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EFFECTS OF FLUCTUATING WATER TABLE

ON CORN ROOT AND SHOOT GROWTH

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IGNACIO AVILA

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IGNACIO AVILA

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ABSTRACT

EFFECTS OF FLUCTUATING WATER TABLE ON CORN ROOT AND SHOOT GROWTH

By

IGNACIO A. AVILA

A greenhouse study was carried out during 1988 and 1989 to achieve quantitative information on the effects that a variable water table and various inundation periods have on corn (Zea mays. L) at several stages of growth, in Wasepi loamy sand soil. These stages were: (a) emergence; (b) four leaf tips; (c) eight leaf tips; (d) 75 percent silking; (e) tasseling; (f) begin of grain fill; and (g) middle of grain fill.

Plant injury by the durations of inundation (3, 6, and 12 days for 1988; and 1, 3, and 6 days for 1989) was determined from root numbers, leaf area, shoot dry weight, yield, and water extraction from the profile. The effects of waterlogging varied according to the stage of plant growth. Susceptibility was greater at the early vegetative stage than at the reproductive stage with the emergence stage being the most sensitive to waterlogging. Inundation longer than 2 days reduced the yield but inundation from 2 to 6 days promoted shoot growth as well as the numbers of roots within a depth of 0.3 m. Both intermittent and constant water tables were detrimental to maize (Zea mays. L) when inundation lasted 12 days.

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1. INTRODUCTION

To better model the effects of a superficial water table on plant growth and root development, a greenhouse study was carried out during 1988 and 1989. The results of this study will be tested as a means to improve the computer crop growth and development model (CERES-Maize), so that it could be used to simulate plant growth and root development under superficial water table conditions. CERES-Maize, which has been used worldwide to predict irrigated and non-irrigated maize (Zea mays. L) and small grain yields, was developed for soils in which the plant growth is not affected by high water tables. As a consequence, CERES-Maize is most suitable for soils that do not develop a shallow water table or when the water table occurs deep enough so as not to affect plant development.

However, there are many agriculturally productive soils with a shallow water table that have different effects on crops, depending on, among other factors: a) species cultivated; b) climatic factors; c) depth of water table; d) duration of waterlogging at different growth stages; and e) water retention and transmitting properties of the soil.

The adverse effects on crop growth of shallow water tables have been widely studied and reported: Chaudhary, et al., (1975); Doty and Parsons (1979); Follett, et al., (1974); Goins, et al., (1966); Ritter and Beer (1969), Williamsom and Kriz (1970); Purvis and Williamsom, et al. (1964); Howell and Hiler 1974. Most of these studies assume either a flooded condition or a constant depth of the water table during the study period. The maize studies that address a fluctuating water table (Follett, et al., 1974; Howell and Hiler 1974; Howell, et al., 1976, and Zolezzi, et al., 1978) provide useful information, but do not lend themselves to the development of algorithms suitable to root and crop growth simulation under fluctuating water conditions. In fact, the point at which excess soil water reduces root development is not known at this time.

For these algorithms, quantitative information is needed regarding root and shoot growth when a fluctuating water table is present. Consequently, this experiment has been designed to evaluate such effects of a fluctuating water table at different growth stages of maize (Zea mays. L). These six selected vegetative development stages are discussed from the emergence stage through the middle of grain fill. Only by having a good understanding of how the plant develops under different stresses, how the stages may be identified, and what their individual and interactive results may be on final grain yield, can one properly assess the crop's performance at a given time.

2. STUDY OBJECTIVES

The purpose of this study is to obtain quantitative information relative to the effects that variable water tables and different durations of inundation have on corn (*Zea mays. L*) at several stages of growth.

The specific objectives of this study are as follows:

1. To determine the effects that variable water tables and different durations of inundation have on corn root and shoot development at several stages of growth, in Wasepi loamy sand soil. These stages are: (a) emergence; (b) four leaf tips; (c) eight leaf tips; (d) 75 percent silking; (e) tasseling; (f) beginning of grain fill; and (g) middle of grain fill.

2. To determine the effects that variable water tables and different durations of inundation have on above ground biomass production and grain yield for corn.

3. REVIEW OF LITERATURE AND THEORY

3.1 Leaf Area and Dry Matter in Relation to Plant Growth

Leaf shape may be profoundly modified by environmental factors Wareing (1978). He writes that the method of measuring the increase in length or height leads to an increase in size and in the case of a root or an unbranched shoot it may be convenient over a given interval of time; however, he notes, this method is not usually appropriate for a complex root or shoot system. This is because if we are studying the growth of a whole plant, it is frequently most appropriate to study changes in the dry weight of the plant, which will reflect the actual amount of new organic material synthesized by the plant. However, he notes, even a change in dry weight is not always a satisfactory measure of growth, since plant tissues may increase in dry weight due to accumulation of reserve materials such as starch, lipids and other complex carbohydrates.

The efficiency of the plant as a producer of new material is called the efficiency index of dry weight production (Wareing, 1978). A small difference in the efficiency index between two plants will soon make a marked difference in the total yield, and the difference will increase with the lengthening of the growing period. The absolute growth rate at any given time is proportional to the size of the plant at that time. The physiological basis of this latter conclusion is easily understood, for when photosynthesis has become active in a young seedling, the ability of the plant to synthesize new material (and hence increase in dry weight) is clearly dependent upon its leaf area. Therefore, as the plant grows and increases its leaf area, the rate at which new material is assimilated will increase proportionately.

Any factor affecting the size of corn plants should affect the leaf area also, Eik, et al., (1966). Even though the potential yield may be determined early in the season, the actual yield obtained will depend on the effects of various factors later in the season.

In a field experiment, Eik, et al., (1966) related leaf area to corn grain yield and found that yields tend to be linearly related to leaf-area indexes (the ratios of the leaf area of total plant cover to the land area) at the silking stage, and to leaf area index day (the integrals of the values of leaf area index over the period from silking date to 45 days after silking) over grain formation period. However, due to the apparent deviations from linearity between grain yield and leaf areas at or near silking time (observed with higher leaf areas per plant), he suggested that total leaf areas may not be as good an indicator of subsequent yield as partial leaf areas. Since some portion of the leaves near the top of the plant could be expected to change less than lower leaves throughout most of the grain formation period, and to be exposed to light more uniformly during this period, the upper leaves may reflect better the grain yields.

Eik, et al. (1966) indicated that the quantity of dry matter accumulated per plant on any date is proportional to the accumulated leaf area index days during the period of most rapid dry matter accumulation; and the quantity of dry matter produced per unit leaf area per day appears to have declined slightly with the increasing number of leaf area days.

3.2 Root Ecology and Root Physiology

A clear separation between root ecology and root physiology does not exist Bohm (1977), because, in every case, root growth is governed by both external and internal factors. Important ecological factors which influence root growth are bulk density, strength, soil water, toxic chemicals, soil resistance, and air and nutrients in the soil (Bohm, 1977).

The primary root system consisting of the radicle and seminal roots (usually 2 or 5 roots) emerges from the basal end of the seed as it germinates Hanway (1971, and Kiesselbach 1949, in Sprague, 1977). These roots serve

the plant until 2 or 3 weeks after plant emergence, then, they cease to develop and usually die. The permanent (nodal) root system develops from the nodes of the stalk after the seedling emerges from the soil. The number of roots per node increases as each successively higher node emerges. By 2 or 3 weeks after seedling emergence this becomes the major root system of the plant and serves throughout the remainder of the season.

The depth of extension of roots in deep soils is a linear function of time until tasseling (Mengel and Barber, 1974). From tasseling to the start of grain fill, brace roots develop. During the rapid grain filling stage, total root length and root dry weight do not increase and may, in fact, decrease before the grain matures Mengel, et al., (1974). Root length density increases rapidly between 50 and 80 days and then decreases. Full silking and maximum root length occurs at approximately 80 days.

Stypa, et al. (1987) studying the effect of three subsoil bulk densities (artificial medium, 1.5 and 1.8 Kg m^{-3}), nutrient availability, and soil moisture, on corn root growth in the field, concluded that growth was not reduced by a subsoil bulk density of 1.5 Kg m^{-3}; the artificial medium provided little mechanical impedance, and roots did not develop into unstructured soil with a bulk density of 1.8 Kg m^{-3}. Likewise, they concluded that root growth and distribution were not affected by marked changes in soil fertility distribution nor by marked differences in soil water content.

3.3 Light Sensitivity of Roots

Light is necessary for the observation, counting, or measuring of roots behind glass walls Bohm (1977). The question, therefore, is how the light during the recording time affects root growth. Bohm (1977) found that continuous exposure to daylight hastened suberization and minimized development of the lateral roots of apple trees. Exposure to light for 20 minutes to 2 hours per day caused some reduction in root length. At the weekly exposure of 30 minutes, the reduction in root length was statistically significant in the early summer when light intensity is high, but not significant in late summer and autumn. A typical negative heliotropic response is not reported even upon continuous exposure to daylight.

According to Pearson (1974), roots of maize, cotton, soybeans, and tomatoes did not show difference in elongation rate on short illumination in front of the glass plates. The short time when the roots were exposed to light during recording in most cases had not strong influence on the results Bohn, et al., (1979), so weak light effects during the short time of recording can be

neglected in the solution of most ecological research questions.

3.4 Methods of Root Observation

The methods of root observation may be grouped according to the classification of Shuurman and Goedewaagen (1971): 1) excavation methods; 2) monolith methods; 3) auger methods; 4) profile wall methods; 5) indirect methods; 6) container methods; 7) other methods.

This research will refer to the profile wall methods (intersection methods), and the indirect methods (neutron probe). The glass methods allow a continuous study of the roots from one or more plants during their entire life span. Certainly, the roots are not growing in completely natural surroundings when they hit the glass panel and grow along it, but this does not seem to be as serious as might be thought, Bohm (1977). A glass panel can be considered to be like a large smooth flint stone or a grain of sand. It was commonly found by the above research workers, that root growth behind the observation windows was much greater in the first year after installation than in the following years, in consequence, it is recommended that glass windows for root observations should be installed several months before the experiment starts.

Using the interception methods instead of tedious direct measurements, root length can be calculated more rapidly by counting the interceptions between roots and regular pattern of lines. Bohm, et al., (1977) used this kind of line intersection method. He counted the total number of roots intersecting the vertical and horizontal lines of a grid on the glass observation windows. Comparisons of estimated intersection data with the measured actual root length showed a linear relation between the number of intersections and the actual root length.

Independently of this practical line intersection method, Newman (1966) developed a theory that root length can be estimated by the equation

$$R = A N/2 H$$

where R is the total length of roots in the field of area A and N is the number of intersections between the roots and random straight lines of total length H.

In recent years Newman's method has been modified and improved by several research workers (eg. Marsh, 1971; Tennant, 1975). The main change is that for the area over which the roots are spread, any convenient size of grid system can be used. Based on the consideration of Marsh (1971), Tennant (1975), Newman's formula can be simplified. For a grid of indeterminate dimensions the intersection counts can be converted to centimeter measurements using the equation :

Root length(R)= 11/14* # of intersections(N)*(Grid unit).

Upchurch and Ritchie (1983) in a root observation study, compared root length densities determined by mini-rhizotrons installed in four orientations with respect to plant rows, with root length density determined by soil sampling. Their results indicated that there was a linear relaticnship between the two techniques and that installation orientation of the mini-rhizotrons was not optimal when only the depths greater than 200 mm were included. Because of the variability of the results from individual mini-rhizotrons, the results from several tubes had to be averaged before there was a satisfactory correlation with the bulk soil root length density. In this study, the number of observed roots intersecting the mini-rhizotron in the 20 mm wide strip were counted for each 100 mm length of the tube. These counts were independent of the length or the diameter of the roots at the interface. If the root branched while intersecting the tube it received one count for the main root and one for each branch. Whenever a root at the interface crossed the depth indication groove it received one count in each depth interval. Root counts were converted to root length densities (RLD), mm/mm^3, using the equation:

$$RLD = Nd/Ad$$

where N is the number of intersecting roots, d the outside tube diameter, and A is the area of tube observed. (The tube diameter is retained in the equation for dimensional consistency). In using this equation they assumed that growing roots intersect the tube at various angles with equal probability; and that the average length of root displaced by the tube, if the roots could continue growth at the angle of intersection, is equal to the tube's outside diameter. Possibly for large diameters, a tortuosity term is needed since roots do not grow in straight lines.

The indirect methods are based on the principle of determining changes in water or nutrients in different soil layers between successive sampling occasions, and from these changes inferring information on the root distribution in a soil profile. Such indirect methods seem appropriate for ecological investigations, especially if the activity and not the absolute amount of roots in a soil profile is the primary research aim, Bohm, et al., (1977). The efficacy of these methods depend on several important assumptions though.

The neutron scattering method (an indirect method), is based on the principle that fast neutrons are slowed down and scattered more by hydrogen atoms than by other atoms. As the concentration of hydrogen atoms in the soil profile is much higher in soil water than in either the inorganic or organic compounds, the method can be used for determining soil water content, Bohm, et al., (1977), and for estimating rooting density in soil profiles, Slack, et al.,(1975); Cahoon and Stolzy, (1959). The number of neutrons attenuated in the soil is proportional to the volumetric water content. Since, however, the count rate recorded is not linearly related to the water content, suitable calibration is necessary. Results can be falsified by a high content of organic material, or atoms of boron, iron or chlorine.

In spite of some good agreements between water extraction and root data obtained by direct study methods, the same assumptions and drawbacks outlined for the gravimetric method also apply to the neutron method. In addition, with the neutron method the limitations of the accuracy of measurement in layers 0-150 mm close to the soil surface should be mentioned. Although appropriate correction factors can be applied, the information obtained should be interpreted with caution.

3.5 Moisture Stress

The atmospheric demand for water is a function of the energy available (solar radiation), the movement of moisture from the evaporating surface (wind), the dryness of the atmosphere (humidity), and temperature of the air

Sprague (1977). Temperature alone does not affect evaporation directly, except as it affects the temperature of the evaporating surface, but it does affect the dryness of the atmosphere by varying its capacity to hold water. Radiation is usually considered the major factor in controlling the atmospheric demand.

Water use varies with the stage of development of the corn crop, Sprague (1977). Early in the growing season the loss is primarily evaporation from the bare soil. As the crop cover increases, transpiration becomes an increasingly dominant factor. Ritchie and Burnett (1971) found that a leaf-area index of 2.7 was necessary for cotton and sorghum (Sorghum bicolor. L.) to reach an evaporation-transpiration rate of 90 percent of the potential evaporation when soil evaporation was small.

The amount of water use may vary with stand Sprague (1977). At very low stands water use is low. As stands increase, water use increases rapidly and then decreases slowly with increasing stands. There is a maximum point at which increased stands will not increase the utilization of solar energy in evapotranspiration.

Beer, et al. (1967), working in Iowa, found a negative relationship between the amount of water required by irrigation to maintain soil moisture above 60 percent of the available water-holding capacity, and the maximum corn yield obtained with several levels of irrigation. The less irrigation water required (i.e., the better the natural moisture of the environment), the higher the yield.

Ritter and Beer (1969) showed that flooding a Cumulic Haplaquoll early in the season, was more detrimental to corn grain yields than flooding it late in the season. At a high soil nitrogen level yields were decreased in one year by 18 percent when corn 150 mm tall was flooded for 72 hours; in the second year yields were decreased 6 percent by flooding for 96 hours. Lal and Taylor (1969) demonstrated that intermittent flooding early in the growing season on a typic Hapludalfs, reduced corn yields more than did constant water tables of 0.15 to 0.30 meters in depth. Plants grown under continuously wet conditions often develop greater intercellular air space, and consequently greater gaseous exchange between leaves and roots.

Corn has been considered reasonably tolerant to low concentrations of oxygen in the soil, Lal and Taylor (1969). Growth damage due to flooding or high water contents on various soils is probably caused by many things, including low oxygen or high carbon dioxide concentrations in the soil air, the plant's respiration rate at the time of flooding, reduced nutrient uptake, and/or toxic chemicals produced by reducing conditions.

Das and Jat (1972) demonstrated that corn cultivars differ in root porosities when grown under conditions of high soil water table. Possibly corn cultivars could be bred for adaptation to high soil water conditions. They also showed that growth in poorly drained soils may be aggravated by traffic compaction.

3.6 Growing-Degree Unit Concept

The growing-degree units or heat units refer to another factor of the different development stages. The actual number of days for corn to reach maturity varies widely with changes in the environment, although cultivars are often designated as a certain number of days to maturity. This approach has been proposed so as to provide a more constant maturity index for varying weather conditions, as long as the other environmental conditions are near optimum Sprague (1977).

The growing-degree-unit (GDU) approach is based on the use of air temperature data, so it is not really a heat unit, but a temperature unit number. It has also been called thermal units Berbecel, et al. (1964, cited by Sprague, 1977). In using it, accumulations of values above a selected base (10 degrees C) are made. The exponential index assumes that for a 10 degrees C increase in temperature the growth rate doubles. This method assigns high efficiencies to temperatures too high for optimum growth. A physiological type of index is one based on the physiological response of the plant to temperature and is often been developed from data obtained from controlled conditions. The third basic type, the remainder index, accumulates units above a base temperature, and is calculated by:

daily max temp + daily min temp/2 - 10 degrees C = GDU

Any maximum temperature above 30 C is put in the equation as 30 and any minimum below 10 C is designated as 10. Growing-degree units can be calculated for any stage of development, or for the total time from planting or emergence to maturity. Another modification to the basic daily heat-unit equation, is that proposed by Newman and Blair (1969, in Sprague (1977). They suggested that when the mean temperatures average 23.9 C (75 F) or higher and the maximum exceeds 32.2 C (90 F), subtract that result from the degree day accumulation for that day. This procedure largely eliminates the excessive accumulation of degree days in dry, hot climates where corn is usually under water stress during the hot part of the day.

Cross and Zuber (1972) tested 22 different growing-degree unit methods in Missouri and found that daily measurements gave almost as good results as the use of hourly temperature data. Also, they found that the best base temperature for estimation of flowering was 10 C, with 30 C optimum. Excess above 30 C was subtracted to account for high temperature stress.

Gilmore and Rogers (1958) compared 15 different methods of calculating heat units as a method of measuring maturity in corn, and they concluded that "effective degrees" (the number of heat units required for silking) rather than "degree days" appears adequate in classifying the maturity of genetic material and sufficiently accurate in applying that classification in different areas and different times. they reported a range of 1363 - 1593 of effective degrees at silking for 4 hybrids (Texas 30, 34, 36, and 38).

3.7 Stages of Growth and Development and the Effects of Weather on Certain Periods of Plant Growth

When we consider the multiple forms of differentiation in the plant it is evident that this occurs at various levels Wareing (1978). At the highest level, there are changes in the plant body as a whole, as seen in the division into root and shoot. Within the shoot one can observe the change into various organs such as stems, leaves, buds, and flowers, and within each of these organs there is differentiation at the cellular and tissue level. These three levels of differentiation also constitute a series of successive stages in time: there is first formation of root and shoot in the embryo, and this is followed, as a result of the activities of the apical meristems, by the formation of organ primordia.

Wareing (1978) writes that in addition to the first step in differentiation (viz., the formation of root and shoot), certain other changes occur during the life cycle of seed plants. These changes must be regarded as aspects of differentiation, the most important of which is the transition to the reproductive phase involving a profound change in the structure of the shoot apex. According to Wareing (1978), in some species the onset of flowering is controlled by environmental factors, but in other species it appears to be determined more by progressive changes occurring during the development of the plant itself than by environmental factors. Often these progressive physiological changes are reflected in morphological characters, such as leaf shape, in which a gradient up the stem may frequently be seen.

Hershey (1934, and Paddick 1944, quoted by Sprague, 1977) divide corn plant development into five different stages, each with its own relation to final yield. Hanway (1971) proposes a 10-stage plant development system ranging from 0, when the plant tip emerges from the soil, to 10, when the plant is physiologically mature.

Sprague (1977) in his book discusses seven different phases referenced in terms of Hanway's stages: 1) before planting, 2) planting to emergence, 3) early vegetative growth from emergence to flower differentiation, 4) late vegetative growth from the beginning of rapid stem elongation (plant height near 50 centimeters) to tasseling, 5) tasseling, silking and pollination, 6) grain production from fertilization to physiological maturity of the grain; and 7) maturation or drying of the grain. Stages one through three include the seedling stage and early leaf growth up to five to six weeks after emergence.

During stages three to four the leaf area of the plant becomes fully developed and the tip of the tassel emerges at the end of stage four. Maximum stalk height, stalk diameter, and leaf area may be reached at the end of stage four.

Stage five, (tasseling, silking, and pollinitation), is a critical stage in the corn plant Sprague (1977). The number of ovules that will be fertilized is being determined. Stress, both moisture and fertility, can reduce yields drastically. The first two weeks of the grain production period are a time of rapid growth of the ear shoot, husks, cobs, and young kernels. The cob has attained nearly full size but little grain weight has been added. From stages five to eight, there is a rapid increase in grain weight. In about a 5-week period, almost 85 of the grain dry weight may be produced. By stage seven, physiological maturity has been reached, i.e., the maximum dry weight of grain has been attained.

3.7.1 Planting to Emergence

The period from planting to emergence depends on the temperature, moisture, and aeration of the soil, and the vigor of the seed Sprague (1977). Before germination, the seed absorbs water and swells. With warmer temperatures, less water has to be absorbed, so that germination will start earlier and proceed faster, assuming water is available. During this stage, development is affected directly by soil temperature and indirectly by air temperatures.

In tests using a silt-loam soil, Wolfe (1927, in Sprague, 1977) demonstrated that the rapidity of germination increased with increased soil moisture up to 80 percent of saturation. At 10 percent saturation, there was no germination because of lack of water, whereas at 100 percent saturation or above, germination was retarded or prevented because of a lack of oxygen. On a silt-loam soil held at 50 percent to 60 percent moisture, a soil temperature of 35 C (95 F) gave slightly more rapid germination than one of 30 C (86 F) and considerably more rapid germination than one of 25 C (77 F).

Another factor to consider is air temperatures, which are often used because of their availability and a lack of soil-temperature data. Soil temperature closely follows air temperature, i.e., there is little daily heat accumulation in the soil.

3.7.2 Early Vegetative Growth from Emergence to Flower Differentiation

During the early part of its life, the corn plant requires a limited amount of moisture for the small growth that takes place Slatyer (1969). Because of this, the initiation and differentiation of vegetative and reproductive primordia in the apical meristem, as well as the enlargement of the cells, are very sensitive to water stress. Maranville and Paulsen (1970), reported that stress shortly after emergence decreases the starch and chlorophyll content of seedlings, but if the weather is somewhat dry at this time, the roots will penetrate deeper into the soil, and the plant seems better able to withstand later dry weather; this may more than offset any immediate detrimental effects of stress.

Salter and Goode (1967, cited by Sprague, 1977), stated that Russian workers found that stress during the early vegetative stage had little, if any, effect on final

yield; deeper, more extensive rooting may be the reason. Root temperatures influenced the proportion of shoots to roots. A relatively greater increase in shoot weight than in root weight occurred as the root temperature was increased from 5 to 40 C (41 to 104 F). Root growth at 40 C (104 F) was inhibited while shoot growth proceeded at a retarded rate, which resulted in a progressive increase in shoot-root ratio. Root temperature did affect the uptake of nitrate, phosphorus, potassium, and magnesium, Salter and Goode (1967, cited by Sprague, 1977). In general, the root temperatures of 5, 10, 15, and 40 C (41, 50, 59, and 104 F) retarded uptake of N, P, and K.

Grobbelar (1963, quoted by Sprague, 1977), reported under his experimental conditions that the internal diffusion pressure of the plant was decreased by a hampered absorption of water of the roots, which decreased the transpiration rate at temperatures below 20 C (68 F) and at 40 C (104 F). According to him, this seemed to be responsible for the immediate decrease in growth of the shoot at these temperatures. In addition, the retarded growth at 20, 25, and 35 C (68, 77, and 95 F) may also have been the result of a relatively higher internal diffusion pressure deficit, although no differences in transpiration rate could be determined. In general, Grobbelar (1963) reported that growth rates followed the temperature curve at night and the moisture supply curve during the day.

Trought and Drew (1982) studied the mechanism by which the response of plants to waterlogging can be modified by soil temperature, with the conclusion that waterlogging damage was greater in plants at higher soil temperatures when the plants were compared at the same chronological age. However, when they compared at the same growth stage, the response to soil temperature was little different i.e plants subjected to waterlogging for a long time at low soil temperatures exhibited a similar reduction in growth as those subjected briefly at higher temperatures. In the same study they found that waterlogging at all soil temperatures (6 - 18 C) caused the shoot fresh and dry weights, final leaf lengths, and total root dry weight, to be smaller than aerated controls. However, plant growth in absolute terms was greater in waterlogged soil at the higher temperatures (14 and 18 C) than in well aerated soil at lower temperatures (6 and 10 C).

Ragland, et al. (1965, cited by Sprague, 1977), found that the rate of increase in leaf area of corn planted very early was more highly correlated with air temperature than any other element they measured, while that of late planted corn was positively and equally correlated with temperature and relative humidity. Solar radiation, precipitation, black bulb evaporation, and wind were not significantly

correlated with leaf area increases. Flooding reduces corn yields; the time and the length of the flooding period affect the yield reduction.

In a greenhouse experiment, Mittra and Sticker (1961) reported that flooding at five-leaf stage reduced dry matter 7.5 percent if flooded 7 days, 34 percent if flooded 14 days, and 43 percent if flooded 21 days. Dry matter was harvested 21 days after flooding. Ritter and Beer (1969) found that flooding when corn was 15 centimeters in height for 72, 48 and 24 hours, reduced corn yields by 32, 22, and 18 percent respectively, at a low nitrogen fertilizer level. At a high nitrogen level, these reductions ranged from 19 to 14 percent in 1 year to less than 5 percent the next year.

3.7.3 Tasseling, Silking and Pollination

This is a very critical stage in the corn plant. Sprague (1977). In this stage, the number of ovules that will be fertilized is being determined. Both moisture and fertility stress at this stage can have a serious effect on yield.

Claassen and Shaw (1970) found that stress imposed at 6 percent silking reduced yield only 3 percent per day, but at 75 percent silking the yield reduction was 7 percent per day with moisture stress. A stress imposed at 75 percent silking and combined with a fertility stress gave a yield reduction of 13 percent per day with a large reduction in the number of developed kernels. Voladarski and Zinevich (1960) also reported that stress could reduce the number of grains per ear.

Berbecel and Eftimescu (1973), found that maximum temperatures above 32 C (90 F) around tasseling and pollination speeded up the differentiation process of the reproductive parts and resulted in higher rates of kernel abortion. If too many kernels are aborted, the total sink size may limit yield, but under normal conditions the number of kernels is not as important as on rice Yoshida (1972), (cited by Sprague, 1977). The maximum size of the kernel of rice is genetically determined so that a change in number will cause a change in total yield.

3.7.4 Grain Production from Fertilization to Physiological Maturity of the Grain

During the ear-filling stage, significant reduction in yield can occur from moisture stress. Mallett (1972), (in Sprague, 1977), subjected corn to stress starting at 10, 20, 30 and 40 days after silking and maintained the stress for up to 8 days. Four days of stress caused an average yield reduction of 4.3 percent per day of stress at each of the times that stress was imposed. Higher reductions occurred where some degree of fertility stress was confounded with the moisture stress.

Data of Claassen and Shaw (1970), also indicate that less yield reduction occurred as a result of stress late in the season. According to them, this reduced damage may have been because of the difficulty of imposing as severe a degree of stress as earlier in the season, because of the lower moisture demand situation that occurred.

3.8 Crops Response to Inundation

Howell, et al. (1976), working with grain Sorghum response to inundation at three growth stages, found that grain sorghum yields were reduced by approximately 25 to 30 percent when inundation for 12 days occurred prior to anthesis. Inundation after anthesis did not reduce grain sorghum yield. Sorghum growth rates were reduced during inundation prior to anthesis. Twelve days of inundation during early vegetative growth reduced the potential maximum leaf area and, on the other hand, the vegetative growth approached the growth rates of the control treatment; however, the potential yield was never regained.

Alvino and Zerbi (1986), dealing with water table level effect on the yield of irrigated and unirrigated grain Maize (Zea mays. L.), state that at the vegetative and flowering stage plant heights reached their maximum values with shallow water table under both irrigated and rained conditions. The moisture content of grain decreased as water table depth increased. In this experiment, they noted that the highest yields were obtained on a very shallow water table, even though the grain water content increased with decreasing water table levels.

Baser, et al. (1981), (cited by Alvino, 1986), found that maize plants had maximum growth when the water table was at 0.3 meters compared with 0.15 and 0.48 meters. Likewise, Chaudhary, et al. (1975), reported that a water table 0.60 to 0.90 meters depth can be a valuable natural water resource for corn production in a relatively dry year, but hazards of poor aeration would increase in a wet year, and they also say that water tables deeper than 1.2 meters reduce water availability to the crop.

In another study, Williamson and Willey (1964), showed that tall fescue yielded approximately the same with water table depths of 0.23 and 0.43 meters, and the reduction in yield with the 0.20-meter water table depth was attributed to leaching nitrogen from the root zone. Williamson and Kriz (1970) evaluated the response of agricultural crops to flooding, depths of water table and soil gaseous composition, and they stated that short-term oxygen deficiency can: (1) cause increased resistance to the movement of water through the roots; (2) reduce respiration; (3) reduce nutrient uptake; and (4) promote formation of toxic products in the plants.

Rattan and George (1969), working with constant and intermittent water table depths, at two levels of nitrogen and two levels of micronutrient (Zn and Cu), reported that constant water table depths, intermittent flooding, and nutrient levels, had significant effects on corn grain yields. They also concluded that grain yields were depressed by water table depths of 0.15 and 0.30 meters; however, intermittent flooding early in the growing season reduced yield more than a constant water table. N, Cu, and Zn applications increased yields under well drained conditions, and for a constant water table depths of 0.15 and 0.30 meters. The uptake of N and Zn by corn was significantly reduced by high water table levels and by intermittent flooding. They also found that the drainage water showed high concentrations of ammoniacal N, particularly under intermittent flooding.

Follett, Allmaras, and Reichman (1974), conducted studies on distribution of corn roots in sandy soil with a declining water table, at silking stage. They found that shoot growth was maximum at intermediate water table depths, and grain yields were lower at either shallow or deep water tables and higher at medium water table depths. Generally, 50 percent of the total root weight was above

10 centimeters and rooting depth increased as the underlying water table depth increased, but shoot growth decreased when the water table was shallow enough to cause poor aeration or was deep enough to decrease water availability. Maximum top growth was observed at intermediate water table depths.

3.8.1 Effects of Excess Water on Ethylene Production by Plant Tissues

The flux of ethylene out of roots and into water increases with temperature, assuming all other things remain unchanged (Roberts, et al., 1985), but in anaerobic conditions almost no ethylene is released.

Roberts (1985) found ethylene to be a powerful promoter of coleoptile extension and a growth stimulant in plants. They showed that rice coleoptile extension was faster when ethylene was combined with oxygen deficiency than when either treatment was given separately. In their experiment they demonstrated that elongation (when measured in sealed containers for 5 days) was inhibited by over 50%, when carbon dioxide and ethylene was removed from the gaseous environment. They concluded that carbon dioxide promotes elongation and plays a significant role in the responses of roots at or near the soil surface, where oxygen from the air is available for the reaction to produce ethylene (ethylene biosynthesis).

Roberts (1985), reported that roots of different species (Vicia faba, rice, tomato, and barley), in well-aerated conditions elongate faster when exposed to small concentrations of ethylene, but more slowly when that concentration is increased above a certain value ($0.1x10^{-6}$ m^3 m^{-3}). In some species poor aeration stimulates the development of gas-space within the root cortex and the outgrowth of preformed adventitious roots (a two week- old maize plant). These roots appear to replace those afflicted by anoxia (for wheat see Trought, 1982); (for maize see Norris, 1913 in Roberts, 1985); (for rice see Katayama, 1961).

Oxygen deficiency and ethylene may inhibit phosphorus uptake but on the other hand, an excess of phosphorus can slow ethylene formation (Roberts, 1985); these effects, however, may require further study.

Root excision experiments Jackson (1976); Bradford and Dilley (1978); suggested that the presence of anaerobic roots provide a precursor of ethylene biosynthesis that passes up the plant in the xylem to the aerial shoot, which, with the available oxygen, would permit its conversion to ethylene.

3.9 Adaptability of Maize to High Soil Water Conditions

Das and Jat (1972), grew corn (Zea mays. L) in furrows and ridges in a lowlying sandy clay loam soil, under high soil water conditions, and the root porosities of 44-day-old plants were studied. They found that plants grown in furrows had higher root porosities than those grown in ridges. This observation indicated that plants growing in the furrows have partially adjusted to high soil-water conditions by increasing air space of roots. On the other hand, he said that changes in root porosity, an inherent characteristic of some plants, may enhance their ability to tolerate excess water in soil, as observed by Kramer (1951) and Luxmoore, et al. (1969), (cited by Das, et al. 1972).

4. METHODOLOGY

The experiment was performed on seed corn plants (Hybrid Great Lakes-188) growing in 22 soil cores in a climate-controlled greenhouse. This hybrid which is a modified single cross, was selected in this research because it was an early hybrid, produced by GREAT LAKES CO.

The 22 containers were watertight steel cylinders, 1.20 meter deep by 0.76 meter in diameter, filled with Wasepi, coarse-loamy, mixed, mesic Aquollic Hapludalf obtained from the Water Management for Agricultural Production Project Site, located N 1/2, SE 1/4, section 30, T7N, R2W; in St. Johns, Michigan. The cylinders were filled with this soil in 50 millimeter layers, using 23 Kilograms (51 pounds) of moist soil per layer so as to obtain reasonable uniformity and to simulate the layering of the soil in situ. Before putting the soil into the barrels, it was sieved to remove all stones. The upper layer consisted of 0.30 meter of topsoil. Each cylinder was subject to two cycles of wetting and drying to permit the material to set in order to approximate the bulk density of the soil in the field. After the wetting and drying, vertical tubes were installed in the center of the cylinders allowing access to a neutron probe so as to monitor the water content of the soil profile. Samples every 0.15 meter (0.15, 0.30, 0.45, and 0.60 meter) were taken to calculate the bulk density and also the volumetric water content; the latter is needed to perform the calibration curve for the neutron probe.

Three horizontal mini-rhizotrons 17 mm inside diameter inserted horizontally were placed at depths of 0.15 meter; 0.30 meter; and 0.45 meter. Careful installation of the mini-rhizotrons was made to ensure that: a) no compaction occurs and, b) to minimize voids around the tube which might encourage proliferation of roots into the voids. A highly refined fibre optic boroscope was used to enable examination and counting of the roots. The tubes were closed at the end, and 100 mm of the plastic tubes which protruded from the barrel were wrapped with a dark tape to prevent light from shining into the tubes.

To facilitate drainage, the cylinders were provided with nipples at 80 mm from the bottom and covered with 20 mm of pea gravel. The water table elevation for each cylinder was controlled by a self-dispensing water supply (Figure 1) at three levels: 0 meter (completely flooded in 1989's experiment); 0.30 m below the soil surface (1988's experiment); and 1 meter below the soil surface. The water supply system consisted of a calibrated closed

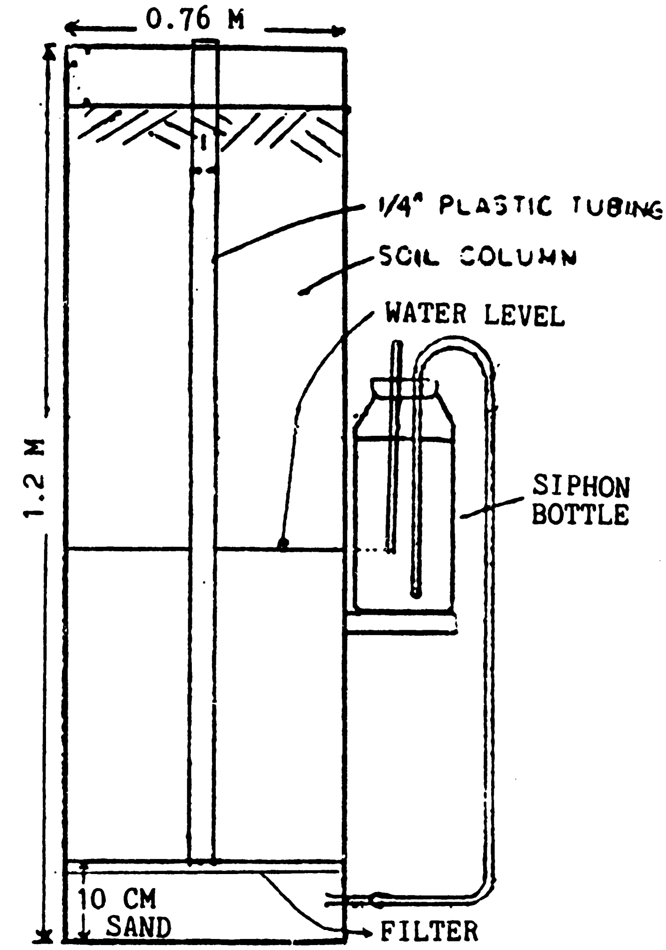

Figure 1. Soil column for water table treatments.

water container with valves attached to the nipples at 80 mm from the bottom of the cylinders. During water table drawdown, the cylinder's valve was opened and the system was converted to a drainage mode. The root observation was made within 0.76 meter of length for the horizontal mini-rhizotron, by counting the visible roots crossing the horizontal transect and noting the color and condition of the roots observed. This observation was made weekly. Water was added from the surface to each container on a regular basis so that the plants always had an adequate amount of moisture for optimum growth.

The treatments needed to meet the study objectives for 1988's experiment were:

Treatment #1: At the silking stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a three day duration.

Treatment #2: At the silking stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a six day duration.

Treatment #3: At the silking stage, raise the water table from 1 meter depth below the soil surface to 0.30 meter, for a twelve day duration.

Treatment #4: At the beginning of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a three day duration.

Treatment #5: At the beginning of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a six day duration.

Treatment #6: At the beginning of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a twelve day duration.

Treatment #7: At the middle of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a three day duration.

Treatment #8: At the middle of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter, for a six day duration.

Treatment #9: At the middle of grain fill stage, raise the water table from a depth of 1 meter below the soil surface to 0.30 meter , for a twelve day duration.

Control #1: Maintain the water table at 0.30 meter depth throughout the study period.

Control #2: Maintain the water table at 1 meter depth throughout the study period.

The treatments needed to meet the study objectives for 1989's experiment were:

Treatment #1: At the emergence stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a one day duration.

Treatment #2: At the emergence stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a three day duration.

Treatment #3: At the emergence stage, raise the water table from 1 meter depth below the soil surface to 0 meter, for a six day duration.

Treatment #4: At the four leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a one day duration.

Treatment #5: At the four leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a three day duration.

Treatment #6: At the four leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a six day duration.

Treatment #7: At the eight leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a one day duration.

Treatment #8: At the eight leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a three day duration.

Treatment #9: At the eight leaf tips stage, raise the water table from a depth of 1 meter below the soil surface to 0 meter, for a six day duration.

Control #1: Maintain the water table at 0 meter depth throughout the study period.

Control #2: Maintain the water table at 1 meter depth throughout the study period. The treatments and controls were replicated within each experiment.

The order of the stages chosen began with the predicted least sensitive stage and ended with the one most sensitive to increases in water table, which are: emergence, 4 leaf tips , 8 leaf tips, silking, beginning of grain fill, and middle of grain fill .

The parameters measured or observed to obtain values that could be used to quantitatively evaluate the preceding effects on corn dry matter production for each treatment and controls, were as follows:

1) Stalk diameter and length.
2) Length and width of leaves.
3) Soil water content vs depth for selected time intervals.
4) Number of active roots visible in the boroscope vs depth for selected time intervals.
5) Water supplied vs time in days.
6) Mature plant stem, ear, and leaf weight.
7) Mature plant root depth and length.
8) Sowing, germination, emergence, 4 leaf tips stage, 8 leaf tips stage, 75 percent silking, beginning of

grain fill, middle of grain fill, and physical maturity dates.

9) Daily air temperature

10) Water used in the soil profile (neutron probe).

The measured and observed parameters were used to calculate and report the following additional parameters:

1) Root length and depth vs time in days.

2) Above ground biomass vs time in days.

3) Leaf area vs time in days.

The plant measurements, soil water content, and water supplied are essential for application of the data for modification of the plant growth computer simulation model CERES-MAIZE (Jones and Kiniry, 1986). The intensity of the measurements taken increased with the one time water elevation and continued throughout the plants' maturity.

Corn for 1988's experiment was planted in June 24th, and harvested in September twenty-first (90 days). The corn experiment for 1989 started in April 13th, and harvested on July second (85 days).

5. RESULTS AND DISCUSSION

The crop cycle was 90 days for the experiment in 1988 and 85 days for 1989. Dates of planting to harvesting for both 1988's and 1989's experiments, including stages of growth, degree days, and application of flooding, are summarized in Table 1.

5.1 Soil Characteristics

The soil characteristics for the Wasepi series are summarized in Table 1.1, for both 1988 and 1989. As we can see in this table, the average bulk density obtained for each depth in this study was very representative of the bulk density in the field.

5.2 Air Temperatures

Maximum and minimum air temperatures were recorded on a daily basis, and the averages for each year were (in degrees C):

For 1988:

maximum= 26.94
minimum= 19.16
mean= 21.76

For 1989:

maximum= 32.78
minimum= 17.22
mean= 25.28

TABLE 1. PHENOLOGICAL DATA FOR 1988 AND 1989 EXPERIMENT

DATES 1988	DATES 1989	DAYS AFTER SOWING 1988	DAYS AFTER SOWING 1989	DEGREE DAYS 1988	DEGREE DAYS 1989	STAGES OF GROWTH 1988 1989
June. 24	April.13	0	0	0.00	0.00	Sowing
June. 28	April.16	4	4	42.22	56.67	Emergence
June. 30	April.18	6	6	70.28	85.28	2 Leaf tips
July. 4	April.23	10	10	110.00	150.83	4 Leaf tips
July. 19	May. 4	25	22	301.67	330.28	8 Leaf tips
August.2	May. 28	40	46	478.33	730.83	Tassel
August.10	June. 1	48	50	593.61	806.67	Silking
August.13	-	51	-	637.78	-	BGF
August.26	-	64	-	778.61	-	MGF
Sept. 21	July. 2	90	85	1049.17	1261.51	Harvest

TABLE 1.1 SOIL INTERPRETATIONS RECORD FOR WASEPI SERIES (ST JOHNS SITE)

DEPTHS CM	BULK DENSITY IN EXPERIMENT (G/CM3) +	BULK DENSITY IN SITU (G/CM3)	AVAILABLE WATER (IN/IN)	SOIL REACTION (PH)	ORGANIC MATER (PCT)	USDA TEXTURE
15	1.37	1.33	0.14	6.5	3	SL,FSL
30	1.41	1.40	0.12	6.5	2	LS,LFS
45	1.57	1.40	0.16	6.5	-	LS,SL,SCL
60	1.53	1.38	0.03	7.5	-	S,G,GR-S

Source: Water management research project 1987

\+ Data obtained from the study 1988

5.3 Roots

The numbers of roots in the soil profile at various depths are summarized in Tables 2 and 3 for 1988, and in Tables 4, 5, and 5.1 for 1989. The data for the 1989 experiment are averages of two replications per treatment, and are shown in Figure 2, 3, and 4.

Data for 1988 with 3, 6, and 12 days of inundation at three different stages (75 percent silking, beginning of grain fill, and middle of grain fill) were obtained when an intermittent water table was raised to 30 centimeters below the soil surface. These data are reported for 41 and 75 days after sowing at three depths: 28, 58, and 89 centimeters. According to the analysis of variance (3 x 3 factor factorial in a randomized design), the stage and duration factors are not significant at 89 centimeters, at the 75th day of the crop's cycle. However, the interaction of these factors is significant -- thus they do not act independently of each other in affecting the number of roots. It is also found in this analysis that the duration factor is significant in reducing the number of roots at 75 days after planting within 28 centimeters, but not at the vegetative and reproductive stages for depths of 58 and 89 centimeters. These results imply that the corn plant is affected by the duration of waterlogging mainly within

TABLE 2. AVERAGE NUMBER OF ROOTS OF 1988 CORN-FLOODING EXPERIMENT WHEN THE WATER TABLE WAS RAISED TO 0.3 M BELOW THE SOIL SURFACE (41 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	DEPTHS CM	AVERAGE NUMBER OF ROOTS
		28	30
	3	58	23
		89	11
		28	21
Silking	6	58	35
		89	0
		28	41
	12	58	29
		89	1
		28	30
	3	58	9
		89	0
		28	14
BGF +	6	58	11
		89	1
		28	22
	12	58	4
		89	0
		28	32
	3	58	7
		89	0
		28	18
MGF ++	6	58	4
		89	0
		28	17
	12	58	8
		89	0
		28	23
CONTROL	No flooding	58	10
		89	5
		28	8
CONTROL	flooding	58	0
		89	0

TABLE 3 . AVERAGE NUMBER OF ROOTS OF 1988 CORN-FLOODING EXPERIMENT WHEN THE WATER TABLE WAS RAISED TO 0.3 M BELOW THE SOIL SURFACE (75 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	DEPTHS CM	AVERAGE NUMBER OF ROOTS
		28	53
	3	58	20
		89	19
		28	53
Silking	6	58	14
		89	6
		28	69
	12	58	13
		89	7
		28	45
	3	58	20
		89	10
		28	23
BGF +	6	58	23
		89	15
		28	38
	12	58	14
		89	6
		28	32
	3	58	22
		89	5
		28	33
MGF ++	6	58	9
		89	6
		28	27
	12	58	16
		89	1
		28	43
Control	No flooding	58	25
		89	13
		28	34
Control	flooding	58	1
		89	0

+ beginning of grain fill

++ Middle of grain fill

TABLE 4. AVERAGE NUMBER OF ROOTS OF 1989 CORN-FLOODING EXPERIMENT (35 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	DEPTHS CM	AVERAGE NUMBER ROOTS
		15	33
	1	30	14
		45	0
		15	33
EMERGENCE	3	30	13
		45	3
		15	32
	6	30	10
		45	1
		15	22
	1	30	6
		45	0
		15	30
4 LEAF TIPS	3	30	7
		45	0
		15	48
	6	30	11
		45	1
		15	34
	1	30	9
		45	1
		15	57
8 LEAF TIPS	3	30	30
		45	1
		15	26
	6	30	9
		45	0
		15	50
Control	No flooding	30	14
		45	0

TABLE 5. AVERAGE NUMBER OF ROOTS OF 1989 CORN-FLOODING EXPERIMENT (67 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	DEPTHS CM	AVERAGE NUMBER ROOTS
		15	88
	1	30	36
		45	2
		15	88
EMERGENCE	3	30	56
		45	23
		15	55
	6	30	35
		45	10
		15	81
	1	30	43
		45	10
		15	60
4 LEAF TIPS	3	30	42
		45	4
		15	80
	6	30	36
		45	4
		15	60
	1	30	40
		45	12
		15	82
8 LEAF TIPS	3	30	42
		45	14
		15	134
	6	30	31
		45	14
		15	72
Control	No flooding	30	36
		45	7

TABLE 5.1 CORN ROOTING PARAMETERS OBTAINED FROM 60 TO 69 DAYS AFTER PLANTING, FOR 1989'S EXPERIMENT

EMERGENCE STAGE

DEPTH CM	1 DAY INUNDATION NUMBER OF ROOTS no.	%	3 DAYS INUNDATION NUMBER OF ROOTS no.	%	6 DAYS INUNDATION NUMBER OF ROOTS no.	%	CONTROL NUMBER OF ROOTS no.	%
15	88.00	69.84	88.00	52.69	55.00	55.00	72	62.61
30	36.00	28.57	56.00	33.53	35.00	35.00	36	31.30
45	2.00	1.59	23.00	13.77	10.00	10.00	7	6.09

4 LEAF TIPS STAGE

DEPTH CM	1 DAY INUNDATION NUMBER OF ROOTS no.	%	3 DAYS INUNDATION NUMBER OF ROOTS no.	%	6 DAYS INUNDATION NUMBER OF ROOTS no.	%	CONTROL NUMBER OF ROOTS no.	%
15	81.00	60.45	60.00	56.60	88.00	68.75	72	62.61
30	43.00	32.09	42.00	39.62	36.00	28.13	36	31.30
45	10.00	7.46	4.00	3.77	4.00	3.13	7	6.09

8 LEAF TIPS STAGE

DEPTH CM	1 DAY INUNDATION NUMBER OF ROOTS no.	%	3 DAYS INUNDATION NUMBER OF ROOTS no.	%	6 DAYS INUNDATION NUMBER OF ROOTS no.	%	CONTROL NUMBER OF ROOTS no.	%
15	60.00	53.57	82.00	59.42	133.50	74.79	72	62.61
30	40.00	35.71	42.00	30.43	31.00	17.37	36	31.30
45	12.00	10.71	14.00	10.14	14.00	7.84	7	6.09

the first 30 centimeters of depth.

The interaction is significant regardless of the depths for both vegetative and reproductive stages. This suggests that these two factors are interdependent in reducing the number of roots.

Root data for 1989 were obtained when an intermittent water table was introduced through the bottom of the lysimeter until it was ponded 5 centimeters above the soil surface, for: 1, 3 , and 6 days, at three different stages of growth: emergence, 4 leaf tips, and 8 leaf tips. These data demonstrate that the number of roots decrease with depth. The analysis of variance (ANOVA) of roots shows that the differences among treatments are not significant at any growth stage, nor was the duration factor significant except for the 30 centimeter depth at the 67th day of the crop's cycle. Interaction between the inundation and stage factors is significant at a 95 percent confidence level for both 35 and 67 days after sowing at depths of 30 and 45 centimeters implying that the effects of inundation periods on different stages of growth are not independent of one another at said depths.

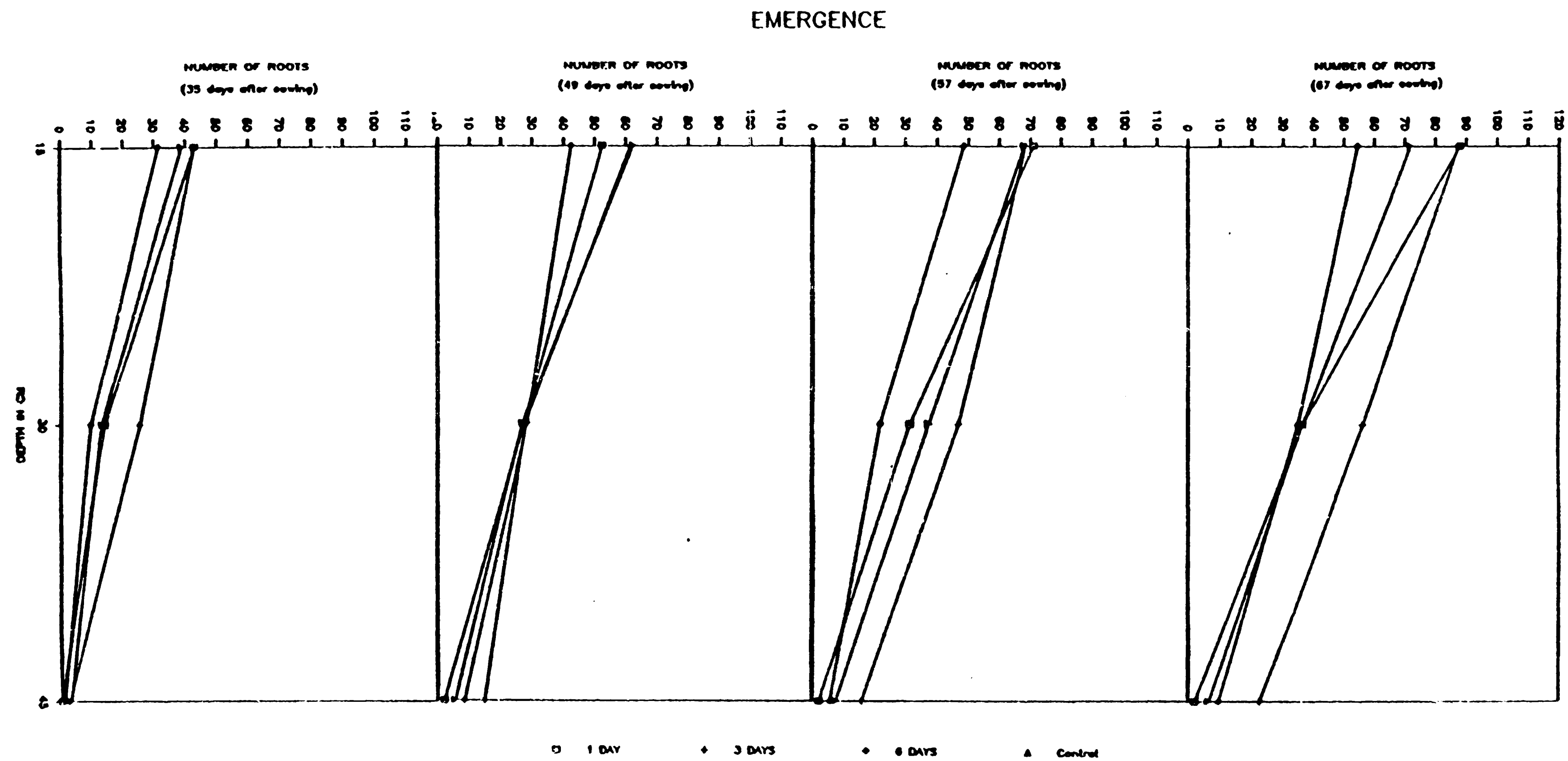

Figure 2. Mean number of roots for each treatment vs. soil depths for various days after planting, at the emergence stage.

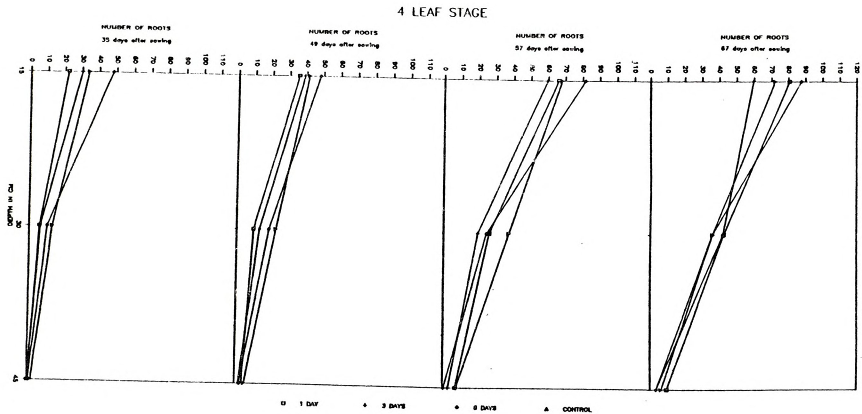

Figure 3. Mean number of roots for each treatment vs. soil depths for various days after planting, at the 4 leaf tips stage.

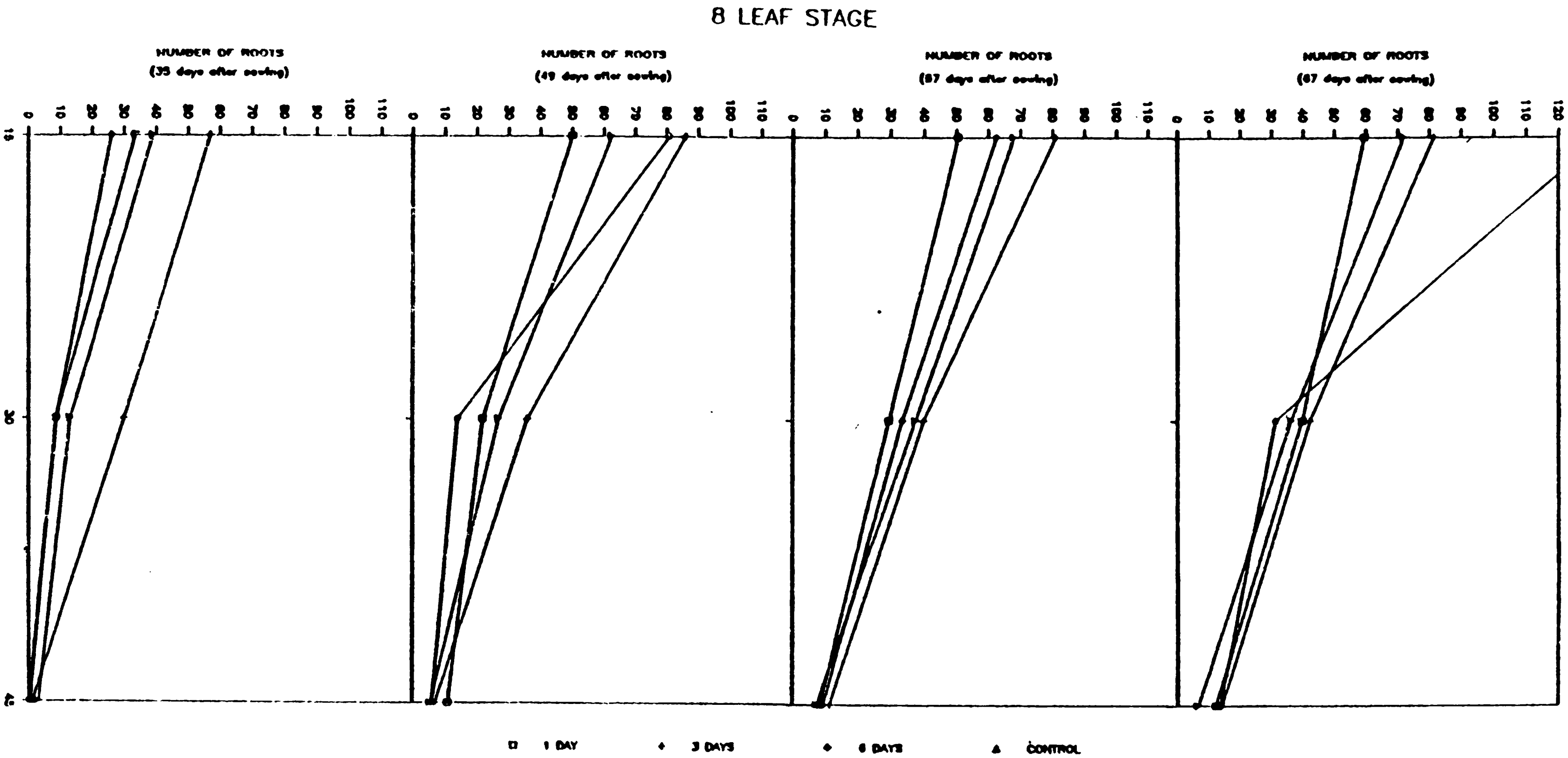

Figure 4. Mean number of roots for each treatment vs. soil depths for various days after planting, at the 8 leaf tips stage.

The recovery of root growth observed in both the 1988 and the 1989 experiments has been reported by Das, et al. (1972), Purvis, et al. (1972), and Trought and Drew (1982). They conclude that corn, which appears to be less sensitive to short-term oxygen concentration than cotton and tobacco, may have some means of supplying oxygen to the root cells or of liberating energy from cell substrates in an anaerobic environment. They claim that the longitudinal diffusion of oxygen transported down the shoot to the root system and the increased internal aeration through increased root porosity reduce corn's requirement for an internal supply of oxygen through the soil system.

The unexpected performance of the control with a constant water table at 30 centimeters below the soil surface on root, leaf area, and dry weight in 1988's experiment may be explained by the adaptation of the plant to the flooded condition, as well as to the beneficial effects of carbon dioxide and oxygen at that depth. Purvis, et al. (1972) outline that excessive carbon dioxide in the presence of adequate oxygen is beneficial to corn and it has no injurious effects on roots. This also may explain why the number of roots within the first 30 centimeters of depth in 1989's experiment is actually greater for a 3 day inundation period than for a 1 day inundation period, regardless of the stage of growth.

According to Purvis (1972), the lack of oxygen is the primary cause of injury and reduced growth of flooded corn. This lack of oxygen may be cause of the reduced number of roots (comparing the treatments to the control) found in the present study for 6 day (1988 and 1989) as well as 12 day (1988) inundation periods.

Trought and Drew (1982), working with winter wheat seedlings grown in a sandy soil show that waterlogging for more than two days affects the root:shoot ratio, by inhibiting root growth more severely than shoot growth. Similar results are presented in this research with corn when considering the number of roots below a depth of 30 centimeters and the above-ground biomass.

5.4 Leaf Area

Leaf area for plants treated at three different inundation periods during three different stages of growth are shown in Table 6 for 1988, and Tables 7 and 8 for 1989.

Analysis of variance of leaf area is performed for 49 and 78 days (1989), and for 80 days after sowing (1988). As shown in Figures 5, 6, and 7 (1989), the

TABLE 6. AVERAGE LEAF AREA OF 1988 CORN-FLOODING EXPERIMENT WHEN THE WATER TABLE WAS RAISED TO 0.3 M BELOW THE SOIL SURFACE (78 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	AVERAGE LEAF AREA CM2
	3	4609.68
Silking	6	4242.60
	12	4220.07
	3	5010.21
BGF +	6	4028.79
	12	3674.69
	3	3995.53
MGF ++	6	4290.17
	12	3827.94
Control	No flooding	3606.50
Control	flooding	5323.59

+ beginning of grain fill

++ Middle of grain fill

TABLE 7. AVERAGE LEAF AREA OF 1989 CORN-FLOODING EXPERIMENT (49 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING DAYS	AVERAGE LEAF AREA CM2
	1	4141.52
Emergence	3	4247.76
	6	3647.53
	1	3636.26
4 leaf tips	3	4455.82
	6	3926.81
	1	4109.20
8 leaf tips	3	3494.72
	6	3532.81
Control	No flooding	3621.60
Control	flooding	327.60

TABLE 8 . AVERAGE LEAF AREA OF 1989 CORN-FLOODING EXPERIMENT (78 DAYS AFTER SOWING)

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING DAYS	AVERAGE LEAF AREA CM2
	1	3700.76
Emergence	3	4135.51
	6	3546.43
	1	3379.38
4 leaf tips	3	4166.70
	6	3291.89
	1	3609.99
8 leaf tips	3	3428.75
	6	3316.82
Control	No flooding	3402.80
Control	flooding	192.00

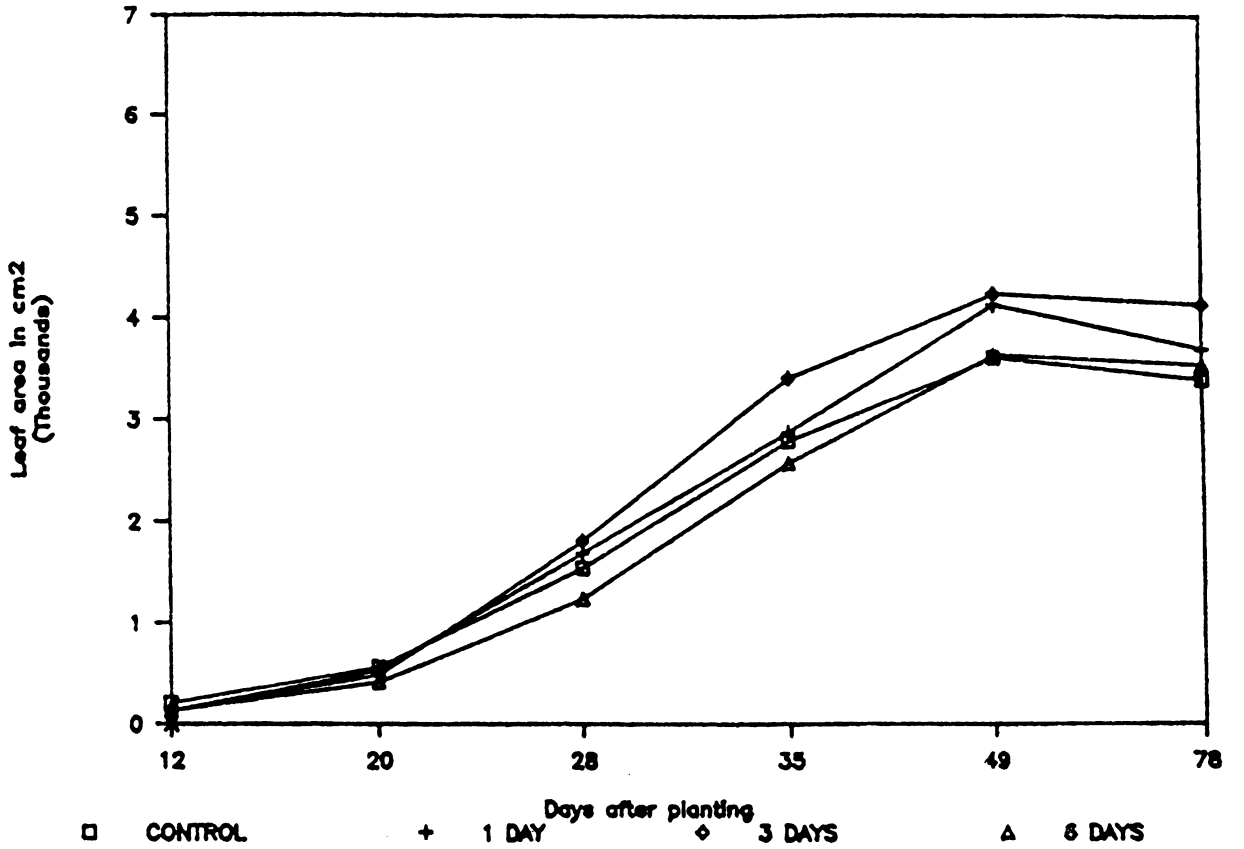

Figure 5. Treatment means (3 plants per barrel, 2 replicates) of accumulated leaf area (cm^2), various days after planting, at the emergence stage.

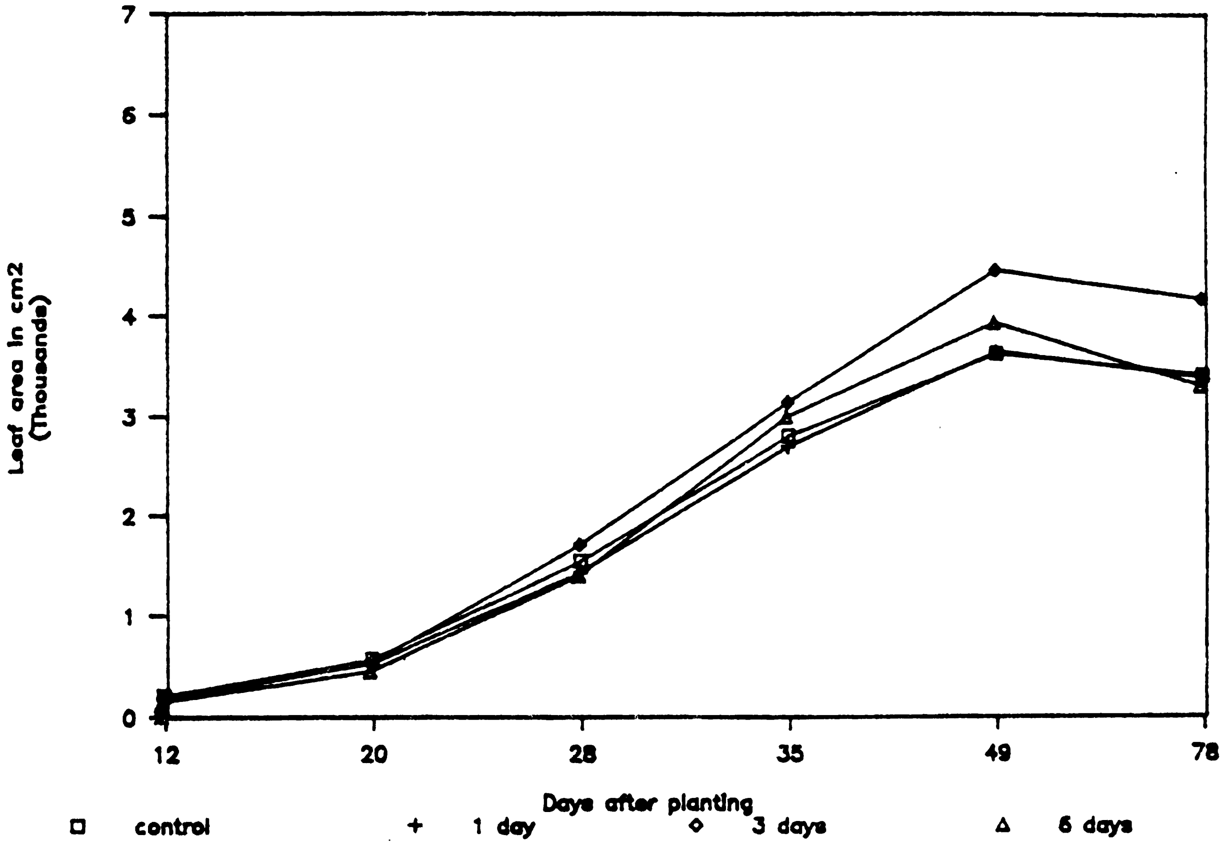

Figure 6. Treatment means (3 plants per barrel, 2 replicates) of accumulated leaf area, (cm^2), various days after planting, at the 4 leaf tips stage.

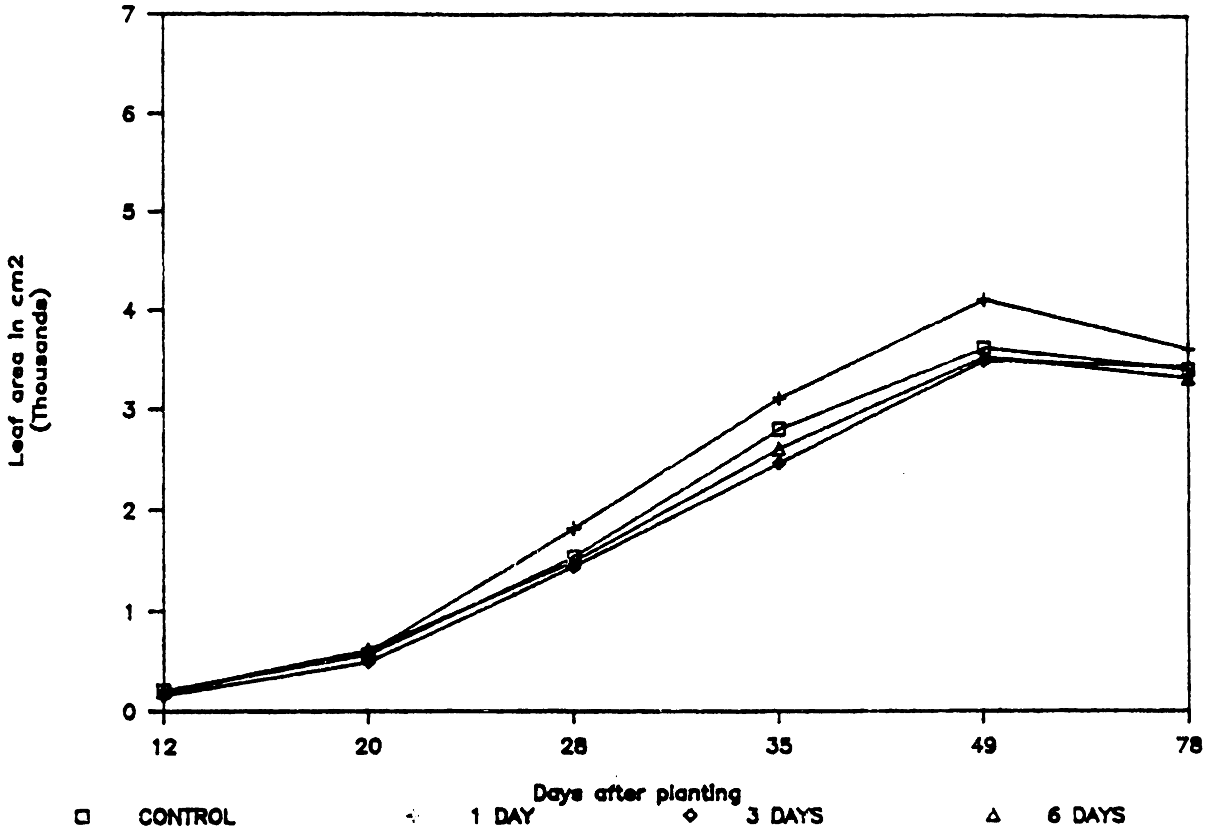

Figure 7. Treatment means (3 plants per barrel, 2 replicates) of accumulated leaf area, (cm^2), various days after planting, at the 8 leaf tips stage.

differences in leaf area are more notable after the 35th day of the crop cycle. The ANOVA does not show significant differences among treatments for the stage factor in both the 1988 and 1989 experiments at a 95 percent confidence level. Nevertheless, it is important to point out that at the emergence stage (1989's experiment), the treatment with the 6 day inundation period shows the least leaf area throughout the plant's cycle. In contrast, the treatment with the 3 day inundation period (1989) shows by far the biggest leaf area. The duration factor is significant for both years at the 78th day after sowing, but it is not significant at the 49th day after sowing in 1989's experiment.

The interaction between stage and duration factor is significant for both 1988 and 1989, which demonstrates that these two factors are not independent of each other. Therefore, the magnitude of reduction in leaf area is dependent on the level of the stage and the duration of the inundation period.

Duncan's multiple range-test does show mean differences among stages of growth, the emergence stage being the least affected by the inundation periods. In Figures 6 and 7, it is observed that there was a larger reduction in leaf area at the stages of 4 and 8 leaf tips during the 6 day inundation period, than during the 1 day inundation period. According to Duncan's test at the 4 leaf tips stage, the 1 and 6 day inundation periods differ from the 3 day inundation period in that the latter is less effective in reducing leaf area. At the 8 leaf tips stage, there are no differences among treatment means, which implies that the leaf area was similarly affected by the durations.

5.5 Dry Weight

Dry weight data are summarized in Table 9 and Figure 8 for 1988's experiment and Table 10 and Figure 9 for 1989's experiment. These data suggest that dry weight for 1988, when the water table was raised to 30 centimeters below the soil surface, is not affected by the treatments, as is shown by the analysis of variance. In this analysis, the differences among treatments are not significant at a 95 percent confidence level, so it is not necessary to perform the Duncan's test for these data. For 1989's experiment, the analysis of variance shows a highly significant effect for the inundation factor but no significant effect for the stage factor. The interaction among factors is significant, which points out that the effects of the duration of inundation on dry weight depends on the growth stages of the plants.

TABLE 9. AVERAGE OF THE FINAL DRY WEIGHT OF 1988 EXPERIMENT WHEN THE WATER TABLE WAS RAISED TO 0.3 M BELOW THE SOIL SURFACE

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	AVERAGE DRY WEIGHT GRAMS/PLANT
	3	61.30
Silking	6	69.75
	12	76.55
	3	84.52
BGF +	6	60.35
	12	57.52
	3	67.12
MGF ++	6	72.69
	12	55.90
Control	No flooding	56.47
Control	flooding	62.68

+ beginning of grain fill

++ Middle of grain fill

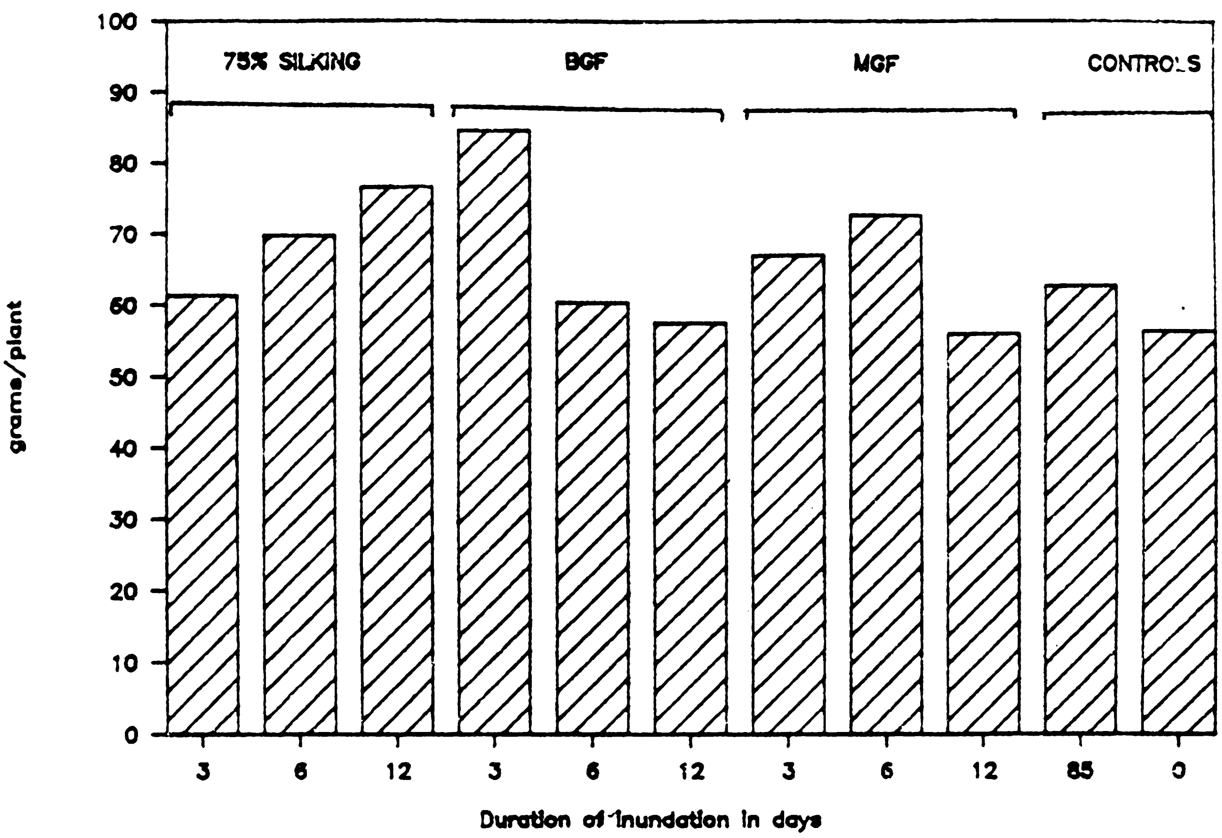

Figure 8. Effect of intermittent water table on corn dry weignt (3 plants per barrel, 2 replicates) when the water table was raised to 0.3 meter below the soil surface, at three different stages of growth, for 1988.

TABLE 10. **AVERAGE OF THE FINAL DRY WEIGHT OF 1989 CORN-FLOODING EXPERIMENT**

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING DAYS	AVERAGE DRY WEIGHT GRAMS/PLANT
	1	60.43
Emergence	3	68.90
	6	57.55
	1	63.35
4 leaf tips	3	81.05
	6	48.30
	1	68.65
8 leaf tips	3	70.55
	6	48.62
Control	No flooding	58.83
Control	flooding	7.59

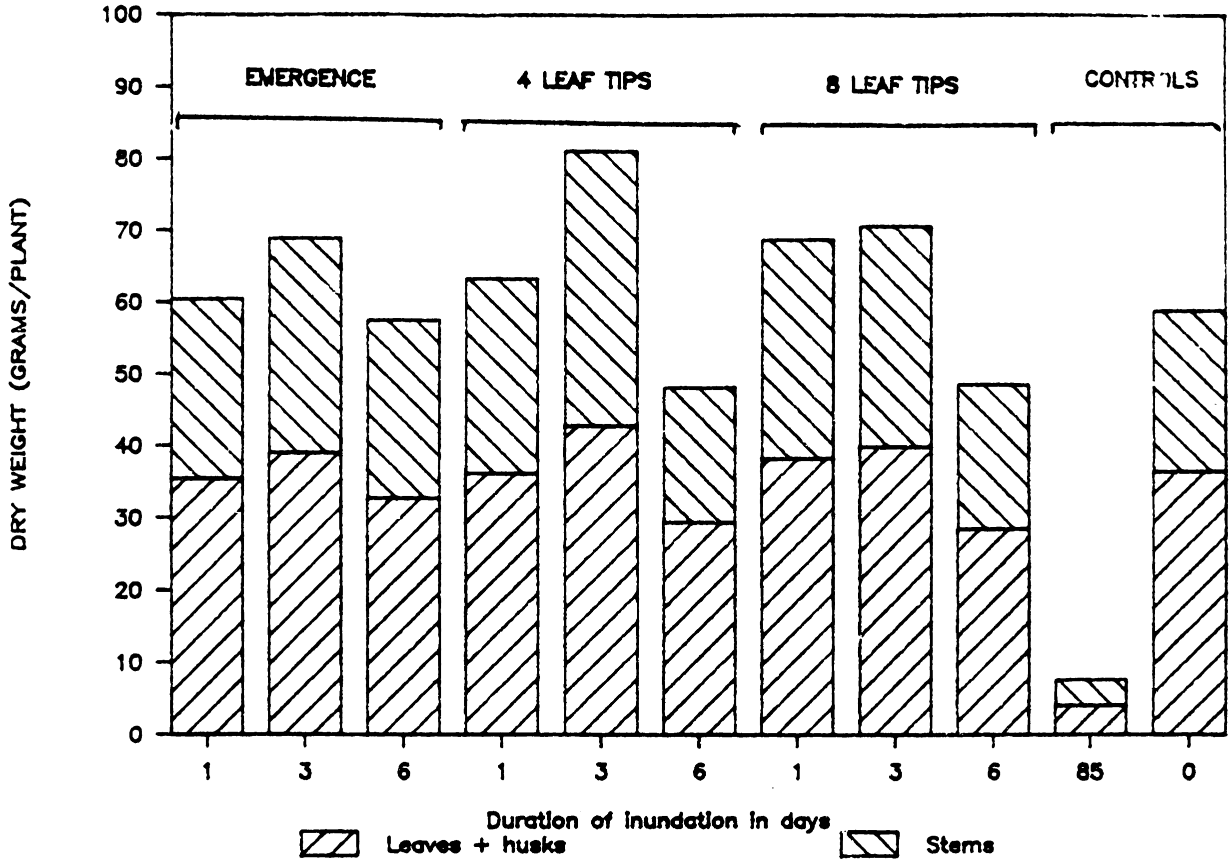

Figure 9. Effect of intermittent flooding on corn dry weight (3 plants per barrel, 2 replicates) at three different stages of growth, for 1989.

In Figure 9, it is shown that the 6 day inundation period is more harmful for each one of the stages than are the 1 and 3 day inundation periods. Also in Figure 9 one can see the effects of 85 days of inundation on the final dry weight for the control.

After completing an F test of treatments in 1989's experiment which showed significance for the duration factor and for the duration and stage interaction, the all pairwise comparisons of means was performed using Duncan's new multiple-range test. This test, when performed for each stage of growth, does not show significant differences between the inundation periods considered when the stress is imposed at the emergence stage. At both the 4 and 8 leaf tips stages, Duncan's test shows significant differences among treatments, the 6 day inundation period being the most harmful in reducing the dry weight.

It is important to point out that the 3 day inundation period seems to increase the final dry weight as compared to the 1 day inundation period and the control. A similar result on wheat has been obtained by Trought and Drew (1982), when they observe that the increase in shoot dry weight, greater than the controls (during the first 8 days of waterlogging), is associated with starch accumulation. According to them, the rapid increases in shoot dry weight and percent dry matter are probably caused by a slowing of

photosynthates translocation to the roots. The same situation is observed by Varade, et al. (1970, cited in Trought and Drew, 1982), when translocation of photosynthates to roots was inhibited by cool temperatures.

With these results, one can demonstrate that shoot dry weight is an unreliable indicator of the early restriction to plant growth and development caused by waterlogging. It is important to note that in previously reported studies, dry weight has been used as the sole criterion of plant response.

5.6 Yields

Yield data are presented in Table 11 and Figure 10 for 1988's experiment, and in Table 12 and Figure 11 for 1989. Figure 10 shows the effects of different inundation periods on different stages of growth (75 percent silking; beginning of grain fill; and middle of grain fill), when the water table is raised to 30 centimeters below the soil surface. As shown in Figure 10, the 12 day inundation period is more harmful to the yields at the beginning and middle of grain fill than at the 75 percent silking stage. At silking stage, the yields are actually not affected by the inundation periods considered.

TABLE 11. AVERAGE OF THE FINAL YIELD OF 1988 CORN-FLOODING EXPERIMENT WHEN WATER TABLE WAS RAISED TO 0.3 M BELOW THE SOIL SURFACE

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING IN DAYS	AVERAGE YIELDS GRAMS/PLANT
	3	77.48
Silking	6	72.92
	12	76.97
	3	76.74
BGF +	6	72.92
	12	50.80
	3	68.69
MGF ++	6	60.33
	12	56.02
Control	No flooding	70.92
Control	flooding	66.97

+ beginning of grain fill

++ Middle of grain fill

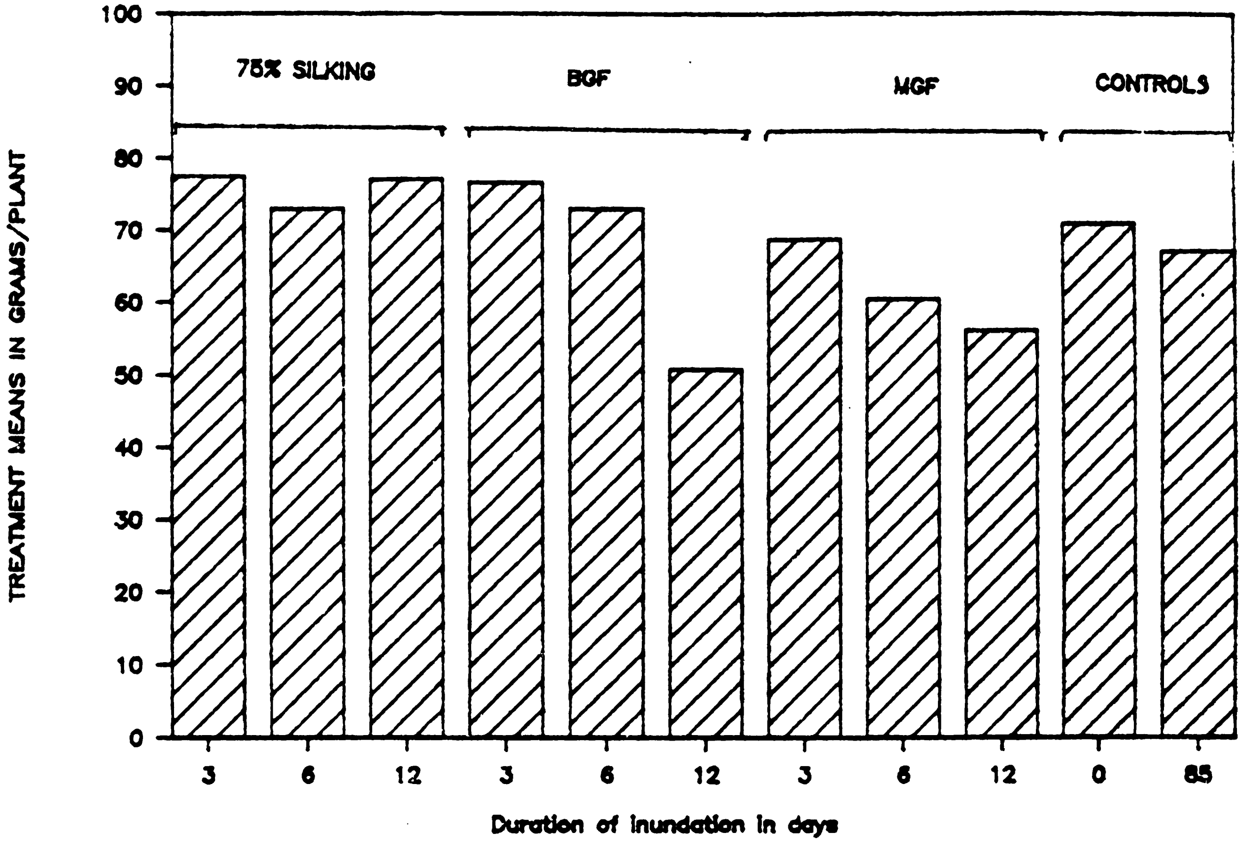

Figure 10. Effect of intermittent water table on corn grain yield (3 plants per barrel, 2 replicates), when the water table was raised to 0.3 meter below the soil surface, at three different stages of growth, for 1988.

TABLE 12. AVERAGE OF THE FINAL YIELD OF 1989 CORN-FLOODING EXPERIMENT

STAGE OF GROWTH WHEN FLOODING OCCURRED	LENGTH OF FLOODING DAYS	AVERAGE YIELDS GRAMS/PLANT
	1	34.64
Emergence	3	30.12
	6	15.87
	1	36.22
4 leaf tips	3	23.28
	6	30.70
	1	37.57
8 leaf tips	3	31.87
	6	27.47
Control	No flooding	34.08
Control	flooding	0.00

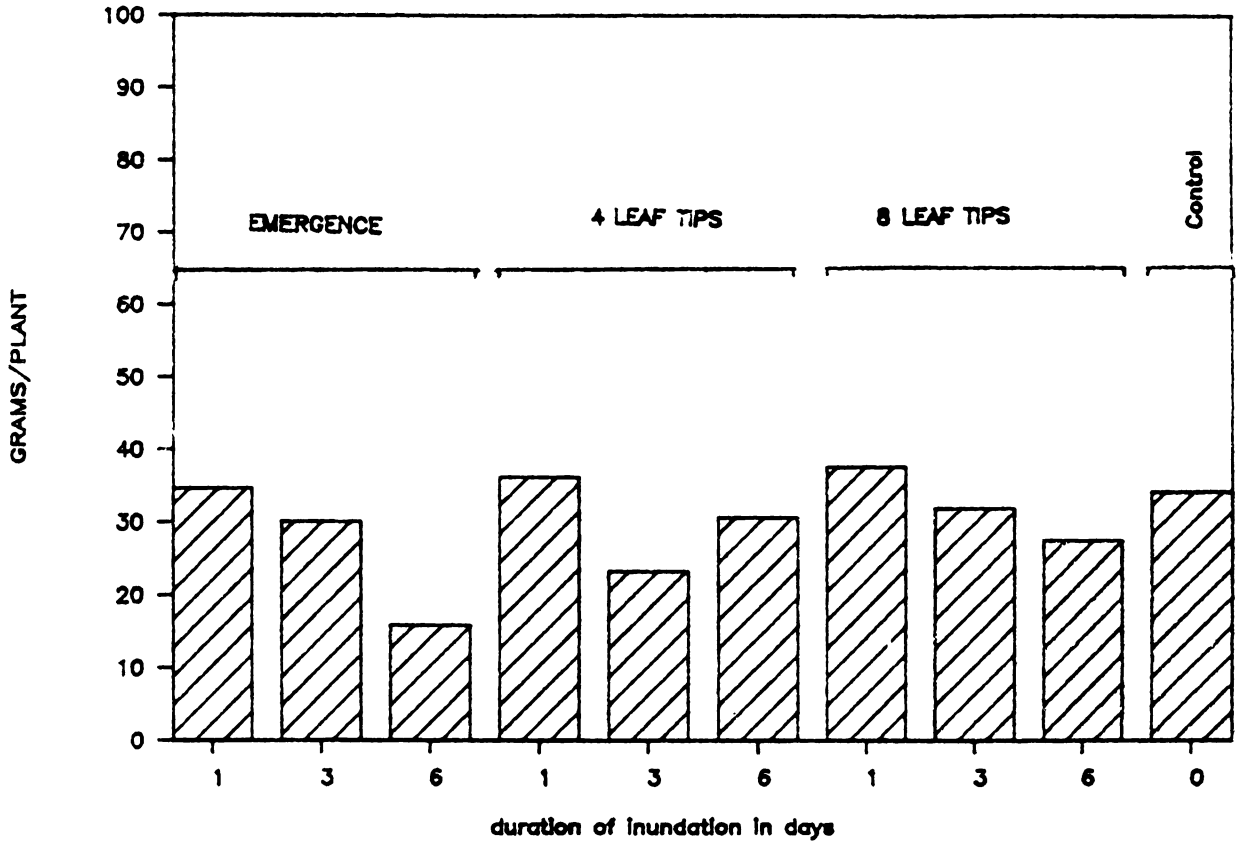

Figure 11. Effect of intermittent flooding on corn grain yield (3 plants per barrel, 2 replicates), at three different stages of growth, for 1989.

The 1988 experiment (Figure 10) demonstrates that a steady water table at 30 centimeters below the soil surface throughout the entire plant's cycle does not affect the yields (as was expected), which indicates the capacity of the corn plants to overcome the stress and to adapt themselves to the external environmental conditions when a non-intermittent water table is present at this depth.

In similar experiment, Lal and Taylor (1969) conclude that intermittent flooding early in the growing season reduce yields of corn more than constant water tables of 15 and 30 centimeters of depth. They also indicate that the uptake of nitrogen and zinc by corn plants is significantly reduced by high water tables and intermittent flooding, because of: 1) limited root system; 2) prevalence of reducing conditions; and 3) deficiency of soil oxygen. The analysis of variance for 1988 is significant for both stage and duration factors, and it is also significant for the interaction between factors at a 95 percent confidence level, suggesting that the inundation periods does affect the yields according to the stage of growth of the plants. According to Duncan's multiple-range test, there are no differences among treatment means at the 75 percent silking stage. However, at the beginning of grain fill stage, the 12 day inundation period (1988) is declared to be different from the 3 and 6 day inundation periods, the 12 day inundation period being the most harmful.

Figure 11 (1989's experiment) shows the effect of inundation periods (1, 3, and 6 days) at 3 different stages of growth: emergence, 4 leaf tips, and 8 leaf tips. In general, one can see that the yield decreases as the inundation period increases, except for treatment #6 (6 day inundation period, at the 4 leaf tips stage), which produces an unexpected value.

For 1989's experiment, the analysis of variance's result is significant for the duration factor which suggests that the durations of inundation considered does affect the yields. The 6 day inundation period has a larger effect on the reduction of yields at the emergence stage than for the other stages. On the other hand, the significant interaction tells us that the yields are not affected merely by the inundation periods, but also according to the stage of growth of the plants.

Duncan's new multiple-range test shows us that a 6 day inundation period at the emergence stage is the only difference to be declared significant at a 95 percent confidence level in reducing the yields. At the 4 leaf tips stage, the test indicates that the yields are more affected by a 3 and a 6 day inundations than by a 1 day inundation period. At the 8 leaf tips stage, the test does not show differences among treatments, which indicates that the yields are affected similarly by the durations considered. From the test it is also determined that the emergence and 4 leaf stages are more sensitive to inundation stress than the 8 leaf stage.

Cannell, et al. (1980), working on winter wheat conclude that waterlogging after germination has large effects on the plant and yield, but does not affect the rate of leaf emergence nor leaf length. On the other hand, spring waterlogging slightly increases the yields.

5.7 Water Used

Table 13 summarizes water used (in millimeters) and number of roots for a specific period of time of the crop's cycle (60-69 days after sowing), for each stage of growth, and also for each duration level. Figures 12, 13, and 14, represent the data contained in Table 13.

As one can see in these Figures in general, the water used within the soil profile decreases as the depth increases, and similarly, the number of roots decrease as the depth increases. The water used decreases as the duration of inundation increases, which may indicate the effects of the variable water table on the effectiveness of the roots to withdraw water from the profile.

TABLE 13. CORN ROOTING AND MOISTURE PARAMETERS OBTAINED FROM 60 TO 69 DAYS AFTER PLANTING, FOR 1989'S EXPERIMENT

EMERGENCE STAGE

	1 DAY INUNDATION		3 DAYS INUNDATION		6 DAYS INUNDATION		CONTROL	
DEPTH CM	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS
15	475.00	88.00	1014.25	88.00	492.00	55.00	1050.75	72
30	581.25	36.00	596.25	56.00	493.50	35.00	811.50	36
45	520.25	2.00	501.75	23.00	690.00	10.00	551.25	7

4 LEAF TIPS STAGE

	1 DAY INUNDATION		3 DAYS INUNDATION		6 DAYS INUNDATION		CONTROL	
DEPTH CM	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS
15	860.25	81.00	930.00	60.00	691.50	88.00	1050.75	72
30	639.75	43.00	634.50	42.00	500.25	36.00	811.50	36
45	483.00	10.00	321.75	4.00	364.50	4.00	551.25	7

8 LEAF TIPS STAGE

	1 DAY INUNDATION		3 DAYS INUNDATION		6 DAYS INUNDATION		CONTROL	
DEPTH CM	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS	WATER USED mm	NUMBER OF ROOTS
15	980.50	60.00	677.25	82.00	633.00	133.50	1050.75	72
30	961.50	40.00	560.25	42.00	452.25	31.00	811.50	36
45	837.75	12.00	428.25	14.00	514.50	14.00	551.25	7

Figure 12. Means of soil water extraction (2 replicates) for treatments subjected to three different inundation periods vs. soil depths, at the emergence stage (60-69 days after planting).

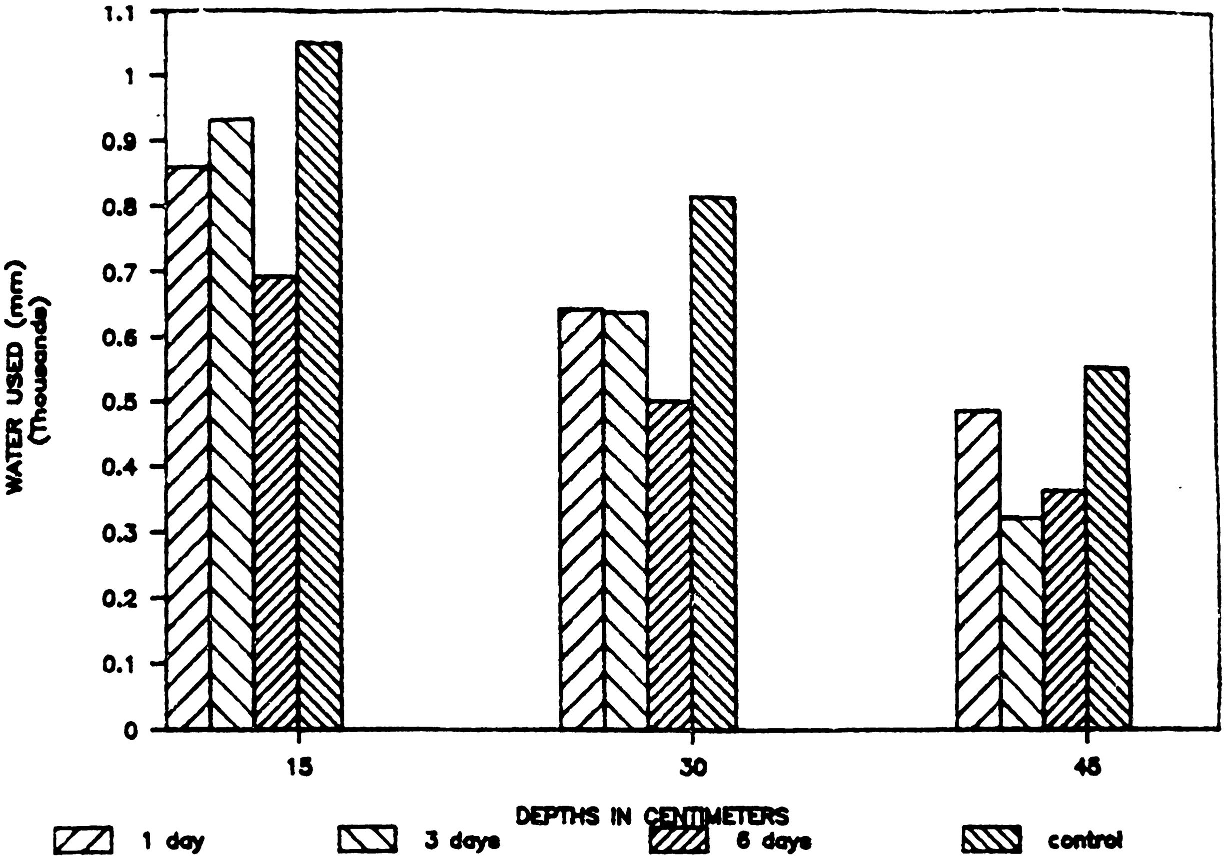

Figure 13. Treatment means of water used (2 replicates) vs. soil depths, for three different inundation periods, at the 4 leaf tips stage (60-69 days after planting).

Figure 14. Treatment means of water used (2 replicates) vs. soil depths, for three different inundation periods, at the 8 leaf tips stage (60-69 days after planting).

6. CONCLUSIONS

The objectives of the proposed research have been addressed in full. These result show the effects of an intermittent water table on: 1) number of roots in the soil profile; 2) leaf area; 3) dry weight; 4) water used; and 5) corn yield (Zea mays. L), at different stages of growth (emergence, 4 leaf tips, 8 leaf tips, 75 percent silking, beginning of grain fill, and middle of grain fill).

The specific conclusions of this research are:

1) The emergence stage was the least sensitive to an intermittent water table when considering roots, leaf area, and dry weight; but when yield is considered, this stage is the most sensitive to waterlogging.

2) An intermittent water table was more harmful to the corn plant than a steady water table, especially at the early stages of growth, when waterlogging lasted more than 3 days.

3) A water table at 0.3 meters below the soil surface for 6 and 12 day inundation periods was more detrimental to the total leaf area than a 3 day inundation period.

4) A water table at 0.3 meters below the soil surface did not affect the yields at 3 and 6 day inundation periods, but a 12 day inundation period reduced the yields.

5) A 3 day inundation period increased leaf area and dry weight for both steady and intermittent water tables at any stage of growth.

6) At the beginning and middle of grain fill, a water table of 0.3 meters below the soil surface for inundation periods of 6 and 12 days was more harmful to root growth than a 1 day inundation. The corn plant was not affected by this water table depth at the silking stage.

7) A 1 day inundation period did not affect the leaf area at any stage of growth considered.

8) Inundation periods and stages of growth act together in reducing leaf area, dry weight, number of roots, and yields.

9) For 0.3 meters of depth, 1 and 3 day inundation periods did not affect the number of roots, but a 6 day inundation period did reduce the number of roots.

RECOMMENDATIONS FOR FUTURE RESEARCH

1) Investigate how soil and water temperatures affect responses of corn roots to waterlogging.

2) Continue this experiment (either in the field or greenhouse) from planting to maturity, but considering a larger number of replications per treatment.

3) Develop a theoretical model to predict the effects of a superficial water table on root growth and its effects on yield.

APPENDIX

ROOT DATA FOR 1988, 41 DAYS AFTER SOWING
(0.28 m of depth)

Water table is raised to 0.3 m below the soil surface

	DURATION = B(in days)			
Stages= A	3	6	12	Totals
Silk = a1 *	25.00	11.00	27.00	63.00
	34.00	30.00	55.00	119.00
	------	------	------	------
Totals	59.00	41.00	82.00	182.00
Means	29.5	20.5	41	
BGF = a2 **	42.00	22.00	34.00	98.00
	18.00	6.00	10.00	34.00
	------	------	------	------
Totals	60.00	28.00	44.00	132.00
Means	30	14	22	
MGF = a3 ***	40.00	26.00	15.00	81.00
	23.00	9.00	18.00	50.00
	------	------	------	------
Totals	63.00	35.00	33.00	131.00
Means	31.5	17.5	16.5	
Totals	182.00	104.00	159.00	445.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	283.44	141.72	3.01	4.26
B	2	535.44	267.72	5.68 *	4.26
AB	4	1243.11	310.78	6.59 *	3.63
Error	9	424.22	47.14		
Total	17	13487.6			

ROOT DATA FOR 1988, 41 DAYS AFTER SOWING
(0.58 m of depth)
Water table is raised to 0.3 m below the soil surface

		DURATION = B(in days)			
Stages= A		3	6	12	Totals
Silk = a1 *		15.00	19.00	18.00	52.00
		30.00	51.00	39.00	120.00
	Totals	45.00	70.00	57.00	172.00
	Means	22.50	35.00	28.50	
BGF = a2 **		10.00	7.00	7.00	24.00
		8.00	15.00	0.00	23.00
	Totals	18.00	22.00	7.00	47.00
	Means	9.00	11.00	3.50	
MGF = a3 ***		11.00	5.00	7.00	23.00
		2.00	2.00	8.00	12.00
	Totals	13.00	7.00	15.00	35.00
	Means	6.50	3.50	7.50	
Totals		76.00	99.00	79.00	254.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F		F(0.025)
A	2	1918.78	959.39	47.47	*	4.26
B	2	52.11	26.06	1.29		4.26
AB	4	2152.78	538.19	26.63	*	3.63
Error	9	181.89	20.21			
Total	17	7889.8				

ROOT DATA FOR 1988, 75 DAYS AFTER SOWING
(0.28 m of depth)
Water table is raised to 0.3 m below the soil surface

Stages= A		DURATION = B(in days) 3	6	12	Totals
Silk = a1 *		42.00	14.00	43.00	99.00
		63.00	91.00	94.00	248.00
	Totals	105.00	105.00	137.00	347.00
	Means	52.50	52.50	68.50	
BGF = a2 **		60.00	32.00	45.00	137.00
		30.00	13.00	31.00	74.00
	Totals	90.00	45.00	76.00	211.00
	Means	45.00	22.50	38.00	
MGF = a3 ***		30.00	29.00	32.00	91.00
		33.00	36.00	22.00	91.00
	Totals	63.00	65.00	54.00	182.00
	Means	31.50	32.50	27.00	
Totals		258.00	215.00	267.00	740.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F		F(0.05)
A	2	2586.78	1293.39	17.95	*	4.26
B	2	257.44	128.72	1.79		4.26
AB	4	3492.78	873.19	12.12	*	3.63
Error	9	648.56	72.06			
Total	17	37407.8				

ROOT DATA FOR 1988, 75 DAYS AFTER SOWING
(0.58 m of depth)
Water table is raised to 0.3 m below the soil surface

		DURATION = B(in days)		
Stages= A	3	6	12	Totals
Silk = a1 *	28.00	2.00	13.00	43.00
	11.00	25.00	13.00	49.00
Totals	39.00	27.00	26.00	92.00
Means	19.50	13.50	13.00	
BGF = a2 **	16.00	22.00	21.00	59.00
	23.00	24.00	7.00	54.00
Totals	39.00	46.00	28.00	113.00
Means	19.50	23.00	14.00	
MGF = a3 ***	18.00	12.00	14.00	44.00
	25.00	6.00	18.00	49.00
Totals	43.00	18.00	32.00	93.00
Means	21.50	9.00	16.00	
Totals	121.00	91.00	86.00	298.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	46.78	23.39	1.22	4.26
B	2	119.44	59.72	3.12	4.26
AB	4	338.44	84.61	4.42 *	3.63
Error	9	172.22	19.14		
Total	17	5610.4			

ROOT DATA FOR 1988,41 DAYS AFTER SOWING
(0.89 m of depth)
Water table is raised to 0.3 m below the soil surface

	DURATION = B(in days)			
Stages= A	3	6	12	Totals
Silk = a1 *	11.00	0.00	0.00	11.00
	10.00	0.00	1.00	11.00
Totals	21.00	0.00	1.00	22.00
Means	10.50	0.00	0.50	
BGF = a2 **	0.00	1.00	0.00	1.00
	0.00	0.00	0.00	0.00
Totals	0.00	1.00	0.00	1.00
Means	0.00	0.50	0.00	
MGF = a3 ***	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00
Totals	0.00	0.00	0.00	0.00
Means	0.00	0.00	0.00	
Totals	21.00	1.00	1.00	23.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	51.44	25.72	2.41	4.26
B	2	44.44	22.22	2.08	4.26
AB	4	192.11	48.03	4.49 *	3.63
Error	9	96.22	10.69		
Total	17	413.6			

ROOT DATA FOR 1988, 75 DAYS AFTER SOWING
(0.89 m of depth)
Water table is raised to 0.3 m below the soil surface

	DURATION = B(in days)			
Stages= A	3	6	12	Totals
Silk = a1 *	32.00	1.00	8.00	41.00
	5.00	10.00	6.00	21.00
	------	------	------	------
Totals	37.00	11.00	14.00	62.00
Means	18.50	5.50	7.00	
BGF = a2 **	14.00	25.00	0.00	39.00
	5.00	5.00	11.00	21.00
	------	------	------	------
Totals	19.00	30.00	11.00	60.00
Means	9.50	15.00	5.50	
MGF = a3 ***	7.00	6.00	1.00	14.00
	2.00	6.00	0.00	8.00
	------	------	------	------
Totals	9.00	12.00	1.00	22.00
Means	4.50	6.00	0.50	
Totals	65.00	53.00	26.00	144.00

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	169.33	84.67	3.96	4.26
B	2	133.00	66.50	3.11	4.26
AB	4	495.00	123.75	5.78 *	3.63
Error	9	192.67	21.41		
Total	17	2142.0			

ROOT DATA FOR 1989, 35 DAYS AFTER SOWING
(0.15 m of depth)

Stages= A		DURATION B(in days) 1	3	6	Totals
Emerg = a1		31.00	29.00	33.00	93.00
		35.00	36.00	30.00	101.00
	Totals	66.00	65.00	63.00	194.00
	Means	33	32.5	31.5	
4 leaf = a2 tips		25.00	19.00	50.00	94.00
		19.00	41.00	46.00	106.00
	Totals	44.00	60.00	96.00	200.00
	Means	22	30	48	
8 leaf = a3 tips		41.00	51.00	13.00	105.00
		26.00	63.00	39.00	128.00
	Totals	67.00	114.00	52.00	233.00
	Means	33.5	57	26	
Totals		177.00	239.00	211.00	627.00

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	147.00	73.50	0.46	5.71
B	2	321.33	160.67	1.01	5.71
AB	4	1905.00	476.25	2.98	4.72
Error	9	1436.67	159.63		
Total	17	25650.5			

ROOT DATA FOR 1989, 35 DAYS AFTER SOWING
(0.3 m of depth)

Stages= A		DURATION = B(in days) 1	3	6	Totals
Emerg = a1		15.00	11.00	12.00	38.00
		13.00	14.00	7.00	34.00
	Totals	28.00	25.00	19.00	72.00
	Means	14	12.5	9.5	
4 leaf = a2		7.00	9.00	7.00	23.00
tips		5.00	4.00	14.00	23.00
	Totals	12.00	13.00	21.00	46.00
	Means	6	6.5	10.5	
8 leaf = a3		4.00	29.00	2.00	35.00
tips		13.00	31.00	15.00	59.00
	Totals	17.00	60.00	17.00	94.00
	Means	8.5	30	8.5	
Totals		57.00	98.00	57.00	212.00

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	192.44	96.22	1.82	5.71
B	2	186.78	93.39	1.77	5.71
AB	4	854.11	213.53	4.05	4.72
Error	9	474.89	52.77		
Total	17	4205.1			

ROOT DATA FOR 1989, 35 DAYS AFTER SOWING
(0.45 m of depth)

Stages= A		DURATION = B(in days) 1	3	6	Totals
Emerg = a1		0.00	5.00	2.00	7.00
		0.00	0.00	0.00	0.00
	Totals	0.00	5.00	2.00	7.00
	Means	0	2.5	1	
4 leaf tips = a2		0.00	0.00	1.00	1.00
		0.00	0.00	0.00	0.00
	Totals	0.00	0.00	1.00	1.00
	Means	0	0	0.5	
8 leaf tips = a3		1.00	0.00	0.00	1.00
		0.00	2.00	0.00	2.00
	Totals	1.00	2.00	0.00	3.00
	Means	0.5	1	0	
Totals		1.00	7.00	3.00	11.00

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	3.11	1.56	3.07	5.71
B	2	3.11	1.56	3.07	5.71
AB	4	10.78	2.69	5.32 *	4.72
Error	9	4.56	0.51		
Total	17	28.3			

(ROOT DATA FOR 1989, 67 DAYS AFTER SOWING)
(0.15 m of depth)

Stages= A		DURATION = B (in days) 1	3	6	Totals
Emerg = a1		90.00	73.00	69.00	232.00
		86.00	102.00	40.00	228.00
	Totals	176.00	175.00	109.00	460.00
	Mean	88	87.5	54.5	
4 leaf = a2		96.00	60.00	86.00	242.00
tips		65.00	59.00	89.00	213.00
	Totals	161.00	119.00	175.00	455.00
	Mean	80.5	59.5	87.5	
8 leaf = a3		61.00	68.00	170.00	299.00
tips		58.00	95.00	97.00	250.00
	Totals	119.00	163.00	267.00	549.00
	Mean	59.5	81.5	133.5	
Totals		456.00	457.00	551.00	1464.00

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	932.33	466.17	0.59	4.26
B	2	992.33	496.17	0.63	4.26
AB	4	9032.00	2258.00	2.86	3.63
Error	9	7107.33	789.70		
Total	17	137136.0			

ROOT DATA FOR 1989, 67 DAYS AFTER SOWING
(0.3 m of depth)

Stages= A		DURATION = B(in days) 1	3	6	Totals
Emerg = a1		46.00	53.00	50.00	149.00
		26.00	59.00	19.00	104.00
		------	------	------	------
	Totals	72.00	112.00	69.00	253.00
	Means	36	56	34.5	
4 leaf = a2		63.00	54.00	32.00	149.00
tips		22.00	30.00	40.00	92.00
		------	------	------	------
	Totals	85.00	84.00	72.00	241.00
	Means	42.5	42	36	
8 leaf = a3		40.00	35.00	33.00	108.00
tips		39.00	49.00	29.00	117.00
		------	------	------	------
	Totals	79.00	84.00	62.00	225.00
	Means	39.5	42	31	
Totals		236.00	280.00	203.00	719.00

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	65.78	32.89	1.12	5.71
B	2	497.44	248.72	8.47 *	5.71
AB	4	827.44	206.86	7.05 *	4.72
Error	9	264.22	29.36		
Total	17	30374.9			

ROOT DATA FOR 1989, 67 DAYS AFTER SOWING
(0.45 m oof depth)

		DURATION = B(in days)			
Stages= A		1	3	6	Totals
Emerg = a1		4.00	27.00	10.00	41.00
		0.00	18.00	9.00	27.00
	Total	4.00	45.00	19.00	68.00
	Means	2	22.5	9.5	
4 leaf tips = a2		13.00	3.00	2.00	18.00
		6.00	4.00	5.00	15.00
	Total	19.00	7.00	7.00	33.00
	Means	9.5	3.5	3.5	
8 leaf tips = a3		14.00	4.00	4.00	22.00
		10.00	24.00	23.00	57.00
	Total	24.00	28.00	27.00	79.00
	Means	12	14	13.5	
Totals		47.00	80.00	53.00	180.00

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	192.33	96.17	2.28	5.71
B	2	103.00	51.50	1.22	5.71
AB	4	675.00	168.75	4.00	4.72
Error	9	379.67	42.19		
Total	17	3150.0			

LEAF AREA FOR 1988
(80 days after sowing)

	DURATION = B (in days)			
Stages= A	3	6	12	Totals
Silking = a1	5017.00	4154.81	3977.19	13149.00
	4202.35	4330.39	4462.95	12995.69
	------	------	------	------
Totals	9219.35	8485.20	8440.14	26144.69
Means	4609.68	4242.60	4220.07	13072.35
BGF = a2 *	4676.43	4405.78	3750.49	12832.70
	5343.99	3651.79	3598.89	12594.67
	------	------	------	------
Totals	10020.42	8057.57	7349.38	25427.37
Means	5010.21	4028.79	3674.69	12713.69
MGF = a3 **	4214.50	4660.74	3599.16	12474.40
	3776.56	3919.60	4056.71	11752.87
	------	------	------	------
Totals	7991.06	8580.34	7655.87	24227.27
Means	3995.53	4290.17	3827.94	12113.64
Totals	27230.83	25123.11	23445.39	75799.33

* BGF= Biginning of grain fill
** MGF= Middle of grain fil

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	312849.3	156424.6	1.25	5.71
B	2	1199265.	599632.8	4.79	5.71
AB	4	2638047.	659511.9	5.27	4.72
Error	9	1125932.	125103.6		
Total	17	3.2E+08			

LEAF AREA FOR 1989
(49 days after sowing)

Stages= A		DURATION = B (in days) 1	3	6	Totals
Emerg = a1		3555.83	3934.60	3869.23	11359.66
		4727.21	4560.91	3425.83	12713.95
		------	------	------	------
	Totals	8283.04	8495.51	7295.06	24073.61
	Means	4141.52	4247.76	3647.53	12036.81
4 leaves= a2		2966.47	4190.00	3330.87	10487.34
		4306.02	4721.63	4522.74	13550.39
		------	------	------	------
	Totals	7272.49	8911.63	7853.61	24037.73
	Means	3636.25	4455.82	3926.81	12018.87
8 leaves= a3		3714.19	3162.28	2826.38	9702.85
		4504.20	3827.15	4239.23	12570.58
		------	------	------	------
	Totals	8218.39	6989.43	7065.61	22273.43
	Means	4109.20	3494.72	3532.81	11136.72
Totals		23773.92	24396.57	22214.28	70384.77

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	353038.3	176519.1	1.38	5.71
B	2	421253.3	210626.6	1.64	5.71
AB	4	1928248.	482062.1	3.76	4.72
Error	9	1153957.	128217.4		
Total	17	2.8E+08			

LEAF AREA FOR 1989
(78 days after sowing)

	DURATION = B (in days)			
Stages= A	1	3	6	Totals
Emerg = a1	3531.33	3794.73	3485.13	10811.19
	3870.19	4476.29	3607.73	11954.21
	------	------	------	------
Totals	7401.52	8271.02	7092.86	22765.40
Means	3700.76	4135.51	3546.43	11382.7
4 leaf tips = a2	3927.96	3983.97	2713.13	10625.06
	2830.80	4349.43	3870.65	11050.88
	------	------	------	------
Totals	6758.76	8333.40	6583.78	21675.94
Means	3379.38	4166.7	3291.89	10837.97
8 leaf tips = a3	3307.22	3092.43	2719.90	9119.55
	3912.75	3765.07	3913.73	11591.55
	------	------	------	------
Totals	7219.97	6857.50	6633.63	20711.10
Means	3609.99	3428.75	3316.82	10355.55
Totals	21380.25	23461.92	20310.27	65152.44

ANOVA

Source	df	SS	MS	F	F(0.025)
A	2	352110.4	176055.2	2.97	5.71
B	2	856172.4	428086.2	7.23	5.71
AB	4	1741433.	435358.3	7.35	4.72
Error	9	533150.5	59238.95		
Total	17	2.4E+08			

(DRY WEIGHT FOR 1988, IN GRAMS/PLANT)
Water table is raised to 0.3 m below the soil surface

		DURATION = B(in days)		
Stages= A	3	6	12	Totals
Silk = a1 *	64.30	86.30	66.30	216.90
	58.30	53.20	86.80	198.30
Totals	122.60	139.50	153.10	415.20
Means	61.3	69.75	76.55	207.6
BGF = a2 **	102.03	73.70	43.03	218.76
	67.00	47.00	72.00	186.00
Totals	169.03	120.70	115.03	404.76
Means	84.515	60.35	57.515	202.38
MGF = a3 ***	78.30	83.00	56.50	217.80
	55.93	62.37	55.30	173.60
Totals	134.23	145.37	111.80	391.40
Means	67.115	72.685	55.9	195.7
Totals	425.86	405.57	379.93	1211.36

* Silking stage
** Begin of grain fill
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	47.44	23.72	0.17	4.26
B	2	176.59	88.30	0.65	4.26
AB	4	1453.92	363.48	2.66	3.63
Error	9	1229.89	136.65		
Total	17	84429.7			

(DRY WEIGHT FOR 1989, IN GRAMS/PLANT)
Water table is raised to the soil surface

		DURATION = B (in days)			
Stages= A		1	3	6	Totals
Emerg = a1		56.96	61.80	68.20	186.96
		63.90	76.00	46.90	186.80
		------	------	------	------
	Totals	120.86	137.80	115.10	373.76
	Means	60.43	68.9	57.55	186.88
4 leaves= a2		69.30	76.30	48.50	194.10
		57.40	85.80	48.10	191.30
		------	------	------	------
	Totals	126.70	162.10	96.60	385.40
	Means	63.35	81.05	48.3	192.7
8 leaves= a3		69.40	55.20	37.40	162.00
		67.90	85.90	59.83	213.63
		------	------	------	------
	Totals	137.30	141.10	97.23	375.63
	Means	68.65	70.55	48.615	187.815
Totals		384.86	441.00	308.93	1134.79

ANOVA

Source	df	SS	MS	F	F(0.05
A	2	13.02	6.51	0.17	4.26
B	2	1464.42	732.21	19.35 *	4.26
AB	4	1817.94	454.48	12.01 *	3.63
Error	9	340.49	37.83		
Total	17	75177.4			

(YIELD DATA FOR 1988, IN GRAMS/PLANT)
Water table is raised to 0.3 m below the soil surface

		DURATION = B(in days)		
Stages= A	3	6	12	Totals
Silk = a1 *	86.83	75.30	68.00	230.13
	68.13	70.53	85.93	224.59
Totals	154.96	145.83	153.93	454.72
Means	77.48	72.915	76.965	227.36
BGF = a2 **	56.63	73.20	60.63	190.46
	96.30	72.63	40.97	209.90
Totals	152.93	145.83	101.60	400.36
Means	76.465	72.915	50.8	200.18
MGF = a3 ***	58.07	47.33	47.40	152.80
	79.30	73.33	64.63	217.26
Totals	137.37	120.66	112.03	370.06
Means	68.685	60.33	56.015	185.03
Totals	445.26	412.32	367.56	1225.14

* Silking stage
** Begin of grain
*** Middle of grain fill

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	613.36	306.68	6.03 *	4.26
B	2	506.99	253.49	4.99 *	4.26
AB	4	1577.91	394.48	7.76 *	3.63
Error	9	457.56	50.84		
Total	17	86542.9			

(YIELD DATA FOR 1989, IN GRAMS/PLANT)
Water table is raised to the soil surface

	DURATION = B(in days)			
Stages= A	1	3	6	Totals
Emerg = a1	33.47	23.20	18.87	75.54
	35.80	37.03	12.87	85.70
Totals	69.27	60.23	31.74	161.24
Means	34.64	30.12	15.87	80.62
4 leaves= a2	32.63	18.83	36.67	88.13
	39.80	27.73	24.73	92.26
Totals	72.43	46.56	61.40	180.39
Means	36.22	23.28	30.70	90.20
8 leaves= a3	32.00	25.93	29.83	87.76
	43.13	37.80	25.10	106.03
Totals	75.13	63.73	54.93	193.79
Means	37.57	31.87	27.47	96.90
Totals	216.83	170.52	148.07	535.42

ANOVA

Source	df	SS	MS	F	F(0.05)
A	2	89.21	44.61	1.64	4.26
B	2	409.81	204.90	7.53 *	4.26
AB	4	743.96	185.99	6.83 *	3.63
Error	9	244.94	27.22		
Total	17	17414.3			

9. BIBLIOGRAPHY

Alvino, A., and G. Zerbi., 1986. Water-table level effect on the yield of irrigated and unirrigated grain maize. American Society of Agricultural Engineers. ASAE 29(4):1086-1089.

Baser, D.K., I.K. Jaggi and S.B. Sinha., 1981. Root and shoot growth and transpiration from maize plant as influenced by various depths of water table. Zeitschrift fur Acker and Pflanzenbau. 150(5): 390-399.

Beer, C.E., W.D. Shrader, and R.K. Schwanke., 1967. Interrelationship of plant population, soil moisture and soil fertility in determining corn yields on Colo clay loam at Ames, Iowa. Iowa Agric. Home Econ. Exp. Stn. Res. Bull. 556.

Berbecel, O., and M. Eftimescu., 1973. Effect of agrometeorological conditions on maize growth and development. p. 10-31. Inst. Meteor. Hydrol. Bucharest. (English translation).

Berbecel, O., M. Eftimescu., E. Gogorici., and I. Rogojan., 1964. The forecast of the vegetative phases of the self sown and cultivated flora. p. 347-358. Culegere de lucrari. Romanian Inst. Meteor. Bucharest. (English summary.)

Bohm, W., H. Maduakor, and H.M. Taylor. 1977. Comparison of five methods for characterizing soybean rooting density. Agron. J. 69: 415-419.

Bradford, K.J., and Dilley, D.R., 1978. Plant Physiology, 70, 1503-1507.

Cahoon, G.A., and Stolzy, L.H., 1959. Estimating root density and distribution in citrus orchards by the neutron moderation method. Proc. Am. Soc. Hortic. Sci. 74, 322-327.

Cannell, R.Q., Belford, R.K., Gales, K., Dennis, C.W., and Prew, R.D., 1980. Effects of waterlogging at different stages of development on the growth and yield of winter wheat. J. Sci. Food Agric. 31: 117-132.

Chaudhary, T.N., V.K. Bhatnagar., and S.S. Prihar., 1975. Corn yield and nutrient uptake as affected by water-table depth and soil submergence. Agron. J. 67:745-749.

Claassen, M.M., and R.H. Shaw., 1970. Water deficit effects on corn. I. Vegetative components. Agron.J.62:649-652.

Cross, H.Z., and M.S. Zuber., 1972. Prediction of flowering dates in maize based on different methods of estimating thermal units. Agron. J. 64:351-355.

Dale, R.F., and R.H. Shaw. 1965. Effect on corn yields of moisture stress and stand at two fertility levels. Agron.J. 57:475-479.

Das, D.K., and R.L. Jat. 1972. Adaptability of maize to high soil water conditions. Agron. J. 64(6):849-850.

Doty, C.W., and J.E. Parsons., 1979. Water requirements and water table variations for a controlled and reversible drainage system. Transactions of the ASAE 22(3): 532-536.

Duncan, W.G., and J.D. Hesketh. 1968. Net photosynthetic rates, relative leaf growth rates and leaf numbers of 22 races of maize grown at eight temperatures. Crop.Sci. 8:370-374.

Eik, K., and J.J. Hanway., 1966. Leaf area in relation to yield of corn grain. Agron.J. 58:16-18.

Follett, R.F., R.R. Allmaras, and G.A. Reichman., 1974. Distribution of corn roots in sandy soil with a declining water table. Agron. J. 66: 288-292.

Gilmore, E., and J.S. Rogers., 1958. Heat units as a method of measuring maturity in corn. Agron.J.50:611-615.

Goins, T,, J. Lunin, and H.L. Worley., 1966. Water table effects on growth of tomatoes, snap beans and sweet corn. Trans. of the ASAE. 9(4): 530-533.

Grobbelaar, W.P. 1963., Responses of young maize plants to root temperatures. Meded. Landbouwhogesch. Wageningen. 63:(5) 1-71.

Hershey, A.L., 1934. A morphological study of the structure and development of the stem and ears of Zea mays L. Unpublished Ph.D. Thesis. Iowa State University, Ames.

Hanway, J.J., 1971. How a corn plant develops. Iowa Coop Ext. Serv.Spec.Rep.48(rev).

Howell, T.A., E.A. Hiler., O Zolezzi., and C. Ravelo., 1976. Grain sorghum response to inundation at three growth stages. ASAE paper No. 12082. ASAE, St. Joseph, MI 49085.

Howell, T.A., E.A. Hiler., 1974. Effects of inundation period on seedling growth. Trans. of ASAE. 17(2): 286-288, 294.

Jackson, M.B., 1976. Planta, 129, 273-274.

Jones, C.A., and J.R. Kininry., 1986. CERES-Maize a simulation model of Maize Growth and Development. Texas A&M University press.

Katayama, T., 1961. Proceedings of the crop Science Society of Japan, 29, 229-233. (English summary).

Kiesselbach, T.A., 1949. The structure and reproduction of corn. Nebr. Agric. Exp. Stn. Res. Bull. 161.

Kramer, P.J., 1951. Causes of injury of plants resulting from flooding of the soil. Plant Physiol. 26: 722-736.

Lal, R., and G.S. Taylor., 1969. Drainage and nutrient effects in a field lysimeter study: I. Corn yield and soil conditions. Soil Sci. Soc. Am. Proc. 33:937-941.

Luxmoore, R.J., and L.H. Stolzy., 1969. Root porosity and growth response of rice and maize to oxygen supply. Agron.J. 61:202-204.

Mallet, J.B., 1972. The use of climatic data for maize yield predictions. Ph.D. Thesis. Dep. of Crop Sci., Univ. of Natal, Pietermaritzburg, S.A.

Marsh, B., 1971. Measurement of length in random arrangements of lines. J. Appl. Ecol. 8:265-267.

Maranville, J.W., and G.M. Paulsen., 1970. Alteration of carbohydrate composition of corn (Zea mays L.) seedlings during moisture stress. Agron. J. 62:605-608.

Mengel, D.B., and S.A. Barber., 1974. Development and distribution of the corn root system under field conditions. Agron.J.66:341-344.

Mittra, M.K., and F.C. Sticker., 1961. Excess water effects on different crops. Trans. Kans. Acad. Sci. 64:275-286.

Newman, E.I., 1966. A method of estimating the total length of root in a sample. J. Appl. Ecol. 3, 139-145.

Newman, J.E., and B.O. Blair., 1969. Growing degree days and dent corn maturity. Part II. Mimeo. Agron. Dep. Purdue Univ., Lafayette, Ind.

Norris, F. De LA. M., 1913. Proceedings of the Bristol Naturalist Society, 4, 134-136.

Paddick, M.E., 1944. Vegetative development of inbred and hybrid maize. Iowa Agric. Exp. Stn. Res. Bull. 331.

Pearson, R.W., 1974. Significance of rooting pattern to crop production and some problems of root research. In: The plant Root and its environment. Carson, E.W. (ed). Charlottesville, U.S.A., University press of Virginia, pp. 247-270.

Purvis, A.C., and R.E. Williamson., 1972. Effects of flooding and gaseous composition of root environment on growth of corn. Agron.J.64:674-678.

Ragland, J.L., A.L. Hatfield, and G.R. Benoit., 1965. The growth and yield of corn. I. Microclimate effects on the growth rates. Agron.J.57:217-220.

Rattan, L., and George, S.T., 1969. Drainage and nutrient effects in a field lysimeter study: I. Corn yield and soil conditions. Soil Sci. Soc. Amer. proc., Vol 33, 1969.

Ritchie, J.T., and Burnett., 1971. Dryland evaporative flux in subhumid climate. II. Plant influences. Agron. J. 63:56-62.

Roberts, J.A., and G.A. Tucker., 1985. Ethylene and plant development. University of Nottingham, school of agriculture. Butterworths. England.

Ritter, W.F., and C.E. Beer., 1969. Yield reduction by controlled flooding of corn. Trans. ASAE 12:46-50.

Salter, P.J., and J.E. Goode., 1967. Crop responses to water at different stages of growth. Commonw. Agric. Bur. Res. Rev. 2.

Schuurman, J.J., and M.A. Goedewaagen., 1971. Methods for the examination of root systems and roots. Center for Agricultural Publication and Documentation, Wageningen, Netherlands.

Slack, D.C., C.T. Haan., and L.G. Wells., 1975. Modeling soil water movement into plant roots. ASAE. paper 75-2581. Am. Soc. Agric. Eng., St. Joseph, Michigan.

Slatyer, R.O., 1969. Physiological significance of internal water relations to crop yield. p. 53-83. In J.D. Eastin, F.A. Haskins, C.Y. Sulivan, and C.H.M. van Bavel (eds.) Physiological aspects of crop yield. Am. Soc. Agron. and Crop Sci. Soc. Am., Madison, Wis.

Sprague, G.F., 1977. Corn and corn improvement. American Society of Agronomy. Madison, Wisconsin, 18: 603-616.

Stypa, M., A. NuDnez., D.A Barry., M.H. Miller., and W.A. Mitchell., 1987. Can. J. Soil Sci. 67:293-308.,

Tennant, D., 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63:995-1001.

Trought, M.C., and M.C. Drew., 1982. Effects of waterlogging on young wheat plants (Triticum aestivun L.) and on soil solutes at different soil temperatures. Plant and soil 69, 311-326.

Upcharch, D.R., and Ritchie, J.T., 1983. Root observations using a video recording system in mini-rhizotrons. Agron.J. 75: 1009-1015.

Varade, S.B., Stolzy, L.H., and Letey, J., 1970. Influence of temperature, light intensity, and aeration on growth and root porosity of wheat, Triticum aestivum. Agron. J. 62, 505-507.

Voladarski, N.I., and L.V. Zinevich., 1960. Drought resistance of corn during ontogeny. Fiziol. Rast. 7:176-179.

Wareing, P.F., and I.D. Phillips. The control of growth and differentiation in plants --2d ed.-- Oxford; New york. Pergamon Press, 1978.

Williamson, R.E., and Kriz, G.J., 1970. Response of agricultural crops to flooding, depth of water table and soil gaseous composition. Trans. Am. Soc. Agric. Engrs. 13:216-220.

Williamson, R.E., and C.R. Willey., 1964. Effect of depth of water table on yield of tall fescue. Agron.J.61:310-313.

Wolfe, T.K., 1927. A study of germination, maturity and yield in corn. Va. State Tech. Bull. 30.

Yoshida, S., 1972. Physiological aspects of grain yield. Annu. Rev. Plant Physiol. 23: 437-464.

Zolezzi, O., T.A. Howell, C.J. Arvelo, and E.A. Hiler. 1978. Grain sorghum response to inundation duration at the early reproductive growth stage. Trans. of ASAE. 21(4): 687-690, 695.

10. ADDITIONAL BIBLIOGRAPHY

Acevedo, E., T.C. Hsiao., and J.W. Henderson., 1971. Immediate and subsequent growth responses of maize leaves to changes in water status. Plant Physiology (48): 631-636.

Allen, J.R., G.W. McKee, and J.H. McGahen. 1973. Leaf number and maturity in hybrid corn. Agron.J. 65:233-235.

Arkin G.F. and H.M Taylor., 1981. Modifying the root environment to reduce crop stress.

Arndt, C.H. 1945. Temperature-growth relations of roots and hypocotyls of cotton seedlings. Plant Physiol. 20:200-220.

Bair, R.A., 1942. Growth rates of maize. Plant Physiol. 17:619-631.

Barnes, D.L., and D.G. Woolley. 1969. Effect of moisture stress at different stages of growth. I. Comparison of a single-eared and a two-eared corn hybrid. Agron.J. 61:788-790.

Barry, D.A., 1987. Effects of nutrient availability and subsoil bulk density on corn yield and nutrient absorption. Can. J. Soil Sci. 67: 281-292.

Beauchamp, E.G., and D.J. Lathwell. 1966. Effects of root zone temperature on corn leaf morphology. Can.J. Plant Sci. 46:593-601.

Boote, K.J., 1976. Root:shoot relationships. Soil Crop Sci. Soc. Fla. Proc. 36: 15-23.

Bourget, S.J., Finn, B.J., Dow, B.K., 1966. Effects of different soil moisture tensions on flax and cereals. Can J. SOil Sci. 46: 213-216.

Cameron, D.G., 1973. Lucerne in wet soils, the effect of stage of growth, cultivar, air temperature and root temperature. Aust. J. Agric. Res., 24: 851-861.

Cannell, R.Q., and Belford, R.K., 1982. Crop growth after transient waterlogging. In: Advances in Drainage, Proc. 4th Nat. Drainage Symp., Am. Soc. Agric. Eng., St. Joseph, Michigan. pp. 163-170.

Cannell, R.Q., Belford, R.K. Blackwell, P.S., Govi, G., and Thompson, R.J., 1982. Effects of waterlogging on soil aeration, root and shoot growth, and yield of winter oats. Agric. Res. Coun. Letcombe Lab. Annu. Rep. 1981, 39-40.

Cannell, R.Q., Belford, R.K., Gales, K., and Dennis, C.W., 1980. A lysimeter system used to study the effect of transient waterlogging on crop growth and yield. J. Sci. Food Agric. 31: 105-116.

Denmead, O.T., and R.H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron.J. 52:272-274.

Drew, M.C., and Sisworo, E.J., 1977. Early effects of flooding on nitrogen deficiency and leaf chlorosis in barley. New Phytol. 79: 567-571.

Everard, J.D. and M.C. Drew., 1987. Mechanisms of inhibition of water movement in anaerobically treated roots of Zea Mays. L. Journal of experimental Botany. N° 192., 38: 1154-1165.

Grable, A.R., 1966. Soil aeration and plant growth. Adv. Agron. 18: 57-106.

Hallauer, A.R., and W.A.Russell. 1961. Effects of selected weather factors on grain moisture reduction from silking to physiologic maturity in corn. Agron.J. 53:225-229.

Hiler, E.A., and R.N. Clark., and L.J. Glass., 1971. Effects of water table height on soil aeration and crop response.

Hook, D. and R. Crawford (eds)., 1978. Plant life in anaerobic environments. Ann arbor.

Hoyt, P., and R.Bradfield. 1962. Effect of varying leaf area on dry matter production in corn. Agron.J. 54:523-525.

Hsaio, T.C., Acevedo, E., and Henderson, D.W., 1970. Maize leaf elongation: continuous measurements and close dependence on plant water status. Science 168: 590-591.

Janes, B.E., 1974. The effect of variations in root environment on root growth and resistance to flow of water in intact plants. In: Mechanisms of Regulation of Plant Growth. Eds. R.L. Bieleski, A.R. Ferguson and M.M. Cresswell. pp.379-385. The Royal Society of New Zealand,Wellington.

Jensen, C.R., Stolzy, L.H., and Letey, J., 1967. Tracer study of oxygen diffusion through roots of barley, corn and rice. Soil Sci. 103: 23-29.

Kramer, P.J., 1969. Plant and Soil Water Relations: A modern Synthesis. Pub. McGraw-Hill, New York.

Letey, J., Stolzy, L.H., Blank, G.B., and Lunt, O.R., 1961. Effect of temperature on oxygen diffusion rates and subsequent shoot growth root growth and mineral content of two plant species. Soil Sci. 92: 314-321.

Meterammon, M., and Crawford, R.M.M., 1971. Metabolic theory of flooding tolerance: The significance of enzyme distribution and behavior. New Phytol. 70: 299-306.

Mees, G.C., and Weatherley, P.E., 1957. The mechanism of water absorption by roots. II. The role of hydrostatic pressure gradients across the cortex. Proc. R. Soc. London Ser. B. 147: 381-391.

Patrick, W.H., and Tusneem, M.E., 1972. Nitrogen losses from flooded soil. Ecology 53: 735-737.

Pirson and Zirmermman (Eds)., 1982. Encyclopedia of plant physiology. New series, volume 12-B. Chapter 14.

Russell, M.B., 1952. Soil aeration and plant growth. In: Soil Physical Conditions and Plant Growth. Ed. B.T. Shaw. pp. 253-301. Academic Press, New York.

Shaw, R.H., and D.R. Laing. 1966. Moisture stress and plant responses. p.73-94. In W.H. Pierre, Don Kirkham, J. Pesek, and R. Shaw (eds.) Plant environment and efficient water use. Am. Soc. Agron. and Soil Sci. Soc. Am., Madison, Wis.

Schuurman, J.J., and DeBoer, J.J.H., 1974. The effect of soil compaction at various depths on root and shoot growth of oats. Neth. J. Soil Sci. 22: 133-142.

Schuurman, J.J., 1966: Effects of soil density on root and top growth of oats. Proc. Int. Sci. Symp. 1966, Brno, Czechoslovakia, 103-120.

Sojka, R.E., H.A. Joseph, and L.H. Stolzy. 1972. Wheat response to shortterm heat stress and to soil oxygen stress at three stages of growth. Agronomy Journal 64: 450-452.

Varapetian, B.B., and Timiriazev, K.A., 1973. Aeration of roots in relations to molecular oxygen transport in plants. In: Plant response to climatic factors. pp. 259-265. Proc. Uppsala Symp. 1970. UNESCO Paris.

Weiss, Lionel, Statistical decisions theory. New York: McGraw-Hill Book Company, 1961.

Willis, A.J., and Yemm, E.W., 1955. The respiration of barley plants. VIII. Nitrogen assimilation and the respiration of the root system. New Phytol. 54: 163-181.

Zadoks, J.C., Chang, T.T., and Konzak, C.F., 1974. A decimal code for the growth stages of cereals. Weed Res., 14: 415-421.