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SIMULATING MOISTURE STRESS AND SOUTHWESTERN CORN BORER EFFECTS ON CORN YIELDS

by

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B. S., KANSAS STATE UNIVERSITY, MANHATTAN, 1980

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

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ACKNOWLEDGEMENTS

I would like to thank my major professor Dr. R. L. Vanderlip for giving me the chance to work on this project.

I would also like to thank Dr. Fredie L. Poston and Stephen M. Welch for their hard work and research which made this project possible.

A special thanks is extended to Dr. Merle Witt and Dr. Mark Hooker for their help, guidance and friendship.

I would further like to thank Dan Baker, Julius Okonkwo, Allen Nelson, Mary Knapp, Ray Sweet, Dennis Calvin, Barbra Kuzmak and the many other individuals who worked hard to make this project a success.

I would like to express gratitude to my parents for their financial support and providing me with an education.

Finally I would like to express my deepest thanks to my wife, Lisa, for her patients, help, understanding and giving up so much while I pursued my education.

INTRODUCTION

Kansas is on the western edge of what would be commonly considered the corn belt. Two reasons Kansas is considered to be on the edge of the corn belt are the high temperatures during the growing season and lack of moisture needed for corn (Zea mays, L.) production. High temperatures and low moisture conditions limit the yield potential because of higher respiration, lower photosynthesis, lower seed set, and lower dry matter accumulation. Many of these problems can be overcome by irrigation but the cost of irrigating and a depleting water table are threatening to make corn production in these areas uneconomical. Another problem limiting corn production is insect damage. In the south central and southwestern parts of the state, infestations of southwestern corn borer have caused severe damage in corn fields.

Under the marginal conditions which exist in Kansas it would be of great benefit to be able to predict the damage that would occur becaue of a given level of moisture stress or southwestern corn borer infestation. Knowing the extent of the damage from a particular stress would allow for a cost-benifit analysis to be calculated to determine if the prevention of the stress would be economical. Much of this work is fairly straight forward and has been done in establishing the economic injury levels for a few insects.

Of particular interest, however, would be the effect of multiple stress factors or the effect of an infestation on a plant over a wide range of moisture conditions.

Determining the effects of multiple stress factors on plants is more complicated than determining the effects of a single stress factor because of the interactions that can take place. With the development of the computer and use of models which embody our knowledge of plants and insects, predicting the effects of multiple stresses on a plant has become easier. In understanding how a plant works and how different types of stress affect the plant, computer models reduce the complications of the interactions (Poston et al., 1983). Models then become very effective as tools to help farmers make decisions concerning control and management of stresses which reduce yields and result in economic losses.

One such model is CORNF (Stapper and Arkin, 1982), a corn growth and development model which collates the knowledge of corn phenology, corn growth and development, water use, soil water dynamics, and the effects of the environment on corn. This model allows flexability to predict yields under a wide range of populations, maturities, latitudes, and moisture conditions. At present it lacks the ability to predict the effects of an infestation of southwestern corn borer on corn yields. The purpose of this study was 1) to generate actual field data sets under a wide range of moisture conditions and infestation levels of southwestern corn borer, 2) to incorporate into CORNF the effects of southwestern corn borer on irrigated corn yields, and 3) to evaluate CORNF's ability to model irrigated corn yields under the field conditions found in the field.

REVIEW OF LITERATURE

Moisture Stress

Water plays a very important function in the plant. As a constituent of protoplasm, water makes up to 85% to 90% of the wet weight of actively growing plant parts. In photosynthesis, water combines with carbon dioxide to form carbohydrates and oxygen. It is also important in the plant as a solvent for moving gases and salts from cell to cell and within the plant. Probably the most important function of water is its use in maintaining the internal water balance of the plant and turgidity of the cells. Both the internal water balance and turgidity are closely related to rates of various physiological processes that take place within the plant (Kramer, 1959).

When water deficits occur within the plant, levels of intermediates change, photosynthetic electron transport is inhibited, stomatal closure occurs and respiration rates change (Boyer, 1970b). Along with these changes there is a slow down of growth, photosynthesis and translocation. When leaf water deficits occur in the plant they are accompanied by a closure of the stomata which reduces the CO_2 available for photosynthesis and reduces translocation (Boyer, 1970b; Kramer, 1959). Any stress which will reduce photosynthesis and translocation can also be expected to decrease total dry matter production (Boyer and McPherson, 1975). During the early vegatative period, the effect of moisture stress is to reduce growth and dry matter accumulation. Later in the season when grain fill is taking place, the effect of moisture stress is to reduce the photosynthetic activity of the leaf and reduce the amount of photosynthate translocated to the grain.

The stress a plant is under depends on the difference between the relative rates of water absorption and water loss which cause water deficits within the plant, not the supply of water in the soil (Kramer, 1959). The rate of water loss from a plant depends on plant factors such as leaf area, internal leaf structure, thickness of cutin, stomatal openings, and environmental factors such as solar radiation, humidity, temperature, and wind. Water absorption depends on the rate of water loss, efficiency of the root system, and the availability of soil moisture. In the field, absorption tends to lag transpiration and on a hot sunny day, midday water deficits can occur. The relationship between soil moisture and atmospheric conditions is shown most dramatically in a field on a hot, sunny day when the soil is at field capacity and the leaves show signs of stress resulting from deficits created by high atmospheric demands. At the other extreme would be a field low in soil moisture on a cool, cloudy, humid day in which the plant would show relatively few signs of stress because of a relatively low water deficit.

Denmead and Shaw (1962) used a more dynamic approach in describing the relationship between atmospheric conditions, soil water, and plant stress. Water is absorbed into the roots, transported through the plants vascular system, and out transpiring leaves because of gradients of diffusion pressure deficits in the plant. The gradient required to move the water from the soil into the plant is proportional to the transpiration rate and inversely proportional to the capillary conductivity of the soil. Higher gradients are required for higher transpiration rates and for drier soils. As the soil dries out large capillary suction gradients develop between the root and the soil caused by the decreasing capillary conductiveness of the soil. This increase in the gradient between the root and the soil requires an increase of the diffusion pressure deficit within the plant to move the water out of the soil and into the plant. As the diffusion pressure gradient increases within the plant there is a loss of turgor, stomata close, and transpiration decreases. At the point where the amount of water being transpired falls below the potential transpiration, or demand from the atmosphere, wilting occurs.

Denmead and Shaw (1962) go on to point out that the increase in potential transpiration or demand from the atmosphere can have as much of an affect on the pressure gradient within the plant as the lowering of soil moisture. In their work they found that the point at which wilting occurred, occurred at higher and higher soil moistures as the potential demand from the atmosphere increased. This study along with others (Boyer, 1973; Kramer, 1963) emphasizes the point that it is impossible to determine the stress a plant is under without knowing both the soil moisture conditions and atmospheric conditions.

There does seem to be some differentiation in plant responses to different levels of moisture stress. At relatively moderate levels of stress, leaf enlargement was inhibited more than photosynthesis (Boyer, 1970a). This was believed to be caused by a decrease in the leaf water potential causing a loss in turgor. At no time was growth observed in the absence of turgor. While photosynthesis was not affected as much as leaf expansion, photosynthesis was always decreased by water stress. At severe levels of moisture depletion, photosynthesis was more sensitive to stress than translocation (Jurgens et al., 1978). This was determined from data which showed that the grain weight accumulation was 2.7 times the amount of the dry matter produced during the grain fill period. They concluded that reserves accumulated earlier were mobilized during the stress period and moved to the ear indicating that translocation to the ear does continue. Similar results were found by McPherson and Boyer (1977).

In another study (Brevedan and Hodges, 1973), in which C_{14} was used to determine the rate of assimilation of photosynthate in the leaf and translocation of the photosynthate out of the leaf, translocation was found to be slowed more by moisture stress than was photosynthesis. Jurgens et al. (1978) believed that this may be because only enough photosynthate being produced to maintain leaf processes and left only a relatively small amount of photosynthate to be translocated. Possibly if the final grain weight and the amount of reserves translocated to the grain had been looked at, Brevedan and Hodges (1973) would have come to the same conclusion as Jurgens et al. (1978).

Along with the amount of water available in the soil and the atmospheric conditions, the stage of growth at which stress occurs is an important factor in determining and understanding the effects plant water deficits have on corn. Claassen and Shaw (1970a) found that the effects of moisture stress on the final dry matter yield of each component closely coincided with the initial or rapid growth phase of the respective period in which stress occurs. The development of corn can be divided into 5 distinctive stages: (1) planting to germination; (2) germination to growing point differentiation (GPD); (3) GPD to tasseling; (4) tasseling to silking; and (5) silking to maturity. Each stage has its own response to water stress and relation to final yield.

During stage 1 water is a basic requirement for germination. Water is imbibed by the seed which starts a series of processes which initiate germination. During stage 2 the apical meristem is differentiaiting into leaf and bud primordia (Hershey, 1934). Water deficits during this stage can reduce the photosynthetic capabilities of the plant later in the season.

Stage 3 is initiated by the differentiation of the apical meristem into the tassel. It is during this stage that almost all of the vegatative, tassel and ear shoot growth take place. Growth is particularly sensitive to water deficits because it is closely related to turgor, and loss of turgidity stops all cell elongation (Kramer, 1963). Denmead and Shaw (1960) found that water stess during this stage resulted in smaller plants by reducing stalk height, cob length, and leaf area. Claassen and Shaw (1970a) found that the stalk, leaf, and cob weights were also decreased. From a yield standpoint this stage is of importance because it is when pollen formation takes place and the maximum ovules of kernels per ear are set. Water stress during this time has been found to decrease the number of kernels per ear (Moss and Downey, 1971). The decrease in kernel number was correlated with the formation of a high number of abnormal embryosacs which developed under the stress conditions.

Stage 4 covers the period from tasseling to fertilization. During this stage pollen is shed, silks emerge, and fertilization occurs. This period is generally very short but of great importance due to the occurrance of seed set (Shaw and Thom, 1951). Yields are decreased most by stress during this stage (Barnes and Wooly, 1969; Claassen and Shaw, 1970b; Du Plessis and Dijkhuis, 1967; Kisselbach, 1922; Lonnquist and Jugenhimer, 1943). Benoit et al. (1964) found that yields were decreased as the average air temperature increased over the ear formation period. This decrease of yields may be related more to temperatures during pollenation and fertiliztion than to the whole ear formation period. In another study, Herrero and Johnson (1980), found that as the temperatures increased and percent pollen germination decreased, nonviable and nongerminated pollen increased. Lonnquist and Jugenheimer (1943) found that as temperatures increased seed set decreased. This was believed to be caused, primarily, to the rapid desiccation of pollen and silks under the stress conditions.

Much of the water stess and phenology literature (Barnes and Wooly, 1969; Claassen and Shaw, 1970a; Du Plessis and Dijkhuis, 1967; Kiesselbach, 1922; Lonnquist and Jugenhimer, 1943) showed that water stress at silking delayed the emergence of silks. Classen and Shaw (1970b) related this delay to the low relative turgidty at the ear. Relative turgidity was found to decrease from the top of the plant to the base of the plant. The relatively high levels of turgidity at the top of the plant would allow the tassel to develop normally while the lack of turgidity at the ear would slow silk growth and emergence. This delay period was found to be as long as 28 days (Du Plessis and Dijkhuis, 1967). In the most severe cases, pollen is shed before the silks emerged and fertilization does not occur. Shorter delays are not considered to be a problem because of the extension of the pollenation period resulting from variability in plants and the large amount of pollen shed per plant (Kiesselbach, 1922). Along with delays of silking, Lonnquist and Jugenheimer (1943) found that stress at this time reduced the amount of viable pollen and caused the silks to desiccate, reducing seed set.

Stage 5, or the grain fill period, is when kernel development takes places. This stage can be broken down into two phases. During the first phase kernel development is dominated mostly by cell division and enlargement of the embryo. Very little translocation of photosynthate to the ear is taking place at this time (Shaw and Loomis, 1950). During this stage water stress can have the affect of reducing kernel numbers by causing the abortion of fertilized kernels. After this first period is completed, kernel number is set and further stress will only affect the amount of photosynthate translocated to the ear. Therefore water stress during the second phase will only result in decreases of kernel weight (Brevedan and Hodges, 1973; Jurgens et al., 1978; Claassen and Shaw, 1970b).

Southwestern Corn Borer

The southwestern corn borer, (SWCB, *Diatreaea grandiosella* Dyar), is found throughout Texas, Oklahoma, Kansas, Arkansas, and Missiouri and farther east (Henderson et al., 1966). The borer causes damage by eating holes in the leaves of the whorl, making tunnels in the stalk, and girdling the base of the stalk (Scott and Davis, 1974). There are generally two generations of southwestern corn borer in Kansas. Infestations of the first generation borers generally occur during the young vegetative stages of corn development. Borer damage at this time occurs mostly caused by leaf feeding in the whorl and can result in deformed, stunted, and unproductive plants (Henderson and Douglas, 1967). Scott and Davis (1974) found yield losses as high as 20% caused by first generation southwestern corn borer infestations. The second generation infestations usually occur during the grain filling period. Damage from second generation infestations usually results from tunneling and girdling of the stalk. Yield reductions caused by second generation southwestern corn borer infestations have been reported to reduce yield as much as 25% when they occurred early in the grain fill period (Whitworth, 1980).

Whitworth (1980) studied the feeding behavior of southwestern corn borer in corn. It was found that the average southwestern corn borer larva tunneled 20.37 cm. Approximately 5% of the tunneling was completed during the 3rd-larval instar, 36% of the tunneling during the 4th-larval instar, and 64% during the 5th-larval instar. Yield reductions from tunneling were also found for infestations occurring during different growth stages of corn. Infestations during 12th-leaf, silking, blister, dough, and dent, had yields significantly different from the control. Yield reductions were found to be as high as 36% at the 12th-leaf stage and 14% at dent. Feeding curves were developed which could be used to predict the amount of tunneling as a function of south western corn borer thermal units.

These feeding curves were adapted to corn thermal units and used to predict the percent reduction in yields as a function of the thermal units left in the season (Whitworth, 1980, Figure A1). Using the equation: yield reduction=0.146+0.000016X, where X equals the number of TUCM's (thermal unit centemeters, corn thermal units times 20 cm, the average tunnel length/larvae) left in the season, yield reductions could be predicted as a function of the duration of the damage.

Yield reductions resulting from southwestern corn borer infestations are thought to be caused by the destruction of vascular bundles (Whithworth, 1980). There may be some physiological basis for this hypothesis. In a study done by

Boyer (1971), it was found that after severe moisture stress in sunflowers, turgor and photosynthesis did not return to normal levels when the stress was relieved. This was believed to be caused by a higher resistance in the plant pathway for water transpiration after desiccation because of the breaking of water columns within the vascular tissue. Because of the permanent destruction of vascular bundles caused by tunneling in the stalk, which would reduce the number of water columns, reductions in turgor and photosynthesis might also be expected to occur with infestations of southwestern corn borer.

CORNF

Several physiologically based models have been developed in the last several years to simulate the yield and development of corn (Curry and Chen, 1971; Childs et al., 1977; Duncan, 1975; Stapper and Arkin ,1980). CORNF (Stapper and Arkin, 1980) is a maize growth simulation model which models corn growth and development based on physiological, phenological, and physical principles. CORNF uses the inputs of potential depth of the root zone, potential plant extractable moisture, initial plant extractable moisture, upper limit of stage 1 cumulative evaporation, planting date, planting depth, population, maturity, leaf area of first leaf and latitude to describe the initial environment of a single plant. The daily inputs of maximum and minimum termperatures, solar radiation, and rain are used to drive eight dynamic subroutines (Figure A2) which simulate stage of development, leaf development, dry matter production, grain production, partitioning of dry matter, evaporation and water balance in the soil profile.

Accumulated daily heat units or growing degree days is the controlling parameter of the model. Growing degree days are used to determine leaf appearance, grain fill rate, root growth, and stage of development. Development and growth are separated in the model to account for response differences to the environment.

In the leaf subroutine, leaf ligule appearance, leaf size, leaf senescence, and daily leaf area index are determined. The total number of leaves a plant develops is determined as a function of the maturity class, and the average day length during the period from emergence to tassel inititiation. With an increase in maturity class or average day length between emergence and tassel initiation over 13.5 hours, leaf numbers are increased. Up until tassel initiation leaves appear at a constant rate. After tassel initiation, leaf appearance is accelerated. Leaf size is calculated by a series of equations which relate the size of a leaf to the size of the leaf that preceeded it and stage of development in which the leaf appears.

Soil water balance is modeled in a dynamic subroutine in which the initial soil moisture conditions are input.

Available soil moisture is then limited by the rooting depth and the amount of water at the depth of the roots. The actual evapotranspiration taking place on any given day is calculated with a model developed by Ritchie (1972). In this subroutine soil moisture index is calculated and used to determine water stress.

CORNF is of particular use in this study because it is designed to be sensitive to moisture stress. Moisture stress is implemented in the model by calculating a water stress coefficent, WATCO, between 0.0 and 1.0 based on the soil moisture index (actual available soil water/maximum amount possible) on any given day. This factor is then used multiplicatively in CORNF to reduce daily dry matter production, root growth, potential evaporation, and kernel number. For dry matter production no moisture stress occurs in the model for soil moisture indexes above 0.4. For soil moisture indexes below 0.4, WATCO is less than 1.0 and when multiplied by the daily dry matter production it reduces dry matter production by a percentage equal to the value of WATCO.

CORNF models grain production by modeling the source-sink relationship between dry matter production and ear demands. Dry matter production is calculated as a function of solar radiation, leaf area, land area per plant and water stress. During the grain fill period all dry matter production is partitioned to either grain or reserves. If daily dry matter production exceeds the ear demand for daily grain production, the extra dry matter is put into reserves. The reserves are then used later when dry matter production does not meet ear demands.

Ear demands are set by kernel number. The greater the number of kernels, the greater the demand. Kernel number is calculated as a function of total dry matter at anthesis. The larger the plant at anthesis the larger the ear and kernel number will be. Kernel number can be reduced by a reduction factor which reduces kernel number caused by stress during the rapid ear development phase.

MATERIAL AND METHODS

Experiments were conducted at the Garden City Branch Experiment Station, Garden City, Kansas during 1979, 1980, and 1981. Corn (Funk's variety 4507) was hand planted in 76.2 cm wide rows at 59,000 plants/ha. Each plot was fourteen rows by 13.7 meters long. Plots were planted on 18 May 1979, 17 May 1980, and 19 May 1981.

A split-plot experimental design of 3 replicates with 9 main plots and four subplots/main plot was used. Main plots consisted of three levels of moisture stress: (1) 0-20% avaialable soil moisture depletion; (2) 45-55% available soil moisture depletion; and (3) 65-75% available soil moisture depletion applied at three growth stages: (1) anthesis; (2) blister and; (3) dent (Hanway, 1971). The nine main treatments were (1) 0-20% soil moisture depletion at silking, (2) 45-55% soil moisture depletion at silking, (3) 65-75% soil moisture deplepletion at silking, (4) 0-20% soil moisture depletion at blister, (5) 45-55% soil moisture depletion at blister, (6) 65-75% soil moisture depletion at blister (7) 0-20% soil moisture depletion at dent (8) 45-55% soil moisture depletion at dent and (9) 65-75% soil moisture depletion at dent. Subplots consisted of selected SWCB infestion levels. In 1979, 4 levels of SWCB infestations were used (0, 10, 20, 30, eggs/plant). In 1980 SWCB damage was simulated by drilling 0, 1, 2 and 3 holes per plant. In

1981, natural infestations were used.

All treatments were maintained at 0-20% soil moisture depletion throughout the growing season except during the stage at which stress was induced and the dry down period preceeding it. Each plot was watered weekly as needed to bring the soil moisture level to field capacity except during the stressed stages. Water was metered to each plot through a gravity flow irrigation system. A border was built around each plot to maintain the individual moisture treatments. An evapotranspiration model (Rosenthal et al., 1977) was used to schedule when the weekly irrigations should be stopped in order to reach a desired level of moisture depletion by a given stage. A neutron access tube was placed in the center of each plot and neutron probe readings were taken weekly to determine the level of soil moisture in the soil profile and update the evapotranspiration model.

Weekly dry matter measurements were taken for all treatments by destructively sampling from the border rows of each treatment. Four plants/replicate were sampled from the nonstressed plots to determine the control dry weights. Unless stress had been applied to a given treatment it was assumed that it was not significantly different from the control and samples were not taken. For stressed plots, 2 plants/replicate were sampled beginning the week before stress was induced.

Leaf area measurements were taken by flagging one plant in each plot. For each plant maximum leaf size was recorded along with weekly recordings of the number of the first and last leaf with collar visable. Leaf area was calculated by summing over all the fully expanded leaves and adding either (1) 70% and 30% of the maximum leaf area for the first two leaves in the whorl that are not fully expanded for dates before ear initiation or (2) 75%, 50%, and 25% of the maximum leaf area for the first three leaves respectively in the whorl that are not fully expanded for all dates after ear initiation (Stapper and Arkin, 1980).

CORNF (Stapper and Arkin, 1980) was used to model dry matter production, leaf development, and yield components for the 1979, 1980, 1981 growing seasons. Daily maximum and minimum temperature, solar radiation and rain fall data were obtained from the Garden City Experiment Station. Parameters used to describe the soil were 0.4 for the soil temperature coefficient and 1.13 cm for the upper limit of cumulative evaporation from the soil during stage 1 drying. The maximum available soil water input was 33.4 cm in 167 cm of soil as determined by taking the difference in available water of the soil at field capacity and 15 atmospheres. Plant inputs used were 4 cm for the size of the first leaf, 7 for the maturity class, and the population determined at harvest.

Two changes in the original model were made. The first change was the addition of code which would adjust yields to account for the effects of southwestern corn borer infestations on the plant. The purpose of this code was to decrease yields due to second generation southwestern corn borer infestations which usually occur during grain fill. Additional harvest losses may occur in the field due to lodged plants but these were not modeled.

Because CORNF only models the growth and development of a single plant and multiplies the result times population to get the yield for an area, both the yields for an infested plant and a noninfested plant had to be generated separately. The model yield for any given plot was then calculated by using the equation YIELD=Y*(1-I)+IY*I where Y equals the yield of a noninfested plant, IY equals the yield of an infested plant, and I equals the percent of infested plants actually found in the plot.

The changes made in CORNF to adjust yields for southwestern corn borer infestations were based on results found by Whitworth (1980). He determined that the percent yield reductions resulting from a southwestern corn borer infestation occurring before dent could be calculated by the equation

$$\text{percent yield reduction} = 0.146 + 0.000016X$$

where X equals the thermal unit centimeters left in the season after 5th instar is reached. The infested yield was found by reducing the nonifested yield by the percent yield reduction.

Percent yield reductions used to obtain the infested yields were calculated based on the thermal unit centimeters left in the season after the borer reached the 5th larval instar. The beginning of the fifth instar was calculated by obtaining peak flight time for the moths, adding 3 days to get to peak egg laying time, and accumulating sufficient heat units for the larvae to develop to 5th instar (Whitworth and Poston, 1979). The corn thermal units left in the season were then calculated from the date of the beginning of 5th instar to maturity and multiplied by 20 cm to calculate the thermal unit centimeters. The dates on which 5th instar was predicted to begin were 1 September 1979, 23 August 1980, and 27 August 1981.

It was believed that under water stressed conditions, the high yield reductions which occurred in Whitworth's study would not be found. To adjust for this factor the percent yield reduction was adjusted proportionally using the equation

adjusted yield reduction=YR/12,313*Y

where YR is the unadjusted yield reduction, Y is the average yield (kg/ha) of the control plots in any given year and 12,313 is the average control yield (kg/ha) in Whitworth's study. Using this method, the reductions used to calculate the yields of infested plots were 23.3% for 1979, 15.3% for 1980, and 27.3% for 1981.

The second change in CORNF was to change the way water stress is calculated. In the model, the water stress coefficient, WATCO, is calculated as a function of soil moisture. Much of the water stress research has shown that soil moisture has only an indirect effect on the plant and to accurately measure plant water stress it is important to consider not only the available soil moisture but also atmospheric conditions. To take the atmospheric conditions into account, CORNF was altered so that WATCO was calculated as a function of the available soil moisture (SMI) and the potential evaporation occurring on any given day (EO).

The relationship between EO, SMI, and WATCO used (Figure A3) was adapted from research done by Denmead and Shaw (1962) in which they showed the relationship between relative transpiration (actual transpiration/potential transpiration) and soil moisture content at several different potential transpiration rates. As relative transpiration fell below 1, deficit gradients were thought to become large enough in the plant to cause wilting. It is the variable relative transpiration that is used to measure water stress in the plant and is set equal to the water stress coefficient WATCO.

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FIELD RESULTS

The 1979 season was relatively cool. During the first month after planting, julian dates 135 to 165, the average daily temperature ranged between 12 to 22 C (Figure 1). During the rest of the vegetative period, anthesis, and early grain fill the temperatures averaged 26 C. For the latter part of the grain fill period, temperatures dropped off. 1979 was also a relatively dry year with the exception of two large rains at silking and dent.

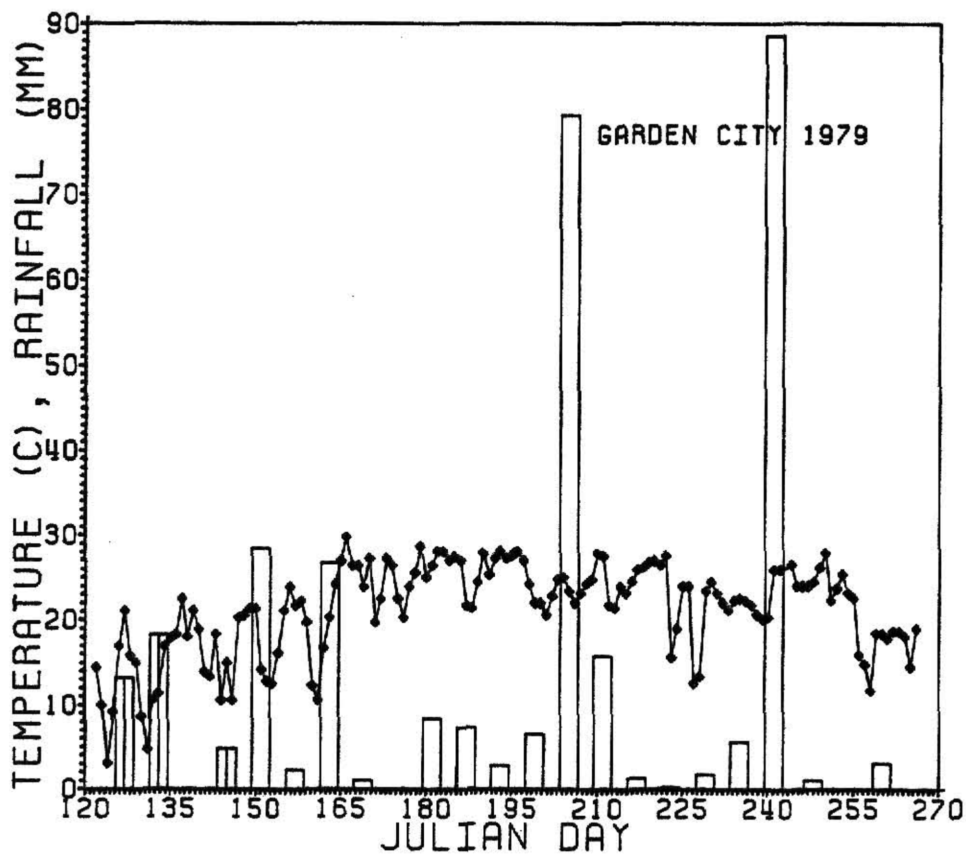


Figure 1. Daily average temperatures (line) and rainfall (bars), 1979.

Even though 1979 was a relative dry year, target depletions were not reached because of low drying conditions and large rains at silking and dent. All plots in 1979 were put into one of three treatments (Figure 2). In trying to keep with the original treatment classifications as much as possible, the three treatments observed were: treatment 1, no depletion; treatment 2, a 28 day period prior to and during silking at 34-36% depletion; and treatment 5, a depletion period occurring during grain fill. Because actual depletion measurements were not taken after julian date 232, treatment 5 can only be assumed to be different from the other two treatments. Since all plots in treatments 3, 4, 6, 7, 8, and 9 were not considered to be different from treatment 1, they were analyzed as such.

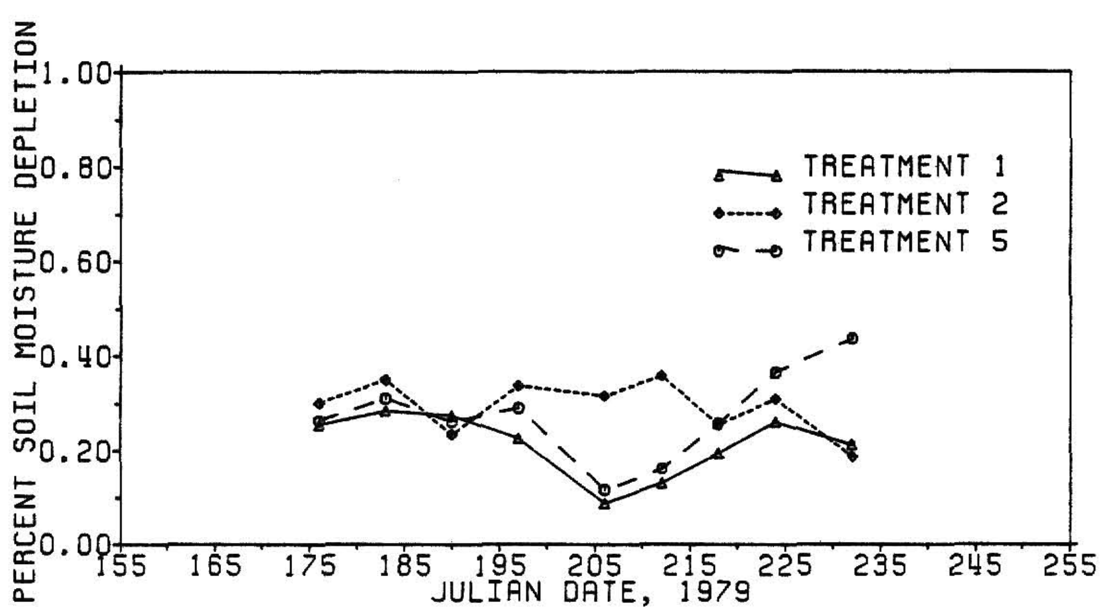


Figure 2. Percent soil moisture depletion for soil moisture treatments, 1979.

Yields were analyzed for the three moisture depletion treatments (Table 1, Table A1) and no significant differences were found. These results would be expected with the relatively mild conditions which existed during the 1979 growing season and the small difference between depletion levels.

Table 1. Actual yields for moisture depletion treatments, 1979.

Treatment	Yield, kg/ha
1	10,320
2	10,755
5	9,236
LSD (.05)	N.S.

The analysis of yields between infestation levels of 0, 10, 20, and 30 eggs/plant, showed no significant differences. There were significant differences found, however, between infested and noninfested plants. When all plants were analyzed as either being infested or noninfested across all infestation levels (Table 2, Table A1), a significant reduction of 15% in yields was found for the infested plants. The lack of significant difference between the infestation levels of 0, 10, 20, and 30 eggs/plant levels was probably resulted from natural infestations occurring within the control rows and the field in general.

Table 2. Actual yields by infestation treatment, 1979.

Infestation Level	Yield kg/ha
Noninfested	11,304
Infested	9,590
LSD (.05)	398

There were no significant differences found for LAI between moisture depletion treatments. There was a significant interaction between date and depletion treatments (Figure 3, Table A2). There were no significant differences in the early part of the season, but there were significant differences later in the season. The significant difference between the leaf area index of treatment 5 and treatment 1 or 2 would not be expected at this time based on depletion levels.

Total dry matter measurements were taken for each replicate during the 1979 season (Table 3, Table A3). No dry matter measurements were taken for the individual treatments.

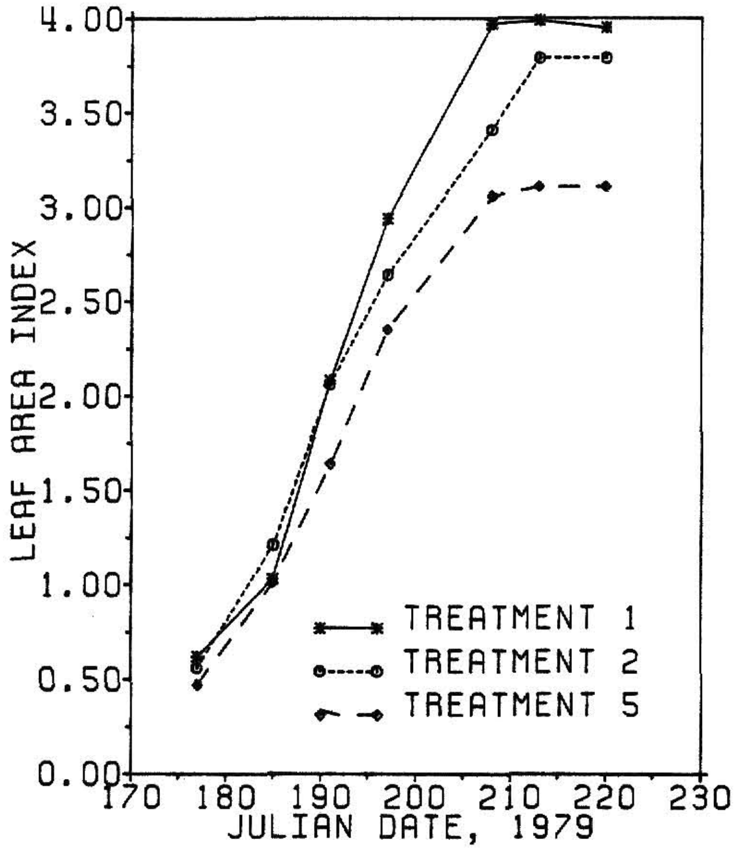


Figure 3. Actual LAI by date for soil moisture depletion treatments, 1979.

Table 3. Actual total dry matter production by date for 1979.

Julian Date	Total Dry Matter, g/plant
180	18
187	39
197	91
206	146
213	180
220	221
227	250
242	312
LSD (.05)	50

The 1980 season was a relatively hot, dry year. While the early part of the season was cool and wet, the last half of the vegetative period, anthesis and early grain fill was relatively hot and dry (Figure 4) with average daily temperatures as high as 31 C. The last half of the grain fill period was cool and wet.

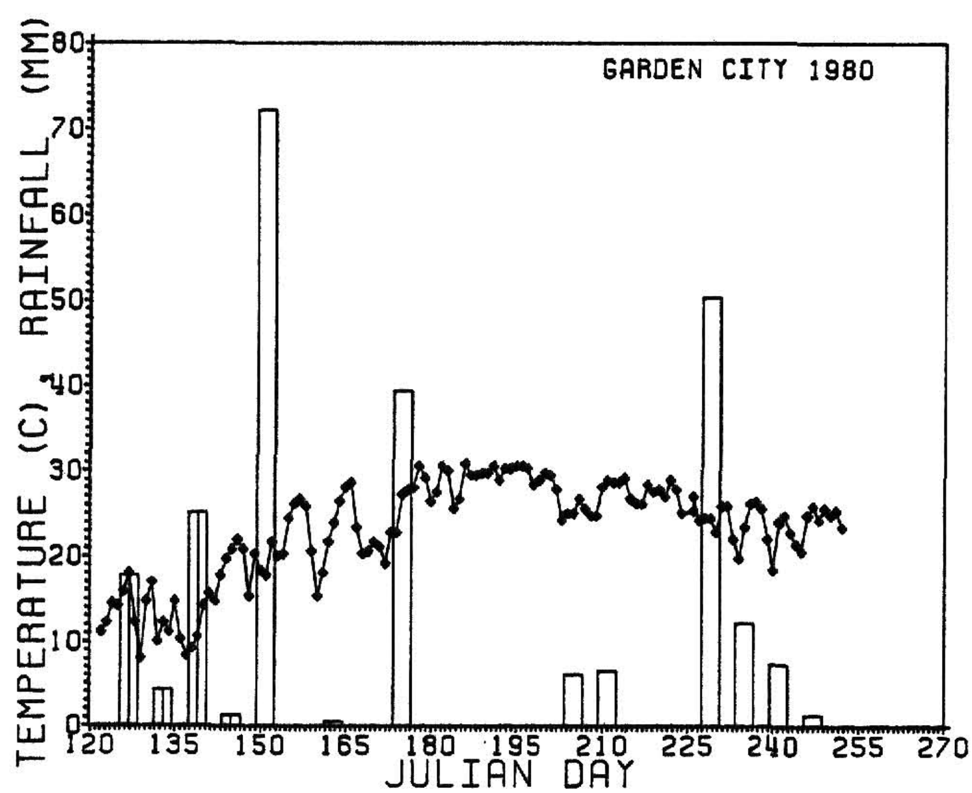


Figure 4. Daily average temperatures (line) and rainfall (bars), 1980.

Five moisture depletion treatments were observed in 1980 (Figure 5). The five treatments shown are: treatment 1, no moisture depletion at any stage; treatment 2, the medium stress treatment at silking which was depleted to 52% over a two week period ending after silking; treatment 3, the high stress treatment at silking which was depleted to 59% over a three week period ending after silking; treatment 5, the medium depletion treatment at blister which was depleted to 48% over a 21 day period; and treatment 6, the high stress treatment at blister which was depleted to

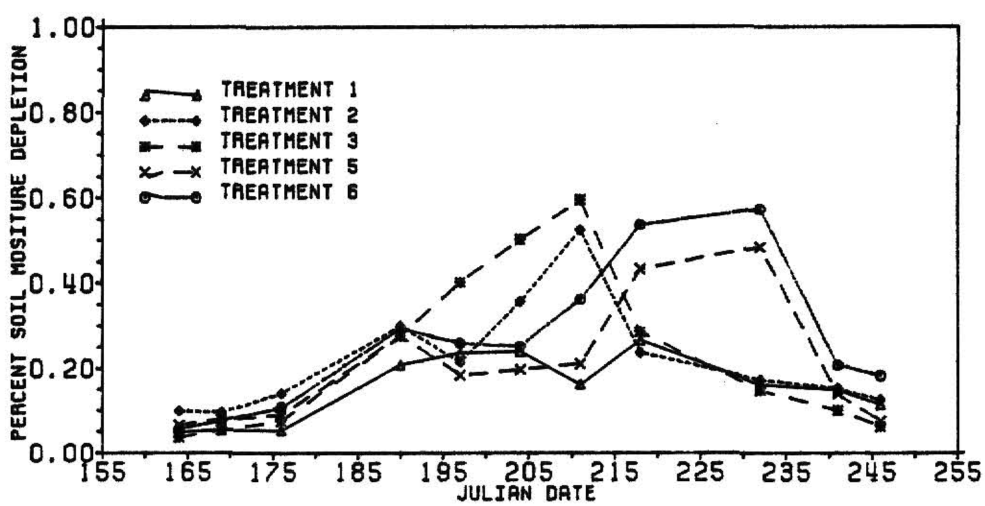


Figure 5. Percent depletion for soil moisture treatments, 1980.

57% over a 28 day period. Treatments 4 and 7, which were designated as no depletion treatments at blister and dent respectively, were not considered to be different from the no depletion treatment, treatment 1, and were analyzed as such. Because of low drying conditions and late season rains, treatments 8 and 9, the stress treatments at dent were not different from treatment 1 and were also analyzed with treatment 1.

Results for the moisture depletion treatments during 1980 are shown in Table 4 (Table A4). The yield for the no moisture depletion treatment, was 6,171 kg/ha. For the two depletion treatments during silking, the medium depletion treatment had a yield reduction of 21%, and the high depletion treatment at silking had a yield reduction of 48%. Only the high depletion treatment was significantly lower than the no depletion treatment.

Reductions in yield of the moisture depletion treatments during silking can be related mostly to reductions in kernel number and, to a lesser extent, barreness. Both the medium and high moisture depletion treatments had a kernel number significantly lower than the no depletion treatment. For the medium depletion treatment, kernel number was reduced 19%, and the kernel number for the high depletion treatment at silking was reduced 34%. While the 14% barrenness for the medium depletion treatment was not significantly different from the no depletion treatment, the 18% barrenness for the high depletion treatment was significantly different.

Table 4. Actual yields, ear weights, kernel numbers, seed weights, and barrenness for moisture depletion treatments, 1980.

Treatment	Yield (kg/ha)	Ear Weight, (g)	Kernel Number	Seed Weight (g/100)	Barrenness (%)
1	6,171 a	139.5 a	491 a	23.09 a	11 a
2	4,877 ab	115.9 b	401 bc	25.20 b	14 ab
3	3,188 c	90.3 c	326 c	24.47 b	18 b
5	5,255 ab	121.7 b	437 ab	24.29 b	13 ab
6	4,367 bc	125.2 ab	434 ab	25.16 b	31 c

Looking at the two depletion treatments after silking (treatments 5 and 6), the medium depletion treatment at blister had a yield reduction of 15%, and the high depletion treatment at blister had a yield reduction of 29%. Only the high depletion treatment yield was significantly lower than the no moisture depletion treatment. The yield reduction in the high moisture depletion treatment was caused mostly by an increase in barrenness and a decrease in kernel number. The 13% reduction in kernel number for the high moisture depletion treatment was not significantly different from the no moisture depletion treatment, but the 180% increase in barrenness was. Since the ear weight for the high depletion treatment was not significantly different from the no moisture depletion treatment, the decrease in yield would appear to be a result of barrenness and the lack of ears, not the lack of photosynthate production.

All of the soil moisture treatments in 1980 had seed weights 5% to 9% higher then the control. Only the medium depletion at silking and the high depletion at blister were significantly higher then the control. These data would indicate that yield reductions were caused by stress occurring during the ear development phase and anthesis which resulted in reduced kernel numbers and increased barrenness. The lack of decrease in seed weight would indicate that there was little difference in stress across all treatments during the period when photosynthate was being translocated to the grain.

During 1980, southwestern corn borer infestations were simulated by drilling tunnels in the stalk. No significant differences in yields were found between simulated infestation treatments (Table A4). The lack of difference could result from several factors. The first would be that the plants photosynthetic capabilities were severely limited by the early moisture stress and that the possible reduction in water and nutrient movement up the stalk caused by the tunnel simulation would have little effect on yields. Second would be that the plant was able to move the water and nutrients around the damaged vascular bundles so that photoshnthesis and translocation would not be effected. The third was that natural populations of southwestern corn borers were present in the field eliminating a noninfested check row.

LAI's for 1980 were found to be significantly different between dates only (Table A5). There were trends that developed for moisture depletion treatments (Figure 6), but were not significant. LAI's tend to be depressed by the high depletion treatment during silking. This would be expected of stress treatments which occurred during the vegetative development period. LAI in the medium depletion treatment during silking did not appear to be appreciably reduced until after the stress had been relieved. The high

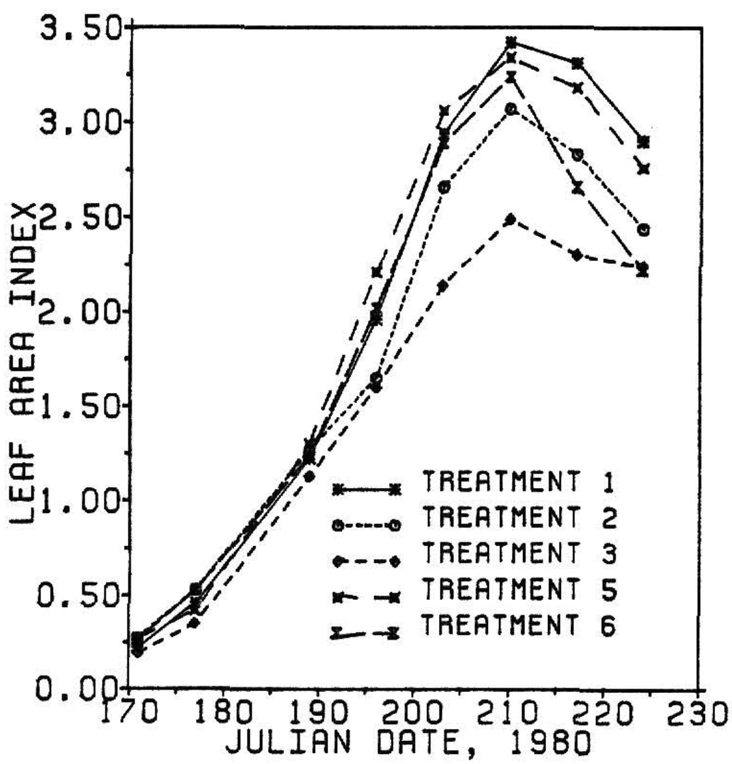


Figure 6. Actual LAI for moisture depletion treatments, 1980.

depletion treatment during blister appears to show a sharp decline in leaf area after julian date 204. This decline could have been caused by the early dropping of leaves caused by stress. Another possibility is that the sharp decline is in response to a mite infestation which reduced leaf area of all plots during this time, especially the stressed treatments.

No significant differences were found between moisture depletion treatments for total total dry matter production during 1980 (Table A6). While differences could be expected, none were found because of the high variation between sampling dates within each of the treatments. Total dry matter production was found to be significantly different between sampling dates (Table 5) as would be expected.

Table 5. Actual total dry matter production by date, 1980.

Julian Date	Total Dry Matter, g.
171	7
177	17
198	95
205	130
212	174
219	196
226	224
233	269
240	263
248	313
LSD (.05)	12

1981 was the wettest of the three years. Rains were abundant and frequent throughout most of the season (Figure 7). Because of the rains and low evaporative conditions throughout most of the growing season, only 3 depletion treatments were attained (Figure 8): treatment 1, a no depletion treatment; treatment 2, a medium depletion treatment at silking ;and treatment 5, a medium depletion treatment during grain fill.

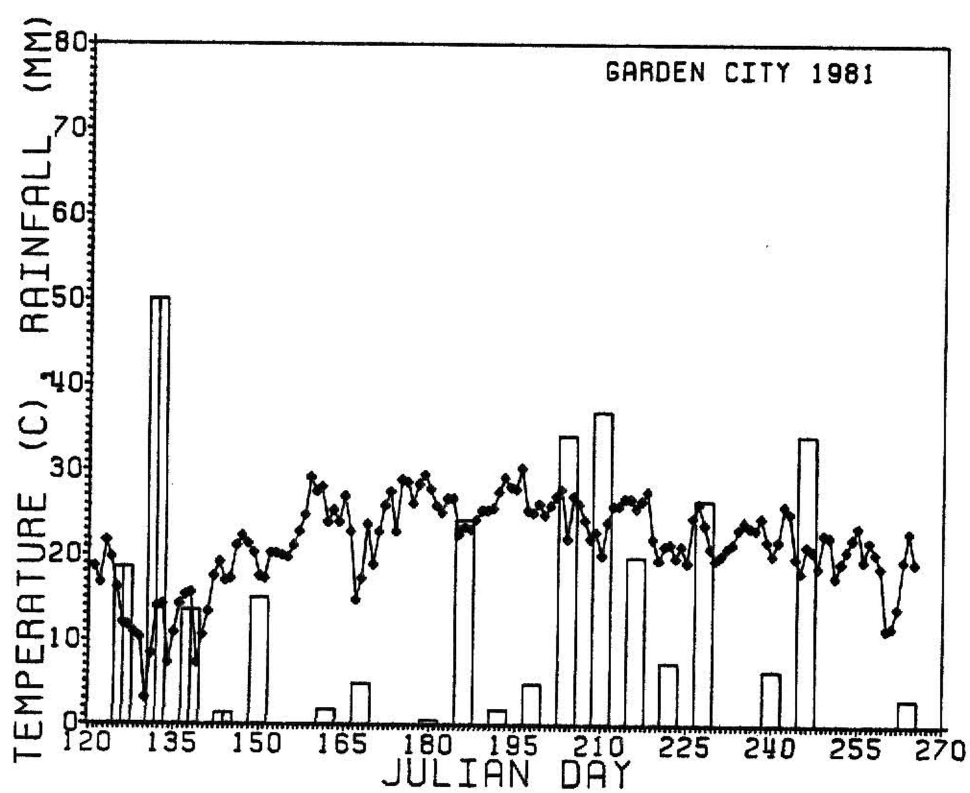


Figure 7. Daily average temperatures (line) and rainfall (bars), 1981.

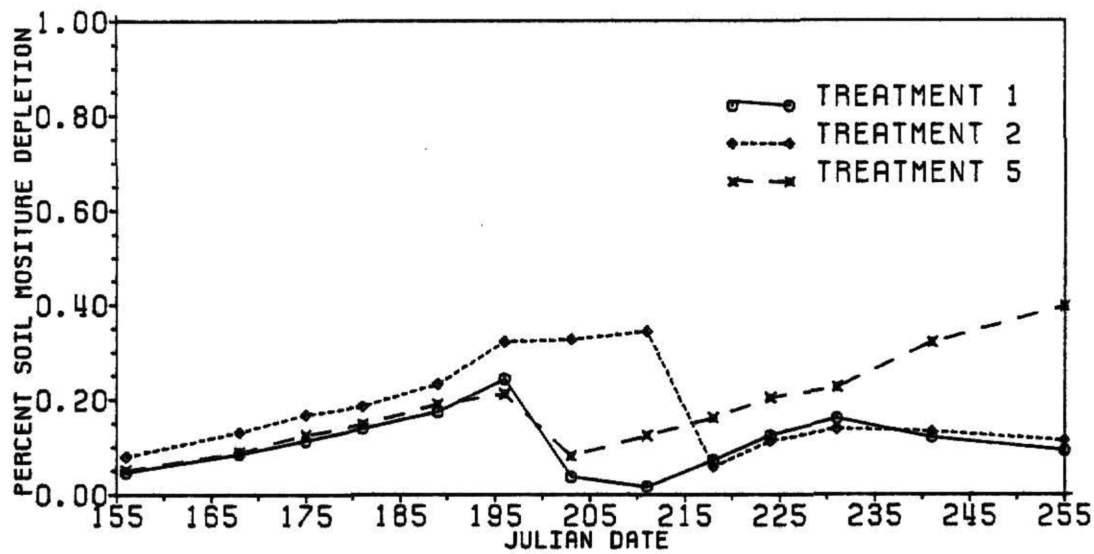


Figure 8. Percent soil moisture depletion for soil moisture treatments, 1981.

The results of the row data (Table 6) adjusted to the same population and infestation level show no significant differences between treatments for any of the yield components. This would be expected because of the low demand conditions which existed during much of the growing season. Results of the individual ear data (Table 7, Table A8) also showed no significant differences for depletion treatments.

Significant differences were found, however, between infested and noninfested plants (Table 8) when adjusted for population and tunnel number per stalk. As a result of southwestern corn borer infestations in 1981, ear weights were reduced 7.4%. Yields projected from the individual ear data showed no significant decreases caused by southwestern corn borer infestations. Significant reductions in kernel

Table 6. Actual yield, ear weight, kernel number, and seed weight for moisture depletion treatments, row data, 1981.

Treatment	Yield (kg/ha)	Ear Weight (g/ear)	Seed Weight (g/100)	Kernel Number
1	10,347	204	30.39	564
2	10,632	212	29.99	591
6	11,041	212	29.60	628
LSD (.05)	N.S.	N.S.	N.S.	N.S.

Table 7. Actual yield, ear weight, kernel number, and seed weight for moisture depletion treatments, individual ear data, 1981.

Treatment	Yield (kg/ha)	Ear Weight (g/ear)	Seed Weight (g/100)	Kernel Number
1	10,968	191	31.46	612
2	11,764	204	31.42	651
6	10,771	195	30.60	638
LSD (.05)	N.S.	N.S.	N.S.	N.S.

Table 8. Actual yields for infestation treatments, 1981.

Infestation Level	Yield kg/ha	Ear Weight, g	Kernel Number	Seed Weight,g
Noninfested	11,092	204	648	31.65
Infested	11,234	189	620	30.69
LSD (.05)	N.S.	4	15.7	0.79

number and seed weight found between infestation treatments. The reduction in kernel numbers resulting from the infestation would not be expected because kernels were already formed at the time that borer damage was initiated.

No significant differences were found between moisture depletion treatments for LAI's and total dry matter production (Table A9, Table A10). Differences would not be expected under the 1981 conditions. LAI (Figure 9) and dry matter production (Figure 10) were found to be significantly different between dates.

When looking at the effects of water depletion on corn yield and development it is important to also consider temperature effects, especially for comparisons between years. Benoit et al. (1975) found that the growth and yield of corn was in a large part a function of moisture stress as it was controlled by soil moisture and temperature levels. For this reason, comparing yields between years becomes difficult because, while moisture depletion treatments may

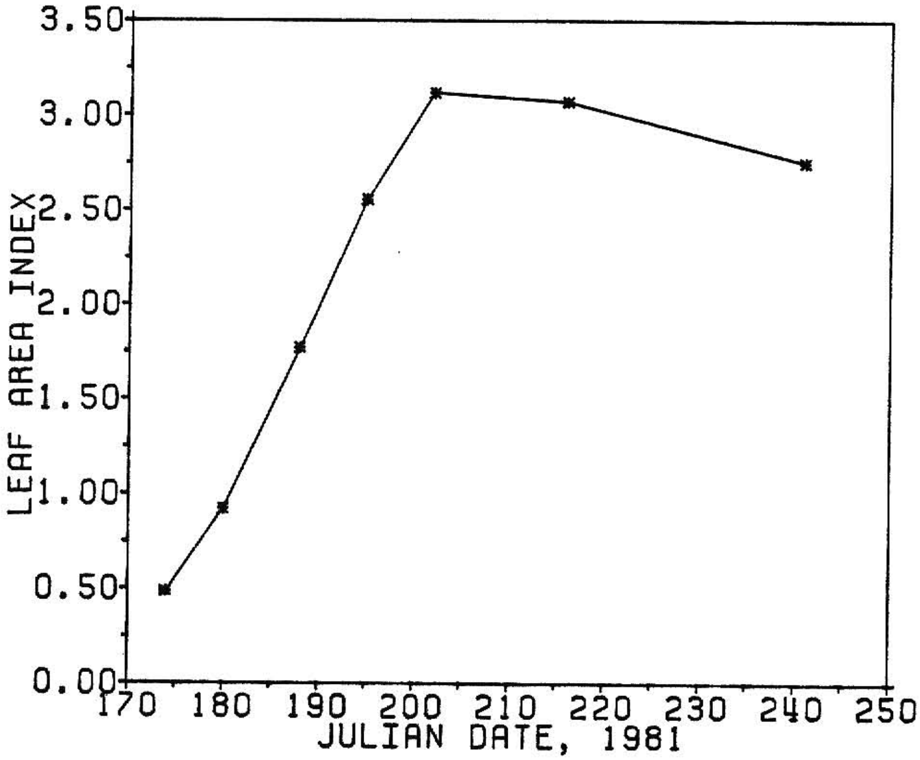


Figure 9. Actual LAI by date for 1981.

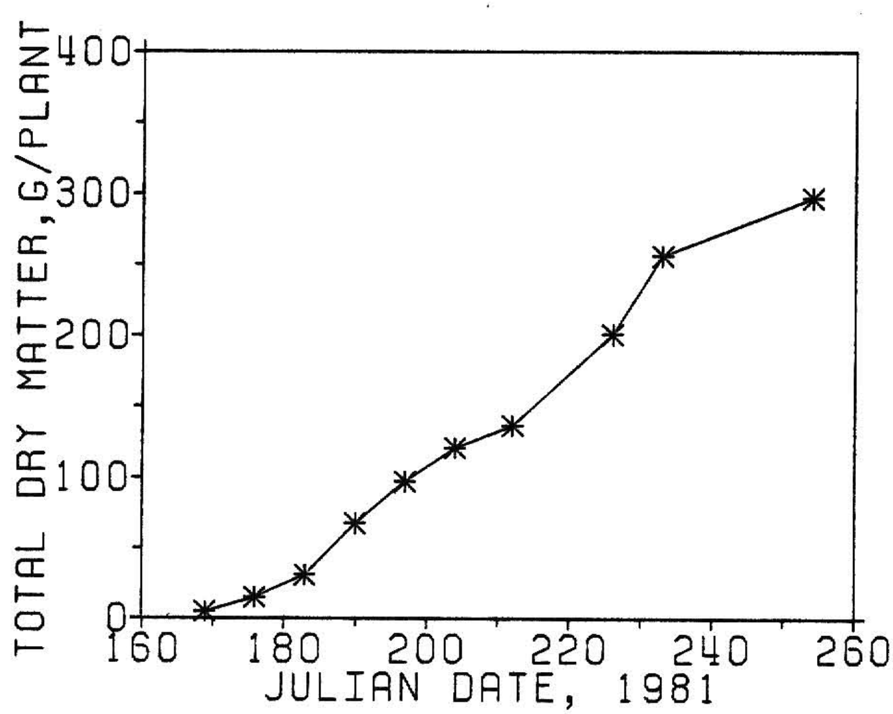


Figure 10. Actual total dry matter production by date for 1981.

be the same, the environment in which the depletions occur is usually different.

Denmead and Shaw (1962) found that stress occured at lower depletion levels as the evaporative demand of the environment increased. This point becomes especially clear when comparing the yields between 1979, 1980, and 1981 (Figure 11). Compared to 1979 and 1981, 1980 was a relatively hot year. Maximum temperatures during 1980 were relatively high during ear formation, fertilization, and the early grain fill period, while maximum temperatures during this same period in 1979 and 1981 were relativily cooler.

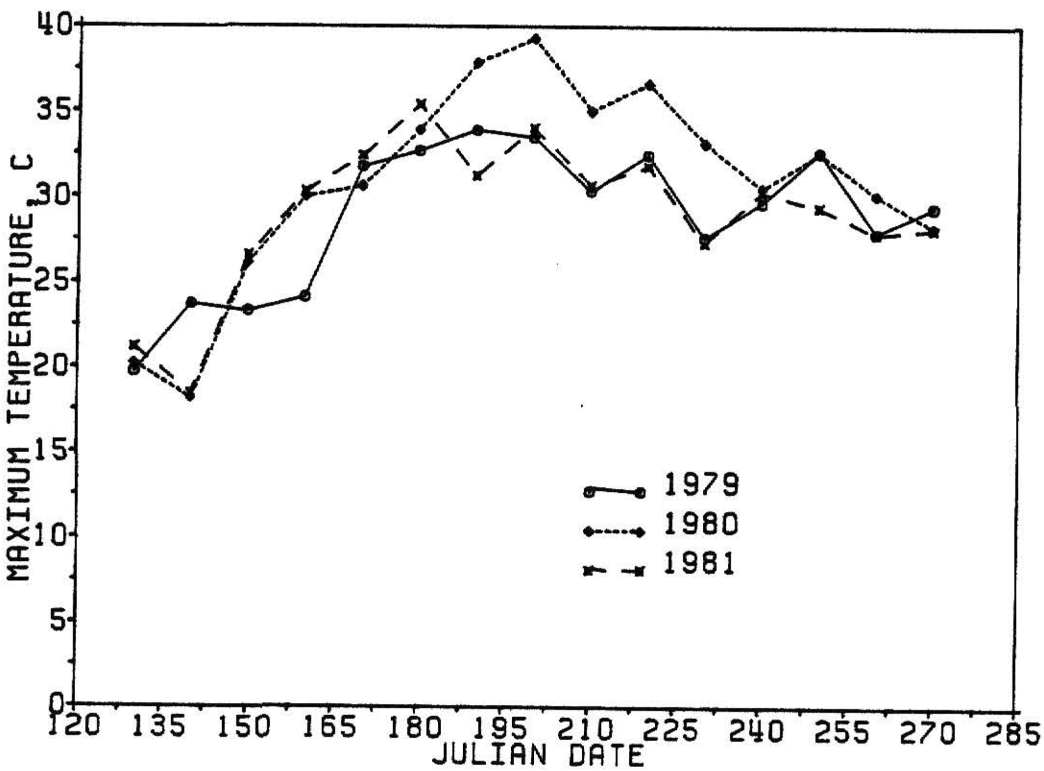


Figure 11. Maximum temperatures for 1979, 1980, 1981.

The effect of high temperatures on yield can be seen when comparing 1980 with 1979 and 1981 at the same moisture depletion levels. Treatment 1, the no moisture depletion treatment, during 1980 was maintained under much the same moisture conditions as treatment 1 in 1979 and treatment 2, the medium moisture depletion treatment, in 1981 (Figure 12). Assuming that the moisture depletion levels were the same for these treatments of the three years being compared,

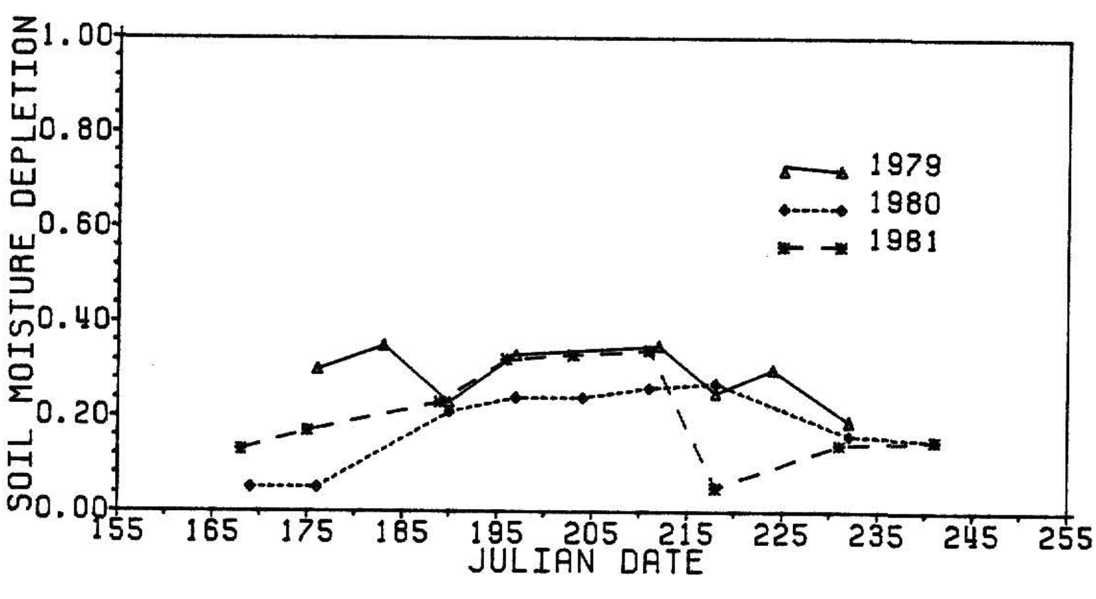


Figure 12. Maximum moisture depletions for treatment 1, 1979, treatment 1, 1980, and treatment 2, 1981.

the differences between years could be related to temperatures and evaporative demand.

When comparing treatment 2 of 1981 with treatment 1 of

1980 (Table 9) there was a 40% decrease in the 1980 yields. This decrease in yield can be accounted for by a 32% decrease in ear weight and 11% increase in barrenness during 1980. The reduction in ear weight appears to be caused by a decrease in kernel number and seed weight. Temperatures

Table 9. Comparison of yield, ear weight, kernel number, seed weight, and barreness for treatment 2, 1979, treatment 1, 1980, and treatment 2, 1981.

	1979	1980	1981
Yield (kg/ha)	10,091.00	6,171.00	10,347.00
Ear Weight (g)		139.50	204.00
Kernel Number		491.00	564.00
Seed Weight (g/100)		23.09	29.99
Percent Barremess		11.00	2.50

were extreamely high through most of the early ear development period and well into grain fill. High temperatures at this time could be expected to reduce kernel number. The reduction in seed weights could possibly result from a limiting in kernel size resulting from high temperatures and stress during ear and kernel development. Reductions in seed weight could also be caused by a decrease in gross photosynthesis and translocation occurring because of stress during grain fill, or a decrease in net photosynthesis because of high respiration rates resulting from high temperatures.

Only yields were available for 1979 to compare with 1980. The temperature conditions were much the same in 1979 as they were in 1981. While depletion levels were the highest of the three years compared, under the mild conditions which existed during 1979, yields were not affected as they were under the more demanding conditions of the 1980 season.

It is impossible to draw definite conclusions because of the unknown effects of a mite infestation and high natural infestaions of European and southwestern corn borer that occurred in 1980.

MODEL RESULTS

Average modeled yield for 1979 was 9,301 kg/ha for a field 100% infested with southwestern corn borer and 12,190 kg/ha for a field not infested. The average model yield using the actual percent infestation for each plot was 9,592 kg/ha, which was not significantly different from the actual yield of 9,759 kg/ha. These results (Table 10, Table All) would indicate that CORNF did a relatively good job modeling yields during 1979. Actual kernel numbers and seed weights were not available for 1979 to compare with the model.

Table 10. Comparison of modeled versus actual yields, 1979.

Method	Yield, kg/ha
Model, 0% Infestation	12,190
Model, 100% Infestation	9,301
Model, Actual Infestation	9,592
Actual	9,758
LSD (.05)	686

An important aspect of modeling corn in a stressed environment is to be able to simulate the soil moisture conditions in the field. Comparing modeled and actual soil moistures (Figure 13), it can be seen that the model over

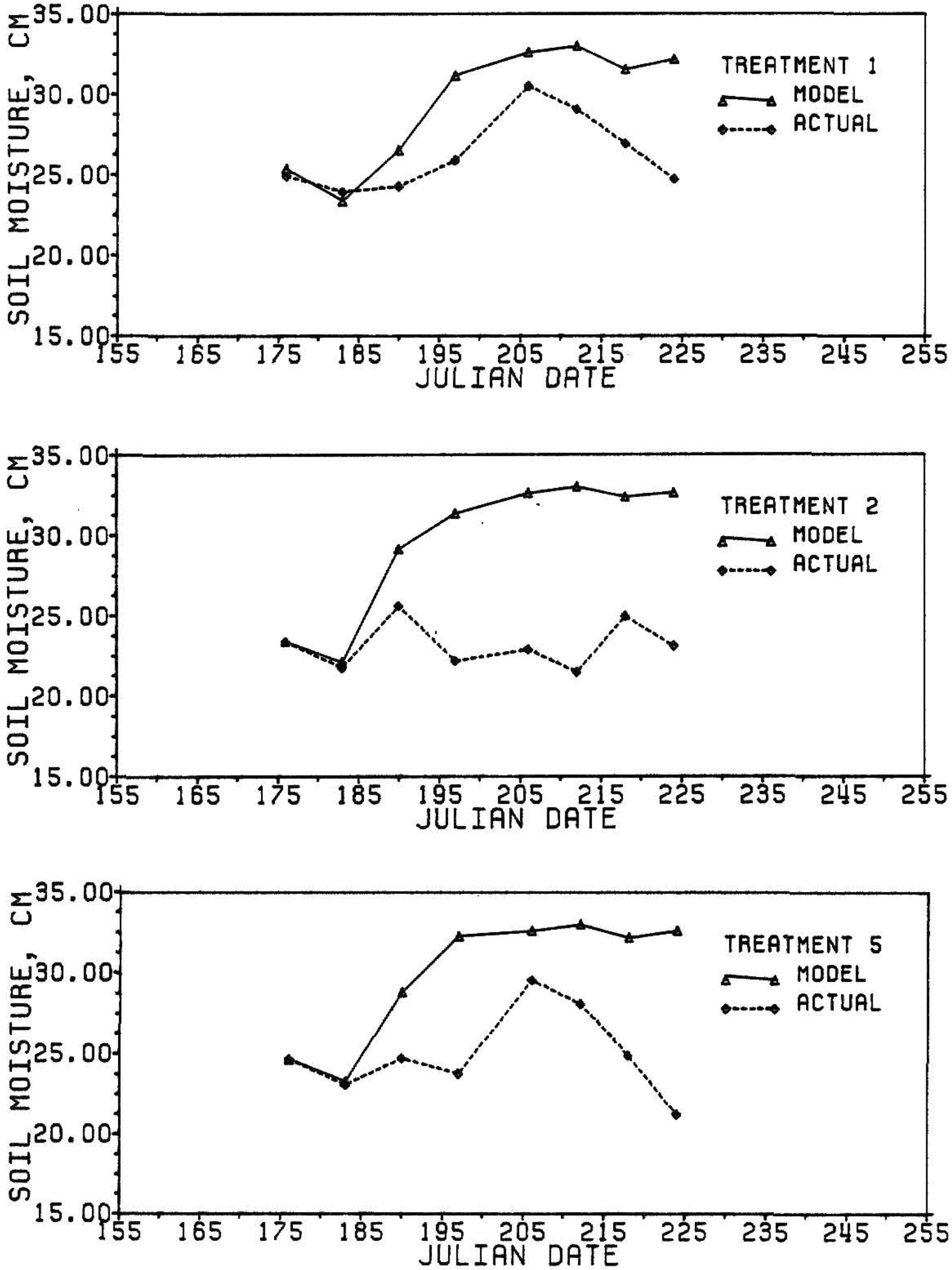


Figure 13. Comparison of modeled versus actual soil moistures for 1979.

estimated soil water especially for treatment 2. This seems to indicate that the model underestimates water use.

To correct for possible errors that may occur in CORNF due to over predicting soil moistures, actual daily soil moistures were input into the model. The results (Table 11, Table A11) were the same as for the model runs without

Table 11. Comparison of modeled and actual yields with actual soil moistures input, 1979.

Method	Yield, kg/ha
Model, 0% Infestation	12,197
Model, 100% Infestation	9,306
Model, Actual Infestation	9,598
Actual	9,758
LSD (.05)	686

actual soil moistures. This would be expected because there were relativlely low stress conditions during 1979 and soil moisture data was only input through anthesis.

To compare reductions in yield due to southwestern corn borer, yields for a 0% and 100% infested field were compared (Table 12, Table A14, Table A15). The model reductions of 23.7% were significantly higher than the actual reductions of 12.6% found in the field. These results would indicate that the southwestern corn borer function used in the model

Table 12. Comparison of modeled and actual yields for an infested and noninfested field, 1979.

	0% Infestation Yields, kg/ha	100% Infestation Yields, kg/ha	Percent Reduction
Model	12,190	9,306	23.7
Actual	11,253	9,741	12.6
LSD (.05)	978	978	5.1

over predicted reductions due to infestations during 1979.

When comparisons were made between actual and modeled leaf area over time no significant differences were found (Figure 14, Table A12). The leaf area data were available only through anthesis when LAI was at its maximum. Unless the leaf senescence part of the model did not work properly it can be assumed that the model did a good job of modeling leaf area throughout the whole season.

Total dry matter production was also compared for 1979 (Figure 15, Table A13). There were no significant differences found between the mean dry matter production for 1979 when compared with the modeled dry matter production for a noninfested field.

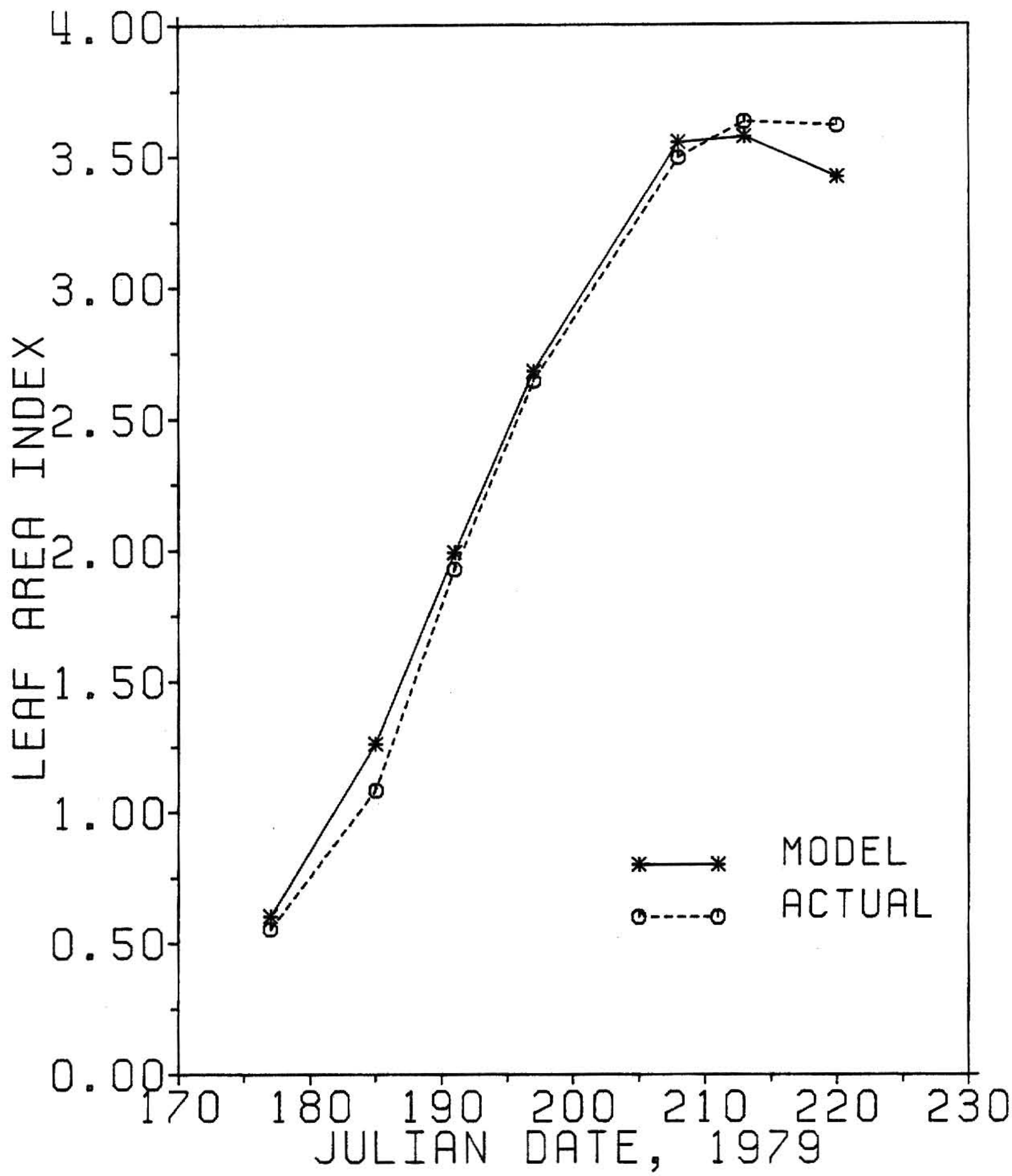


Figure 14. Comparison of modeled versus actual LAI by date for 1979.

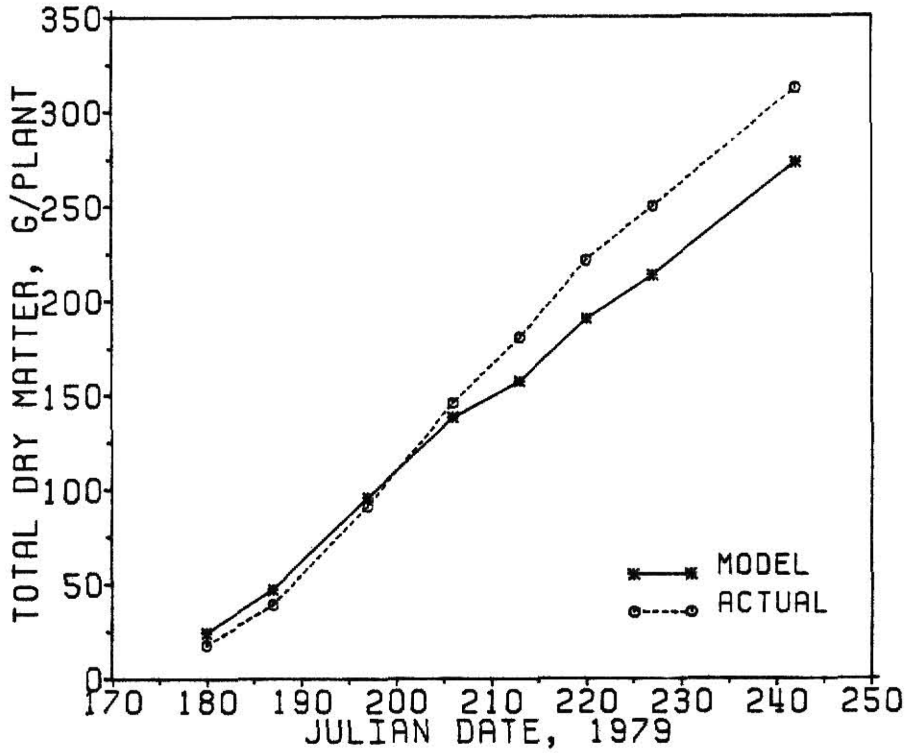


Figure 15. Comparison of modeled versus actual total dry matter production for 1979.

The 1980 season provided an excellent opportunity to test CORNF's ability to model corn yields under moisture stress conditions. As shown earlier in the discussion of field results, maximum temperatures were well over 32 C for a large part of the season. There were 17 consecutive days prior to silking that temperatures were over 38 C. With the high temperatures, relatively high demand conditions would be expected. These high demand conditions coupled with a wide range of soil moistures provided a good test of CORNF's sensitivity to moisture stress.

Because actual infestation counts were not taken for 1980, modeled estimates of yields at actual field infestation levels could not be made. For the purposes of discussion, the model yields for a 0% and a 100% infested field are shown. Based on 1979 and 1981 data for which infestation counts were taken, a good estimate of model yields would probably lie close to the 100% infestation level. As shown earlier, there were no significant differences found between infestation treatments in the actual field study during 1980. There was a 16% reduction in the model yields due to southwestern corn borer.

Modeled yield, kernel number, and seed weights compared with actual values (Table 13, Table A16, Table A17, Table A18) show that the average modeled yield for the study in 1980 was between 8,616 kg/ha for a field 100% infested to 10,330 kg/ha for a field not infested. Both the 100% infested model yield and the 0% infested model yield were significantly higher than the average actual yield of 4,723 kg/ha. There were no significant differences found between actual and noninfested model seed weights. There were significant differences however, between the 100% infested model seed weights and actual seed weights. Assumming that the infestation levels were quite high for 1980, the data would indicate that the model under predicts seed weights for an infested plant. This would be expected however due to over predicting the number of kernels, which would decrease the amount of dry matter available per kernel. The average actual kernel number per ear was 419, which was significantly lower than the modeled kernel number of 736.

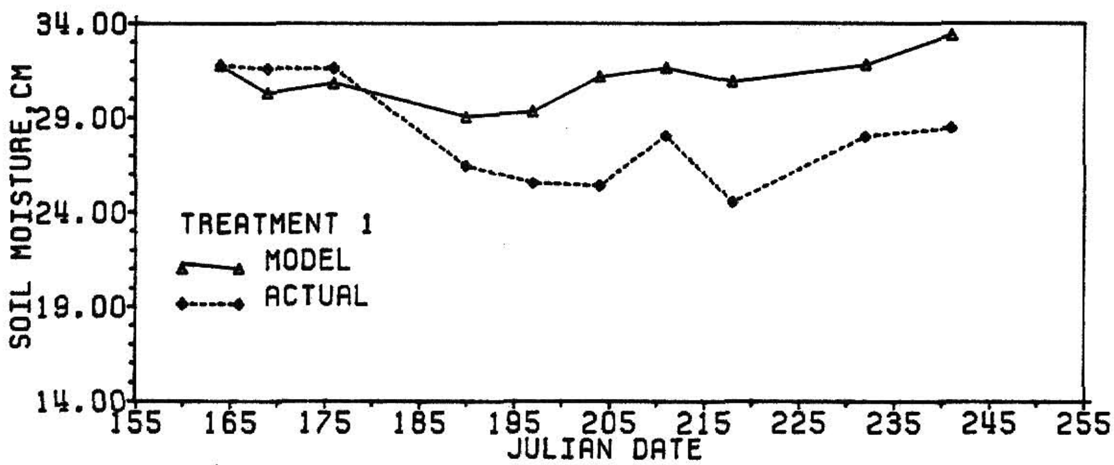
At this point it would be easy to conclude that since the model over predicts the yield and kernel number of a noninfested plant while accurately predicting the seed weight, all that would be necessary to accurately predict yields is to correct the model to simulate kernel numbers properly. This would be an over simplification of the problem since kernel weight is calculated as a function of kernel number and kernel weight itself would change as kernel number was corrected. The potential for modeling the yield componets of seed weight and kernel number properly does exist in the model through the modifying affect of WATCO, the water stress coefficient.

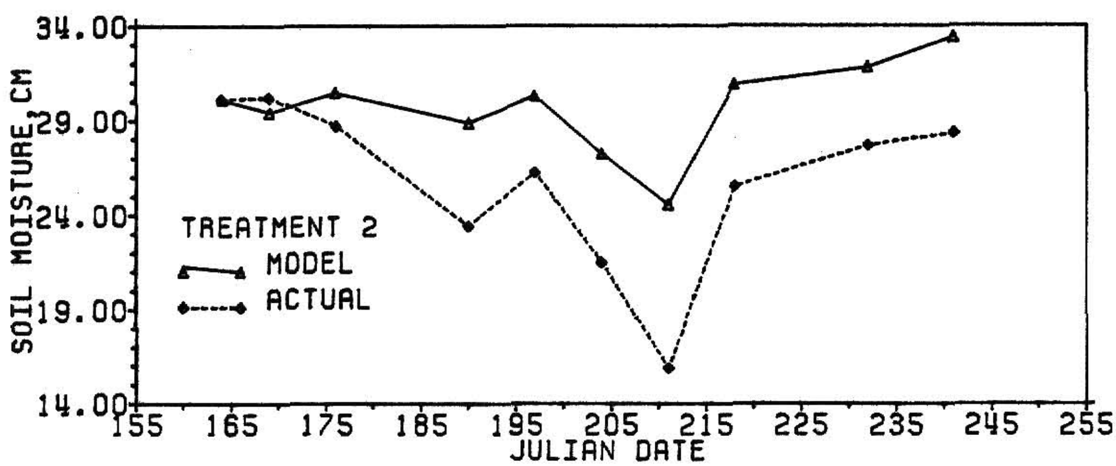
In looking at previous discussions of WATCO and its components, it can be seen that stress occurring on any

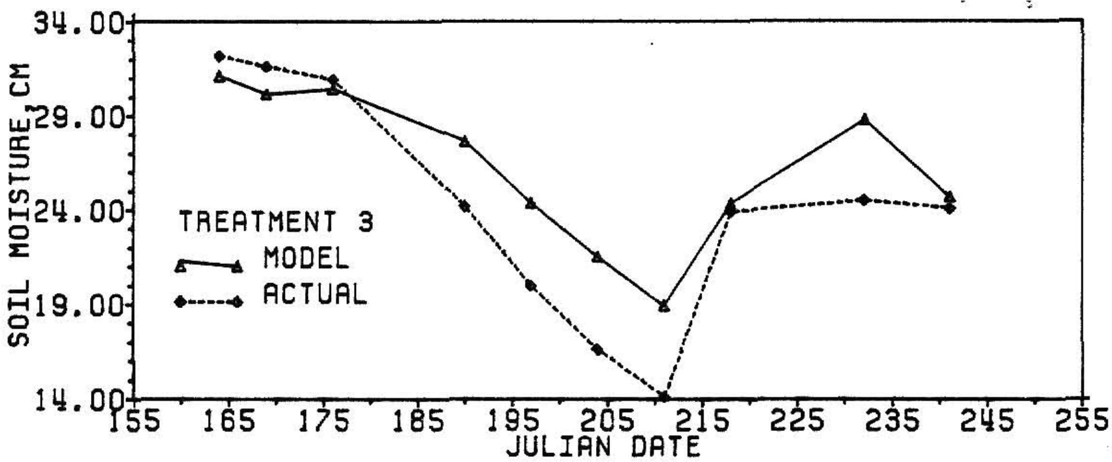
Table 13. Comparison of modeled and actual yield, kernel number, and seed weight, 1980.

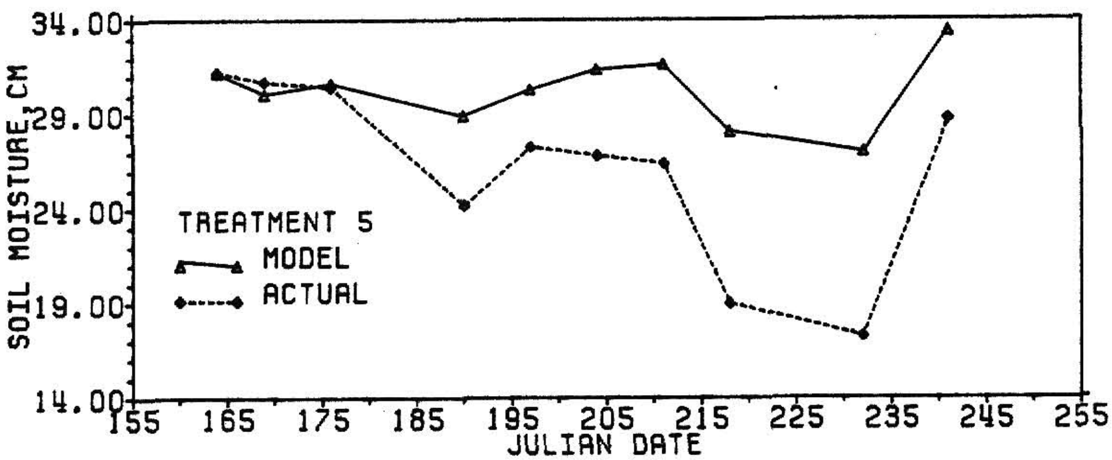
Method	Yield, kg/ha	Kernel Number	Seed Weight, g/100
Model, 0% Infestation	10,334	736	24.9
Model, 100% Infestation	8,616	736	20.8
Actual	4,723	419	24.4
LSD (.05)	804	80	1.7

given day is a function of the potential demand (EO) and soil moisture index (SMI). Therefore, CORNF's ability to model stress depends on 1) modeling the soil moisture correctly, 2) determining the actual EO, and 3) determining the correct relationship between EO, soil moisture, and water stress. If any of these three factors are modeled incorrectly the model would be unable to accurately model yields under stress conditions.









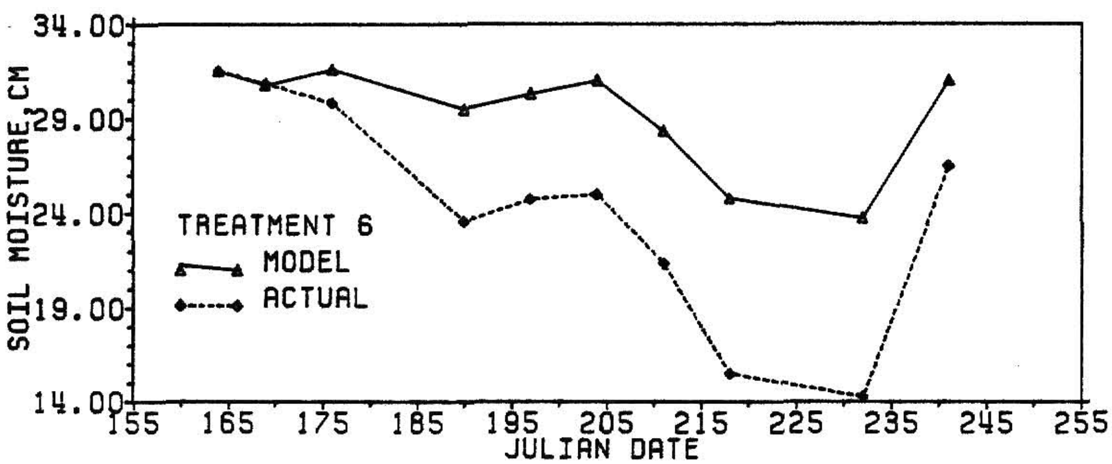


Figure 16. Comparison of modeled versus actual soil moistures for 1980.

When actual versus model soil moistures were compared throughout the growing season, it was found that there were differences between the two (Figure 16). In general it appears that the modeled soil moistures move in the right direction but are too insensitive to changes in the environment which increase water use. The model appeared to be relatively insensitive to the treatment 2 stress period which could be characterized as a relative short stress period during which temperatures were extremely high. The model appeared to do a little better job on treatment 3 which was characterized by a longer dry down period with more of a gradual decline. The model was particularly insensitive to stress treatments 5 and 6 which occurred after anthesis and during a relatively cooler period.

To remove the possible error caused by the incorrectly modeled soil moistures, actual daily soil moistures for each plot were input into the model. The results (Table 14, Table A16, Table A18) show the average modeled yield when the soil moisture was input into the model was 8,495 kg/ha for a field 100% infested and 10,189 kg/ha for a field not infested. The model yields were still significantly different from the average actual yield of 4,723 kg/ha. Model and actual kernel numbers were also significantly different. Of interest here is that there were no significant changes in the model yield, kernel number, and seed weight between the model runs shown in table 13 where water was not input into the model and the values shown in table 14. It appears that WATCO is not sensitive to the changes in soil moisture which occurred, indicating that EO was under predicted or that the relationship between EO, soil moisture, and WATCO does an inadequate job of describing the stress.

Table 14. Comparison of modeled and actual yield, kernel number, and seed weight with actual daily soil moisture input, 1980.

Method	Yield, kg/ha	Kernel Number	Seed Weight, g/100
Model, 0% Infestaion	10,189	710	25
Model, 100% Infestation	8,495	710	21
Actual	4,723	419	24
LSD (.05)	804	80	17

Daily modeled EO values (Figure 17) appear to be in a range that might be expected for the 1980 season. The EO values represent an attempt to quantify evaporative demand or maximum evaporative rate of which the atmosphere is capable. Another estimate of evaporative demand is open pan evaporation in which the amount of water evaporated from a pan on any given day is recorded. When modeled EO values were regressed against daily open pan evaporation (Figure 18), it was found that modeled EO values were generally higher than open pan evaporation. EO values and open pan values would not be expected to be equal, but to parallel each other. The modeled EO values were found to be less responsive to changes in the environment than open pan values. Modeled EO values were relatively higher than expected at lower open pan evaporations and relatively lower than expected from higher open pan evaporations.

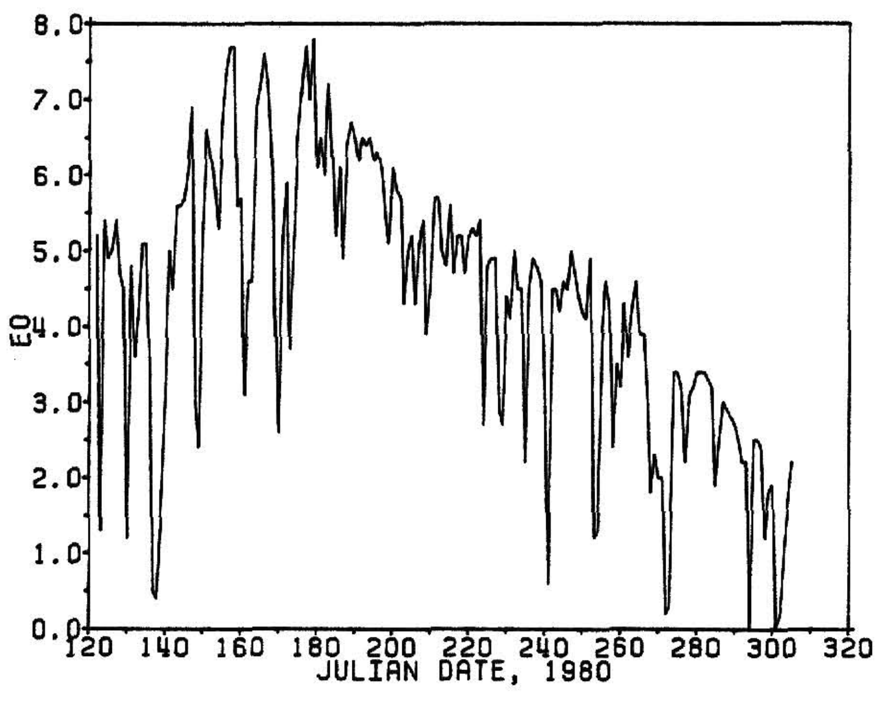


Figure 17. Modeled EO values for 1980.

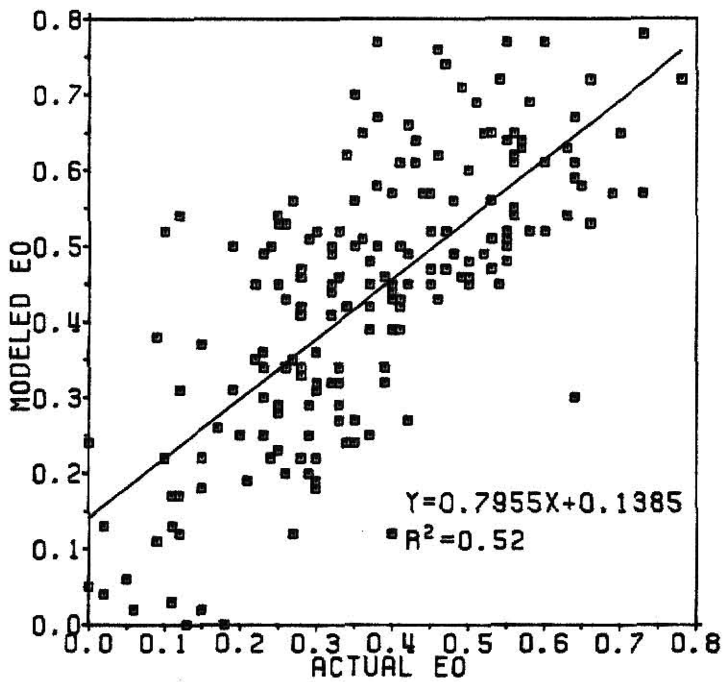


Figure 18. Modeled EO versus open pan evaporation, 1980.

If it is assumed that the EO values are acceptable, even though modeled EO values do not exactly parallel open pan values, the relationship between EO, SMI and WATCO becomes questionable. In this relationship (Figure A3), for soil moisture indexes above 0.5, only on peak demand days when EO is 6 or above would there be any water stress. When using this relationship little water stress could be expected in the model. Most of the grain fill period would take place after julian day 220 when EO values were 4 to 5.

At this level there would be no stress as long as the available soil moistures were above 17 cm. Only in treatment 6 does the available soil moisture get below 17 cm. This could be a particular problem in a year like 1980. The soil moisture could be depleted to 50% for all of the grain fill period and no stress would occur.

The above results challenge the assumptions used to develop the WATCO function. The first is that water stress in the model could be equated with the degree of wilting in the Denmead and Shaw (1962) study. The second one is that because the soil characteristics described in the Denmead and Shaw paper were similar to the soil characteristics at Garden City, the soil would have the same moisture release curve. The differences in moisture release and moisture availability could affect the relationship between EO, SMI and water stress. The modeling attempt here shows an attempt to apply the theory using a limited availablilty of information. Possibly with the development of moisture release curves for the soil at Garden City and the development of wilting point relationships, the theory could be successfully applied.

To model water stress correctly the WATCO function would be expected to 1) reduce pre-anthesis dry matter production due to stress occurring early in the season, 2) reduce kernel number due to stress occurring during the rapid ear development phase, and 3) reduce dry matter available for grain production due to stress during the grain fill period. When modeled and actual dry weights were analyzed, it was found that there were significant differences in dry weight throughout most of the season (Figure 19, Table A20). As the season progressed, differences between the actual and modeled total dry weight became larger. The result of over predicting dry matter production could result in higher kernel numbers and higher yields.

Predicting total dry weight at anthesis is of particular importance because kernel number is calculated as a function of total dry weight at anthesis. The equation for calculating kernel number is:

Kernel number=5*DMANTH-50

where DMANTH is the dry weight of the plant at anthesis. Arkin and Stapper (1982) reported a very high correlation between the size of the plant at anthesis and the actual kernel number. A plot of the relationship used in the model is shown in Figure 20. For dry weights above 160 grams per plant the kernel number is set at a maximum of 750. For dry weights less than 160 grams, kernel number is calculated using the equation above. When comparing the total dry weight at anthesis, the models total dry weight per plant was 195 grams. This was significantly different from the actual dry weight of 153 grams. If the average dry weight per plant was used in the equation it would drop kernel numbers from 750 to 715.

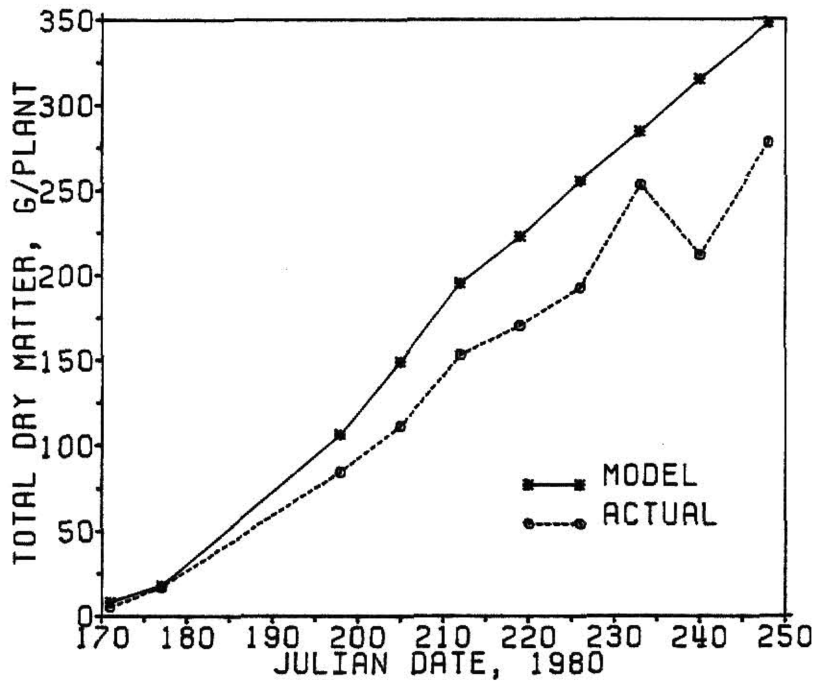


Figure 19. Modeled versus actual total dry matter production, 1980.

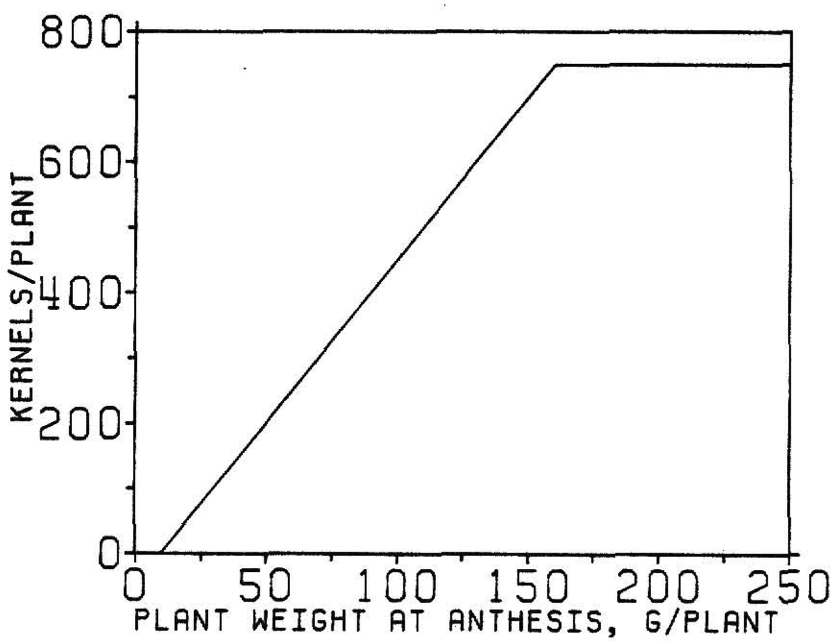


Figure 20. Relationship between kernel number and dry weight per plant at anthesis used in CORNF.

While reducing dry matter at anthesis will decrease kernel numbers, kernel numbers can also be reduced by stresses occurring during the rapid ear development period. To do this a kernel number reduction factor KRNRED is used. KRNRED is a coefficient between 0 and 1 which is used one time at the beginning of grain fill to further adjust kernel number for stress which may have occurred during the rapid ear development phase. KRNRED is recalculated daily during the rapid ear develpment phase by the following equation.

KRNRED=KRNRED-(1-WATCO)*.04

KRNRED is initially 1. With this equation the maximum reduction that can take place on any given day is 4%. For the model to calculate the average actual kernel number of 419 it can be calculated that the average KRNRED for the year would have to be 0.58. This compares with the KRNRED computed by the model of 0.99. The kernel number reduction required can be calculated by substituting into the above equation that for the rapid ear growth stage which was approximately a 25 day period, the average WATCO would have to be 0.58. This would give a possible value for recalibrating the relationship between EO and soil moisture.

To correct for the possible errors caused in the model by over predicting kernel numbers, actual kernel numbers were input into the model to calculate yields for each plot. As shown in table 15 the average model yield for the experiment was 6,450 kg/ha for a field 100% infested and

7,739 kg/ha for a field not infested. Both of the 0% and 100% yields and kernel weights were significantly different from actual yields. By inputing kernel number into the model there was a 25% reduction in yields compared to model runs made without inputing kernel number. The reduction in yield is short of the 31% reduction that might be expected due to decreasing kernel numbers. This is because while kernel numbers decreased, dry matter production stays the same. The extra dry matter that had been partitioned into many kernels was put into fewer kernels increasing the seed weight.

Table 15. Comparison of modeled and actual yield, kernel number and seed weight with actual kernel numbers input into the model, 1980.

Method	Yield, kg/ha	Kernel Number	Seed Weight, g/100
Model, 0% Infestation	7,739	419	32.8
Model, 100% Infestation	6,450	419	27.4
Actual	4,723	419	24.4
LSD (.05)	804	N.S.	1.7

To decrease yields further and offset the effect of decreased kernel numbers on kernel weights, dry matter needs to be decreased accordingly. Table 16 shows what happens to yield and kernel weights when kernel number is held constant and dry matter production is reduced. With the first 25% reduction in dry matter production, yield was reduced 15% and kernel weight 13%. At this level, reserves are generated and used in the model to meet demand resulting in kernel weights not being decreased as much as dry matter production. For a 50% reduction in daily dry matter production there is a 40% decrease in yield and a 38% reduction in kernel weight indicating that reserves were still being used. At higher kernel number the effect of reserves would possibly not be seen due to the increased kernel numbers increasing demand and decreasing any extra dry matter that may be put into reserves and used during stress periods.

Table 16. Effect of daily dry matter reductions on grain yield, kernel number, and seed weight as predicted by CORNF with daily dry matter production reduced by 0, 25, and 50 percent.

Dry Matter Reduction	Yield (kg/ha)	Kernel Number	Seed Weight, g/100.
1.00	8,665	477	32
0.75	7,330	477	28
0.50	5,158	477	20

A factor which had a large effect on actual yields in 1980 but is not accounted for in the model is barrenness.

During 1980 there was an average of 18% of the stalks that did not produce an ear. When model yields were decreased by the percent of barrenness found in each plot, yields were 7,085 kg/ha for a field 100% infested to 8,494 kg/ha for a noninfested field. The model yields were significantly different from the actual yield of 4,723 kg/ha. While not being the total answer, the barreness factor will account for 18-20% of the yield. A factor not accounted for in the model is the effect of water stress on leaf area. When analyzed it was found that there were significant differences between actual and modeled LAI's across dates and treatments. The results (Figure 21) show the actual leaf area is 10-20% less than the modeled leaf areas for most of the season. When compared by treatment (Figure 22) the model does respond to the different moisture treatments but not in the same magnitude. Because leaf development is not affected by water stress in the model, changes can by related to population differences between treatments.

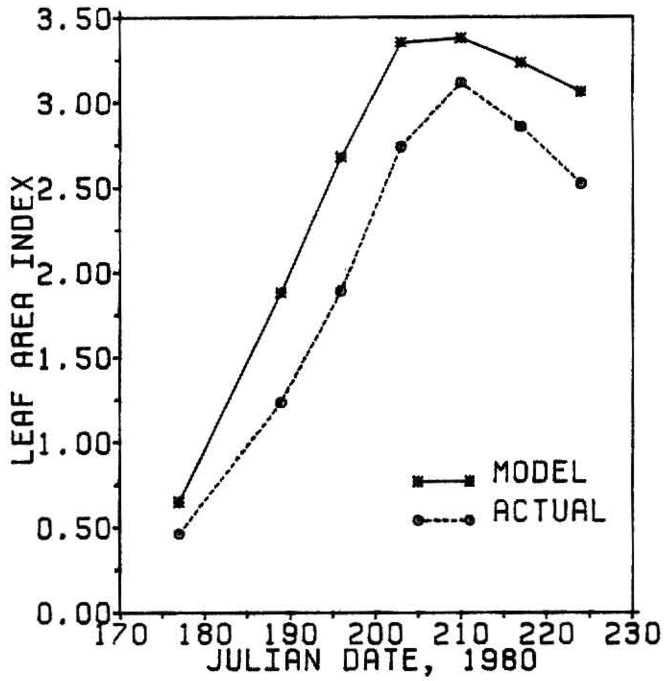


Figure 21. Comparison of modeled and actual LAI by date, 1980.

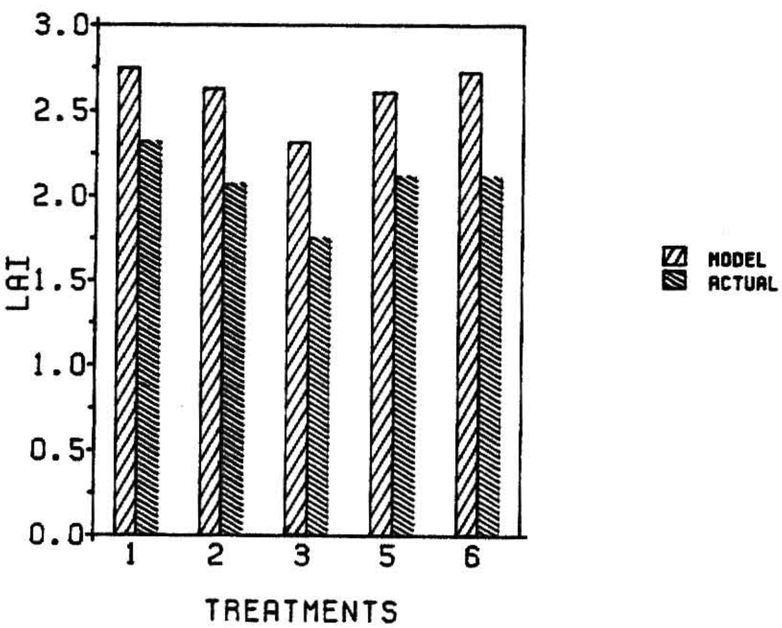


Figure 22. Comparison of modeled and actual LAI by treatment, 1980.

1981 was the coolest and wettest of the three years. Under the 1981 conditions the model did quite well. The results (Table 17, Table A25, Table A26, Table A27) show that the average yield for the row data would be 13,449 kg/ha at the 0% infestation level, 9,778 kg/ha at the 100% infestation level and 11,527 kg/ha at the actual infestation level found in the field. The model yield at the actual infestation level was not significantly different from the actual yield of 10,554 kg/ha.

Table 17. Comparison of modeled and actual yield, kernel number, and seed weights from row data, 1981.

Method	Yield (kg/ha)	Kernel Number	Seed Weight, /100
Model, 0% Infestation	13,449	749	29.2
Model, 100% Infestation	9,978	749	21.2
Model, Actual Infestation	10,227	749	22.2
Actual	10,554	590	30.3
LSD (.05)	680	41	9.0

When the yields were broken down into yield components the model did not do as well. The average model kernel number was 749 kernels per ear which was significantly higher than the average actual kernel number of 590. While kernel numbers were over predicted, seed weights were under predicted. The average seed weight for a field 0% infested was 29.2 g/100 kernels which was not significantly different from the actual seed weight of 30.0 g/100 kernels, but the seed weights for the model at the actual infestation level were 22.2 g/100 kernels which was significantly different from the actual.

To remove the possible errors that may have occurred due to over predicting kernel number, actual kernel numbers were input. Results (Table 18, Table A25, Table A26, Table A27) show that yields were reduced by inputting kernel number. With kernel number input the model yield at the actual infestation level was significantly different from the actual yield. The seed weights were relatively unchanged by the lower actual kernel numbers indicating that

Table 18. Comparison of modeled and actual yield, kernel number, and seed weights with actual kernel numbers input, 1981.

Method	Yield (kg/ha)	Kernel Number	Seed Weight, g/100
Model, 0% Infestation	11,491	590	29.2
Models, 100% Infestation	8,354	590	21.6
Model, Actual Infestation	8,741	590	22.6
Actual	10,554	590	30.0
LSD (.05)	680	N.S.	1.0

even at the higher kernel numbers more than enough dry matter was being produced to meet grain fill needs in the model. Yield reductions occurring due to inputting kernel number were the result of limiting the grain fill production by decreasing kernel numbers.

Table 19. Comparison of modeled and actual yields for an infested and noninfested field, 1981.

	0% Infestation Yields, kg/ha	100% Infestation Yields, kg/ha	Percent Reduction
Model	14,048	10,299	26.52
Actal	11,572	11,201	0.97
LSD(.05)	884	884	7.46

To compare reductions from southwestern corn borer infestations, individual ear data were used. In the model there was a 26.5% reduction in yield between a field 0% and 100% infested (Table 19, Table A21, Table A22). There were no significant differences found in the field during 1981 indicating the model overpredicted yield reductions due to southwestern corn borer. The yield reductions compared here were calculated from the mean values of all ears within a plot. When determining the percent yield reduction in the field using ear weights, instead of yield means, the yield reduction was 7.4%. Even with this higher value the model still over predicted the losses that would be expected from a southwestern corn borer infestation.

Total dry matter production per plant was found to be significantly different between model values and actual values. Figure 23 (Table A24) shows that the model over predicted total dry matter production. The dry matter curves shown are for a single noninfested plant. If the dry matter production for the model was adjusted downward to account for infestation effects, there would not be as much difference.

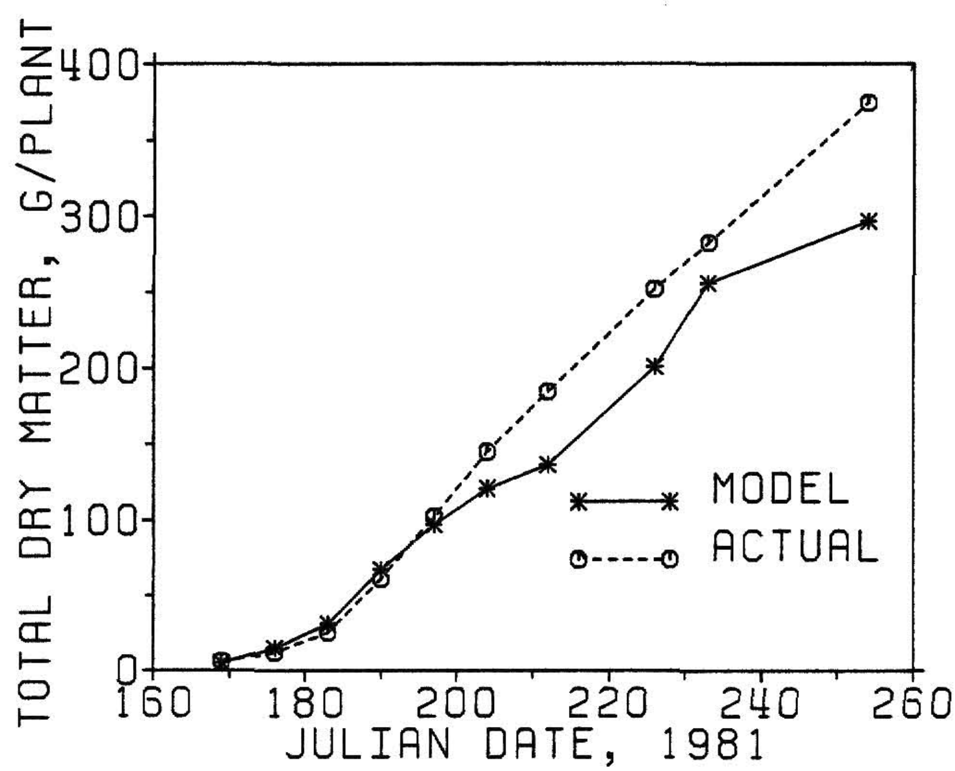


Figure 23. Comparison of modeled and actal total dry matter production for 1981.

The model did a very good job predicting leaf area in 1981. There were no significant differences between the modeled and actual LAI's shown in figure 24 (Table A23).

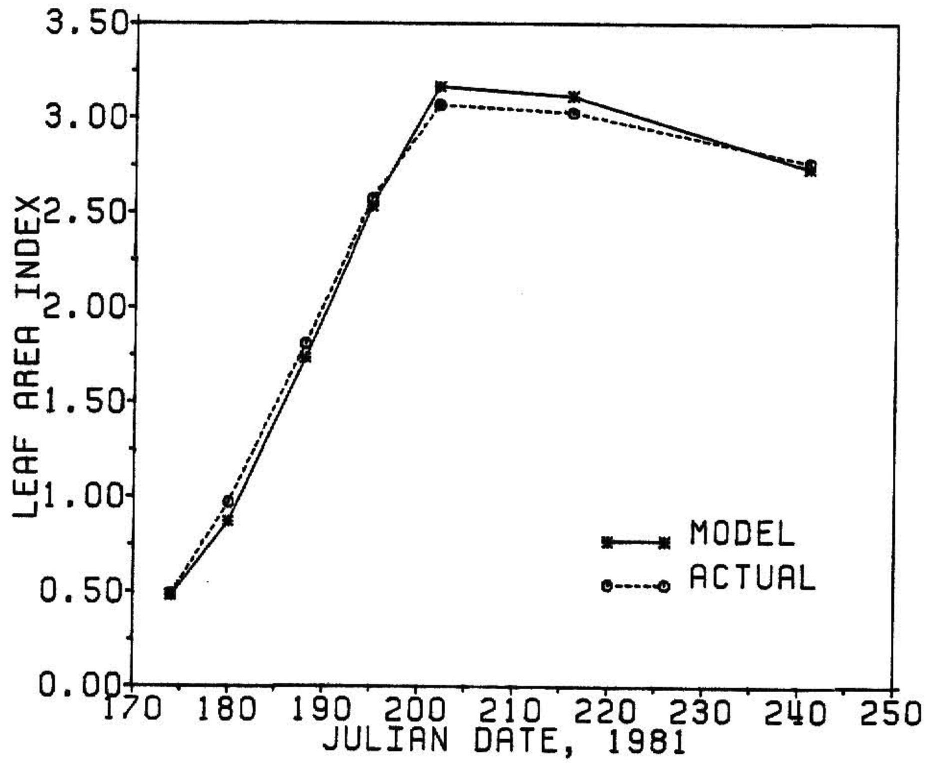


Figure 24. Comparison of modeled and actual LAI by date for 1981.

The modeled and actual soil moistures in figure 25 show that the model also did a very good job modeling soil moistures. While the model did not predict the short dip in treatment 2 it did a good job of modeling the long term decrease in treatment 6.

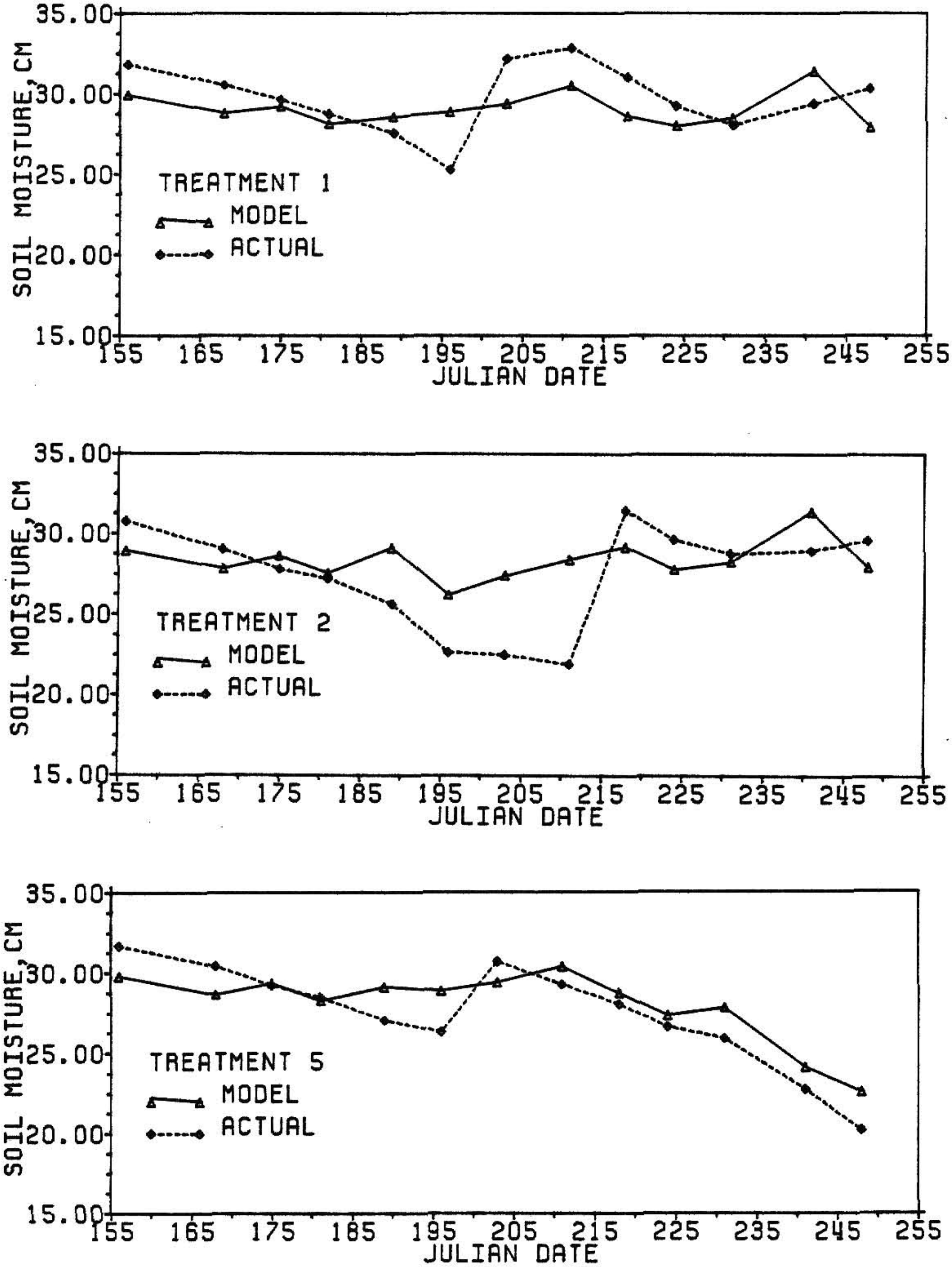


Figure 25. Comparison of modeled and actual soil moistures, 1981.

To look at how well CORNF performed over the three years, modeled yields for a noninfested field were were compared with actual yields (Figure 26). Noninfested model yields were used to compare across all three years because model yields at actual infestation levels could not be calculated for 1980. Model yields in this case would be expected to be somewhat higher because they do not reflect yield losses due to southwestern corn borer infestations. In general, the model appears to do relatively well under high yielding conditions. At the higher yields of 10,000 to 12,000 kg/ha the model does relatively well if yields are adjusted down 10 to 15% to account for infestation affects. Under the lower yielding conditions CORNF over predicts

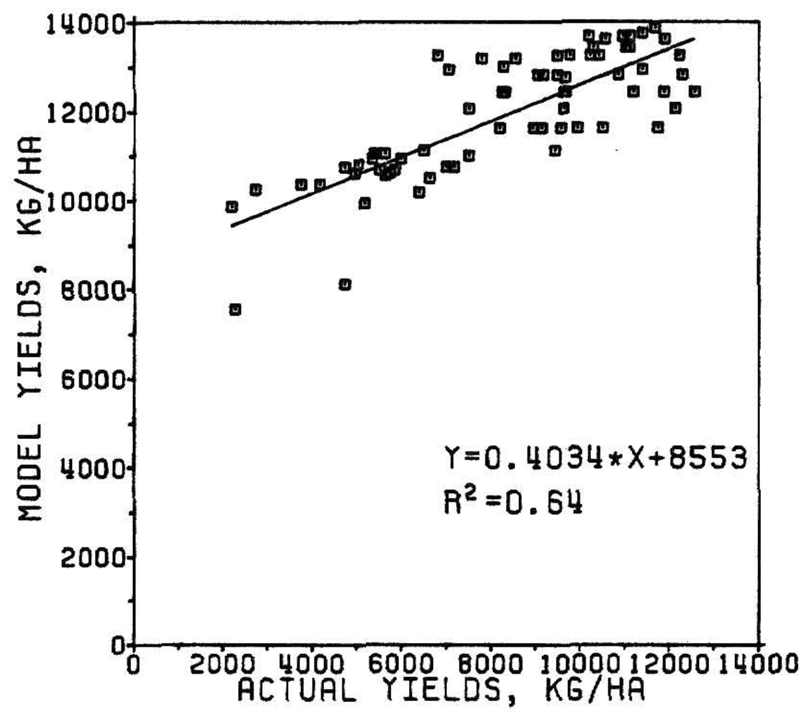


Figure 26. Modeled yields for a noninfested field versus actual yields for 1979, 1980, 1981.

adjusted down 10 to 15% to account for infestation affects. Under the lower yielding conditions CORNF over predicts yields. The regression line indicates that the model is relatively insensitive to environmetal factors which reduce yields.

When modeled yields in which kernel number were input were compared with actual yields (Figure 27), the model yields tended to be more variable. While yields were still over predicted there is a wider range in the modeled values. Yields are over predicted most at lower yields. This would be expected since dry matter production would not be

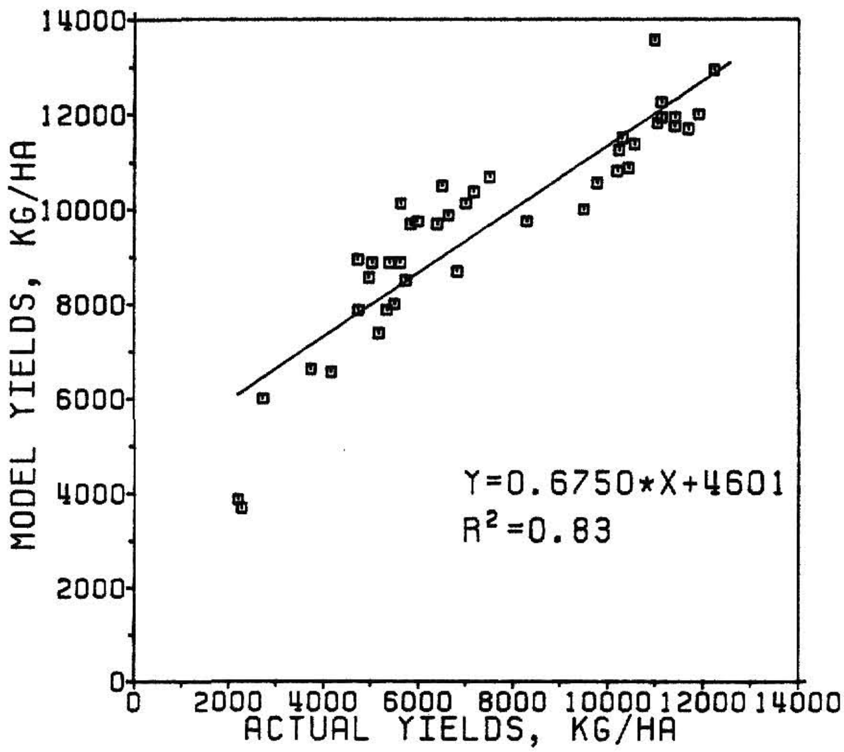


Figure 27. Noninfested model yields versus actual yields with actual kernel numbers input into the model, 1979 and 1981.

reduced by decreasing kernel number, and seed weights would tend towards a maximum value. At higher yields where actual seed weights would tend towards a maximum value, yield differences were not as great.

The lack of response to environmental stresses seems to be due mostly to choosing incorrect parameters to describe the environmental effects on yields. While functions do exist, such as WATCO and KRNRED, to adjust kernel numbers and dry matter production for stress, the thresholds at which stress occurs in the model were rarely reached. To arbitraily adjust the parameters to get the model to respond in the right magnitude would be of little use since the parameters would change from environment to environment and no permenant inprovement would be made. Within the framework of this model, a better solution would be to further develop the relationship between soil water, atmospheric demand, and plant stress. By using such a relationship, moisture release curves could be developed to determine the amount of water the plant was able to take up, evaporative demand could be used to determine the water needed by the plant, and the moisture deficits within the plant could be used to determine stress as a function of water uptake and the water needed. Some emperical evidence by Boyer (1979b) shows that leaf expansion stops in corn at water deficits of 8 bars and photosynthesis stops at 12 bars. By setting realistic thresholds which are related to functions within the plant, the modeled function would more nearly approach plant proccesses.

By using functions as mentioned above, the complications of the duration of the stress and stage of development when the stress occurs could be handled quite well. Sufficient detail is built into the model to handle the phenology and development sequences that occur. Through the developmental sequences, water stress affects on dry matter production, leaf expansion, ear growth, kernel development, and grain fill could be approximated.

In looking at how well CORNF did in predicting yield losses from southwestern corn borer, only estimates from 1979 and 1981 were avaliable. When comparing model yields adjusted for infestation against actual yields for 1979 and 1981 (Figure 28), the model did not show as much variation in yields as did the actual yields. This follows from earlier discussions when CORNF was shown to be fairly unresponsive to environmental stresses. What little variation is shown in the model yield is due mostly to population differences between plots and not a differential response to the environment and depletion treatments.

While the variation in model yields is not as large as the variation in the actual yields, the mean of the model yields adjusted for southwestern corn borer infestations do closely approximate the mean of the actual yields found in the field. This would indicate that on the average the

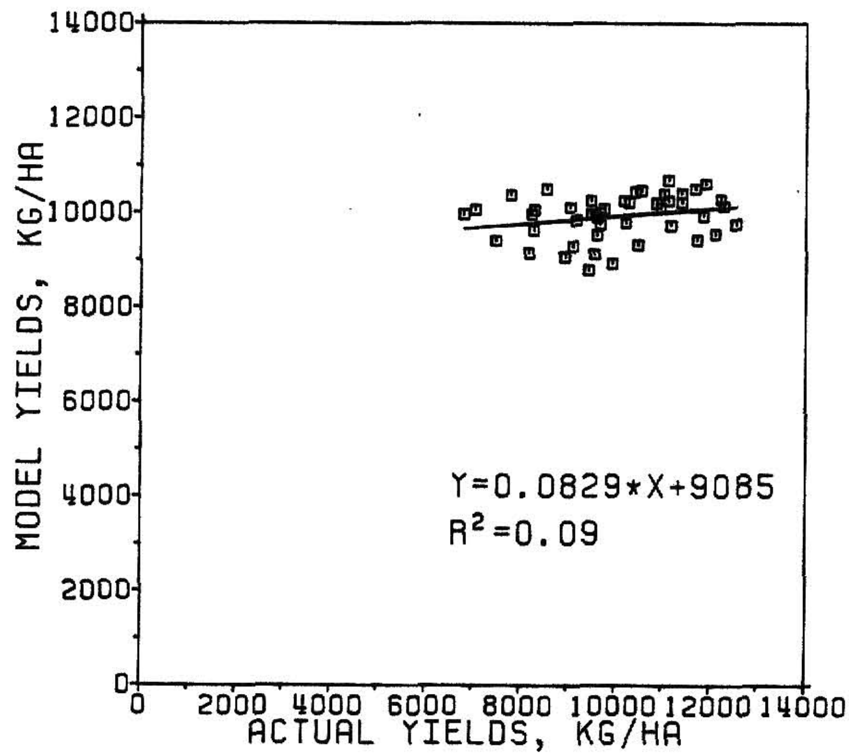


Figure 28. 0% and 100% model yields adujsted to actual infestation levels versus actual yields, 1979 and 1981.

model does quite well. When further examined though it can be seen that the model over predicts the percent reduction in yields for both 1979 and 1981. During 1979 the model reductions of 23.7% were twice as large as the 12.6% reductions found in the field plots analyzed. For 1981 the model reduction of 27.7% was larger than the 10.4% found in the field. Judging by how high the model yields are for a noninfested field, if the model yields would have been calculated at the lower actual reduction percentages, yield differences between the model yields adjusted to actual infestation levels and actual field values would have been greater.

Some specualtion can be made about the function used to model southwestern corn borer infestation reductions. In examining the curve from Whitworth's (1982) study that was used to determine the reductions from infestations (Table A2), it can be found that approximately a 16% reduction in yields can occur with only 1,000 TUCM's left in the season. At this time in the model however, 95% to 96% of grain fill has already taken place. Assumming that there was a 16% reduction, this would indicate that the endpoint, or point at where physiological maturity occurred would be much later. According to the model outputs, if infestations were to reduce yields 16% there would have to be at least 3,750 TUCM's left in the at this point. Making this adjustment in the curve would add 2,750 TUCM's to the end of the season and change the percent reduction=0.00016*TUCM+0.102. Using this equation, yield reductions would change from 23.3 to 19.9 for 1979 and 27.3 to 23.0 for 1981. If the assumption was made that infestations would not totally stop the movement of carbohydrates to the grain, the endpoint would have to be moved even further, decreasing the percentage of reduction even more.

As a corn growth and develpment model, CORNF shows good potential. As shown earlier, during 1979 and 1981 when mild weather conditions existed, CORNF did a relatively good job of modeling LAI, dry matter production, and yields. With this as a starting point, potential exists for modeling growth and development under stressed conditions. The greatest limitation at this time to modeling moisture stress and infestation effects is the lack of understanding in how these two factors affect the plant.

SUMMARY

Water stress in a plant is determined by the difference between relative rates of water absorption and water loss. When water loss exceeds water absorbtion, water deficits occur within the plant. When stress occurs during the vegetative stages, growth of vegetative parts is reduced. Those parts affected most are the ones actively growing. Anthesis is the time when the plant is the most sensitive to moisture stress. Stress at anthesis will reduce kernel number and ear size. During grain fill, water stress will reduce photosynthate translocated to the ear resulting in reduced kernel weights.

Another factor often reducing yields in the southwestern parts of Kansas is southwestern corn borer. These borers tunnel into the stalk, destroy vascular

bundles, girdle the base of the stalk, and reduce yields. The yield decrease resulting from southwestern corn borer infestations is thought to be caused by reduction of translocation of water, nutrients, and photosynthate within the plant. Computer models which simulate the growing conditions of a plant can be used to predict the effects of a particular stress on a plant. Of particular interest is the use of the model to sort out the complications of interactions between multiple stresses such as water stress and southwestern corn borer. CORNF is a corn growth and development model which models the phenology, leaf development, dry matter production, grain production, evaporation, and water balance in the soil profile.

Data were collected over a three year period from 1979 to 1981 from a moisture stress study infested with southwestern corn borer to validate CORNF's ability to model yields under moisture stress and infested conditions. Both 1979 and 1981 were relatively mild years compared to 1980 which was relatively hot throughout most of the growing season. Because of the relative mild, wet conditions which existed during 1979 and 1981, no significant differences were found between yields for moisture treatments in 1979 and 1981. Yield reductions from southwestern corn borer infestation were found only during 1979.

During the hot, dry year of 1980, significant differences were found between nonstressed treatments and high moisture depletion treatments occurring at both silking and blister. The yield reductions at silking were caused by significant reductions in kernel numbers and barrenness. The reduction would be expected due to stress at anthesis. The reduction at blister was caused by 31% of the plants being barren. No significant differences were found between infestations in 1980. The lack of difference is believed to be due to natural infestations in the check rows.

Data sets from 1979, 1980 and 1981 were used to test CORNF's ability to predict corn yield and development. CORNF. CORNF, which does not directly simulate the affects of southwestern corn borer infestations on the plant, was used to predict the yields of a noninfested field. The yields of the noninfested plant were reduceed by a reduction factor to get the yield for an infested plant. The reduction factor used was taken from a study (Whitworth, 1980) in which the percent reduction in yields was related to the number of thermal unit centimeters left in the season after the 5th-larval instar had occurred. The yield reductions occurring from southwestern corn borers is believed to be more severe under optimum conditions and less severe under moisture stressed conditions. To adjust for this, yield reductions were adjusted proportinally to the yield and yield reductions found in Whitworth's study. Model yields were then calculated by using the equation: YIELD=Y*(1-I)+IY*I where Y equals the yield of a noninfested field, IY equals the yield of an infested field, and I equals the percent of infested plants actually found in the plot.

When modeled yields were compared with actual yields for each plot, no significant differences were found during 1979 and 1981. Under the mild conditions of 1979 and 1981, the model did a relatively good job modeling yields. Under the relatively hot, dry conditions of 1980, the model significantly over predicted yields. Model yields were twice as high as actual plot yields on the average during 1980. This difference was due to CORNF being relatively insensitive to the stress conditions which occurred. This insensitivity is believed to be due to incorrectly modeling the relationship between soil moisture, atmospheric demand, and water stress.

While no significant differences were found between modeled and actual yields during 1979 and 1980, significant differences were found for the percent reduction in yields due to southwestern corn borer infestations. For 1979 the model estimated that yields would be reduced 23.7% which was significantly higher then the 12.6% reduction found for the same plots. For 1981 the model estimated that yields would be reduced 26.5% which was also larger then the 7.4% reduction in ear weights found in the field study. The model predicted a 16% reduction between infested and noninfested plots for the 1980 season, but there were no significant differences found in the actual data.

CORNF did do a good job modeling LAI and dry matter production. During 1979 and 1981 there were no significant differences found between modeled and actual LAI. During 1980 differences were found between modeled and actual LAI. These differences would be expected because leaf area is not affected by water stress in the model. There were no significant differences found between modeled and actual dry matter production during 1979. There were significant differences found during 1980 and 1981. Differences during 1981 could be accounted for somewhat by decreasing total dry matter production to reflect the effects of southwestern corn borer infestations on yields.

In general the model did quite well modeling yield, LAI and dry matter production under nonstressed conditions.

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APPENDIX

Table A1. Analysis of variance for yield, field study, 1979.

Source	d.f.	Yield
Total	17	--------- Mean Square --------------------
Rep	2	1720481
Tmt	2	3221045
Rep*Tmt	4	1805972**
Infest	1	7173856**
Tmt*Infest	2	1626637
Error	6	564071

** Significant at 1%
* Significant at 5%

Table A2. Analysis of variance for LAI, field study, 1979.

Source	d.f.	LAI
Total	62	--------- Mean Square -------------------
Rep	2	0.7402
Tmt	2	1.6885
Rep*Tmt	4	1.3146
Date	6	14.4390**
Tmt*Date	12	0.1224*
Error	36	0.0590

** Significant at 1%
* Significant at 5%

Tmt*Date

$$\text{LSD}(.05) = \sqrt{\frac{.05908889 * 2}{3}} * 2.0012 = .379$$

Table A3. Analysis of variance for total dry matter, field study, 1979.

Source	d.f.	Dry Matter
Total	23	-------- Mean Square --------------------
Rep	2	334.25
Date	7	32134.17**
Error	14	878.58

** Significant at 1%
* Significant at 5%

Date

$$LSD\ (.05) = \sqrt{\frac{878.589 * 2}{3}} * 2.069 = 50.07$$

Table A4. Analysis of variance for yield, kernel number, seed weight, ear weight, and percent barrenness, field study, 1980.

Soruce	d.f.	Ear Weight,g.	Yield kg/ha	Seed Weight,g.	Kernel Number	%Plants Barren
Total	102	--------------------MEAN SQUARES				
Rep	2	5075.6**	21647977**	21.6543	103129**	0.05392*
Tmt	4	6038.2**	25109877**	19.5314	76632**	0.10114**
Rep*Tmt	8	651.7	3526202**	4.6275	10444*	0.01057
Infest	3	166.9	1200286	3.6843	3096	0.02452
Tmt*Infest	12	115.9	423077	2.7100	1686	0.00849
Error	73	358.0	724131	25.1100	4867a	0.01153

** Significant at 1%
* Significant at 5%
a Error d.f.=70, Total d.f.=99

Ear Weight

Tmt 1 vs 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{651.7}{55} + \frac{651.7}{11}} * 1.96 = 15.94$$

Tmt 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{651.7 * 2}{11}} * 1.96 = 20.42$$

Yield

Tmt 1 vs 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{3526202}{59} + \frac{3526202}{11}} * 1.96 = 1300$$

Tmt 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{3526202}{11}} * 1.96 = 1569$$

Seed Weight

Tmt 1 vs 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{4.6275}{59} + \frac{4.6275}{11}} * 1.96 = 1.3847$$

Tmt 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{4.6275 * 2}{11}} * 1.96 = 1.7978$$

Kernel Number

Tmt 1 vs 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{10444}{56} + \frac{10444}{11}} * 1.96 = 66.06$$

Tmt 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{10444 * 2}{11}} * 1.96 = 85.41$$

% Barrennes

Tmt 1 vs 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{0.010573}{59} + \frac{0.010573}{11}} * 1.96 = 0.06619$$

Tmt 2, 3, 5, 6

$$LSD\ (.05) = \sqrt{\frac{0.010573 * 2}{11}} * 1.96 = 0.085939$$

Table A5. Analysis of variance for LAI, field study, 1980.

Source	d.f.	LAI
Total	119	----- Mean Square -----
Rep	2	0.6178075
Tmt	4	1.0355429
Rep*Tmt	8	0.7644397**
Date	7	18.6995700**
Tmt*Date	28	0.1135114
Error	70	0.0900704

** Significant at .01%
* Significant at .05%

Date

$$LSD\ (.05) = \sqrt{\frac{0.09007048 * 2}{3 * 5}} * 1.96 = 0.21479$$

Table A6. Analysis of variance for dry matter, field study, 1980.

Source	d.f.	Dry Matter
Total	149	----- Mean Square -----
Rep	2	893.50
Tmt	4	4844.87
Rep*Tmt	8	2110.11
Date	9	128832.72
Rep*Date	18	954.81
Tmt*Date	36	2213.49
Error	72	1450.24

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD } (.05) = \sqrt{\frac{1450.24 * 2}{3 * 5}} * 1.96 = 27.25$$

Table A7. Analysis of variance for yield, kernel number, ear weight, and seed weight, row data, field study, 1981.

Source	d.f.	Yield (kg/ha)	Seed Weight	Kernel Number	Ear Weight(kg)
Total	17	-------- Mean Sqiare	--------------------		
Rep	2	2165256	0.5803	6753	0.00227
Tmt	2	536319	0.7456	4561	0.00012
% Infestation	1	11208684*	6.1829	28	0.00031
Population	1	8425984*	18.9381*	7775	0.00320*
Error	11	1216152	3.0552	3657	0.00054

** Significant at 1%
* Significant at 5%

Table A8. Analysis of variance for yield, ear weight, seed weight, and kernel number, individual ear data, field study, 1981.

Source	d.f.	Yield	Ear Weight	Seed Weight	Kernel Number
Total	17	--------- Mean Square			
Rep	2	8870517	149	1.5	572
Tmt	2	1657825	249	1.4*	2329
Rep*Tmt	4	2207869	156	0.4	1994
Infest	1	103103	475**	2.08*	3451**
Tmt*Infest	2	756777	41	0.08	1053*
Error	6	1174860	13	0.42	165

** Significant at 1%
* Significant at 5%

Table A9. Analysis of variance for LAI, field study, 1981.

Source	d.f.	LAI
Total	61	----- Mean Square -----------------------
Rep	2	0.664422
Tmt	2	0.014685
Rep*Tmt	4	0.427214
Date	6	9.088966**
Tmt*Date	12	0.001044
Error	35	0.036348

** Significant at 1%
* Signigicant at 5%

Date

$$\text{LSD}\ (.05) = \sqrt{\frac{0.036348 * 2}{3 * 3}} * 2.0007 = 0.1798$$

Table A10. Analysis of variance for dry matter, field study, 1981.

Source	d.f.	Dry Matter
Total	89	----- Mean Square -----
Rep	2	521
Tmt	2	580
Rep*Tmt	4	433
Date	9	144918**
Rep*Date	18	52
Tmt*Date	18	49
Error	36	59

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD } (.05) = \sqrt{\frac{58.8598 * 2}{3 * 3}} * 1.986 = 7.0885$$

Table A11. Analysis of variance for actual versus model yields, 1979.

Source	d.f.	Yield
Total	188	------- Mean Square -------
Rep	2	1608941
Tmt	2	459069
Method	6	2192675**
Tmt*Method	12	47312
Error	166	550918

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}(.05) = \sqrt{\frac{550918 * 2}{3 * 3}} * 1.96 = 686$$

Table A12. Analysis of variance for actual versus model leaf area index, 1979.

Source	d.f.	LAI
Total	125	------- Mean Square ---------------
Rep	2	1.42972
Tmt	2	1.91167
Rep*Tmt	4	2.07874
Date	6	27.15400**
Tmt*Date	12	0.10326
Rep*Tmt*Date	36	0.06266
Method	1	0.01123
Date*Method	6	0.06103
Tmt*Method	2	0.22277*
Tmt*Date*Method	12	0.03251
Error	42	0.05060

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD}(.05) = \sqrt{\frac{0.06266 * 2}{3 * 3 * 2}} * 1.96 = 0.1635$$

Table A13. Analysis of variance for actual versus model dry matter, 1979.

Source	d.f.	Dry Matter
Total	47	----- Mean Square -----
Rep	2	658
Date	7	52869**
Rep*Date	14	368
Method	1	2645
Date*Method	7	596
Error	16	12366

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD } (.05) = \sqrt{\frac{368 * 2}{8}} * 2.01 = 19.279$$

Table A14. Analysis of variance for actual versus model yields for an infested and noninfested field, 1979.

Soruce	d.f.	Yield
Total	161	------ Mean Square ------
Rep	2	12034646**
Tmt	2	160937
Method	5	24140988**
Tmt*Method	10	350390
Error	142	1120053

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD } (.05) = \sqrt{\frac{1120053 * 2}{3 * 3}} * 1.96 = 977.84$$

Table A15. Analysis of variance for actual versus model percent yield reduction between infested and noninfested plants, 1979.

Source	d.f.	% Reduction
Total	80	------- Mean Square ----------------------
Rep	2	0.0111390*
Tmt	2	0.0016517
Method	2	0.0513327**
Tmt*Method	4	0.0016517
Error	70	0.0029338

** Significant at 5%
* Significant at 1%

Method

$$\text{LSD}\ (.05) = \sqrt{\frac{0.0029338 * 2}{3 * 3}} * 1.989 = 0.050786$$

Table A16. Analysis of variance for actual versus model yields of infested and noninfested fields, 1980.

Source	d.f.	Yield
Total	263	------ Mean Square ------
Rep	2	44911675**
Tmt	4	24896453**
Method	10	52507094**
Tmt*Method	40	1207247
Error	207	1261717

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD } (.05) = \sqrt{\frac{1261717 * 2}{5 * 3}} * 1.96 = 804$$

Table A17. Analysis of variance for actual versus model kernel number, 1980.

Source	d.f.	Kernel Number
Total	95	------ Mean Square ------------------------
Rep	2	77661**
Tmt	4	10402
Method	3	490705**
Tmt*Method	12	4907
Error	74	12310

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}\ (.05) = \sqrt{\frac{12310 * 2}{3 * 5}} * 1.965 = 79.608$$

Table A18. Analysis of variance for actual versus model seed weight, 1980.

Source	d.f.	Seed Weight (mg/100)
Total	167	----- Mean Square -----
Rep	2	0.0053586**
Tmt	4	0.0043381**
Method	6	0.0257807**
Tmt*Method	24	0.0004256
Error	131	0.0005420

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}(.05) = \sqrt{\frac{0.00054 * 2}{5 * 3}} * 1.96 = 0.0166$$

Table A19. Analysis of variance for actual versus model LAI, 1980.

Source	d.f.	LAI
Total	209	------- Mean Square ---------------
Rep	2	1.69509
Tmt	4	1.60701
Rep*Tmt	8	1.67685
Date	6	29.11015**
Tmt*Date	24	0.08129
Rep*Tmt*Date	60	0.07450
Method	1	12.50744**
Date*Method	6	0.36145**
Tmt*Method	4	0.18539**
Tmt*Date*Method	24	0.04249
Error	70	0.04455

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD}(.05) = \sqrt{\frac{0.745 * 2}{3 * 5 * 2}} * 1.96 = 0.138$$

Method

$$\text{LSD}(.05) = \sqrt{\frac{0.04455 * 2}{3 * 5 * 7}} * 1.96 = 0.057$$

Date*Method

$$\text{LSD}(.05) = \sqrt{\frac{0.04455 * 2}{3 * 5}} * 1.96 = 0.151$$

Tmt*Method

$$\text{LSD}(.05) = \sqrt{\frac{0.04455 * 2}{3 * 7}} * 1.96 = 0.1276$$

Table A20. Analysis of variance for actual versus model dry weights, 1980.

Source	d.f.	Dry Weight
Total	295	------ Mean Square ------
Rep	2	2321
Tmt	4	35221
Rep*Tmt	8	3621
Date	9	325590**
Tmt*Date	36	920
Rep*Tmt*Date	90	794
Method	1	154992**
Date*Method	9	5084**
Tmt*Method	4	5323*
Tmt*Date*Method	36	1050
Error	96	1155

** Significant at 1%
* Significant at 5%

Table A21. Analysis of variance for actual versus model yield, 1981.

Source	d.f.	Yield
Total	71	----Mean Square ----------------------------
Rep	2	4106371**
Tmt	2	2379235
Method	7	190567601**
Tmt*Method	14	3283165
Population	1	13820720**
Error	45	885428

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}\ (.05) = \sqrt{\frac{885428 * 2}{3 * 3}} * 1.994 = 884.49$$

Table A22. Analysis of variance for actual versus model percent reduction between an infested and non-infested field, individual ear data, 1981.

Source	.d.f.	% Reduction
Total	35	------- Mean Square ----------------
Rep	2	0.03370713**
Tmt	2	0.00311843
Method	3	0.14426466**
Tmt*Method	6	0.00151396
Population	1	0.06167621**
Error	21	0.00601830

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}(.05) = \sqrt{\frac{0.00601830 * 2}{3 * 3}} * 2.03 = 0.074238$$

Table A23. Analysis of variance for actual versus model LAI, 1981.

Source	.d.f.	LAI
Total	124	------- Mean Square -----------------
Rep	2	0.6358898
Tmt	2	0.0307655
Rep*Tmt	4	0.3723796
Date	6	19.0485700*
Tmt*Date	12	0.0057974
Rep*Tmt*Date	36	0.0268186
Method	1	0.0026529
Date*Method	6	0.0262421
Tmt*Method	2	0.0749619
Tmt*Date*Method	12	0.0055503
Error	41	0.0375745

** Significant at 1%
* Significant at 5%

Date

$$\text{LSD } (.05) = \sqrt{\frac{0.02681861 * 2}{3 * 3 * 2}} * 1.96 = 0.10699$$

Table A24. Analysis of variance for actual versus model dry matter, 1981.

Source	.d.f.	Dry Matter
Total	179	------- Mean Square ----------------
Rep	2	352
Tmt	2	2294*
Rep*Tmt	4	187
Date	9	233292**
Tmt*Date	18	254*
Rep*Tmt*Date	54	121
Method	1	21781**
Date*Method	9	3773**
Tmt*Method	2	260
Tmt*Date*Method	18	192
Error	60	142

** Significant at 1%
* Significant at 5%

Table A25. Analysis of variance for actual versus model seed weight, row data, 1981.

Source	.d.f.	Seed Weight
Total	179	------- Mean Square -------
Rep	2	0.00016614
Tmt	2	0.00060925**
Method	9	0.02505260**
Tmt*Method	18	0.00008544
Error	148	0.00011162

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}(.05) = \sqrt{\frac{0.00011162 * 2}{3 * 3}} * 1.96 = 0.00976$$

Table A26. Analysis of variance for actual versus model kernel number, row data, 1981.

Source	.d.f.	Kernel Number
Total	71	------ Mean Square ------
Rep	2	6440*
Tmt	2	1384
Method	3	114875**
Tmt*Method	6	1581
Error	58	1862

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD}\ (.05) = \sqrt{\frac{1862 * 2}{3 * 3}} * 1.994 = 40.56$$

Table A27. Analysis of variance for actual versus model yields, row data, 1981.

Source	.d.f.	Yield
Total	179	------- Mean Square -----------------------
Rep	2	458618.52
Tmt	2	314850.87
Method	9	44700243.58**
Tmt*Method	18	174491.71
Error	148	542482.34

** Significant at 1%
* Significant at 5%

Method

$$\text{LSD } (.05) = \sqrt{\frac{542482 * 2}{3 * 3}} * 1.96 = 680$$

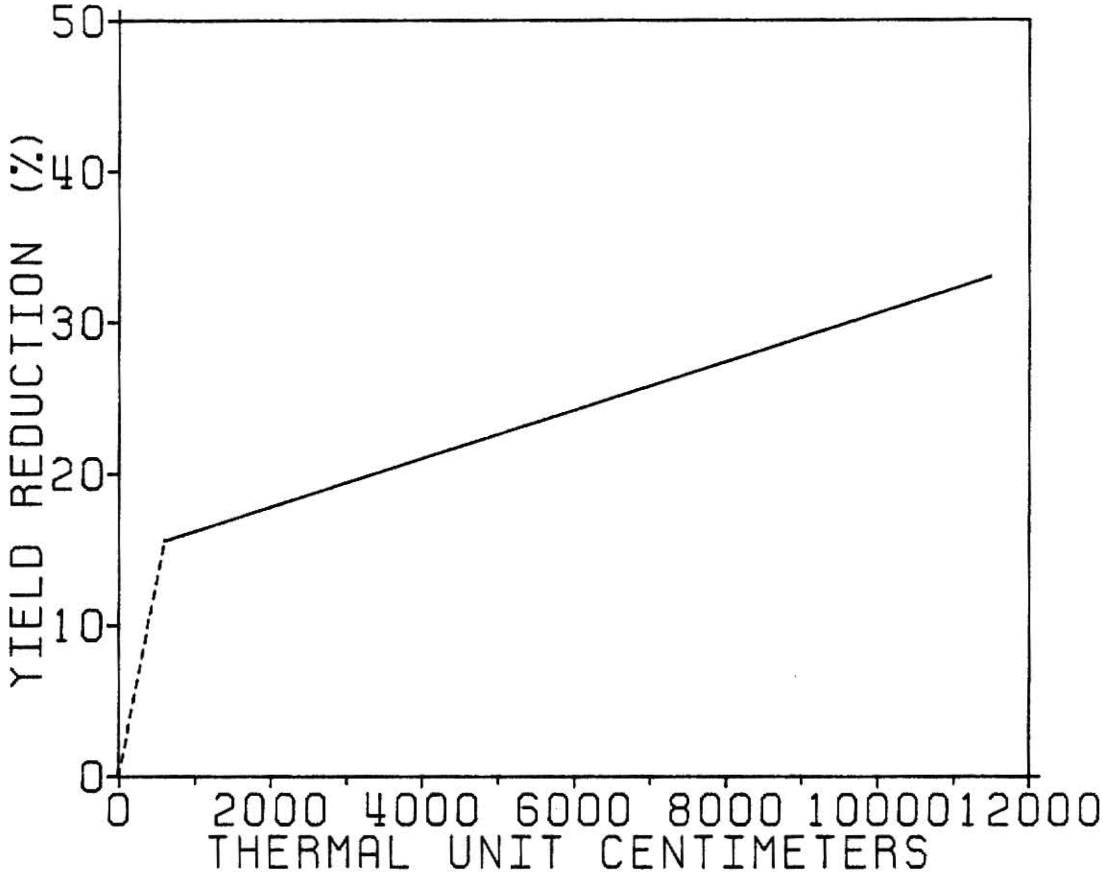

Figure A1. Southwestern corn borer function used to calculate yield reductions due to infestations.

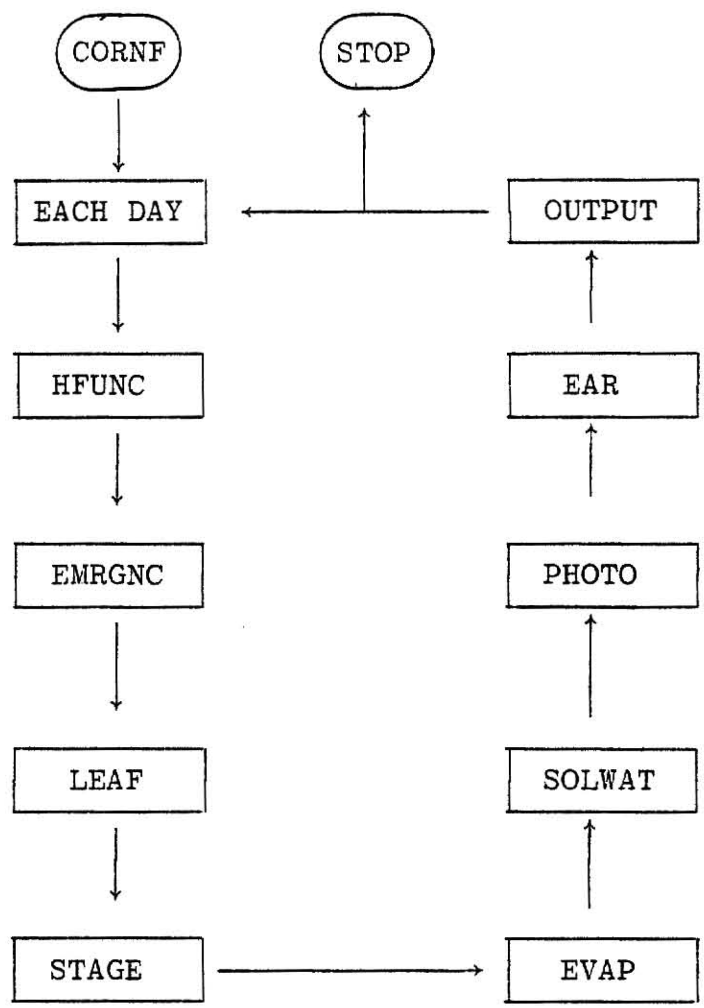

Figure A2. Flow chart of CORNF's subroutines.

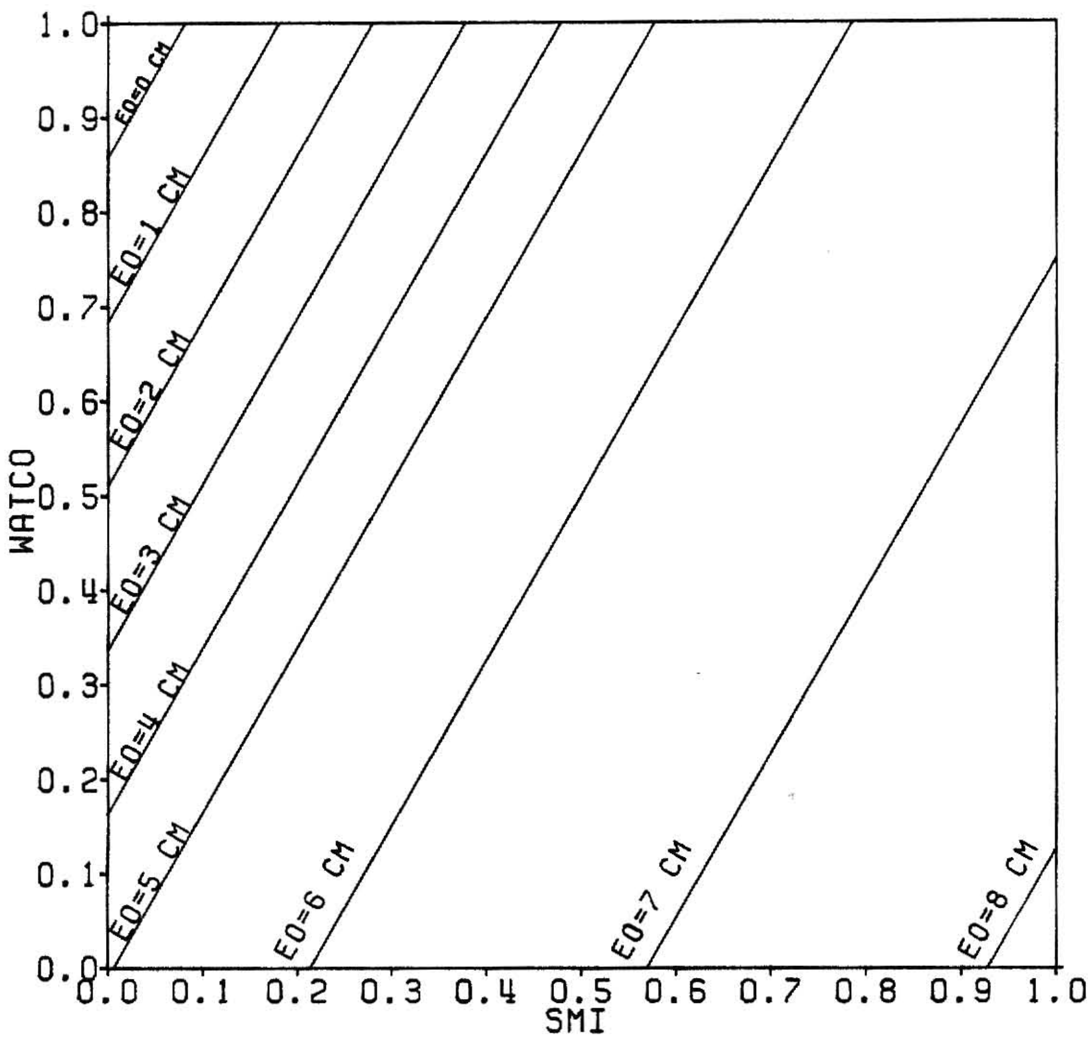

Figure A3. Watco function used in model runs.

SIMULATING MOISTURE STRESS AND SOUTHWESTERN CORN BORER EFFECTS ON CORN YIELDS

by

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B. S., KANSAS STATE UNIVERSITY, MANHATTAN, 1980

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1983

During 1979, 1980, and 1981 field studies were conducted at the Garden City Experiment Station, Garden City, Kansas in which the affect of different moisture stress treatments and southwestern corn borer infestations on corn yields were studied. Corn yields were simulated using Cornf (Stapper and Arkin, 1980) a maize growth and development model which models yield components, dry matter, and leaf area in response to environmental factors. Objectives of this study were 1) to generate actual field data sets under a wide range of moisture conditions and infestation levels, 2) to incorporate into CORNF the ability to simulate the effects of southwestern corn borer on yields, and 3) evaluate CORNF's ability to model yields under the various conditions found in the field.

Effects of southwestern corn borer on corn yields were incorparated into CORNF by reducing model yields at the end of the season using an equation developed by Whitworth (1980). Using this method, yield reductions were over predicted by CORNF 10-15% in all three years. With this overprediction in yield reduction the model did quite well predicting yields in 1979 and 1981. No significant differences were found between the average model yield and average actual yields found in the field. During the relatively hot, dry year of 1980, however, large significant differences were found between modeled and actual yields. The same general pattern followed for dry matter and leaf area comparisions.

CORNF appeared to be relatively insensitive to moisture stress and unable to accurately predict yields under stressed conditions, but did a relatively good job under optimum condtitions. The reduction factor put into CORNF which overpredicted the yield reduction resulting from the southwestern corn borer infestations seemed to be partly responsible for the lack of significant differences found between yields during 1979 and 1981.