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The influence of irrigation timing on corn root growth, water use, and yield

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THE INFLUENCE OF IRRIGATION TIMING ON CORN ROOT GROWTH, WATER USE, AND YIELD

by

Ahmed Omar Jama

A Thesis Submitted to the Faculty of the

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For the Degree of

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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STATEMENT BY AUTHOR

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ABSTRACT

The adverse effect of moisture stress at flowering and maturation stages on corn (<u>Zea mays</u> L.) grain yield is well documented. Stress at vegetative stages, on the other hand, affects dry matter more than grain yield but is also reported to condition the corn plant to withstand later stress. The objectives of this study were (1) to determine if moisture stress at vegetative stages could condition the corn crop to minimize the effect of stress at reproductive stages, and (2) to document the effect of this vegetative stress on corn root growth, water use and yield.

Secondary root initiation was reduced by moisture stress at the 4 and 7 leaf stages. Moisture stress during vegetative stages reduced water use and stover weight but not grain yield. However, stress at silking reduced grain yield. Stress at vegetative stages did not precondition the corn to endure water deficit later in the season.

INTRODUCTION

Corn (Zea mays L.) is the third most important crop in world agriculture. However, it is the most widely grown crop and has the highest yield potential. Even though corn is originally native to semi-arid summer rainfall areas, it requires irrigation water for optimum yield in semi-arid areas. Where corn is grown in warm climates and under irrigation, growers need to optimize the water application for the maximum yield with the least cost of irrigation. The two obvious ways to optimize corn irrigation are: 1) the quantity of seasonal water to apply that best correlates with the seasonal water requirement of the crop and
2) the timing of this irrigation.

While the importance of irrigation at the critical time of flowering is well known, irrigation timing through out the season is not well studied. There are contradictions in the literature as to the effect of moisture stress at the vegetative stages. Moreover, some farmers believe that moisture stress at early vegetative stages favors corn root growth and, therefore, do not irrigate the crop at those times even when water is available to them.

Root growth is related to environmental and soil factors as well as other plant organs. Many growers assume that increased root growth results in greater water use and higher yield. Again, the available results in the literature do not agree with this assumption.

Water use is closely related with yield. The relationship lies in the leaf stomates which lose water as they fix carbon dioxide from the air. Corn is one of the most efficient crop plants in its water use.

Corn water use efficiency and yield are related to irrigation timing according to specific growth stages. Farmers can improve their productivity and reduce their irrigation costs if they know which growth stages are critical for yield formation and which are not. The objectives of this study were to determine if moisture stress at early vegetative stages could condition the corn crop to minimize the efect of stress at reproductive stages and to document the effect of this vegetative stress on corn root growth, water use, and yield.

LITERATURE REVIEW

Botanical Description of Corn

Corn (_Zea mays_ L.) is a coarse, annual grass having a fibrous root system usually with a single dominant stem. Corn is related to and is fully fertile with the wild maize (_Zea mays_ var. _Mexicana_, _Teosente_) which is native to the summer rainfall, semi-arid lands of central America (Hall et al., 1979). The above ground parts of corn include the nodes, internodes and leaves. Flowers are borne separately on the same plant. Corn seeds are produced on the ear (female flower).

A general classification of the growth stages of corn could be : (1)seed germination and seedling emergence, (2)rapid growth, (3) tasseling, ear silking and pollination, and (4) grain filling and maturation (Dennis, 1979). A more detailed classification of the growth stages was, however, developed by Hanway (1971) which defines vegetative growth stages according to the leaf number of the upper most leaf whose collar is visible. Leaf number varies with the hybrid and environmental differences and may reach up to 18 leaves before tasseling. The reproductive growth stages, on the other hand, consist of six subdivisions: silking, blister, milk, dough, dent, and physiological maturity. Consequently, this method of classification can have about 25 different growth stages of the corn plant. The duration of these stages is mainly a function of genotype, temperature and photoperiod (Fischer and Palmer,1984).

Economic Importance of Corn

Corn is grown throughout the temperate and tropical regions of the world. It ranks third, after wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.), in the world production of cereal crops (Waldren, 1983). It is grown in more countries than any other cereal crop and has the largest grain yield of any cereal (Fischer and Palmer, 1984). Under irrigation, a good commercial grain yield is about 6 to 9 t ha^{-1} with 10 to 13 percent moisture (Doorenbos and Kassam, 1979). Goldworthy et al. (1974) measured a dry weight production of 24 t ha^{-1} in 130 days.

Corn Root Growth and Moisture Stress

Corn Root Growth and Morphology.

Seed germination begins with the radicle (embryonic root), rather than epicotyl (shoot) protrusion through the seed coat. Elongation is caused by growth of cells that formed when the embryo was developing in the mother plant (Salisbury and Ross, 1985).

Root growth in corn starts with the seminal roots which support the plant in its earliest stage of establishment. Seminal roots also absorb nutrients but do not grow excessively and may not live to the maturity of the plant (Waldren, 1983). The growth of the seminal roots slows down as soon as the the secondary or the main root system develops from the nodes (Petinov, 1965).

The secondary roots are the most important root system. They are also called crown or nodal roots because they grow from the crown or first node and then from the other nodes that follow. Moreover, they are formed just below the soil surface, regardless of seed depth (Kearney et al., 1980). Petinov (1965) reported the volume of seminal roots as only 0.7 to 0.95 cm^3 compared to a volume of 40 to 50 cm^3 for the secondary roots. The secondary roots are initiated 1 to 2 weeks after germination (Kearney et al., 1980; Waldren, 1983).

Corn roots do not grow downwards directly. Foth (1962) reported that early root growth occurred largely in a downward-diagonal direction followed by extensive lateral growth. Lateral growth was completed a week or two before tasseling and caused a marked uniformity in root density in the upper 0.31 to 0.38 m of the soil. Martin et al (1976) found that the usual spread of corn roots was about 1.25 m.

Root growth changes in intensity during the life cycle of the plant. Mengel and Barber (1974) found that the size of the root system of a corn plant increases rapidly until tasseling and then declines during grain filling. During early growth stages, roots grow rapidly and few if any die so that the size of the root system increases exponentially. As the plant reaches flowering, roots begin to die as fast as new roots are produced so that size of the root system remains constant. At later growth stages, the number of roots dying exceeds the numer being produced and the overall size of the root system declines. Foth (1962) also described corn root system as a series of overlapping stages which associated with top growth. This shoot-root ratio increased early, declined as brace roots developed, and rose again at grain development when root growth ceased. In this study Foth (1962) also found that extensive root growth below the 38-cm depth of the soil occurred near tasseling time with a root density of about 10 cm cm^{-3}.

Corn roots reach great depths into the soil and absorb water from deeper layers of the profile. Although in deep soils the roots may reach a depth of 2 m, the highly branched system is located in the upper 0.8 to 1 m (Doorenbos and Kassam, 1979). In other findings, corn roots were found to reach up to 1.6 to 2 m deep in the soil (Martin et al., 1976). Similarly, Russell and Danielson (1956) reported that corn utilized water to a depth of 1.52 m in a deep brunizen soil. Taylor and Klepper (1973) stated that roots deep within the soil are often considered less effective in water absorption than more shallow roots since they occur at distances farther from the plant center. However, these deep roots are more efficient in water uptake quite often because they are younger, are usually in wetter soils, and are less crowded than roots closer to the surface. Waldren (1983) suggested that this could explain why total root weight declines after flowering while plant water use is still quite high.

Varieties of corn differ in their root growth and morphology. Martin et al. (1976) compared corn varieties and found that the large varieties have more functional main roots, greater spread, deeper penetration, greater weight, larger diameter of main roots,
and greater combined length of main roots than smaller varieties.

The Effect of Moisture Deficit on Corn Root Growth.

Rain-fed corn experiences some degree of stress at the vegetative stages when it does not rain after crop establishment.
Where irrigation water is available, farmers believe that mild

stress during early vegetative periods favors root growth. However, the available literature does not indicate if moisture deficit at early vegetative stages of corn growth encourages root growth. These studies deal more with the secondary roots rather than seminal roots.

The few studies concerning the effect of moisture deficit on seminal roots of corn do indicate that root growth is reduced by soil moisture deficits. Peters (1957) found that not only does seminal root growth increase with decreasing soil water tension, but also increases with increasing soil water content at the same tension. Petinov (1965) reported that corn seminal roots were best developed in maize plants that received a pre-irrigation plus the growing season irrigations compared to the non-irrigated plants. In this same study moisture deficit reduced the active period of seminal root growth. In the absence of other limiting factors, radicle elongation decreased with increasing soil moisture tension or osmotic stress over the range of 1/3 through 12 atmospheres. Root growth between germination and emergence for the corn hybrids Pioneer 3995, Northup King 403, and Pride 1108 was examined in the study of Cutforth et al. (1986). Pioneer 3995 was less sensitive to soil water stress than was Northup King 403, while Pride 1108 was the most sensitve (Cutforth et al., 1986). Salisbury and Ross (1985) stated that the response of cellular growth to water stress appears as a retardation of shoot and root growth.

The effect of moisture deficit on secondary root growth is more dramatic than the effect on seminal root growth. Kearney et al.(1980) reported that corn secondary roots will not grow in dry soil and recommend irrigation at the time of the secondary root intiation and development. Petinov (1965) found that dry matter accumulation by the plant was identical for the irrigated and the non-irrigated treatments during the initial phases of the development when seminal roots were supplying water and nutrients. In contrast, when secondary roots extracted most of the nutrients and water, the irrigated plots had a 43% increment in the aerial mass as well as 63% increment in the root system compared to the non-irrigated control. Day (1981) explained that because of water stress, shortage of assimilates in roots may not only decrease root growth, but the roots may be less able to utilize the soil reserves as result of this decrease in their growth.

Moisture stress continues to affect root growth until grain formation when roots are still growing. Petinov (1965) reported that in the grain formation phase the increase in root growth on the irrigated plots was 13 times that of the control. There is a significant correlation between corn yields and the amount of available stored soil moisture which is attributed to the potential for an increased root system in moist soil since most of the cell elongation in young roots is directly due to water uptake (Waldren, 1983). Doorenbos and Kassam (1979) recommend that the root zone should be, where feasible, wetted at or soon after sowing to obtain a good stand and rapid root development.

In fact, the rate of root growth is greatly affected by the rainfall pattern and irrigation practices adopted. A range of soil water contents were tested in the study of Cutforth et al. (1986) where the rate of root growth of corn decreased with decreases in the soil water content.

Other Factors Affecting Corn Root Growth.

Apart from soil moisture there are many other factors that affect corn root growth. They include temperature, mechanical impedance, aeration, fertilizers as well as genotype. These factors are often interrelated with each other. However, extremes in soil water content can mask the effect of other factors on corn root growth.

Temperature has direct influence on root growth. Dry weights of roots at different growth stages were found to decrease significantly with increasing soil temperature, with 20^{0}C being the optimum soil temperature for dry matter accumulation of corn seedlings (Beauchamp and Cathwell, 1967).

Soil temperatures of 15, 19, 25, and 30.5^{0}C were studied in an experiment by Cutforth et al. (1986) and it was found that decreases in soil temperature decreased root growth rate. Blacklow (1972) also found that during emergence there is a linear relationship between rate of elongation of roots and temperature over the range of 10 to 30^{0}C. Waldren (1983) summarized the effect of temperature by stating that when temperature exceeds 32^{0}C there is a sharp decline in the rate of root elongation and a constant temperature of 42^{0}C can be lethal to the seedlings. At temperatures below 9^{0}C, however, there is little if any elongation of roots. The amount of soil water can alter the effect of soil temperature on root growth.

Mechanical impedance also directly affects root growth of corn. Philips and Kirkham (1962) found mechanical impedance as measured by the the bulk density of the soil to be the physical property most highly correlated with reduction in growth and corn yield. Bertrand and Kohnke (1957) noted that physical resistance of the soil to root penetration can greatly affect corn root depth and distribution. They found that corn roots 5 weeks old were unable to penetrate a subsoil compacted to a bulk density of 1.5 g cm^{-3} but could grow satisfactorily in a subsoil of a 1.3 to 1.4 g cm^{-3}. Tillage experiments showed that, in general, corn grown under conventional tillage (plowing to 20 cm in the fall, disking, planting, and cultivating once) had more roots deeper in the soil than no tillage and rototilling to 5 cm and chiselling to 20 cm (Barber, 1970).

Aeration is closely related with mechanical impedance and soil moisture but is an important factor in itself and affects corn root growth. Under the conditions of low moisture stress, the oxygen concentration of the root atmosphere should be 10.5% for maximum root growth (Gingrich and Russel, 1956). It is also suggested that inadequate oxygen content in the soil water next to the plant root hairs may have been a factor responsible for the reduced plant growth observed in some studies (Philips and kirkham, 1962).

Since water utilization is closely related to root growth, plant nutrition has a very positive effect on water use efficiency, specially under conditions of less than optimum soil moisture (Waldren, 1983). Fertilizer can affect root growth and water use significantly. Linscott et al. (1962) reported that well fertilized corn uses water more efficiently through deeper roots and that corn with adequate nutrients, especially nitrogen, will produce deeper and more extensive root systems during early growth than unfertilized corn. Maizlish et al. (1980) found that primary root numbers per plant increased with increasing nitrogen while there was a slight increase in the numbers of the lateral roots. In contrast, first order lateral root elongation rate increased more strongly with increased nitrogen fertilizer than primary roots which did not respond to it. Organic additives increased root growth and proliferation (Mitchell and Sparks, 1982) but corn residues appeared to depress root growth (Barber, 1970).

Water Use and Moisture Deficit

The term water use may be confusing since we do not know whether one is considering evapotranspiration or the applied irrigation water, which is not easily comparable between different experiments because it can be affected by various factors. Water use and evapotranspiration are used interchangeably in the literature when the loss of water by plants includes both evaporation and transpiration. Quantatively, the two are identical but evapotranspiration (ET) implies loss of water while water use indicates utilization of the water by the plants (Arnon, 1976). Plants must lose water through the stomatal openings when they are fixing carbon dioxide. But different plant species do that differently resulting in different efficiencies.

Water Use Efficiency.

Water use efficiency is defined in two ways depending on whether one is using ET (Arnon, 1976; Begg et al., 1976) or transpiration alone (Hall et al., 1979) in the denominator as follows:

Water Use Efficiency = Grain or Total Yield/ ET

or " " " = Yield/ Transpiration

Corn is one of the most water use efficient crop plants. For example ,it requires about 372 unit weights of water per unit weight of dry matter produced compared to 271 for sorghum, 505 for wheat, 562 for cotton, and 585 for alfalfa (Martin et al., 1976).

Water use efficiency increases with yield and is closely correlated with it but only under optimum conditions. If corn is stressed at flowering, yield will be greatly reduced and may not be correlated with water use efficiency (Waldren, 1983). Doorenbos and Kassam (1979) reported that the water utilization efficiency for harvested yield for grain varies between 0.8 and 1.6 kg m^{-3}.

Different cultivars have different water use efficiencies. Early maturing corn hybrids are more efficient in using water for grain production while later maturing hybrids are more efficient in using water for forage production (Waldren, 1983).

Plant spacing may also affect the water use efficiency. Water use efficiency was highest for the 53-cm spacing treatment and lowest for the 107-cm spacing treatment (Yao and Shaw, 1964a). Narrower row spacing was found to increase water use efficiency by increasing yield through more light interception and reduction of transpiration. This is not true, however, under less optimum conditions (Waldren, 1983).

Water Use.

Although corn is one of the most efficient crop plants in its water use, it requires large amounts of water to produce good yields. The actual amount of water required depends on the environmental and soil factors. Ordinarily, the amounts of water use in a season are about 406 to 635 mm, although up to 838 mm and as low as 305 mm have been reported (Robins and Rhoades, 1958). In Minnesota, Dylla et al (1980) reported 609 mm (1975) with sprinkler irrigation and 602 mm (1976) and 435 mm (1977) with drip irrigation. A seasonal total of 486 mm was used by 120-day corn in the Guinea Savanna of West Africa (Kowal and Kassam, 1973a). Doorenbos and Kassam (1979) also estimated a 500 to 800 mm range for a medium cycle grain crop giving maximum yield. In the United States the best non-irrigated corn regions have annual precipitation of 600 to 1000 mm (Waldren, 1983).

Water use varies with the growth stage of the corn crop. Early in the season the water loss is mainly accounted for by evaporation but transpiration soon becomes the major factor as the crop cover increases. The magnitude of the water used also changes with time as the plants grow. Doorenbos and Kassam (1979) estimated that the water depletion was about 40% of the maximum evapotranspiration during the period of crop establishment, between 55 and 65% during the vegetative, flowering, and grain formation and up to 80% during the the ripening period. Water consumption per plant averages about 2.5 mm per day early in the season and peaks at about 10 mm per day shortly after silking on the average (Shaw, 1963).

Daily water use depends on climatic factors. In general corn uses more water on a hot, sunny day than on a cool, cloudy day. Daily water use by corn is greater in the southern latitudes of the U.S than the northern latitudes (Waldren, 1983).

Water use is also related to root growth. A linear relationship was found between root density and water use and water uptake values for a fully transpiring corn crop was 2.33 $X10^{-3}$ cm^3 water/ cm root/ day (Grimes et al., 1975).

The relationship between yield and water use is not always linear depending on the timing of stress. Hanks et al.

(1978) found a linear relationship between water use and yield of both grain and dry matter. On the other hand, Retta and Hanks (1979) found that an evapotranspiration deficit below a critical level may result in yields of dry matter and grain not linearly related to evapotranspiration. In areas were annual precipitation is 750 mm or less yield potential can vary from 3.7 t ha^{-1} to 10 t ha^{-1} while it can exceed 12.5 t ha^{-1} in more wetter areas (Waldren, 1983). Russel and Danielson (1954) found that when sufficient soil moisture was available the rate of water disappearance from the soil profile of corn plots exceeded the open pan evaporation rate during the period of rapid crop development. The total water disappearance under the widely different moisture treatments (no rain, rain, and rain + 5 cm of supplementary irrigation) was proportional to corn yield. Hanks (1974) developed a model to predict corn yields, both grain and dry matter, as a function of evapotranspiration using different irrigation treatments. He found a good fit of predicted versus measured dry matter and grain in Israel and grain yields in Nebraska. Considering final yield as the integrated result of different but related physiological processes, Verasan and Philips (1978) recommended cummulative evapotranspiration as the better integrator of the effects of water stress on corn dry matter production and nutrient accummulation than soil water potential.

Water use from different depths of the profile can vary due to the soil and the rooting factors of the plants. The maximum water use was found to be from the top 0.23 m depth in both row spacings of 0.53 and 1.07 m (Yao and Shaw, 1964a). About 80 percent of the soil water uptake was found to occur at a depth of 0.80 m, with a 100 percent of the water used from the first 1.0 to 1.7 m of the soil depth (Doorenbos and Kassam, 1979). However, Carlson et al. (1959) reported in Iowa that 70 to 75 percent of the water used by non-irrigated corn plants from a 1.30 m-profile was extracted from the top 0.65 m of the profile.

Stress adversely affects corn water use. Plants close their stomates as soon as the supply of water to the roots fails to keep up with atmospheric demand. Haynes (1948) reported plants that undergo temporary wilting transpire less water per unit of dry weight than plants that do not undergo wilting. The weather variable found highly associated with corn yields in Iowa was the number of days on which the corn was estimated to be under no moisture stress in the 9-week period before silking to 3 weeks after silking (Dale and Shaw, 1965).

Narrower spacing does not necessarily reduce water use even though it may increase the water use efficiency. On the contrary, Yao and Shaw (1964a) found less water use from a 53-cm row spacing than from an 81-cm or a 107-cm spacing.

The Effect of Water Stress on Corn Yield

The effect of moisture stress on corn yield is reported in different ways according to what method was used to impose the stress treatment and what growth stage is being studied.

Irrigation Timing.

Apart from naturally occuring seasonal drought situations irrigation timing is the common method to impose moisture stress. According to Hiler et al. (1974) :

> " Two areas which offer considerable promise for increasing water use efficiency in irrigated agriculture are improved irrigation timing techniques and intensified water application methods."

Hall and Butcher (1968) state the magnitude of the losses [in yield] may depend equally on the timing of the soil-moisture deficiency and the total magnitude of the seasonal shortage. Yaron (1971) suggested that irrigation timing has the greatest effect on crop yield because at some crop growth stages excessive soil moisture stress due to delayed or inadequate irrigation, can cause irreversible reduction in yield potential and crop quality or both. The effect of irrigation timing at grain filling stage was studied in Morocco by Ouattar et al.(1987) and it was found that grain filling was not significantly affected by severe water deficits of short duration regardless of the stage within the grain filling the deficit occurs. Moreover, continuous water deficits decreased final grain yield only when it was initiated during the the lag phase (R2-R3 of Hanway (1971) classification) rather than the linear phase (R4-R5). Hall and Butcher (1968) concluded from their study that optimum water use does not only imply good irrigation uniformity but also the timing of irrigation to the critical growth stage. They underlined the importance of obtaining information concerning the critical period characteristics for commercial crops - the growth stages in which yield is the most affected.

Growth Stages.

Growth stages for corn was described in detail by Hanway (1971) but most researchers combine the vegetative stages together while considering different stages of the reproductive and grain filling periods. More researchers have studied the effect of moisture stress at the reproductive stages as compared to the vegetative stages and fewer still examined the complete life cycle of the plant in the same experiment.

The effect of moisture stress on corn yield at the reproductive and grain formation stages is generally agreed upon and is supported by much research work. The studies of Robins and Domingo (1953) showed that water deficits for 1 to 2 days during the tasseling period resulted in as much as 22% yield reduction while periods of 6 to 8 days caused a yield reduction of 50%. Similarly, Denmead and Shaw (1959) found that moisture stress prior to silking reduced grain yield by 25%, that moisture stress during silking reduced grain yield by 50%, and that moisture stress after silking reduced grain yield by 21%. Further more, Claassen and Shaw (1970b) found that stress at late silking reduced grain yield by about 53% while the stress at tasseling and grain formation (post silking) reduced yield by 10 to 24% and 30 to 33%, respectively, depending on the year. Doorenbos and Kassam (1979) recommended that, in situations of limited water availability, irrigation scheduling be based on avoiding water stress during pollination followed by the grain formation period. Downey (1972) reported greatly reduced corn yields resulting from evapotranspiration deficits in certain growth stages and agreed with other researchers that the pollination period is the most sensitive. He generalized for non-forage crops including corn :

" ...water stress at any time from flowering to maturity is undesirable and gives [in-efficient] use of water..."

Hanks et al. (1978) reported that even though the elimination of irrigation during pollination was expected to decrease yields without corresponding decrease in evapotranspiration based on previous research, this did not occur in their study. But Stegman (1982) examined three growth stages of corn: planting to 12-leaf stage, 12-leaf stage to blister kernel (stage R2 of Hanway (1971)),

and blister kernel to physiological maturity. He used two levels of stress according to the allowable soil moisture depletion and found that the greatest yield depression was caused by the stress at the 12-leaf to blister kernel stage. Stress at blister kernel to physiological maturity was less detrimental to yield and the least damaging was the one at planting to 12-leaf stage. More recently Eck (1986) studied the effect of moisture stress at the vegetative and grain filling stages. Stress at pollination was not included in this experiment because the vulnerability of corn to stress during that period was decided to be well established. He found that grain yields were reduced 1.2% for each day of stress before maturity was reached. These reductions were mostly due to decrease in kernel weight. Moreover, deficits imposed for the last 20 and 30 days of grain filling period reduced ear dry matter about 24 and 47% respectively.

The effect of moisture stress during vegetative stages is not well documented and conflicting results appear in the literature. Retta and Hanks (1980) reported that water stress during the vegetative stages decrease relative yield of dry matter more than relative yield of grain yield. Similarly, Claasen and Shaw (1970a) found that stress during the vegetative stages was most influential in reducing the final dry weight. Doorenbos and Kassam (1979) in their recommendation for irrigation scheduling stated that when severe water deficit during flowering is unavoidable, water may be saved by reducing supply during the vegetative period as well as during grain filling without incurring additional yield losses. But other studies do not agree with this suggestion. McPherson and Boyer (1977) reported that dry matter accumulated throughout the season was better correlated with grain yield rather than the dry matter specially accumulated during grain filling period. This indicates, they said, that translocation is less inhibited than photosynthesis by drought and that the total photosynthetic accumulation for the whole season controls yield during a drought that does not disrupt the flowering process. Eck (1986) found that stress imposed at the vegetative stages for a period of 2 and 4 weeks reduced grain yield by 23 and 46% respectively. These yield reductions were mostly due to reduced kernel numbers.

However, stress at the vegetative period did not affect grain yield for some of the years that were reported in this study. Eck (1986) also found that the stress at the vegetative period reduced dry matter accumulation but the timing and duration were both important. For example, a 4-week water deficit beginning 41 days after planting reduced dry matter accumulation in leaves, stalks, and ears while a 2-week deficit 14 days later affected the dry matter accumulation of the stalks only.

Conditioning of the corn plants to withstand water stress at flowering by subjecting them to some stress during the vegetative period was discussed by Stewart et al (1975). They found that the evapotranspiration deficit of corn plants stressed during pollination was less for the treatment that was well watered during the vegetative period than the one that was stressed during the vegetative period. They explained this as a "conditioning" factor that diminished the relative impact of the evapotranspiration deficit during the pollination period. The researchers then concluded that while their findings support the idea that corn grain is specially vulnerable to water deficits during the pollination period, provided the crop experienced little or no evapotranspiration deficits in the late vegatative period, the susceptibility of corn yield to deficits in the pollination period could be greatly lessened if there have been prior deficits i.e the "conditioning" factor. Hanks et al. (1978) also attributed some effects to this conditioning factor. Their treatments at the vegetative stages included low and high water level treatments. When both treatments were stressed during pollination, however, the treatments that were low watered at the vegetative stages were less affected than the treatments with high water level at vegetative period which indicated that the low water level might have stressed the plants to condition them for the later stress.

Timing irrigations according to the growth stages of the corn plant is important for yield and water use efficiency. Some farmers believe that root growth is favored by moisture stress in the early vegetative stages. These farmers stress their corn early in the season to encourage root growth in contrast with some of the experimental results reported in the literature. In many arid land regions of the world such early vegetative stress on corn is inevitable due to rainfall pattern and irrigation water availability. This apparent contradiction among the available research results and farmers beliefs and practices needs to be addressed. It is equally important to assess the effect of this early vegetative stress on corn yield and water use efficiency. Farmers could benefit from the answers to these questions by saving precious and limited water supply or by applying irrigation in a more efficient manner. Furthermore, there are contradictory results in the literature on the ability of the corn plant to endure moisture stress later in the season when subjected to early vegetative stresses.

MATERIALS AND METHODS

A field study was conducted in 1988 on a Pima clay loam soil, (fine-loamy, mixed, Thermic Typic Torrifluvent) at Marana Agricultural Center in Marana, Arizona. The experimental plots were planted with Pioneer corn hybrid 3183 on 9 March 1988. The total area planted was about 1 ha with a plot size of 300 m^2 at a spacing of 1.02 m X 0.15 m. A graded furrow irrigation system was used at pre-plant for seed germination as well as for seasonal irrigations. Preplant fertilizer included 71 kg N ha^{-1} and 89 kg P_2O_5 ha^{-1} as (16-20-0) broadcast and incorporated into the soil. A minor insect problem with southwestern corn borer and corn ear worm was controlled by an aerial spray of Methomyl (Lannate) on 26 April 1988 at the rate of 0.40 kg ha^{-1}.

The study was repeated in 1989 on an Aqua Loam and Sandy clay loam soil(coarse-loamy over sandy, mixed, Thermic Typic Torrifluvent) at the Campus Agricultural Center in Tucson, Arizona. The field was planted on 22 March 1989 with Pioneer corn hybrid 3183 with a plot size of 49.25 m^2 at an spacing of 1.02 m X 0.15 m. The corn germinated on a stored soil moisture from a furrow pre-plant irrigation. After germination, a drip irrigation system was installed. Atrazine herbicide was applied on 21 March 1989 at the rate of 1.56 kg

ha^{-1}. A urea-ammonium nitrate solution (32-0-0) was added through the irrigation water (fertigation) at the 8 and 16 leaf stages at a rate of 84 kg ha^{-1} of nitrogen. Stem borers were effectively controlled by a manual application of Diazinon at the 8 and 13 leaf stages. Other insect problems such as ear worms were considered minor.

The experimental design used was a randomized complete block with 3 replications (1988) and 5 replications (1989) and 8 treatments arranged as a 4 X 2 factorial (Table 1).There were four vegetative treatments: well watered and withholding irrigation water at 2, 4, and 12-leaf stages. At anthesis these four groups were either irrigated or stressed. Irrigation water was applied at 50% depletion of the available water for the well-watered treatments to fill the soil profile back to field capacity.

Water Use Measurements

Soil moisture measurements were made with a neutron hydroprobe (Campbell Pacific) placed on access tubes that were located at the center of each plot. Measurements were recorded for five depths: 0 to 0.30 m, 0.31 to 0.60 m, 0.61 to 0.90 m, 0.91 to 1.20 m, and 1.21 to 1.50 m, before and three days after each irrigation. A calibration curve was generated for the neutron probe by simultaneous gravimetric soil moisture measurements recorded at the same locations. Water use for any period was obtained by summing up the differences between respective neutron probe readings. The 1988 water use data will not, however, be presented for the purposes of this thesis due to missing data.

Root Measurements

The number of secondary (crown) roots were directly counted at the 7 leaf stage in 1988 and at the 2 and 7 leaf stages in 1989. This was accomplished by excavating roots of 8 and 10 randomly selected plants respectively for the two years. Root density measurements were made at harvest by collecting soil samples from each plot with soil augers of .05 m in diameter. Three locations were sampled and composited for each plot at depths 0 to 0.30 m, 0.31 to 0.60 m, 0.61 to 0.90 m, 0.91 to 1.20 m for both years and 1.21 to 1.50 m for 1988 (1989 data not presented). Additional root density measurements were made at the 16 leaf stage in 1989. These samples were later ground, sieved, and further subsampled in the laboratory. Roots were recovered by washing and filtering the soil. Root density was obtained by the line intersect method of Newman (1966) as modified by Tennant

(1975).

Yield Measurements

Yield of grain and cob were harvested from a 9.12 m row length of the two center rows on 2 August 1988. Stover yield was determined from a 3 m row length of one center row the same date. Similarly, stand count was made at harvest. The ears were air dried and counted before threshing. Both grain and cob weight were measured after threshing the ears. Grain moisture percentage was determined and was later used for adjusting grain weight. To obtain kernel weight, one thousand kernels were counted with an electronic seed counter and weighed after recording seed moisture. Ears per plant and harvest index values were calculated from the above data.

In 1989 above ground dry matter measurements were recorded by harvesting 10 plants at random per plot before each differential irrigation. The fresh weights were made at the field at 4, 7, and 16-leaf stages and then the samples were placed in the oven for 48 hours at a constant temperature of 65^{0}C. Subsamples were placed in the oven when corn plants grew larger (7 and 16 leaf stages) and the moisture percentage from the subsamples were used to calculate dry weight.

Yield of grain and cob were harvested from a 6 m row length at the two center rows on 7 August 1989. Stover yield was determined from a 1.5 m row length at one center row. Later on, the grain was shelled from the cobs weighed and adjusted for moisture. Kernel weight was obtained by counting 1000 seeds by an electronic seed counter adjusting for moisture and weighing. Cobs were counted before shelling to calculate ears per unit area.

The results were statistically analysed by the analysis of variance (ANOVA) and by Fisher's F-test protected least significant diference (LSD) using Statistical Analysis System (SAS Institute, 1988).

Table 1. Irrigation treatments according to growth stages.

Treat. no.	Stages When Stressed	Growth Stage† V2	V4	V8	V12	V16	R1	R2	R3	R4
1	None	I	I	I	I	I	I	I	I	I
2	R1	I	I	I	I	I	0	I	I	I
3	V2	0	I	I	I	I	I	I	I	I
4	V2,R1	0	I	I	I	I	0	I	I	I
5	V2,V4	0	0	I	I	I	I	I	I	I
6	V2,V4,R1	0	0	I	I	I	0	I	I	I
7	V2,V12	0	I	I	0	I	I	I	I	I
8	V2,V12,R1	0	I	I	0	I	0	I	I	I

† I= Irrigation; 0= No irrigation.

V2, V4, V8, V12, V16 = 2, 4, 8, 12, and 16-leaf.

R1 = silking, R2 = blister, R3 = milk, R4 = dough.

RESULTS AND DISCUSSIONS

Water Use

Moisture deficits during the vegetative stages reduced water use in 1989 even after soil moisture was resupplied (Tables 2a, 2e and 2f). The stressed plants had reduced initial growth and did not utilize soil moisture at the same rate as those that were well watered (Table 6). There was significant interaction between the irrigation treatments and the soil depth for certain growth stages of the vegetative period (Table 2f). The well-watered treatment used more water from the top 0.30 m depth at the period between 2 and 4-leaf stages than other treatments, while the the treatment that was stressed at 2 and 4-leaf stages used more water at the 0.61 to 0.90 m depth than the treatment stressed only at the 2-leaf stage. Later on, between 5 and 7 leaf stages the difference in water uptake was at 0.30 m depth only in which the treatment stressed at 2 and 4-leaf stages used the least amount of water. At 8 to 12 leaf stages, the well-watered treatment used more water from the 0.61 to 0.90 m depth than any other treatment while the treatment that was stressed at the 2 and 4-leaf stages used significantly less water at that depth than any other treatment. At the period between 15 and 16-leaf stages, however, the treatment that was stressed at the 2 and 12-leaf stages depleted less water from the top 0.30 m depth than any other treatment but took more water at the 0.91 to 1.20 m depth than the treatment that was stressed at the 2 and 4-leaf stages. The differences in water uptake by the different treatments was mainly due to differences in water use at the top 30 cm of the soil profile. The treatment that was stressed at the 2 and 4 leaf stages used the least amount of water during the vegetative stage while the well watered control used more water than any other treatment. Even though stressed the same number of times, the treatment that was stressed at the 2 and 12-leaf stages depleted more water than the one stressed at the 2 and 4th leaf stages which indicates that the plants responded to the timing of stress rather than the total amount of water deficit or the number of times of that stress was applied (Table 2a). One such response could be that root initiation was affected more by the stress at the 4th leaf stage than at the 12 leaf stage or that simply the larger plants were using more water at the 12-leaf stage than earlier.

Water use at silking period was not significantly different among treatments stressed at the vegetative stages (Table 2b). More water was used from the 0.61 to 0.90 m depth for treatment 6 compared to other treatments and from the 0.91 to 1.20 m depth for treatment 8 compared to treatment

2. The water extraction patterns did not seem related to root density (Table 2b) which is similar to other reports (Waldren, 1983; Shaw, 1974).

The overall water used seem to be relatively high for this year due to the evaporative demand of a particularly dry season (Table 2e) but compare well with the water use reported by Eck (1986). The water use efficiency defined here as the ratio of estimated water use divided by the yield (Table 2c) and the irrigation efficiency defined here as the applied irrigation water divided by the yield (Table 2d) and both expressed in kg ha^{-1} mm^{-1} were both higher for the treatments irrigated at anthesis. This reflects the response of grain yield to stress at that stage and thereby indicates the inefficiency of withholding corn irrigation at anthesis.

Root Growth

Secondary (nodal) root initiation was significantly reduced by moisture stress at 4 and 7-leaf stages in 1989 (Table 3a) but while there was no measurements at the 4th leaf stage in 1988, the reduction in root number at 7th leaf stage was not significant at
the 5% probability level (Table 3b).

Root density was measured at harvest in 1988 and there was no significant differences between the treatments (Table 3c). This could, however, be explained by earlier results which reported that corn roots grow to a maximum level up to flowering time then start declining in growth to a low level at harvest (Mengel and Barber, 1974; Foth, 1962). Root density was measured at the 16-leaf stage in 1989 and the treatments that were stressed at the 12-leaf stage had a deeper rooting pattern (Table 3d). In contrast, the treatments stressed at the 4th leaf stage (treatments 5 & 6) had the shallowest rooting pattern as well as the lowest root density. The highest root density was obtained from the well-watered treatments (1 & 2). Obviously, soil moisture deficits during the vegetative stages reduced rather than encouraged rooting which is contrary to what some farmers believe and may have adverse effects in yield in areas were natural climatic factors make it inevitable for a corn crop to under go such early stress.

Yield

Water deficits at the vegetative stages did not significantly affect grain or total plant yield but did affect stover yield in both years of this study (Tables 4a & 4b). These results agree with earlier results (Retta and Hanks, 1980; Claassen and Shaw, 1970; McPherson and Boyer, 1977) but are at variance with others (Eck, 1986; Stewart et al., 1975). These different results may be due to the different ways of imposing moisture stress and/or the timing of stress. Unfortunately, this makes any comparison among these experiments less valuable. For example, the treatments of Eck (1986) used longer periods of stress for most years than we did but it seems that his 1976 experiment is similar to ours and the two results seem to agree. Also none of these earlier experiments used the Hanway (1971) classification of corn growth stages which is particularly useful for specifying vegetative growth stages.

Above ground dry matter was reduced by moisture stress at all the growth stages that were sampled (Tables 5) in 1989. Treatment 5 yielded lower in dry matter than treatment 7 at the 16-leaf stage. This indicates the effect of irrigation timing on dry matter growth rather than number of irrigations since both treatments were stressed twice. They were, however, both lower yielding than the well-watered treatment. This reduction in dry matter did not translate itself into reduction in grain yield in the season.

One may speculate that in this study the corn plants were mainly using direct photosynthetic assimilates for grain formation except for those treatments stressed at the vegetative stages which might have compensated any yield difference by translocating stored assimilates as well. McPherson and Boyer (1977) documented such difference in mobilization of stored assimilates between stressed and well-watered treatments of corn.

As expected, stress at anthesis was detrimental to grain yield and through it reduced the total plant yield and the harvest index (tables 4a & 4b). The yield components that were reduced by stress were the ear number and kernel weight. Clearly, stress at the vegetative stages did not condition the corn plants for a subsequent stress at anthesis contrary to earlier reports (Stewart et al., 1975).

In summary, this study confirms earlier findings on the importance of avoiding moisture stress at the reproductive stages of corn growth. But it also indicates that stress at the vegetative stages did not significantly reduce grain yield even when root growth and water use were both affected. Further more, we can conclude from this study that moisture stress at early vegetative stages does not encourage deep rooting nor does it precondition the plants to endure water stress later in the season.

Table 2a. Corn water depletion between certain growth stages during the vegetative period, Tucson, Arizona, 1989.

Stages When Stressed	Vegetative Growth Stages†				
	V2-V4	V5-V7	V8-V12	V15-V16	Sum
	water use (mm)				
None	19.0	36.0	64.0	34.0	153.0
V2	12.5	22.5	54.5	29.5	119.0
V2,V4	8.5	15.0	47.5	25.5	96.5
V2,V12	11.5	36.5	56.5	16.5	121.0
LSD 0.05	6.0	16.0	NS	7.5	26.5

† V2, V4, V5, V7, V8, V12, and V16 = 2, 4, 5, 7, 8, 12, and 16-Leaf

Table 2b. Water depletion near silking for a one week period as influenced by irrigation treatments, Tucson, AZ.,1989.

	Stages When Stressed[†]							
Depth	R1		V2,R1		V2,V4,R1		V2,V12,R1	
cm	mm	%	mm	%	mm	%	mm	%
0-30	19.3	20	17.7	21	15.9	16	19.4	19
31-60	24.7	26	18.4	22	22.5	22	23.1	23
61-90	28.6	30	23.4	28	38.4	38	26.3	26
91-120	12.6	13	14.1	17	14.8	15	20.8	21
121-150	10.0	11	11.4	13	10.2	10	10.5	11
Sum(100%)	95.0		85.0		102.0		100.0	

LSD (0.05) = 7.27

Treatment = NS; Depth = **; Depth*Treatment = *

[†] R1 = silking, V2, V4, and V12 = 2, 4, and 12-leaf stage.

Table 2c. The water use efficiency as related to the estimated water use and grain yield, Tucson, AZ., 1989.

Stages when stressed†	Water use (mm)	Grain yield (kg ha^{-1})	Water use efficiency (kg ha^{-1} mm^{-1})
None	1019	9330	9.2
R1	922	6590	7.1
V2	995	9020	9.1
V2, R1	907	5630	6.2
V2, V4	982	9120	9.3
V2, V4, R1	931	5310	5.7
V2, V12	918	8830	9.6
V2, V12, R1	863	5640	6.5

† V2, V4, V12 = 2, 4, 12-leaf stages

R1 = Silking

Table 2d. The irrigation efficiency as related to the applied water and grain yield, Tucson, Arizona, 1989.

Stages When Stressed†	Applied water (mm)	Grain yield (kg ha^{-1})	Irrigation efficiency (kg ha^{-1} mm^{-1})
None	1186	9330	7.9
R1	1173	6590	5.6
V2	1175	9020	7.7
V2, R1	1137	5630	5.0
V2, V4	1165	9120	7.8
V2, V4, R1	1118	5310	4.7
V2, V12	1104	8830	8.0
V2, V12, R1	1055	5640	5.3

† V2, V4, V12 = 2, 4, 12-leaf stages   R1 = Silking

Table 2e. Corn seasonal estimated water use as affected by irrigation treatments, Tucson, AZ., 1989.

	Growth stage†										
Stages	V2	V4	V7	V12	V16	R1	R2	R3	R4	R5	Sum
when stressed	7Ap-18Ap	18Ap-2My	2My-23My	23My-31My	1Jn-13Jn	13Jn-22Jn	22Jn-26Jn	26Jn-2Jl	2Jl-18Jl	18Jl-2Aug	7Ap-2Aug
	-----Water use (mm)-----										
None	36.6	37.3	81.2	52.7	182	200	53	72.7	180	124	1019
R1	29.9	39.4	75.9	51.2	164	22	136	63.7	217	122	922
V2	22.0	25.4	60.2	59.5	169	198	63	72.4	202	125	995
V2,R1	18.8	25.8	72.8	49.1	167	66	84	56.7	255	112	907
V2,V4	16.0	10.0	52.5	54.5	171	203	61	67.5	197	148	982
V2V4R1	17.9	6.7	66.3	46.5	172	110	50	99.4	228	133	931
V2,V12	22.9	26.1	69.4	-2.2	159	189	52	63.9	199	139	918
V2V12R1	19.4	24.2	72.5	-3.3	152	104	60	42.6	251	139	863
$LSD_{.05}$	10.7	10.9	NS	20.2	NS	35	25	30.8	28	NS	47

† V2, V4, V7, V12, V16 =2, 4, 7, 12, and 16 leaf stage

R1=Silking R2=Blister R3=Milk R4=Dough R5=Dent stage

Table 2f. Water depletion by depth as affected by irrigation treatments during the vegetative period, Tucson, AZ., 1989.

Stages When Stressed	Depth	Growth Stages† V2V4	V5V7	V8V12	V15V16	VTR1	R4	SUM
	(cm)	water use (mm)						
Control	0-30	12.7	23.4	18.7	14.7	2.4	22.2	94.1
	31-60	1.6	6.7	14.7	8.6	13.0	12.6	57.2
	61-90	1.1	2.6	24.2	7.2	14.8	6.2	56.2
	91-120	2.6	2.3	7.0	2.7	9.8	2.1	26.5
	121-150	1.1	1.3	-0.8	0.6	9.2	0.9	12.3
	Total	19.1	36.3	63.8	33.8	49.2	44.0	246.2
Stressed at V2	0-30	6.9	19.7	18.3	14.7	1.1	11.3	71.9
	31-60	0.7	4.5	14.0	7.3	9.5	6.8	42.8
	61-90	3.7	3.1	18.2	5.3	12.6	5.4	48.4
	91-120	0.8	-6.3	4.4	1.8	10.2	2.7	13.5
	121-150	0.2	1.5	-0.7	0.5	9.0	1.7	12.1
	Total	12.3	22.5	54.2	29.6	42.4	27.9	188.7
Stressed at V2,V4	0-30	5.9	5.7	24.1	15.0	0.7	21.1	72.5
	31-60	0.8	4.8	11.0	6.3	12.0	14.2	49.1
	61-90	-0.2	2.1	6.8	3.0	22.8	7.7	42.3
	91-120	1.5	1.5	3.3	0.6	12.2	3.0	22.2
	121-150	0.4	0.9	2.0	0.5	8.9	1.0	13.7
	Total	8.4	15.0	47.2	25.4	56.6	47.0	199.8
Stressed at V2,V12	0-30	6.8	27.7	20.2	1.5	0.7	22.0	78.8
	31-60	0.5	3.3	15.4	5.0	12.3	9.5	46.0
	61-90	0.9	2.2	17.6	3.9	12.0	4.7	41.3
	91-120	3.2	1.6	3.4	5.6	13.3	5.1	32.3
	121-150	0.2	1.5	-0.1	0.7	9.3	1.9	13.4
	Total	11.6	36.3	56.5	16.7	47.6	43.2	211.4
$LSD_{0.05}$ (treatment)		6.0	16.0	NS	7.3	NS	NS	40.4
$LSD_{0.05}$ (trmt*depth)		3.6	9.9	5.9	4.5	NS	NS	NS

† V2, V4, V5, V7, V8, V12, V15, and V16=2, 4, 5, 7, 8, 12, 15, & 16 leaf stages.
VT=Tasseling R1 = Silking R4 = Dough

Table 3a. Number of corn nodal roots at 4th and 7th leaf stages as influenced by earlier irrigation treatments, Tucson, Arizona, 1989.

Growth stage†	Stages When Stressed	Roots/plant
V4	1,2	10.2
	3-8	7.8
	LSD 0.05	1.8
V7	1,2	19.5
	3,4,7,8	16.2
	5,6	14.5
	LSD 0.05	1.9

† V4 and V7 = 4 and 7-Leaf

Table 3b. Number of corn secondary roots at the 7th leaf stage as influenced by irrigation treatments, Marana, AZ., 1988.

Stages when stressed†	Roots/plant.
Control	12.4
V2	12.1
V2 , V4	12.4
LSD(0.05)	NS

† V2, V4 = 2, 4 leaf stages

Table 3c. Root density at harvest as affected by irrigation treatment and depth, Marana, AZ., 1988.

	Stages when stressed†			
Depth	V2, R1		V2, V12, R1	
(cm)	$cmcm^{-3}$	%	$cmcm^{-3}$	%
0-30	1.34	42	1.28	43
31-60	0.84	27	0.77	26
61-90	0.46	15	0.43	14
91-120	0.32	10	0.37	12
121-150	0.19	6	0.14	5

LSD (0.05): Among depths = 0.16, Between treatments = NS

Treatment*depth = NS

† V2, V12= 2, 12 leaf stages R1= Silking

Table 3d. Root density at the 16th leaf stage as influenced by irrigation treatment and depth, Tucson, Az., 1989.

	Stages when stressed†							
Depth	Control		V2		V2,V4		V2,V12	
cm	cm cm^{-3}	%	cm cm^{-3}	%	cm cm^{-3}	%	cm cm^{-3}	%
0-30	1.82	44	1.61	45	1.60	49	1.44	37
31-60	0.72	18	0.71	20	0.76	23	0.59	15
61-90	0.88	21	0.86	24	0.52	16	1.03	27
91-120	0.70	17	0.40	11	0.38	12	0.80	21
Sum	4.11	100	3.58	100	3.26	100	3.86	100

LSD 0.05 (Treatments by depth) = 0.36

LSD 0.05 (Treatments averaged over depths) = 0.07

† V2, V4, and V12 = 2, 4, and 12-Leaf

Table 4a. Grain, stover, total plant yield and harvest index at harvest as influenced by irrigation treatment, Tucson, 1989.

Stages when Stressed†	Yield				Harvest index
	Grain	Stover	Cob	Total	
	----------g m^{-2}----------				%
None	933	1193	196	2322	40
R1	659	1195	156	2011	32
V2	902	1166	186	2254	40
V2, R1	563	1203	146	1912	29
V2, V4	912	1148	180	2240	41
V2, V4, R1	531	1291	136	1958	26
V2, V12	883	1083	174	2140	41
V2, V12, R1	564	1049	142	1755	32
Vegetative	NS	*	NS	NS	NS
Anthesis	**	NS	**	**	NS
Veget*Anthesis	NS	NS	NS	NS	NS
LSD (0.05)	165	155	29	288	6

† V2, V4, and V12 = 2, 4, and 12-leaf stage

R1 = Silking

Table 4b. Grain, stover, total plant yield and harvest index at harvest as influenced by irrigation treatment, Marana, 1988.

Stages when stressed†	Yield: Grain	Stover	Cob	Total	Harvest index
	$g\ m^{-2}$				%
None	696	679	119	1495	47
R1	240	680	47	971	16
V2	556	594	95	1223	44
V2, R1	420	645	66	1158	37
V2, V4	717	757	121	1569	44
V2, V4, R1	251	665	47	1026	27
V2, V12	569	623	100	1340	44
V2, V12, R1	268	593	53	899	25
Vegetative	NS	*	NS	NS	NS
Anthesis	**	NS	**	**	**
Veget*Anthesis	NS	NS	NS	NS	NS

† V2, V4, and V12 = 2, 4, and 12 leaf stages
R1 = Silking

Table 4c. Yield components of corn as influenced by irrigation treatments at Tucson, AZ., 1989.

Stages when stressed†	Ear number (Ears m^{-2})	Kernel number (Kernel ear^{-1})	Kernel weight (mg $kernel^{-1}$)
None	6.1	554	276
R1	5.6	469	246
V2	6.1	536	275
V2, R1	5.8	376	256
V2, V4	6.4	515	276
V2, V4, R1	5.4	385	245
V2, V12	6.1	512	281
V2, V12, R1	5.7	380	253
Vegetative	NS	*	NS
Anthesis	**	**	**
Veget*Anthesis	NS	NS	NS
LSD(0.05)	0.6	70	21

† V2, V4, and V12 = 2, 4, and 12-leaf stage

R1 = Silking

Table 4d. Yield components of corn as influenced by irrigation treatments at Marana, Arizona, 1988.

Stages when stressed†	Ear number (Ears m^{-2})	Kernel number (Kernel ear^{-1})	Kernel weight (mg $kernel^{-1}$)
None	6.0	535	215
R1	3.2	248	196
V2	6.0	492	186
V2, R1	4.8	429	189
V2, V4	5.5	557	235
V2, V4, R1	2.7	378	207
V2, V12	5.3	486	207
V2, V12, R1	3.2	365	209
Vegetative	NS	NS	NS
Anthesis	**	**	NS
Veget*Anth	NS	NS	NS

† V2, V4, and V12 = 2, 4, and 12-leaf stage

R1 = Silking

Table 5. Above ground dry matter of corn as influenced by irrigation treatments at different growth stages, Tucson, Arizona, 1989.

Stages when stressed	Growth stages† of sampling			
	V4	V7	V16	R3
	-----grams $plant^{-1}$-----			
None	0.85	10.8	74	318
R1				378
V2	0.50	5.0	55	303
V2, R1				254
V2, V4		1.4	42	277
V2, V4, R1				243
V2, V12			53	284
V2, V12, R1				241
LSD (0.05)	0.3	2.5	4	32

† V2, V4, V7, V12, V16= 2, 4, 7, 12, and 16 leaf stages
R1= Silking R3= Milk stage

Table 6. Growth stages of corn over time as affected by irrigation treatments, Tucson, AZ., 1989.

Stages when stressed	7Ap	18Ap	2My	16My	23My	28My	31My	6Jn	13Jn	20Jn	7Jl
	Growth stages†										%Bl††
None	V2	V4	V7	V11	V13	V15	V16	V20	R1	R1	60
R1	V2	V4	V7	V10	V13	V14	V15	V18	V22	R1	80
V2	V2	V4	V7	V10	V13	V15	V16	V20	R1	R1	60
V2, R1	V2	V4	V7	V11	V11	V15	V16	T20	R1	R1	80
V2, V4	V2	V4	V6	V9	V11	V12	V13	V16	V20	R1	40
V2,V4,R1	V2	V4	V6	V10	V12	V13	V14	V18	V21	R1	40
V2, V12	V2	V4	V7	V10	V11	V12	V13	V16	T21	R1	60
V2,V12,R1	V2	V4	V7	V10	V12	V13	V13	V16	V21	R1	100

† V2, V4, V6, V7, V9, V10, V11, V12, V13, V14, V15, V16, V18, V20, V21, V22 = 2 to 22 leaf stages

T20 and T21 = Tasseling at 20 and 21 leaf stages, R1 = Silking

†† %Bl = Percent showing black layer indicating physiological maturity

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