the soil surface. Under the plastic treatments especially the south slope, the roots were growing in a more vertical direction (Plate IX). In later stages of growth this difference in angle of root development was less distinct.

The total number of roots emerging from the hypocotyl of sweet corn (Table 16) consist of the total number of seminal roots, early crown roots, and any other lateral root arising from the hypocotyl. At the one-leaf and two-leaf stages of sweet corn, some laterals emerged on the lower side of the hypocotyl in the white wax mulch and bare south slope treatments. At the three-leaf to six-leaf stages, the plants growing in the south slope mulched with clear plastic and in the row tent had the greatest number of roots emerging. The majority of these roots were crown roots.

The plants with clear plastic emerged five days before those on bare soil, hence there was more time for root development by the plants with bare soil. At emergence,

Table 18 - Effects of soil treatments in the early stages[1] of sweet corn showing number of laterals on primary root[3]

	STAGES OF DEVELOPMENT				
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf
Bare	0	15	40	45	50
Black plastic	0	20	40	60	70
Clear plastic (C/P)	5	25	55	60	85
C/P off after 3-leaf	5	25	55	60	70
C/P on row tent	5	15	20	55	70
C/P on south slope	10	20	45	65	70
S. slope bare	0	-	-	-	- [2]
Asphalt mulch	0	20	35	40	55
White wax mulch	0	-	-	-	-
C/P on at 2-leaf	0	15	40	60	85

1/See Appendix 1 for sampling dates.

2/No check made.

3/Mean of 6-10 plants.

there were a few laterals on the primary root of plants grown with clear plastic mulch flat or with the row tent, and with clear plastic mulch on the south slope treatment (Table 18). All plants had laterals on the primary root at the two-leaf stage; however, plants in bare soil and in the row tent had the least amount (Plates X to XIII). In addition plants grown in bare soil had their primary roots still horizontal to the soil surface. At the three-leaf and four-leaf stages, the lower section of the primary root had begun to become fibrous as some of the laterals were growing as rapidly as the main growing point. Plants from clear polyethylene mulch treatments and from row tents had more laterals on the primary root than those from the bare soil (Plates XIV to XVIII).

The number of seminal roots (Table 17) and number of laterals on the primary root (Table 18) on corn plants differed slightly between treatments. In the ten plants sampled under the row tents at emergence, only three had a seminal root, while plants grown on the bare south slope had up to three seminal roots. Plants under the row tent did not appear to have their maximum number of seminal roots until the three-leaf stage was reached. The maximum number of seminal roots in plants ranged from one in bare soil to four in the white wax mulch and black plastic mulch treatments.

At the three-leaf stage, all treatments had a whorl of three to five crown roots and most of the endosperm from the corn seed had been consumed (Plates XIV-XVII). This period, therefore, appeared to be a transition from the seedling stage to self-sufficiency. At this stage both secondary and tertiary root growth occurred. In general, there seemed to be the greatest number of rootlets and smaller feeder roots near the surface under the black plastic compared with other plastic treatments.

Soil surface treatments altered sweet corn root growth pattern and development: low temperature causing a more shallow, horizontal root development. Considering the relatively large soil temperature differences among treatments and between clear plastic mulches and bare soil, the results show that soil temperatures influence both growth and type of root development. However, this was partially masked by the relatively longer time taken for plant grown in bare soil to reach the same stage of development as those in plastic mulches. There is still a great deal of conflict on root responses to environment and stress (47,52,95,96,97,107,137,160). This experiment demonstrated the importance of temperature and indicated that further studies are required.

PLATE XVIII

PLATE XIX

PLATE XX

Plates XVIII to XX. Longitudinal sections of sweet corn (Z.mays, L) shoot apex (100x) show the apical meristem in the vegetative phase at emergence (Plate XVIII), at the 4-leaf stage (Plate XIX) and at the 5-leaf stage. Note that no differences were observed between treatments.

PLATE XXI (40x)

PLATE XXII (40x)

PLATE XXIIIa (40x)

PLATE XXIIIb (40x)

Plates XXI - XXIII. Longitudinal sections of sweet corn's shoot apex (40x) show Tassel initiation at the 6-leaf stage in bare soil (Plate XXI), in the row tent (Plate XXII) and in the clear plastic mulch (Plate XXIII). Notice the axillary buds (Plate XIIIb) one of which may develop into the marketable ear.

Shoot Development Responses

Although the clear plastic increased the rate of shoot morphological development over other treatments, there was little differences in morphology of the sweet corn shoot at the same stage of development (leaf appearance). The "stem" height was slightly higher at the four-leaf to six-leaf stages in plants in the row tent and clear plastic mulched flat when compared with other treatments (Fig. 8). Tillers developed at the lowest three leaf bases in all clear plastic treatments at the six-leaf stage except in the treatment where clear plastic mulch was removed at the three-leaf stage. This observation was not consistent for the other treatments. At tassel appearance, the number of tillers was relatively the same for all treatments but the largest tillers developed in the row tent.

When the leaf bases were dissected from the true corn stem at each stage of development, the apical meristem was found to be vegetative and was below the soil surface late in the five-leaf stage (Plates XVIII toXXIIIb). At the six-leaf stage, the tassel had initiated. There were no differences in growth pattern from the vegetative to reproductive phases between treatments.

These data are quite similar to those of Beauchamp and Lathwell (14,15) and Hortik and Arnold (82). It is apparent that leaf appearance is an accurate external

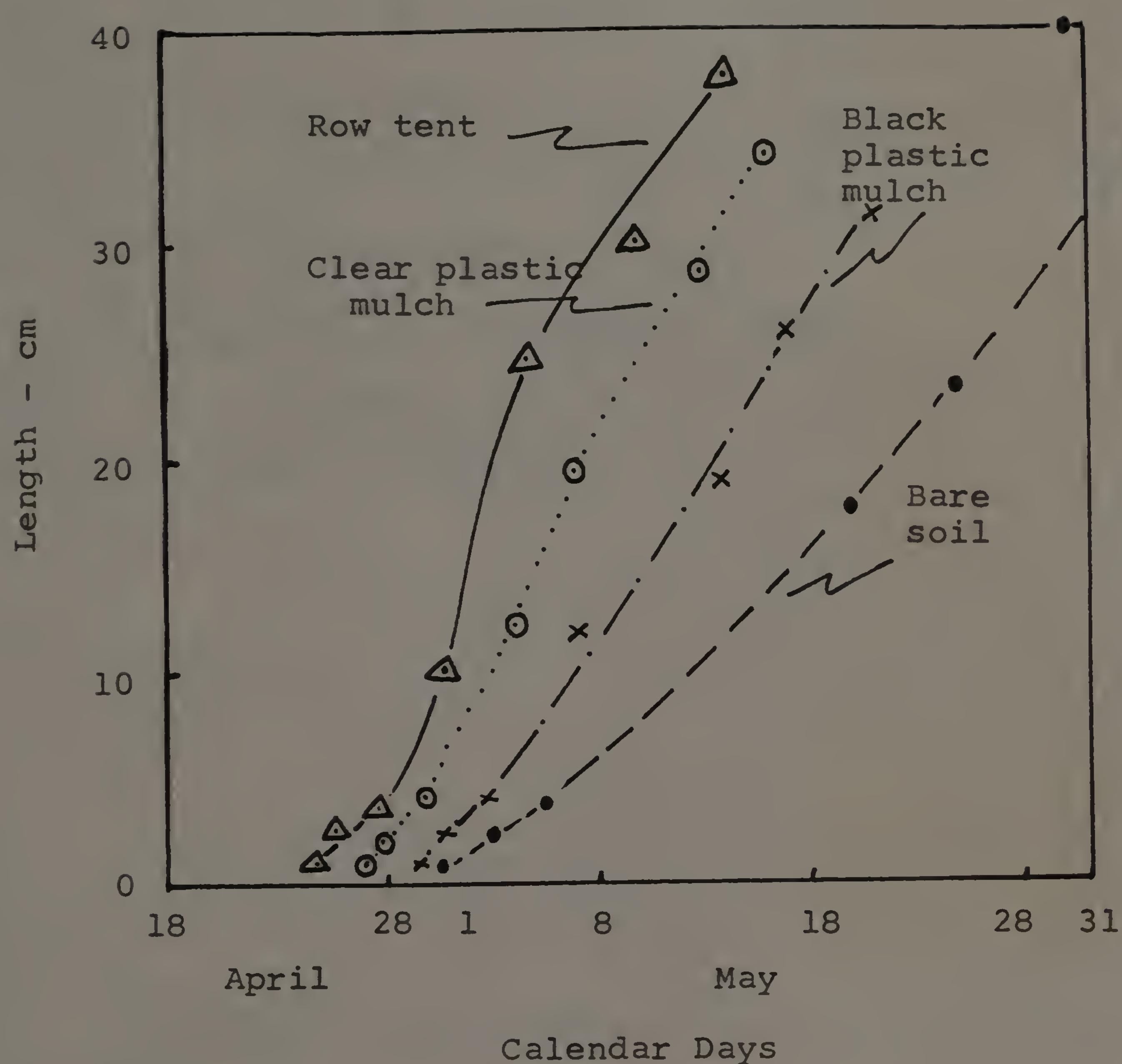


Figure 7. Effect of row tent and plastic mulches on rate of elongation of tops.

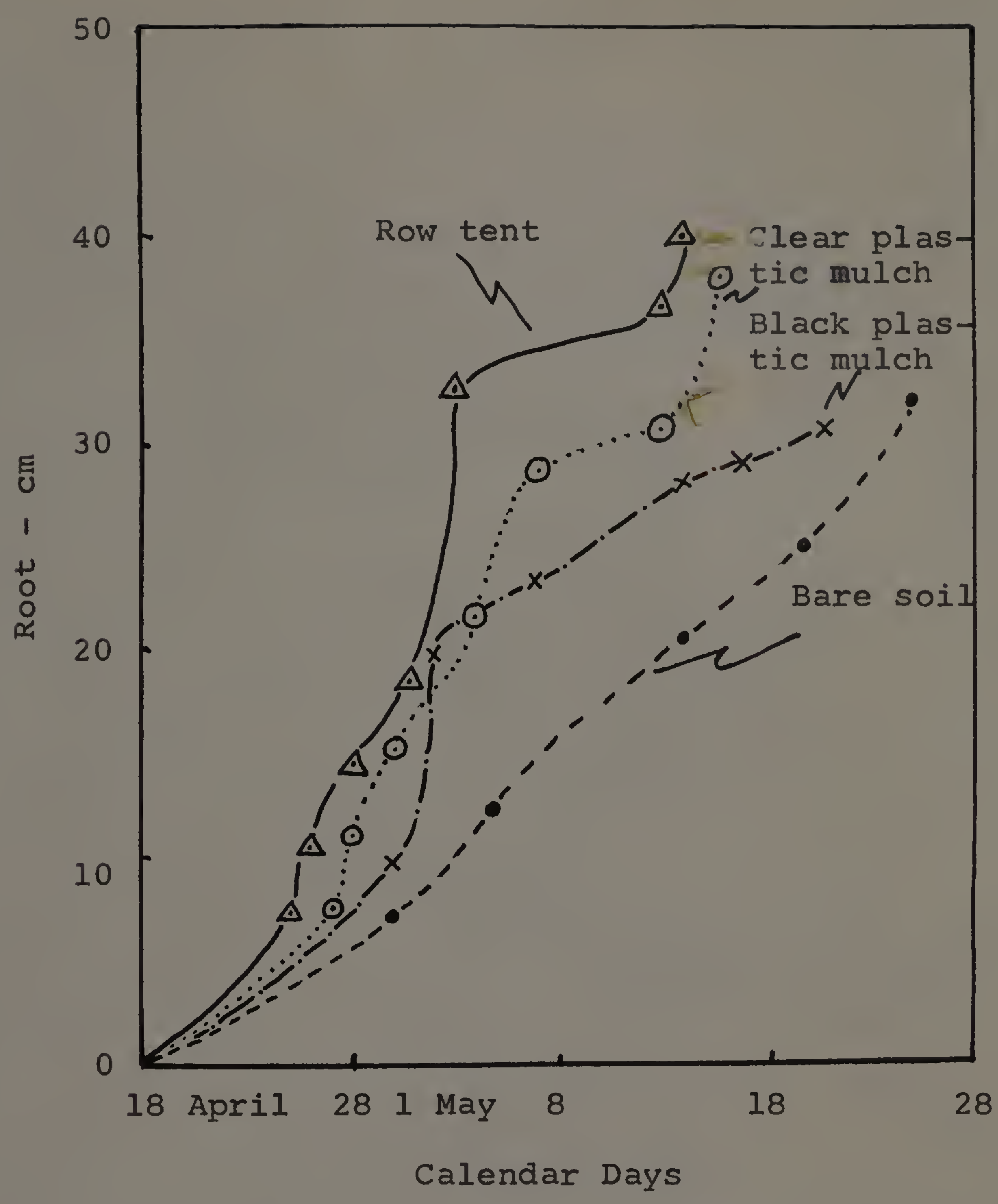


Figure 8. Rate of elongation of primary root in _Z. mays_, L.

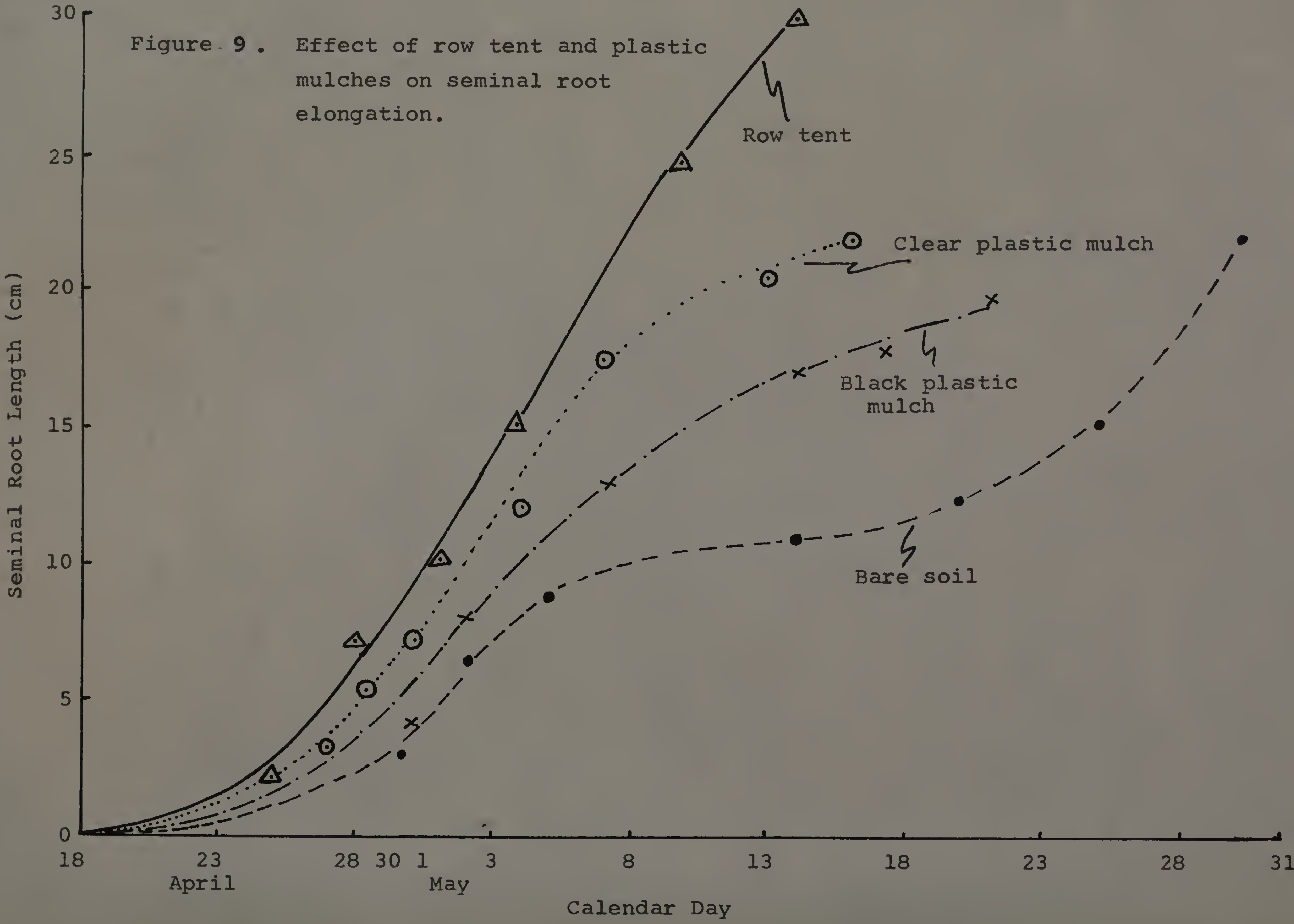


Figure 9. Effect of row tent and plastic mulches on seminal root elongation.

Table 19 - Effects of soil treatments on sweet corn shoot length in the early stages[1] (leaf extended).

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	0.5	1.5	3.5	9.5	18.5	23.0	32.0
Black plastic	0.5	2.5	3.5	11.7	18.5	25.5	31.0
Clear plastic (C/P)	0.5	3.8	4.0	11.0	18.4	28.5	34.0
C/P off after 3-leaf	0.5	3.8	4.0	11.0	18.5	25.0	30.5
C/P row tent	0.5	3.9	4.5	10.2	16.4	28.0	34.0
C/P on south slope	0.5	2.0	2.3	9.4	14.7	26.0	31.0
S. slope bare	0.5	2.0	3.5	10.0	18.0	22.0	32.0
Asphalt mulch	0.5	2.5	3.8	9.9	15.9	22.6	32.0
White wax mulch	0.5	2.4	3.9	6.6	10.0	18.6	30.0
C/P on at 2-leaf	0.5	1.5	3.5	11.0	18.5	28.9	32.9

1/ See Appendix 1 for sampling dates.

2/ Mean of six plants.

criterion for judging certain anatomical developments in Early Golden Giant sweet corn.

Quantitative Growth Responses (Lengths)

Growth responses were measured as increases in shoot length (leaf extended) and root lengths, and in fresh weight and dry weight. There were marked length increases with time (Figs. 8-10).

During the early development stages, plants grown under row tents had the greatest increase in shoot lengths, there was a slow period of growth up to the two-leaf stage followed by a rapid period up to the four-leaf stage (Fig. 8). This growth pattern was less distinct in all plants of the other treatments.

There were relatively great differences in shoot lengths between plants grown in the row tent and plants grown in bare soil at the one-leaf and two-leaf stages (Table 19). At the later stages (five-leaf and six-leaf stages) most of these differences were no longer apparent.

The rate of elongation of the primary root in the early development stages of sweet corn showed a distinct pattern; this growth pattern was most distinct in the row tent and least apparent in bare soil. In late April and in early May, there was rapid primary root elongation with plastic treatments followed by a very slow period of growth (Fig. 9). This was not related to a particular development stage in the treatments, because plants grown in the row tent were at the three-leaf stage while plants grown with black polyethylene mulch were between the one-leaf and two-leaf stages. The growth response in the seminal roots (Fig. 10) did not correspond to the rapid and slow primary root elongation. After the one-leaf stage, the number of seminal roots (Table 17) hardly increased but laterals emerged on the rapidly developing roots. The seminal roots of plants grown under row tents increased in lengths most rapidly. (Fig. 9)

All the previous data on the root system seem to suggest that a compensatory effect occurred among types of roots formed, number of roots formed and the lengths of roots formed. Thus if one of the factors is limiting another one develops to fill its function to the plant.

As Table 20 shows, at emergence, the primary root lengths of plants grown in all treatments except the white wax mulch and bare south slope were the same. At the one-leaf stage, plants grown in the asphalt mulch had the longest primary root, almost twice the length of roots grown in bare soil. For the next few stages of development, plants grown with black polyethylene mulch had the longest primary root. However, by the five-leaf and six-leaf stages, plants grown in the row tent had the longest root—about eight centimetres longer than of plants grown in

Table 20 - Effects of soil treatments on length of primary roots in the early stages[1] of sweet corn development (cm).[3]

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	7.1[1]	8.0	11.9	20.5	25.0	32.0	32.0
Black plastic	- [2]	9.6	19.7	23.0	28.0	29.0	30.5
Clear plastic (C/P)	7.5	11.0	15.0	20.7	28.1	30.1	38.5
C/P off after 3-leaf	7.5	11.0	15.0	17.0	22.5	28.5	38.5
C/P row tent	7.3	10.5	14.5	18.5	31.4	36.4	40.0
C/P on s. slope	7.5	12.0	15.6	(6.5)	28.2	31.5	35.0
S. slope bare	5.6	8.0	9.6	12.0	28.5	28.5	34.0
Asphalt	7.1	15.7	19.1	20.2	22.5	22.5	34.0
White wax	4.5	10.1	13.8	15.5	20.5	22.5	34.0
C/P on at 2-leaf	7.1	8.0	11.9	16.2	26.0	30.8	30.8

1/ See Appendix 1 for sampling dates.

2/ No roots had emerged.

3/ Mean of six plants.

Table 21 - Effects of soil treatments on sweet corn seminal root lengths in the early growth stages[1] (cm).[3]

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	2.0	6.6	8.5	11.0	12.5	15.0	22.0
Black	- [2]	3.8	7.6	12.6	17.0	17.5	18.5
Clear plastic (C/P)	3.0	5.0	7.2	12.0	17.5	20.5	22.0
C/P off after 3-leaf	3.0	5.0	7.2	12.0	12.0	15.0	15.0
C/P row tent	-	2.0	7.0	10.0	20.0	25.0	30.0
C/P on south slope	2.0	6.3	8.2	9.0	12.9	13.5	20.5
S. slope	2.0	4.0	4.5	6.5	15.0	15.0	18.0
Asphalt	1.6	2.0	7.1	9.0	11.6	15.0	20.5
White wax	0.8	1.8	3.8	4.0	4.0	10.5	15.5
C/P on at 2-leaf	2.0	6.6	8.5	10.0	13.5	14.5	18.5

1/ See Appendix 1 for sampling dates.

2/ No readings taken.

3/ Mean of six plants.

Table 22 - Effects of soil treatment on sweet corn crown (nodal) root length in the early growth stages[1/] (cm).[3/]

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	- [2/]	-	-	3.0	12.5	14.0	16.0
Black	-	-	-	3.3	10.5	10.5	15.5
Clear plastic	-	-	3.0	7.0	15.5	15.5	21.1
C/P off after 3-leaf	-	-	3.0	7.0	9.3	15.3	20.0
C/P row tent	-	-	2.5	7.0	9.3	17.5	22.0
C/P on south slope	-	-	3.5	5.0	10.7	16.5	24.0
S. slope bare	-	-	0.5	3.0	10.0	15.0	15.5
Asphalt	-	-	-	4.0	13.5	14.0	20.0
White wax	-	-	0.9	3.5	9.5	13.0	20.5
C/P on at 2-leaf	-	-	-	7.0	17.5	19.3	28.6

1/ See Appendix 1 for sampling dates.

2/ No roots had emerged.

3/ Mean of six plants.

Table 23 - Effects of soil treatments on sweet corn fresh weight in the early stages[1/] (g/plant).[2/]

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	0.46	0.96	1.07	1.89	3.76	6.83	8.23
Black plastic	-	0.86	1.26	2.02	3.92	7.62	9.73
Clear plastic (C/P)	0.65	0.98	1.65	2.05	3.81	7.85	9.93
C/P off after 3-leaf	0.65	0.98	1.65	1.99	3.46	7.38	9.83
C/P row tent	0.68	0.98	1.63	2.28	5.06	9.30	11.24
C/P on south slope	0.56	0.88	1.06	2.11	3.47	7.00	11.13
S. slope bare	0.56	0.79	1.00	1.45	3.05	6.80	9.76
Asphalt mulch	0.56	1.06	1.47	2.20	3.22	6.80	9.92
White wax	0.43	1.06	1.40	1.67	3.08	6.84	9.76
C/P on at 2-leaf	0.46	0.98	1.07	2.60	4.53	7.80	10.55

1/ See Appendix 1 for sampling dates.

2/ Mean of six plants.

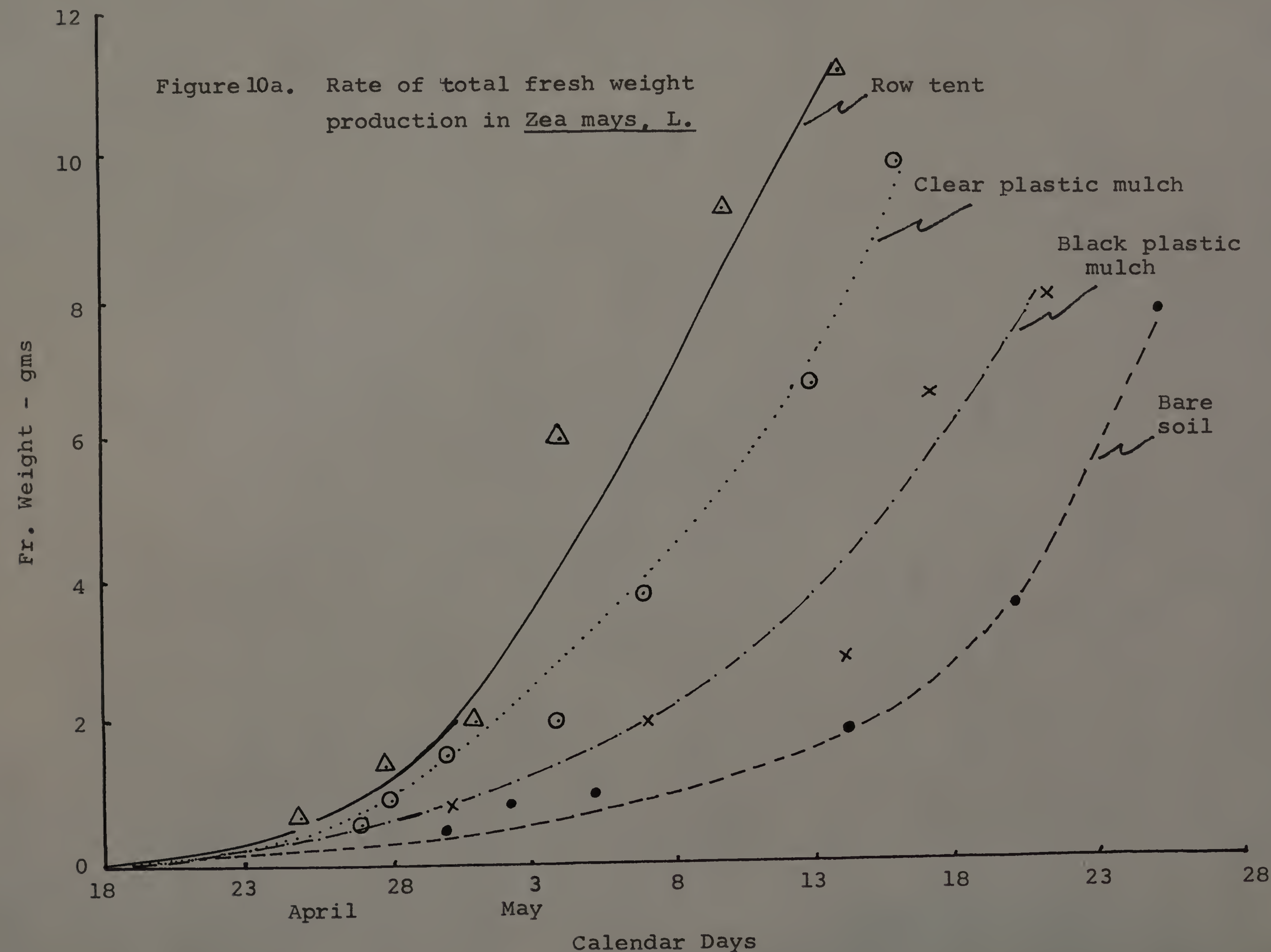


Figure 10a. Rate of total fresh weight production in *Zea mays, L.*

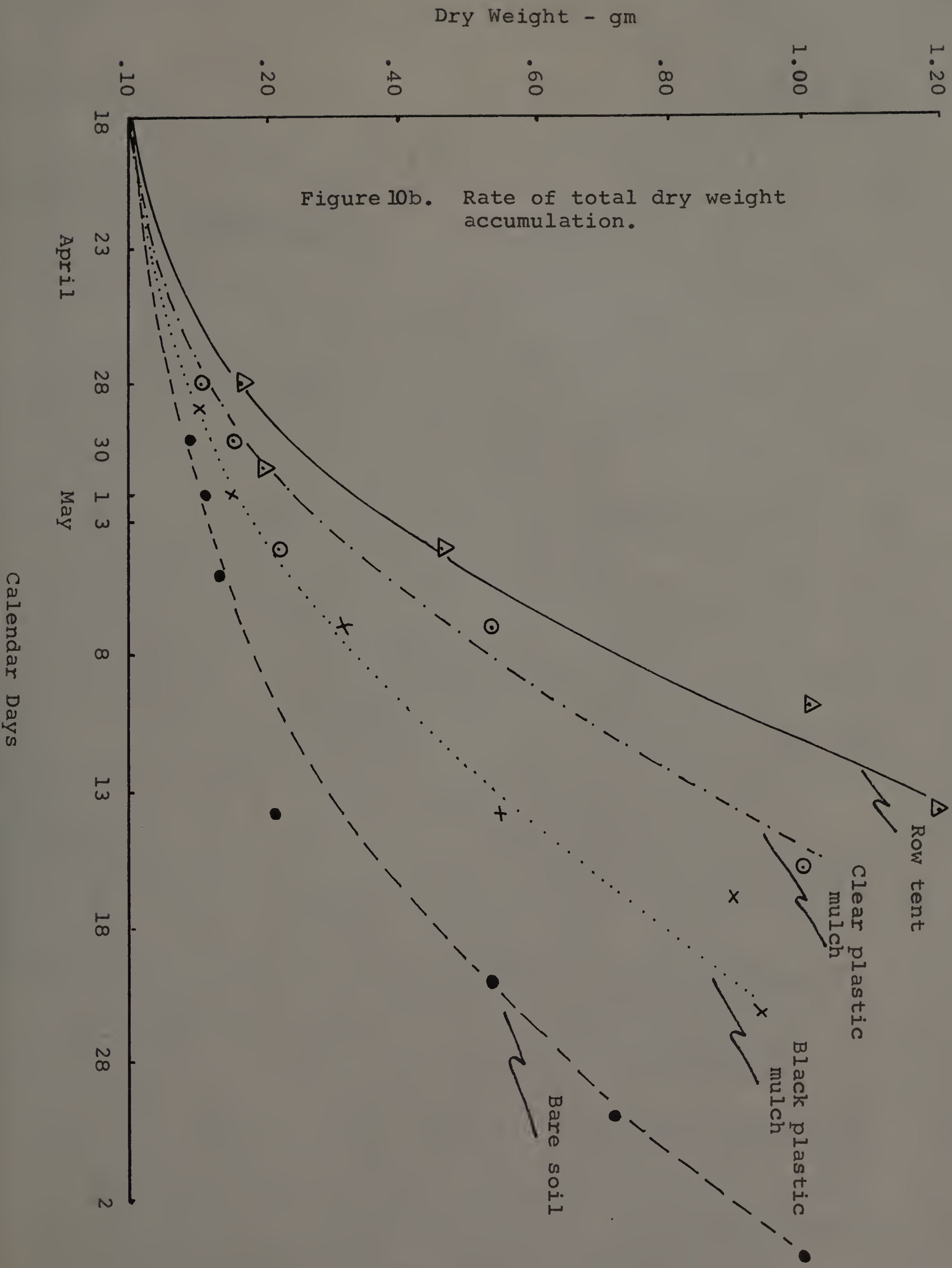


Figure 10b. Rate of total dry weight accumulation.

bare soil. The seminal root lengths (Table 21) of plants in all treatments followed a supplementary growth pattern to that of the primary roots. The crown root lengths (Table 22) were measured when they appeared in the two-leaf and three-leaf stages. They also followed the same growth pattern.

Quantitative Growth Responses (Weight)

Fresh Weight: As Fig.10a shows, the rate of total fresh weight production of plants grown with the row tent and plastic mulches had a similar growth pattern to rate of shoot elongation and seminal root elongation. The plants grown with row tents had the greatest fresh weight production and those in bare soil had the least. However, at any one stage of growth, the plants grown with row tent had the greatest fresh weight and those grown in bare soil or on the bare south slope treatments had the smallest fresh weight (Table 23). In general, a plant increased its fresh weight by about 10 g from emergence to the six-leaf stage.

Dry Weight: The rate of total dry weight production, Fig.10b, for plants grown with row tent and plastic mulches was similar to the growth pattern of total fresh weight production. However, there were less differences between the amount of dry weight in plants grown with row tents than in those grown with bare soil. In the early stages

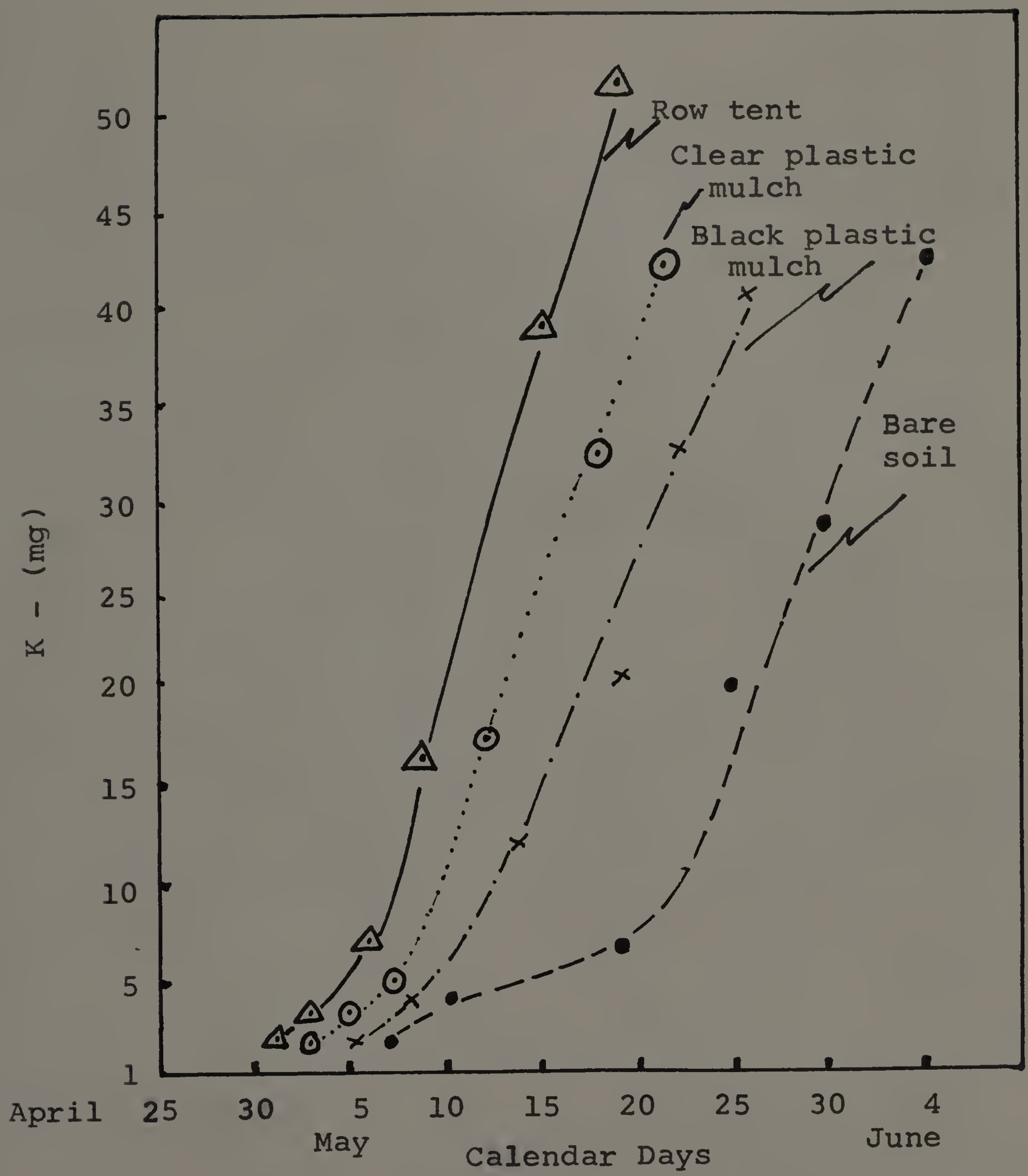


Figure 11. Effect of row tent and plastic mulches on rate of total potassium accumulated in _Z. mays. L._

Table 24 - Effects of soil treatments on sweet corn dry weight in the early stages[1] (g/plant).[2]

Treatments	STAGES OF DEVELOPMENT Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	0.09	0.15	0.18	0.21	0.53	0.72	1.02
Black plastic	0.09	0.10	0.14	0.32	0.55	0.90	0.93
Clear plastic (C/P)	0.10	0.11	0.16	0.22	0.53	0.83	1.06
C/P off after 3-leaf	0.10	0.11	0.16	0.22	0.55	0.83	1.21
C/P row tent	0.10	0.11	0.16	0.19	0.46	1.09	1.20
C/P on south slope	0.10	0.12	0.15	0.25	0.44	0.97	1.07
S. slope bare	0.10	0.13	0.17	0.22	0.52	0.98	1.06
Asphalt mulch	0.09	0.16	0.20	0.32	0.42	0.76	0.99
White wax mulch	0.09	0.18	0.26	0.23	0.40	0.78	1.01
C/P on at 2-leaf	0.09	0.15	0.18	0.35	0.53	0.88	1.14

1/ See Appendix 1 for sampling dates.

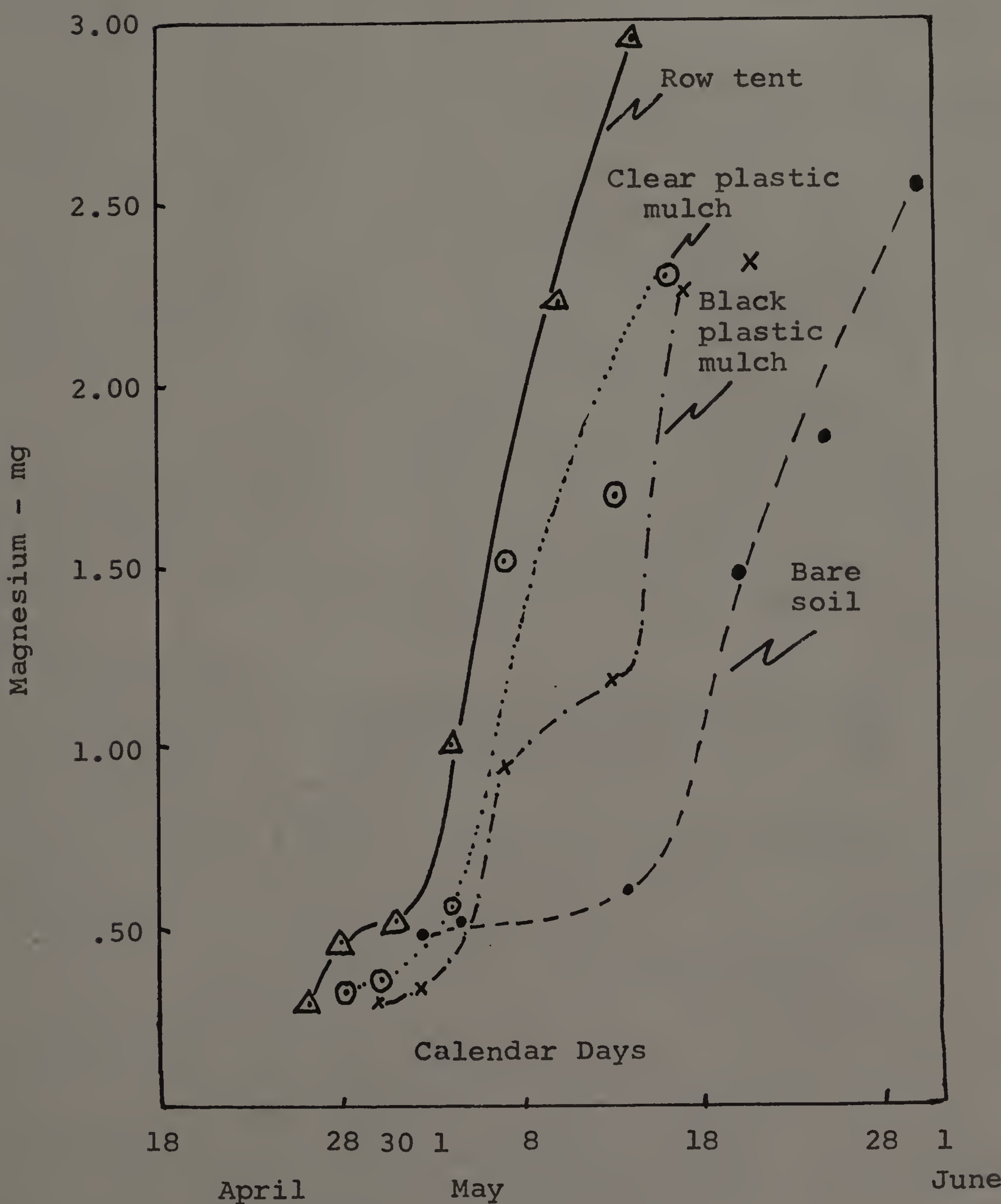
2/ Mean of six plants.

Table **25** - Effects of soil treatments on potassium content in the early stages of sweet corn (%)[1/]

Treatment	STAGES OF DEVELOPMENT Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	-	1.34	2.22	3.10	3.80	4.01	4.25
Black plastic	-	1.40	3.60	3.64	3.80	3.65	4.40
Clear plastic (C/P)	-	1.80	2.22	3.65	3.30	3.90	3.98
C/P off after 3-leaf	-	1.80	2.22	3.40	3.40	3.55	3.78
C/P on row tent	-	1.79	2.23	3.56	3.56	3.58	4.30
C/P on south slope	-	1.79	2.28	2.94	3.40	3.56	4.30
S. slope bare	-	1.57	2.73	2.80	3.64	4.00	4.56
Asphalt mulch	-	1.40	2.70	3.21	3.40	3.90	4.50
White wax mulch	-	1.56	2.12	3.00	3.25	4.07	4.51
C/P on at 2-leaf	-	1.34	2.22	3.96	3.10	4.48	4.74

1/See Appendix 1 for dates of sampling.

Figure 12. Effect of row tent and plastic mulches on rate of magnesium accumulation.



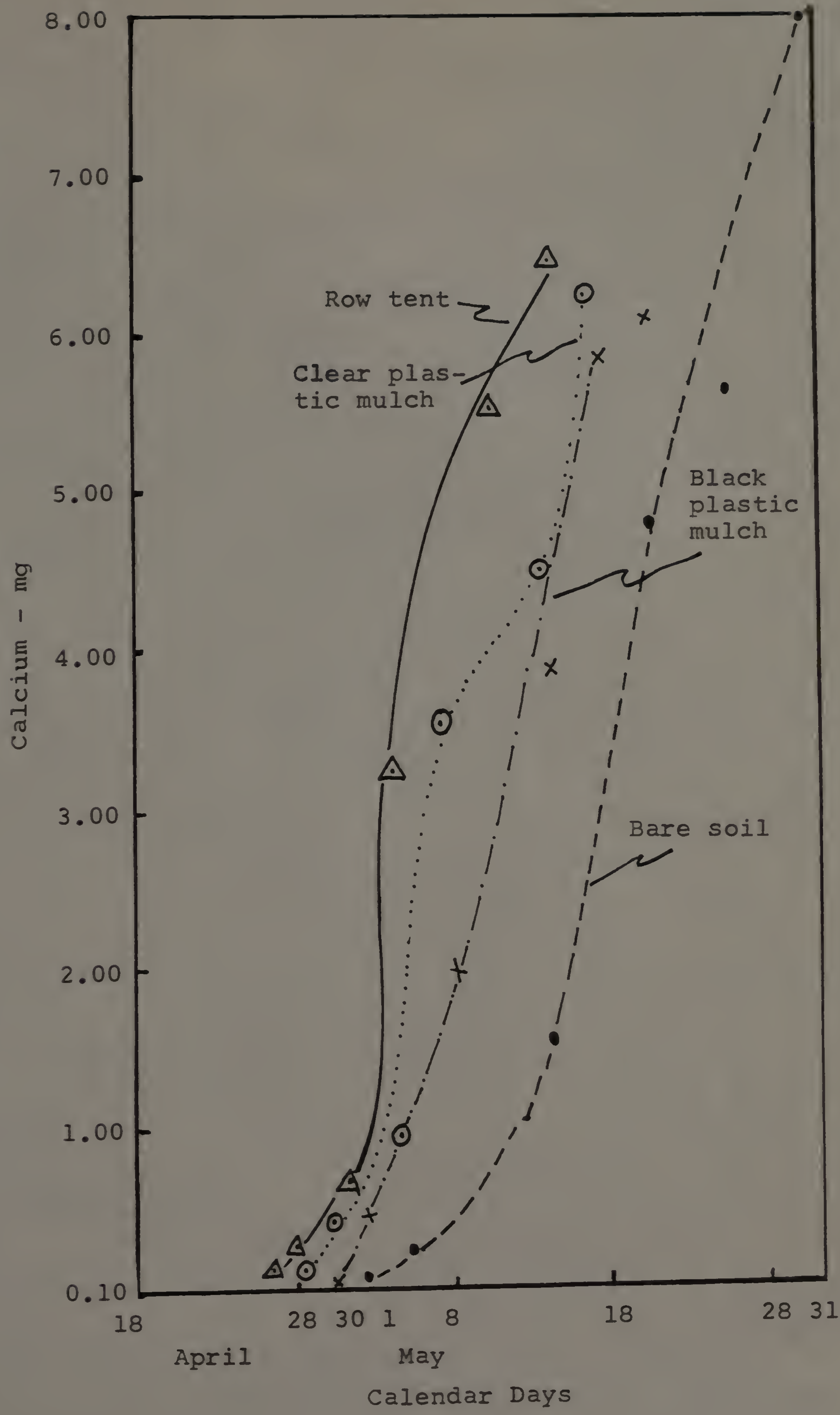


Figure 13. Effect of row tent and plastic mulch on rate of total calcium accumulation.

Table 26 - Effects of soil treatments on magnesium content in the early stages of sweet corn (%)[1/].

STAGES OF DEVELOPMENT

Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	-	0.322	0.301	0.290	0.278	0.255	0.250
Black plastic	-	0.296	0.218	0.294	0.219	0.252	0.248
Clear plastic (C/P)	-	0.350	0.232	0.245	0.286	0.203	0.220
C/P off after 3-leaf	-	0.350	0.232	0.263	0.213	0.213	0.271
C/P row tent	-	0.350	0.284	0.263	0.220	0.203	0.238
C/P on south Slope	-	0.350	0.266	0.248	0.219	0.209	0.230
South slope bare	-	0.290	0.286	0.320	-	-	0.230
Asphalt mulch	-	0.298	0.249	0.320	0.256	0.275	0.245
White wax mulch	-	0.90	0.287	0.305	0.244	0.274	0.256
C/P on 2-leaf	-	0.322	0.285	0.294	0.282	0.283	0.277

1/ See Appendix 1 for dates of sampling.

of growth, the dry weight of plants grown in different treatments were quite similar (Table 24) but at the five-leaf and six-leaf stages, plants with row tent and clear polyethylene mulch had accumulated more dry weight.

Chemical Content: In all treatments, the potassium content of plants increased with increasing plant development from emergence to the six-leaf stage (Table 25 and Fig. 11). The most rapid rate of potassium increase was in plants from the row tent treatment, followed by those from clear and black polyethylene flat mulch and those from bare soil (Fig. 11); but plants treated with clear polyethylene mulch after the two-leaf stage accumulated the most potassium at each stage of development up to the six-leaf stage (Table 25).

Magnesium accumulation increased most rapidly in plants from the row tent, clear and black polyethylene mulch, treatments and in plants from bare soil, after the three-leaf stage of development (Fig. 12). However, percent of magnesium in the tissues was highest at the one-leaf stage for all treatments and decreased with increase in stage of development and time (Table 26).

The calcium content in corn plants followed the same pattern as for Mg, but in this case there was no slow period in early development stages as in magnesium accumulation (Fig. 13). However, percent of calcium in the

Table 27 - Effects of soil treatment on calcium content in the early stages of sweet corn (%) 1/

STAGES OF DEVELOPMENT

Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	-	0.084	0.158	0.752	0.901	0.784	0.787
Black plastic	-	0.110	0.276	0.584	0.710	0.650	0.645
Clear plastic (C/P)	-	0.175	0.314	0.488	0.670	0.540	0.590
C/P off after 3-leaf	-	0.175	0.314	0.351	0.690	0.580	0.700
C/P on row tent	-	0.175	0.200	0.348	0.697	0.510	0.540
C/P on south slope	-	0.175	0.221	0.348	0.707	0.594	0.610
South slope bare	-	0.064	0.122	0.550	-	-	0.730
Asphalt mulch	-	0.123	0.239	0.690	0.640	0.860	0.760
White wax mulch	-	0.149	0.283	0.585	0.660	0.867	0.715
C/P on at 2-leaf	-	0.084	0.158	0.566	0.660	0.587	0.620

1/ See Appendix 1 for sampling dates.

Figure 14. Effect of plastic mulches and bare soil on rate of phosphorus accumulated in _Z. mays, L._

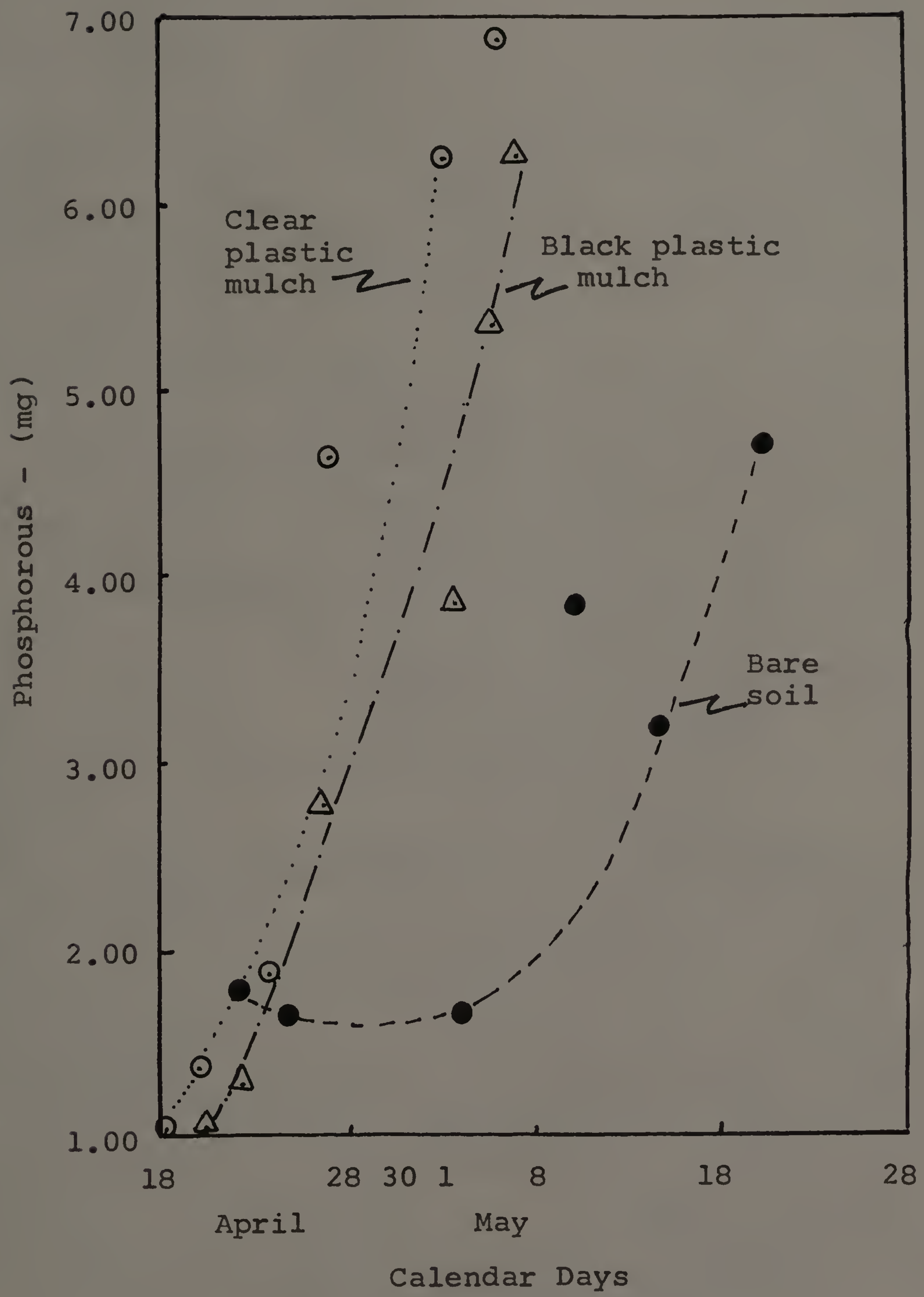


Table 28 - Effects of soil treatments on sweet corn phosphorous content in the early stages (%).1/

	STAGES OF DEVELOPMENT						
Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
Bare	-	1.18	0.90	0.78	0.72	0.44	0.46
Black plastic	-	1.01	0.92	0.86	0.70	0.69	0.48
Clear plastic (C/P)	-	1.00	0.84	0.84	0.88	0.75	0.65
C/P off after 3-leaf	-	1.00	0.84	0.66	-	0.66	0.62
C/P on row tent	-	1.00	0.80	0.67	-	0.70	0.63
C/P on south slope	-	1.00	1.07	1.01	-	0.81	0.68
South slope bare	-	1.08	0.90	0.99	0.76	-	0.57
Asphalt mulch	-	0.85	0.78	0.63	0.70	0.50	0.50
White wax mulch	-	0.92	0.83	0.50	0.60	0.65	0.48
C/P on at 2-leaf	-	1.18	0.90	0.84	0.55	0.42	0.49

1/ See Appendix 1 for sampling dates.

tissues increased with increase in the stage of development and with time (Table 27).

Phosphorous accumulation in corn plants was greatest for clear plastic and increased with time and stage of development; however, percent of phosphorous decreased (Fig. 14 and Table 28).

The foregoing data show that temperature related growth responses are measured more accurately by using both the criteria of lengths and weights. This agrees with work by Grobelaar (67) and Meyer et al. (116). The rate of increases in lengths of both shoots and roots (especially primary roots) reflected both the higher temperatures the last week of April and the lower temperatures the first half of May. Growth responses by weight did not show up these temperature changes. But the treatments with higher temperatures had greater rate of growth (by weight).

The high dry matter content (Table 24) in the unmulched treatments indicated reduced growth rate and accumulation of metabolites and other substances. These may include carbohydrates as suggested by Brouwer (27,28), phosphorous as reflected in mineral analyses, or other substances (138,139). It is clear that since, Ca, Mg, K and P content increased with time and development, these could not contribute to increased dry matter content in slow growing plants. However, the total accumulation of minerals (particularly K and Mg) seemed to be influenced by temperature. Any temperature response will be masked in growing tissue however this does not preclude large differences from showing up. In this experiment, however, all the plants were given an additional increment of N and P banded in the rooting zone; this may have further masked the effect of temperature on phosphorous accumulation "per se". Yet from the results, it can be concluded that there were increased uptake of K, Mg, Ca and P in treatments with higher soil temperature.

Davis and Lingle (47) proposed that soil temperature may affect the metabolic pathways concerned with growth; as a result there are more "building blocks" available than are used. This may partially explain the reason for larger ears in the treatments with lower soil temperatures. The changes that take place at floral initiation of corn plants occur much more slowly with cooler temperatures and should result in greater use of these raw materials.

GENERAL DISCUSSION

The micro-climate of the rooting zone can be altered by surface covers. During periods of low temperature when these covers increase temperatures in general, and soil temperature in particular, the rate of early growth and development of plants is increased. Present data indicate that the rate of early plant development (measured as leaf appearance) in the field can determine time of harvest.

Clear plastic covers increased soil temperatures about 8°C (14°F) more than opaque ones and up to 14°C (26°F) more than in bare soil, early in spring. Corn seedlings grew underneath clear plastic and the difficulty of determining seedling emergence (as in opaque covers) was avoided. Use of clear plastic row tent for sweet corn, maintained a micro-environment that promoted growth and protected seedlings, advanced time of harvest by two weeks, and produced higher yields through increased numbers of marketable ears. Because of ease of handling, relatively low cost, durability and resistance to rains, plastic films are more satisfactory than asphalt or white wax emulsion mulches.

The clear plastic mulch produced a highly favorable micro-climate for emerging seedlings. There was reduced soil surface crusting and less resistance to penetration. In the spring soil temperatures at the 5-10 cm depth under clear plastic increased more than 12°C (21.5°F) compared to temperatures in bare soil at the same depth. In late spring and summer soil temperatures may exceed the optimum temperature for corn growth (40,132).

The effect of plastic covers on improved rate of growth and development produced early in the sweet corn's growth cycle, is of interest and deserves further study. The present data indicate that clear plastic mulch may hasten maturity by two weeks as well as affect the number and the length of ears. A rapid initial growth period (as the row tent) or a fast-growing period up to the three-leaf stage followed by a slow growing period produced an increased number of ears, but these ears were shorter. In contrast a slow initial growing period followed by a rapid growing period from the two-leaf stage produced both increased number and length of ears. This indicates a critical development period between the two-leaf and four-leaf stages, although it was not noticed in microscopic studies nor in chemical analysis made at that period.

CONCLUSIONS

Clear plastic covers increased the rate of early growth and development of sweet corn, advanced harvest time by as much as two weeks as compared to bare soil and increased yields mainly through increased number of ears. Black plastic, white wax and asphalt mulches were not effective in promoting early development but produced relatively longer ears.

In early spring, air temperatures of over 40°C (105°F) were recorded under the row tent during the day; and (night) minimum air temperature at 7.30 a.m. remained above 10°C (50°F) (the critical temperature for growth). Soil temperatures at 5 and 10 cm. depth under clear plastic mulch and row tent were more than 12°C (21.5°F) greater than bare soil on afternoons while soil temperatures under black plastic mulches were only 2-3°C (3.5-5°F) greater than under bare soil. At 7.30 a.m., soil temperature 5 cm under the row tent was 5.5° to 9°C (10°-16°F) greater than for bare soil and effects of treatments in raising soil temperature for both 5 cm. and 10 cm. depths were in decreasing order: clear polyethylene on south slope, row tent, clear polyethylene flat, black polyethylene flat and bare soil.

Qualitative and quantitative responses associated with early development show the following trends:

a) rate of early development, early harvesting and plant height were linearly correlated with soil temperatures at both the 5 cm and 10 cm depths;

b) there was a high correlation between plant height and period to harvest ($r = 0.96$);

c) roots of sweet corn seedlings developing in the colder soils (about 10^{o}C) grew near the surface. Under the black plastic mulches there seemed to be another factor encouraging superficial root growth at late stages of corn growth;

d) plants growing in treatments with lower soil temperature were delayed in developing tassel and ear initials;

e) there is reduced development but increased per cent dry matter in treatments with lower soil temperature. Calcium, phosphorus, magnesium and potassium accumulated more rapidly at higher soil temperatures.

From these experiments it is, therefore, concluded that because clear plastic mulches can influence sweet corn's growth, development, and yields by increasing the soil temperature in the field, this is a feasible technique for use in the production of early sweet corn in New England.

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APPENDIX 1 - Sampling dates at stages of leaf development in corn, _Z. Mays, L._ Amherst, Mass. 1969.

Treatment	Emergence	1-leaf	2-leaf	3-leaf	4-leaf	5-leaf	6-leaf
	STAGES OF DEVELOPMENT						
Bare	4/30	5/2	5/5	5/14	5/20	5/25	5/30
Black plastic	4/29	4/30	5/2	5/7	5/14	5/17	5/21
Clear plastic (C/P)	4/27	4/28	4/30	5/4	5/7	5/13	5/16
No C/P after 3-leaf	(4/27)	(4/28)	(4/30)	(5/4)	5/7	5/15	5/23
C/P row tent	4/25	4/26	4/28	5/1	5/4	5/10	5/14
C/P on south slope	4/26	4/27	4/30	5/4	5/7	5/14	5/16
South slope bare	5/2	5/3	5/5	5/14	5/20	5/24	5/30
Asphalt mulch	4/30	5/1	5/4	5/12	5/17	5/22	5/29
White wax mulch	5/1	5/4	5/7	5/16	5/22	5/28	6/1
C/P on at 2-leaf	(4/30)	(5/2)	(5/5)	5/10	5/15	5/17	5/22

APPENDIX 2 - *Growing Degree Days at Amherst, April 16 - July 22 based on a 50°F Temperature for Growth.

Day	APRIL Mean Temp.	APRIL Degree Days	MAY Mean Temp.	MAY Degree Days	JUNE Mean Temp.	JUNE Degree Days	JULY Mean Temp.	JULY Degree Days
1			49.0	-	61.0	11.0	77.0	27.0
2			49.5	-	68.5	18.5	63.5	13.5
3			62.5	12.5	74.5	24.5	63.5	13.5
4			58.5	8.5	59.5	9.5	64.0	14.0
5			53.5	3.5	57.5	7.5	73.0	23.0
6			47.5	-	62.0	12.0	70.5	20.5
7			49.5	-	63.5	13.5	64.5	14.5
8			52.0	2.0	62.0	12.0	61.0	11.0
9			60.0	10.0	63.0	13.0	61.0	11.0
10			52.0	2.0	61.5	11.5	63.0	13.0
11			51.5	1.5	64.0	14.0	72.5	22.5
12			46.0	-	70.5	20.5	73.0	23.0
13			47.0	-	77.0	27.0	66.5	16.5
14			51.5	1.5	78.0	28.0	69.5	19.5
15			50.0		74.0	24.0	69.0	19.0
16	64.5	14.5	62.0	12.0	70.5	20.5	76.5	26.5
17	65.0	15.5	66.0	16.0	61.5	11.5	78.5	28.5
18	66.0	16.0	70.0	20.0	63.0	13.0	78.5	28.5
19	53.5	3.5	68.5	18.5	67.5	17.5	73.5	23.5
20	44.5	-	67.5	17.5	73.0	23.0	71.5	21.5
21	42.5	-	58.0	8.0	68.0	18.0	69.5	19.5
22	49.5	-	57.0	7.0	61.0	11.0	61.0	11.0
23	50.5	0.5	55.5	5.5	64.5	14.5		
24	45.5	-	58.0	8.0	64.5	14.5		
25	49.0	-	61.0	11.0	66.5	16.5		

APPENDIX 2 (CONTINUED)

26	52.5	2.5	57.5	7.5	65.5	15.5	
27	60.0	10.0	49.5	-	78.0	28.0	
28	66.5	16.5	58.5	8.5	80.5	30.5	
29	65.5	15.5	71.0	21.0	70.5	20.5	
30	56.0	6.0	73.0	23.0	72.5	22.5	
31	-	-	64.0	14.0	-	-	
TOTAL		100.5		239.0		523.5	409.5

Total Degree Days in bare soil 1272.5

*Record of climatological data: U.S. Dept. of Commerce, Environmental Science Services administration. Environmental Data Service, New England, 1969, Vol. 81:No. 4-7.

APPENDIX 3 - Showing precipitation at Amherst, Mass.
April 16 - July 2

DAY	APRIL	MAY	JUNE	JULY
1		-	-	0.03
2		-	-	-
3		-	T	-
4		-	-	-
5		-	-	0.18
6		-	T	-
7		0.02	0.35	-
8		0.04	-	-
9		0.49	0.02	-
10		0.01	-	-
11		0.34	-	-
12		-	-	0.12
13		0.01	-	0.25
14		0.08	T	0.22
15		-	0.41	-
16	0.21	-	1.62	-
17	0.03	-	-	-
18	-	-	-	-
19	0.70	0.03	0.01	0.02
20	-	0.65	0.01	-
21	-	0.37	0.51	0.10
22	0.62	-	-	0.12
23	0.75	-	0.51	0.01
24	0.21	T	0.08	-
25	-	-	T	-
26	-	0.41	-	-
27	-	-	-	T
28	-	-	-	0.41
29	0.12	0.01	-	2.96
30	-	0.27	-	2.33
31	-	-	-	0.14
TOTAL	3.93	2.73	3.52	6.89

Appendix 4 - Maximum and minimum air temperatures (°F) at Amherst, April 16- July 22, 1969[1/]

DAY	APRIL		MAY		JUNE		JULY	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	-	-	66	32	78	44	87	67
2	-	-	69	30	81	56	81	46
3	-	-	78	47	81	68	79	48
4	-	-	76	41	78	41	79	49
5	-	-	72	35	72	43	83	63
6	-	-	68	27	76	48	83	58
7	-	-	68	31	77	50	79	50
8	-	-	59	45	78	46	77	45
9	-	-	63	57	76	50	78	44
10	-	-	63	41	83	40	80	47
11	-	-	64	39	82	46	80	65
12	-	-	61	31	87	54	81	65
13	-	-	63	31	93	61	70	63
14	-	-	64	39	90	66	81	58
15	-	-	68	32	80	68	87	51
16	75	54	75	49	80	61	92	61
17	76	54	86	46	76	47	92	65
18	76	56	84	56	76	50	92	65
19	67	40	76	61	76	59	85	62
20	55	34	71	64	84	62	79	64
21	60	25	70	46	79	57	76	63
22	58	41	71	43	78	44	78	64
23	56	45	70	41	78	51	-	-
24	50	41	66	50	64	55	-	-
25	65	33	72	50	74	59	-	-
26	69	36	70	45	82	49	-	-
27	81	39	69	30	91	65		
28	82	51	75	42	92	69		
29	82	49	88	54	83	58		
30	68	44	88	58	87	58		
31	-	-	83	45	-	-		

1/Courtesy of U.S. Environmental Sciences Services report, 1969.