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Influence of Potassium Nutrition on
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By

Jorge Eduardo Arboleya

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ABSTRACT

INFLUENCE OF POTASSIUM NUTRITION ON ASSIMILATION RATE AND FRUIT PRODUCTIVITY OF PICKLING CUCUMBERS (*Cucumis sativus*) UNDER VARIABLE SOIL MOISTURE.

By

Jorge Eduardo Arboleya

Three experiments were conducted to determine the effects of K^+ application rates and salt sources on vegetative and reproductive growth of pickling cucumbers under different irrigation regimes. In a rainout shelter experiment, cucumbers (cv. Calypso) were preplant fertilized with 0 or 252 Kg $K^+.ha^{-1}$ under irrigated or drought stress conditions. K^+ rates did not affect vegetative growth, $\underline{A}$ rates or fruit growth. Irrigation treatments enhanced vine length, leaf area, and fruit yield. On a sandy soil with medium-low native K^+ fertility, preplant application rates of 0, 84, 168 and 252 Kg $K^+.ha^{-1}$ using KCl and K_2SO_4, did not influence vegetative growth, yield or fruit quality. When cucumber plants were cultured in nutrient solution containing 0.01, 0.1, 1.0 and 10 mM K^+ under different water regimes during reproductive development, leaves from 0.01 and 0.1 mM K^+ treatments exhibited K^+ deficiency symptoms and lower $\underline{A}$ rates.

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INTRODUCTION

Cucumbers have a high water requirement for growth and development (Motes, 1975; Loomis and Crandall, 1977; O'Sullivan, 1980; Janoudi, 1989). In the midwestern United States, short-term periods of no rainfall (7 to 10 days) are common during the summer months and can lead to moderate to severe plant water deficits (Janoudi, 1989). Transient water deficits also are observed frequently in cucumbers due to high transpirative water loss at midday.

Plant water deficits have been shown to significantly limit photosynthesis in cucumber (Janoudi, 1989), bell peppers (Rao and Bhatt, 1988), and cowpea (Hall and Schulze, 1980), thus limiting growth of both vegetative and reproductive organs.

Moderate plant water deficits in cucumbers, especially during the reproductive stage of development, have been shown to significantly limit photosynthesis, fruit set, growth of vegetative and reproductive tissues, (Janoudi, 1989), and ultimately fruit quality (O'Sullivan, 1980; Widders and Kwantes, 1989; Janoudi, 1989). The incidence of misshapen fruit is commonly high under drought stress conditions.

The concentration of potassium (K^+) an important osmoticum electrolyte, and a cofactor for numerous enzyme systems, within plant tissues might influence the response of pickling cucumbers to water deficits. Relatively little is known about the K^+ nutritional requirements of cucumbers, moreover how plant water status might influence physiological processes involving K^+ within plants.

A current dogma within the pickling cucumber industry is that a symptom of a K^+ deficiency is a high incidence of misshapen fruit. Considering the role of K^+ as a primary osmotic solute, it is reasonable to hypothesize that low import and accumulation of K^+ within cucumber fruit, especially under drought conditions, might limit the ability of fruit tissues to develop sufficiently low water potentials to maintain turgor, and thus facilitate expansive growth.

The objectives of this study were: 1) to determine the effects of K+ application rate and the salt source of K^+ on vegetative plant growth, assimilation rate, and expansive growth of pickling cucumber fruit, 2) to better understand the potential physiological importance of K^+ in photosynthesis (A) and osmotic regulation under water-deficit conditions (low soil moisture, high evapotranspiration), and 3) to develop K^+ fertilization strategies and recommendations for pickling cucumbers.

LITERATURE REVIEW

The importance of potassium in plants.

Potassium (K^+) is a primary inorganic cation in plant tissues with an important role in balancing the negative charge of organic acids produced within the cell and of inorganic anions such as sulphate, chloride and especially nitrate absorbed by roots (Bould et al. 1983). A second function of K^+ is that of activation for numerous enzymes. Protein synthesis is especially dependent on K^+ concentration within the cytosol. K^+ also functions as a primary osmoticum in the modulation of turgor in plant cells. The control of stomatal aperture involving the regulation of guard cell turgor is an example of such a role for K^+.

Effects of potassium on opening and closing of stomata.

Stomata open and close as the result of changes in turgor balance between guard cells and surrounding epidermal cells (Stalfelt, 1966; Sawhnet and Zelich, 1969; Humble and Hsiao, 1970; Fischer, 1970; and Hsiao and Lanchli (1986). The mechanism underlying stomata opening is uptake of K^+ in osmotically significant amounts by guard cells. As guard cells take up K^+, and the intracellular solute potentials are lost when K^+ is deficient in plants (Hsiao and Lauchli, 1986). Levitt (1967) suggested that K^+ uptake leads to stomatal opening because it involves H^+ exchange, thereby increasing guard cell pH and stimulating starch hydrolysis. In contrast, Fischer and Hsiao (1970), attribute to K^+ a direct role in stomatal opening, as the major solute causing the lowered solute potential. Hsiao and Lauchli (1986) concluded that other physiological cations can not replace K^+ in its osmotic role in stomatal movement.

Although stomatal aperture increases as extracellular K^+ concentrations increase, a decrease in aperture occurs when K^+ concentrations in the buffer solution are higher than 300 mM (Willmer and Mansfield, 1969). Thomas (1970a) observed the same result in _Nicotiana tabacum_, although the largest aperture occurred at K^+ extracellular concentrations less than 10 mM.

Open stomata of several species contained higher concentrations of K^+ in the guard cells than when the stomata were closed (Fujino, 1967). The absorption of the extracellular solutes, such as K^+, is the primary mechanism of stomatal opening, with both opening and K^+ absorption being stimulated by light and CO_2-free air (Fisher and Hsiao, 1968). Sawhnet and Zelich (1969) reported that stomatal width and mean K^+ concentration in guard cells were linearly related. K^+ was specifically required for the light-activated opening stomata of _Vicia faba_ (Humble and Hsiao, 1969).

Stomata aperture is adjusted depending on the water potential in the leaf, on the relative humidity of the air, and on the location of stomata in the leaf. Any change in the water supply to a leaf is transmitted as a change in water potential to the guard cells through the agency of the epidermis (Raschke, 1970). K^+ ion flux rate is sufficient to account for a decrease in osmotic potential, necessary for the opening of stomata. Thus, K^+ ion transport might be under the direct influence of temperature, since the "ion-pump" of plant membranes is known to be temperature dependent (Humble and Raschke, 1971).

Role of K^+ in osmotic adjustment.

Osmotic adjustment may be described as the decrease in cell osmotic potential caused by the active accumulation of solutes in response to water or salt stress (Janoudi, 1989).

Tomato cells in suspension culture have large capacities for osmotic adjustment when subjected to water stress (Handa et al., 1983). Accumulation of reducing sugars and K^+ ions make the largest contribution to the intracellular changes in osmotic potential.

Sucrose, glucose and fructose accumulate as leaf water deficits develop in fully expanded leaves of sorghum (Jones et al., 1980). K^+ is the only inorganic cation which increases in concentration with the development of leaf water deficits. At moderate and severe levels of stress, approximately 60% of all increases in K^+ ions are balanced by increases in Cl^- ion concentrations (Jones et al., 1980).

Ions and carboxylates contribute significantly to osmotic adjustments in sorghum and sunflower (Pitman, 1980). These solutes play a key role as turgor generators for expansive cell growth (Pitman and Cram, 1977). The increase in inorganic ion accumulation within leaves of water-stressed plants may be due to increased uptake, reduced retranslocation or to disproportionate changes in expansive growth relative to uptake. However, ion uptake is generally reduced in response to low soil water potentials.

Munns, Brandy and Barlow (1979), found that K^+ was a significant component of osmotic adjustment of tissues during drought stress.

Osmotic potential in cucumber plants were found not to change in response to an initial exposure to low soil moisture conditions. This indicates that prior exposure to water deficit might be needed before osmoregulation can occur. Cucumber leaves have a limited capacity for osmoregulation as evidenced by a lack of an increase in the magnitude of osmotic adjustment following a second drought stress exposure. Increased K^+ concentrations in the leaves of stressed plants could account for 100% of the decrease in leaf osmotic potential (Janoudi, 1989).

Role of K^+ in photosynthesis, respiration, stomatal conductance, and translocation.

Low A rates as a result of low leaf tissue K^+ concentrations have been reported in tung seedlings (Loustalot, Gilbert and Drosdoff, 1950) and corn (Peasless and Moss, 1986). A rates can be affected by the K^+ status of leaves before deficiency symptoms are observable and chlorophyll content declines (Peasless and Moss, 1966). K^+ deficient leaves were also found to regain appreciable photosynthetic ability within 24 hours after being resupplied with K^+. Stomatal aperture declined with the development of a K^+ deficiency condition.

Higher A rates of individual alfalfa leaves with added K^+ were reported by Cooper et al.(1967). Higher K^+ content in plants leads to higher carbohydrate storage and consequently an increase in growth.

Under severe K^+ deficiency in sugar cane, the CO_2 assimilation rate and the conversion of intermediates to end products were slowed down. Higher respiration rate in K^+-deficient blades were found for about 2 months before a lower photosynthetic rate became apparent in comparison with the control (Hartt, 1969). Bershtein (1971) showed that photosynthetic rate was usually lower in K^+ starved sugar beet plants, but respiration rates were higher. He suggested that the factors promoting K^+ remobilization and transport to the upper leaves were higher photosynthetic and respiration rates in these leaves.

Normal-appearing corn leaves in K^+-starved plants had sharply diminished photosynthetic rates (Estes et al., 1973). Uptake of CO_2 by photosynthesizing leaves was nearly 60% higher when nutrient culture solution K^+ concentrations were increased from 0.25 to 0.50 mM K^+. K^+ concentrations higher than 0.50 mM K^+ in the culture solution resulted on higher K^+ concentrations in leaf tissue, but A rates exhibited little change. A tissue K^+ concentration between 0.75 and 1% in the youngest fully expanded leaf (42 days) was considered critical for maximum A rate. Below this range a large reduction in CO_2 fixation occurred (Estes et al., 1973).

Low K^+ diminishes Hill reaction activity (consistent with the results of Spencer and Possingham, 1960), the rate of ATP production, and the NADP level in beet leaf cells. Thus low K^+ may increase the carboxylation resistance through an effect on the photochemical reactions of A rate (Terry and Ulrich, 1973).

Leaf tissue containing high concentrations of K^+ appear to maintain a higher photosynthetic capability than leaves under K^+ stress (Koch and Estes, 1975). The cause for the difference is probably due to a combination of factors including changes in the resistance to CO_2 diffusion, changes in mesophyll resistance (or the intracellular resistance to CO_2 transfer; Catsky et al., 1985) and lower metabolic activity.

Evans et al. (1977) reported that chlorotic K^+-deficient leaves of french prune transpire significantly less than green leaves in the field. They pointed out that a severe K^+ deficiency such as observed in their study could perhaps result in reduced stomatal opening.

Cao and Tibbits (1991) did not find differences among K^+ treatments (0.10, 0.55, 1.59, 3.16, 6.44 and 9.77 meq L^{-1}) in CO_2 assimilation rate, stomatal conductance, intercellular CO_2 concentration, and transpiration rate in potato.

A rate, g_s, and intercellular conductance were lower at the highest K^+ solution concentration(8 mM KNO_3) in beans as compared to the 0 K^+ and in 4 mM KNO_3 treatments (Catshy et al., 1987). They found no significant differences in respiration rate were measured between K^+ treatments (Catshy et al., 1987). Brag (1972) stated that low K^+ concentration in the nutrient solution during a long growth period will result in plants with high transpiration rates. High K^+ levels are correlated with low rates of transpiration both in wheat and peas. Peoples and Koch (1979) concluded that alfalfa plants supplied with sufficient K^+ (4 mM) in the nutrient solution maintained vigorous growth. A rate and photorespiration were relatively low at low levels of substrate K^+ (0 or 0.6 mM K^+). The reduction in photosynthetic rates in mildly K^+-deficient alfalfa leaves (levels at which visible symptoms were not apparent) were associated with decreased synthesis of RuBPC.

Plants supplied with luxury amounts of K^+ can dramatically enhance leaf K^+ concentrations without affecting photosynthesis under well-watered conditions. The inhibitory effect of low water potentials on photosynthesis was nearly eliminated in the presence of high leaf K^+ (Pier and Berkowitz, 1987). They also reported that in the presence of Mg^{2+}, which activated the chloroplast ATPase, and at low extrachloroplastic K^+ concentrations, K^+ moved out of the stroma of isolated chloroplast in exchange for H^+, causing stromal acidification which in turn inhibited photosynthesis. Suboptimal pH of the stroma during water stress is thought to inhibit A rate. Hartt (1969) reported that a K^+ deficiency decreases the amount and velocity of ^{14}C export from the blade to the rest of the sugar cane plant. K^+ is thought to adversely affect phloem translocation. Translocation was also slower in sugarcane plants with a low moisture supply than in control plants. K^+-deficient plants retained a higher percentage of ^{14}C-label within a treated leaf blade as compared to similarly treated blades on non-deficient control plants. K^+ deficiency did not completely inhibit translocation but slowed it down; 73% of ^{14}C was recovered from the stalk of the K^+ deficient plant as compared with 50% in the stalk of the control plant after 8 days. This higher percentage in the deficient stalk was attributed to less carbohydrate utilization for growth of the sheath and upper joints of the stem. It appears that the mechanisms of phloem loading might directly or indirectly involve K^+ fluxes (Geiger and Conti, 1983).

Potassium deficiency symptoms.

Interveinal and mottled leaf chlorosis, bronzing, and marginal necrosis are symptoms of K^+ deficiency reported for cucumber leaves (Purvis and Carolus, 1964; Roorda van Eysinga and Smilde, 1969; Wetzold, 1972; and Holcomb and Hickman, 1978). Loustalot et al. (1950) reported that K^+ deficiency symptoms typically appear in tung leaf lamina tissue when concentrations reach approximately 0.4% (dry weight basis). Peaslee and Moss (1966) stated that older leaves first exhibit first K^+-deficiency symptoms in plants. The decrease in A rate in K^+-deficient leaves however occurs before visible symptoms appear on the leaves. According to Hartt (1969), a conspicuous symptom of K^+ deficiency in sugarcane is the drying of the margins and tips of the lower blades.

K^+ deficiency symptoms in peas consist of necrotic lesions on the upper slender leaves, accompanied by general chlorosis, (Brag, 1972). Deficiency symptoms of K^+ do not appear until K^+ in the plant tissue reaches relatively low concentrations. Visible deficiency symptoms do not appear in young corn plants until leaf tissue concentration decline to between 0.88 and 1.37 % K^+ (Estes et al., 1973).

Leaves of K^+ deficient cucumber plants were described as being pale green and smaller than normal (Holcomb and Hickmann 1978). Malformation of the fruit was also observed including enlarged blossom ends but undeveloped stem ends (Hoffman, 1933).

In a review article by Adams (1987), K^+ deficiency symptoms were reported to have been associated with lamina tissue K^+ concentrations of 0.5 % (Roorda van Eysinja and Smilde, 1969), of 0.8-1.5 % (Wetzold, 1972) or of less than 2 % K^+ (Adams, 1982). In young cucumber plants exposed to low K^+ availability, leaf tissue K^+ concentrations averaged at 1.5 %. The corresponding concentration in petiole tissue was 8.5 K^+ or less in deficient plants.

Potassium in leaves and petioles.

Geissler (1957) reported K^+ concentrations of 3.6 % dry weight in young cucumber leaves as compared with 2.5 % in the older leaves. From nutritional trials with container-grown and field-grown pickling cucumbers, Bradley et al. (1961) associated 3.1-3.7 % K^+ in the young expanded leaves with good growth and 1.8-2.5 % K^+ with low yields. Ward (1967), studying the distribution of K^+ within plants, found an overall average of 4.44 % K^+ in the leaf lamina. Roorda van Eysinga and Smilde (1969, 1970) reported 2.5-5.4 % K^+ in the leaves of healthy cucumber plants.

Petioles of cucumber leaves contain four times higher concentrations of K^+ than do lamina tissue (Ward, 1967). Ward found 8.5-14.8 % K^+ in the petioles from leaf position 1-25 on the main stem, the lower values tending to occur at the lower nodal positions of the plant. Bishop, Chipman and Mac Eackern (1969) found that K^+ petiole concentrations in cucumber were higher (8.98, 9.30 and 9.52 % K^+) as rates of K^+ fertilization increased (0, 28 and 56 kg/ha K^+), nevertheless yield differences were not significant.

A "reference" concentration of 4% K^+ in young cucumber lamina was suggested by Ward (1973 a), while a "diagnostic" value of 3.5 % K^+ was proposed for field-grown crops by Cheng and Forest (1977). Sunneveld (1974) recommended a critical concentration of 2.5 % K^+ for young, fully developed cucumber leaves.

Potassium-deficient plants exhibit a characteristic gradient of low to high K^+ concentrations from older to younger leaves. K^+-sufficient plants exhibit an opposite and less obvious gradient. Bengtsson and Jensen (1983) stated that K^+ concentration in individual cucumber leaves decreases with age but that within a whole plant, leaf tissue K^+ concentration increases as one progresses from the oldest to the youngest leaf along the stem axis. They concluded that young leaves and fruits, which are mainly supplied with phloem sap, are therefore high in K^+.

Leaf K^+ status is highly sensitive to changes in K^+ concentrations in soil solution or within the nutrient culture solution. The effect of withholding K^+ from the culture solution was to rapidly diminish the K^+ concentration in the blade tissue (Brag, 1972). Cooper et al. (1967) reported that the K^+ content of leaves generally increases with an increase in nutrient solution K^+ concentration. Terry and Ulrich (1973) found a decrease in K^+ concentration in leaf blade and petiole tissue from sugar beet with time; 1500 to 3000 meq/kg in the blades and from 2250 to 750 meq/kg in the petioles after K^+ was withheld from the plants.

Potassium levels reported by Wetzold (1972) for cucumber plants grown in sand culture were far higher in young leaves (5.5-7.0% K^+) than in the older foliage (3.5-5.0% K^+). Pike and Jones (1989) found that in greenhouse cultured cucumbers, K^+ concentrations in the leaf petioles were as high as 15% of dry weight. They stated that severe K^+ deficiency symptoms included low vigor and reduced disease resistance. Interveinal yellowing or bronzing appeared initially in older K^+ deficient leaves, but eventually these symptoms spread to the entire plant's leaf surface. The leaf margins also became necrotic.

Effect of water stress on photosynthesis, stomatal conductance and transpiration.

The stomata constitute the major pathway for CO_2 movement from the atmosphere into the mesophyll of leaves. The existence of this pathway also facilitates water loss from the hydrated surfaces of the cells walls within leaf tissue to the atmosphere. Stomatal aperture appears to be controlled by a complex mechanism which operates to maintain a variable balance between allowing CO_2 uptake to proceed, while restricting the loss of water vapor, and preventing leaf desiccation. When plants are subjected to constant atmospheric conditions and soil water is not replenished, plant water deficits develop and leaf conductance decreases. Drought affects the stomata of C_3 species to a relatively greater extent than it affects photosynthetic metabolism. This response to drought by C_3 species may have adaptive significance since intrinsic water use efficiency becomes higher as the soil water supply declines. Stomatal responses are the principle mechanism in plants for short-term regulation of carbon gain and water loss. This regulation operates within specific ranges and depends on the naturally variable conditions of the habitat (Schulze and Hall 1982).

Reduction in stomatal conductance (g_s) with increasing water stress has been reported in many plants species including cowpeas (Hall and Schulze, 1980) and bell peppers (Rao and Bhatt, 1980). As water stress became greater, $\underline{A}$ was found to declined in tomato and loblolly pine (Brix, 1962), in Lolium temelentum and wheat (Wardlan, 1967), in sorghum and cotton (Sungg and Krieg, 1979), in Coryllus avellana (Farquhar, Schulze and Kuppers, 1980), in chickpea (Singh et al., 1987), in cowpea (Hall and Schulze, 1980), and in lupin (Hensen et al., 1989).

Leaf resistance in Sesamum indicum L. increased when the humidity gradient between leaf and air was increased (Hall and Kaufmann, 1975). Mesophyll resistance remained relatively constant when humidity gradients were changed, indicating that increases in leaf resistance were mainly caused by reductions in stomatal aperture and that nonstomatal aspects of photosynthesis and respiration were not affected. Effects of humidity gradients on photosynthetic and stomatal responses to temperature suggested that large humidity gradients may contribute to mid-day closure of stomata and depression in Pn.

Lower A rates due to high temperatures or greater vapor pressure differences between leaf and air were found by Khairi and Hall (1976). The water requirement for net CO_2 fixation in the dark at typical nocturnal vapor pressure differences was about 10 times lower than that of net CO_2 fixation in the light at vapor pressure differences typical of the late afternoon (Osmond et al., 1979). A, E, and stomatal conductance (g_s) of wheat flag leaves decreased with decreasing leaf-water potential (Lawlor, 1976).

Leaf conductance and A rate declined as both humidity and available water became low. A declined linearly as humidity diminished in all the experiments that were conducted.

In apple trees well supplied with water, the photosynthetic activity is higher and the respiration rates lower than in trees with a reduced water supply. A favorable water supply involves higher water consumption, but at the same time results in better water utilization due to the increased dry matter production. Cock, Porto and El-Sharkawy (1985) did not find a correlation between A and bulk leaf water potential in both well-watered and unirrigated cassava plants. Leaf transpiration, as with A rate, was always lower in the unirrigated plants at any given vapor pressure deficit (VPD). The water use efficiency (WUE) was sharply reduced at high VPD when both E and A rate decreased due to closure of stomata at midday and early afternoon (Gergely and Erdelgi, 1985).

A decline in canopy photosynthesis in the late morning, when the quantum flux density was still increasing, is indicative of stomatal closure or a diminishing E rate per unit area as plant water deficit develops (Singh et al., 1987). Rao and Bhatt (1988) reported that the parallel decrease in A and E found in bell peppers strongly indicated stomatal closure as the principal causal factor in the water stress mediated reduction of A.

Water stress induced osmotic adjustment in corn leaf tissue, an acclimation response to low leaf water potential, may involve less cell shrinkage at a given plant water potential. This physiological change should allow for the maintenance of relatively higher photosynthetic activities at low water potentials.

There was a linear decrease in ^{14}C translocation rate as leaf water potential declined ($r=0.97$) in cacao seedlings (Deng et al., 1990). When water potential dropped below approximately -1.5 MPa, no radioactivity was detected in growing leaves over a 24 hour measurement period. A was relatively unaffected by plant water deficit until leaf water potential fell below approximately -1.0 MPa. Between -1.0 and -1.5 MPa, A rate declined to near zero. Nandwal et al. (1990) reported that drought led to a decline in respiration of pigeon pea leaves compared to well irrigated plants. Decreasing leaf and soil water potentials also led to a decline in g_s and consequently A and E rates. Pillay and Beyl (1990), when comparing drought-susceptible and drought-resistance tomato plants, found that the former had lower E as drought stress developed.

Effect of water stress on leaf area.

Leaf elongation rate was reduced in response to drought stress prior to any effect on leaf photosynthesis. As relative turgidity fell below 85%, photosynthesis became less sensitive to water deficit than extensive growth. Wheat and *Lolium temelentum* stressed leaves reached maximum photosynthetic rates at lower light intensities than turgid leaves (Wardlaw, 1969). The leaf area of the experimental shoot of Mitchell Grass continued to increase until water potential fell below -2.0 MPa. Curling of leaves occurred below -4.0 MPa, reducing the exposed leaf surface by approximately 50% (Doley and Trivett, 1974).

Leaf area or water potential of tobacco plants grown in pots 20 cm in diameter, were not different up to 3 days after withholding water from plants which were watering daily. Thereafter, leaf growth rate was lower in the droughted plants as evidenced by lower leaf areas when compared to control plants (Clough and Milthorpe, 1975). Yegappan and Paton (1980) withheld water for 5-7 days from approximately 2 week old sunflower seedlings. Leaf primordia initiation and total leaf number were reduced. Leaf area in the stressed plants was about half that of control plants. Cell division ceased at about 35 per cent of maximum leaf area in sunflower, consistent with the findings in cucumber (Clough and Milthorpe, 1975).

The low E rate of cowpeas growing at 30 C in a hot dry environment without irrigation for 24 days was attributed to a small leaf area, which was only 27% of the area of well watered plants (Hall and Schulze, 1980). Similar stunting due to drought during vegetative development was observed in field studies by Turk and Hall (1980). Garrity et al., (1984) found that the average leaf area index for stressed sorghum plants was 1.28 as compared to 1.92 for unstressed plants.

The leaf area of well watered tropical grain legume plants was 20% greater than those of droughted plants. When the ability of the stomates to compensate for a declining rate of water uptake from the soil had been exhausted, stomatal closure occurred and plants wilted ultimately (Sinclair and Ludlow (1986).

Peppers (Rao and Bhatt, 1988) and sunflower (Yegappan et al., 1982) appear to be highly sensitive to water deficits as evidenced by significantly lower leaf areas at all stages of development as compared to control plants.

Effect of water stress on cucumber growth and productivity.

Lorenz and Maynard (1988) classified vegetable rooting depths as shallow (18-24 inches), moderately deep (36-48 inches) and deep (more than 48 inches). Cucumbers are considered to have a moderately deep root system according to this classification. According to Loomis (1977), the effective rooting depth for cucumber is 90 cm. He based this conclusion on the observation that cucumbers extract 50% of the total amount of water consumed from the upper 30 cm of the soil profile, 30% from the next 30 cm and 10% from the bottom 30 cm.

Cucumber is a high water requiring vegetable (Hughes et al., 1983). Nonencke (1989) confirmed that even in rainy humid northeastern regions, supplemental sources of water were required to prevent crop stress. O'Sullivan (1980) showed that irrigation was essential at high cucumber plant populations.

Cucumbers are estimated to require, on the average, 25 mm of water each week. During hot, dry weather, it may need as much as 50 mm per week, particularly if the plants are fruiting. If moisture is not provided as rain or irrigation, cucumber fruit quality and yield are reduced (Hughes et al., 1983).

The rate of consumptive use (C.U.) increases during flowering and early fruiting, then levels off during late harvest. The ratio of C.U. to evaporation, as estimated by the pan method, increases to a maximum of 1.5, 10 days after first picking, and then declines but still remaining high when picking is terminated (Loomis and Crandall 1977). This agrees with Motes (1975), Loomis and Crandall (1977), Janoudi (1989) and Hughes et al. (1983) who affirm the need for water during flowering and fruiting.

The irrigation requirements of pickling cucumbers are also know to be influenced by plant density and the method of harvest, once-over destructive harvest versus multiple harvest (Tan et al., 1983, and Motes, 1975). In a multiple harvest production system, total yield increased as the level of soil moisture supply was increased. The total and marketable yield were similar as plant population increased from 12,300 to 24,700 plants/ha when grown without irrigation. The population effect on yield was not significant under irrigated conditions.

Vine length was significantly lower in water-stressed plants seven days after water was withheld from field cultured pickling cucumbers (Ortega and Kretchman, 1982). Non-stressed irrigated plants grew an average of 11 cm in vine length while stressed plants grew only 2 cm. Two weeks after the treatments were initiated, vine length of the control plants had grown an average of 13 cm while water-stressed plants had ceased to elongate.

Drought stress during flower and fruit development adversely affected both vegetative and reproductive growth in pickling cucumber plants during 2 years of experimentation. The lower fruit biomass production under drought conditions was attributed to fewer fruits being set on the plants and slower expansive fruit growth rates (Janoudi, 1989). According to the same author, water deficits caused reductions in photosynthetic rates by stomata closing in stressed plants.

Moreover, the combined effects of a smaller leaf area and reduced photosynthetic rates would limit the plant's capacity to produce dry matter. Widders and Kwantes (1989) showed that water deficits within pickling cucumber plants, as a result of infrequent irrigation following fruit set, significantly reduced the rate of expansive fruit growth. According to Tan et al. (1983), irrigation increased the percentage of marketable yields.

Adequate rainfall prior to harvest ensured that soil moisture was not a limiting factor of yield during the critical early fruit growth stages (O'Sullivan, 1980). Nevertheless, he pointed out that irrigation would be beneficial if soil moisture level were moderately low at fruit set. Additionally, he found that low soil moisture conditions lowered the mean fruit length:diameter ratio (L:D) of the pickling cucumber fruits. Janoudi (1989) and Widders and Kwantes (1989) found that irrigation affected quality parameters. The latter authors showed that fruits of non-stressed plants were on average 15.8 mm longer, and had high L:D ratios than stressed fruits of equivalent diameter. O'Sullivan (1980) reported a relation between irrigation and L:D ratio, and that irrigation reduced the percentage of off-shape fruits. Janoudi (1989) stated that the incidence of misshapen fruits by cucumber plants did not increase in response to water deficits, but were more influenced by genotype.

Effect of potassium on fruit growth and productivity.

Cucumbers grown on a Hillsdale sandy loam soil testing 81 kg/ha K^+ yielded 86 bushels per acre more with the addition of 90 kg/ha K^+ in comparison to treatments receiving no K^+ fertilization (Ries and Carolus, 1958). Higher K^+ application rates did not result in an additional yield enhancement. On a Duphin fine sandy loam soil containing 0.2 meq K^+/100 gr, pickling cucumber yield differences were only found between the control (0 kg K^+/ha), and the 45 and 90 Kg K^+/ha fertilization treatments (McCollum and Miller, 1971). They concluded that the small differences in yield were due to differences in the capacity of the cucumber plants to set fruit. Although the well-fertilized plants produced a larger vegetative shoot than those under nutritional stress, the increase in the number of fruit set was about 1 per plant. They stated that there is a tendency for developing fruit to inhibit further fruit set in cucumbers.

Pike and Jones (1989) reported that a crop of once-over-harvested pickling cucumbers absorbed 100 kg/ha N, 13 kg/ha P and 162 kg/ha K^+. They also concluded that cucumbers have a remarkable capacity to set fruit even under severe nutritional stress. However the nutritional status of the plant affects fruit quality. Too little or too much fertilizer will result in a high percentage of "culls" or nonmarketable fruits. Plants grown at marginal fertility levels also tend to have slower growing fruit than plants under optimum fertility conditions.

Although application of 0, 28 and 56 kg/ha K^+ was reflected by higher percentages of K^+ in the petioles, yield differences were not significant (Bishop et al., 1969). Growth and yield differences in responses to different levels of K^+ 0, 1, 3, and 6 mM K^+ in the nutrient solution were large in tomato. Fruits yields were extremely low when no K^+ was added to the nutrient solution. Yields of plants receiving 1mM K^+ were reduced about 25 % below those cultured at the higher K^+ level (Lingle and Lorenz, 1969).

A higher volume flow rate in the xylem was required to transport K^+ from the root after fruit set in processing tomato plant. This was supported by a slight onfogenic decline in xylem K^+ concentrations (Widders and Lorenz, 1982). The high net rates of K^+ accumulation mainly contributed to tomato fruit development. The maximum rates of K^+ accumulation in tomatoes are related to high K^+ transport rates in the transpirational stream (Widders and Lorenz, 1982). They concluded that water stress following fruit set might limit K^+ uptake by the root system and thus limit K^+ supply to developing fruit and potentially reduce fruit yield.

A higher K^+ supply (10 meq K^+ l^{-1}) did not result in higher rates of CO_2 assimilation in tomato, but did affect the distribution of the labelled photosynthates to the various plant organs (Mengel and Viro, 1974). Treatment with higher K^+ concentrations in solution resulted in higher concentrations of labelled assimilates in the fruits and lower concentrations in the leaves. This indicates that K^+ favors the translocation of photosynthates from leaves to developing fruits. There seem to be a tendency for high K^+ supply to result in a lower content of labelled sugars in the leaves and in a higher content in the fruit. Transport of photosynthates is more sensitive to K^+ supply than to CO_2 assimilation rate (Mengel and Viro, 1974). This in agreement with the experimental results of Hartt (1970) who found that K^+ favored the transport of assimilates in sugarcane, even under conditions where the CO_2 assimilation was not affected. Mengel (1980) reported a higher flux rate of the phloem sap without diluting the concentration of the solutes in high K^+ fertilization treatments in tomato. The flux rate was about twice as high in the high K^+ plants as compared with the low K^+ plants.

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MATERIALS AND METHODS

Two field experiments were designed to study the effect of potassium (K^+) nutrition and water relations on the assimilation rate, fruit growth, yield and quality of pickling cucumber fruits.

Experiment 1

Location and plant material.

Experiment 1 was conducted at the Kellog Biological Station (K.B.S.), Hickory Corners, Michigan, from June to August, 1990. The soil in the rainout shelter was a Kalamazoo fine-loamy, mixed, mesic Typic Haphidalfs soil type (Table 1). The fertility level of each nutrient was considered to be high for cucumber production.

Seeds of the pickling cucumber cultivar "Calypso", (Asgrow Seed Company, Kalamazoo, MI) were sown by hand on June 13, 1990 under a rain-out shelter. Rows were spaced 56 cm apart. At the cotyledonary stage plants were thinned to a within row spacing of 7.6 cm between plants. All plots were irrigated after planting to insure good germination and plant emergence.

Treatments and Experimental Design

Preplant treatments were 0 and 252 kg of K^+ per ha. Potassium sulfate (K_2SO_4) was chosen as the K^+ source instead

Table 1. Characteristics of Kalamazoo fine-loamy, mixed, mesic, Typic Haphidalfs soil, at the Kellogg Biological Station (Exp 1, 1990).

	Amount of available nutrient	% bases
Phosphorus	153 kg.ha^{-1}	
Potassium	557 kg.ha^{-1}	9 %
Calcium	2081 kg.ha^{-1}	67 %
Magnesium	431 kg.ha^{-1}	23 %
Cation Exchange Capacity:		8 meq.100g^{-1}
Soil pH		5.9
Lime index		69.0

of potassium chloride (KCl), to avoid the possibility of chloride interaction with plant response to drought stress. K fertilizer was broadcast and mixed into the soil in the upper 10 cm, 43 days before planting using a rototiller.

The experiment was conducted in a rainout shelter in order to prevent rainfall on the plots (Nesmith et al., 1990). It was closed at night most of the time and was opened 1.5 hours after sunrise. This altered the nocturnal microclimate of the plots as compared to plants growing in the field. Plants under the shelter experienced warmer night temperatures and thus less dew and were exposed to lower wind velocities than plants growing in the field.

Irrigation was applied using an overhead Toro FS-LG series sprinkler system operating with a pressure of 103.5 $Kg.Pa^{-1}$, giving a flow rate of approximately 19 $l.min^{-1}$ (Nesmith et al., 1990). Water was applied from 6 to 10 P.M.

Irrigation treatments were established as follows:

a) <u>normal irrigation</u>: 40 mm of water per week during vegetative development and 51 mm of water per week during reproductive development, from anthesis (41 DAP) until harvest (56 DAP).

b) <u>drought stress</u>: Drought stress treatments were initiated six days after planting by withholding water. Additional irrigation was applied during the fruiting period to insure good fruit set. The amount of water applied was 4, 4 and 8 mm at 37, 45 and 48 days after planting, respectively.

Nitrogen was sidedressed 37 days after planting, at the rate of 28 kg $N.ha^{-1}$, and incorporated into the soil by irrigation on all plots. Ammonium nitrate (NH_4NO_3) was used as the N source.

The experimental design was a completely randomized block design with two replications. Four plots per block were used. Each plot was 4.5 meters wide with eight rows of plants, 6 meters long.

Parameters Measured.

Leaf width at the widest point and vine length, from the soil surface to the end of the vine, were initiated when plants reached the third true leaf developmental stage, and continued every six days up to harvest. Leaf area per node and total plant leaf area were estimated using a linear function describing the relationship between individual leaf diameter and measured leaf area.

Net CO_2 assimilation rate (A), photon flux density (PFD), relative humidity and leaf temperature determinations were made under field conditions at 29, 41, 42, 48, 50, 53, and 55 days after planting, using a portable open system LCA-2 infrared gas analyzer (IRGA, Analytical Development Corporation, Hodesdan, England) . An air supply unit with a flow rate of 400 $cm^3.min^{-1}$, and a Parkinson broadleaf chamber with a window area of 6.25 cm^2 also were used with the IRGA (Gucci, 1988). Parameters were determined between 10:30 A.M. and 5:00 P.M. to avoid cloudy conditions that would result in extremely low A rate readings.

Diurnal changes in leaf gas exchange rates were estimated from measurements taken at 8-10 A.M., 2-3:30 P.M., and 4:30-6:00 P.M., during both vegetative and reproductive stages of development (42 and 48 days after planting, respectively).

Assimilation rate (A), transpiration rate (E), stomatal conductance (g_s), and water use efficiency were calculated using the computer program developed by Moon and Flore (1986). All measurements were made under natural sunlight. Ambient CO_2 levels were between 323 and 371 ppm, temperature between 24 and 34 C, reference humidity between 8 and 21% and PFD between 800 and 1530. Measurements were made on the most recently matured leaf, the fifth or the sixth leaf from the shoot apex of each plant. Six plants were measured in each plot.

Lamina and petiole K^+ concentrations were determined on randomly selected mature fully expanded leaves, sampled at 29, 35, 39, 43, and 54 days after planting. Leaves were dried at 60 C in a forced air oven for three days, and ground in a Wiley mill to pass a 20 mesh screen, prior to elemental analysis.

The water potential of the first fully expanded leaf was measured using a Scholander pressure chamber (Soil Moisture Equipment Corporation Model 3000 Series). Measurements were made between 3 and 7 P.M., 50 days after planting.

Leaf osmotic potential and relative leaf water content were measured on fully expanded leaf sections that were collected during vegetative and reproductive development .

After weighing, the leaves were rehydrated by floating on distilled water for 4 hours at room temperature, blotted dry, weighed and placed in sealed plastic vials for storage at -20 C. After thawing, the lamina tissue was placed into the barrel of a 5 ml syringe and pressed for extraction of cell sap. A 10 µl aliquot of sap was used to determine solution osmolality with a Wescor 5000 Vapor pressure osmometer (Logan, Utah). Soil moisture was monitored with Time Domain Reflectometry (TDR). Steel rods were installed to a depth of 15 and 30 cm in each plot leaving 2 cm above the soil surface. Readings were taken at 44, 49 and 53 days after planting. Moisture content was estimated using the following calculations (Topp et al., 1980a):

$TIME^{15} = (HR^{15} - LR^{15}) \times 30.48 / (0.74^{y} \times 30)$

$KA^{15} = [(30 \times TIME^{15})^{2}] / [(15)^{2}]$ where KA^{15} represents percent moisture content at the 15 cm depth.

HR^{15}: high reading at 15 cm depth.

LR^{15}: low reading at 15 cm depth.

y: cable length.

The same formula, but replacing HR^{15} and LR^{15} with HR^{30} and LR^{30}, was used to estimate the moisture content at the 30 cm depth.

Expansive fruit growth was evaluated by measuring the lengths and diameters of ten tagged fruits per plot daily . Measurements were initiated when fruits reached a diameter of 1.5 cm and continued until the fruit were 4-4.5 cm in diameter.

Cucumbers were harvested 56 days after planting. Three central rows, 4.5 meters long, were harvested, and the number of gynoecious and monoecious plants in each plant were counted. Fruits were graded mechanically into size classes: 1a (less than 2 cm), 1b (2-2.7 cm), 2a (2.7-3.2 cm), 2b (3.2-3.8 cm), 3a (3.8-5 cm), oversize (>5 cm), and nubs and crooks. Fruit weight and fruit number for each size grade were recorded.

The following fruit quality parameters were measured from a random sample of ten fruits per plot: length /diameter ratio, seed cavity (%), seed set (%), seed size (1=small, 3=large), carpel separation and placental hollows.

After harvest, samples of small (17.7 mm diameter), medium (30 mm diameter), and large fruits (50 mm diameter) were collected for fruit tissue K^+ analysis and for fruit osmotic potential determinations. Each fruit was divided into pericarp and endocarp tissues. The tissue was dried at 60 C in a forced air oven for 6 days and ground as described previously. Pericarp and endocarp tissue fresh weight and dry weight for individual fruit were recorded. Fresh samples were also stored at -20 C for future osmotic potential determinations.

Leaf temperature, stomatal conductance and transpiration were recorded from irrigated and drought-stressed plots at harvest time. Readings were taken at 10:50 A.M., 12:00 noon, 2:40 and 5:10 P.M. using a LI-1600 Steady State Porometer, LI-COR, INC (Lincoln, Nebraska). Photon flux density was also recorded concurrently at the surface of the canopy, within the canopy and on open soil, using a LI-185A quantum sensor, LI-COR, INC (Lincoln, Nebraska). Just prior to harvest, a computer data logging system was used to record fruit and leaf temperature under irrigated and drought stress conditions. Surface thermocouples, T probes with gold sensors, were positioned on the abaxial surface of the leaf to prevent direct exposure to the sunlight. Probes were attached to the interveinal lamina tissue. Micro-thermocoples T type, 0.08 cm thick, were also inserted approximately 3 cm into the blossom end of fruit 4-4.5 cm in diameter. Three fruits and three leaves from an irrigated and from a drought-stressed plot were chosen for recording these data. Data were recorded at 5-minute intervals from 9 A.M. to 6 P.M.

Statistical analysis by analysis of variance with Factor and separation of means with Range, were conducted using MSTAT (Michigan State University; E. Lansing, Michigan). PlotIt was used for the regression analysis and curve fitting (Scientific Programming Enterprises; Haslet, Michigan).

Experiment 2.

Location and plant material.

Experiment 2 was conducted at the Horticulture Teaching and Research Center (HTRC) of Michigan State University, East Lansing, during July and August, 1990. The soil was a Spinks loamy sand, (sandy, mixed, mesic Psammentic Hapludalfs; Table 2).

Table 2. Characteristics of sandy, mixed, mesic Psammentic Hapludalfs soil at the HRC (Exp. 2, 1990).

	Amount of available nutrient	% bases
Phosphorus	81 kg.ha^{-1}	
Potassium	99 kg.ha^{-1}	2 %
Calcium	2481 kg.ha^{-1}	92 %
Magnesium	106 kg.ha^{-1}	7 %

Organic matter: 1.2 %
Soil pH: 7.8
Cation Exchange Capacity: 6 meq.100g^{-1}

Seeds of the pickling cucumber cultivar "Calypso", (Asgrow Seed Company, Kalamazoo, MI) were mechanically (Heath vacuum precision seeder) sown on a flat bed, 2.25 cm wide and 6 m long, with 3 rows, 75 cm apart, on July 6, 1990. Guard beds were planted between all treatment beds.

Potassium level was medium-low while the levels of the other elements were relatively high, with an extremely high amount of available Ca. All treatments were preplant fertilized with 75, 94, and 101 kg.ha^{-1} of magnesium ($MgSO_4$, 10% Mg), phosphorus (superphosphate, 17% P_2O_5), and nitrogen (NH_4NO_3, 33.5% N), respectively.

The plots were irrigated with 12.7 mm of water immediately after planting to insure good emergence of plants. Irrigation also was applied at 1, 2, 4 and 7 days after planting to all treatments, 6.4, 12.2, 6.4 and 6.4 mm, respectively. At the cotyledonary stage, plants were thinned to a within-row spacing of 7.6 cm between plants. Nitrogen was sidedressed 24 days after planting at the rate of 31 Kg N.ha^{-1} using NH_4NO_3.

Treatments and Experimental Design.

Two K^+ salt sources (KCl and K_2SO_4) and 4 K^+ application rates (0, 84, 168, and 252 Kg K^+/ha) were combined with two irrigation levels, normal (40 mm of water per week during the vegetative and 51 mm of water during the fruiting period) and no irrigation. The experimental design was a split plot with irrigation as the whole plot treatment and the combinations of K^+ rates and salt sources randomized as subplot treatments.

Irrigation was applied using a drip system. Two-lay flat tubing lines (3.8 cm diameter) were placed in each irrigated bed between the 1st and 2nd rows and between the 2nd and 3rd rows. Drip orphics were spaced 30.5 cm apart on the lay-flat tube. An irrigation of 24 mm was applied on irrigated treatments 29 DAP. All treatments receive 50 mm of sprinkling irrigation at 31 DAP due to a short period of dry weather conditions.

Cumulative rainfall of 84 and 71 mm were recorded during July and August, respectively. There were nine cloudy days and eight days when dew was present during July and seven cloudy days and seven days when dew was present during August. The average high and low temperatures for July and August were 24 C/16 C, and 26 C/15 C, respectively.

Parameters Measured.

Net CO_2 assimilation rate (A), photon flux density (PFD), relative humidity (H) and leaf temperature (C) determinations, were made under field conditions with the same instrumentation described for Experiment 1.

All measurements were made under sunny conditions, with ambient CO_2 levels between 334 and 355 ppm, temperature between 25.8 and 32.0 C, PFD between 1180 and 1530 $\mu moles.m^{-2}.sec^{-1}$, and reference humidity between 3 to 5%. Measurements were made on the most recently matured leaf that corresponded to the fifth or the sixth leaf from the shoot apex of each plant. Data were recorded between 11:30 A.M. and 3:30 P.M..

Mature fully expanded leaf samples, from the fourth to the sixth node from the shoot apex, were randomly collected 41, 47, and 51 days after planting for K^+ analysis. Leaf lamina and petiole tissue were dried and ground separately as described for Experiment 1.

Steel rods were vertically installed to depths of 15 and 30 cm (having 2 cm above the soil surface) in each plot for soil moisture determinations, using Time Domain Reflectometry (TDR). Measurements were recorded 42, 46, and 51 days after planting. Soil moisture content was estimated using the formula described for Experiment 1.

Ten plants, excluding fruits, were sampled randomly at harvest time to determine total shoot dry weight. Samples were dried and ground as described for Experiment 1.

Fruits were harvested between 52 and 53 days after planting from 4.5 m of bed. All three rows per bed were harvested. The number of plants per plot were recorded. Fruits were graded mechanically, and endocarp and pericarp tissue were collected from fruits and prepared for K^+ analysis.

Fruit samples (4.5 cm) were taken to the M.S.U. Food Science Laboratory for fruit texture determinations, using the Kramer Shear Press, TMS 90 (Food Technology Corp.). Pericarp and endocarp tissue from four fruits were analyzed. The fruit texture was measured on a 0.6 mm transverse slice obtained from the midsection of the fruit.

Fruits from treatments receiving no K^+ or 252 Kg K^+/ha, of either KCL or K_2SO_4 were processed at the Food Science Laboratory according with the following procedure:

1.- Each fruit was cut longitudinally into four equivalent spears. Spears from 3 fruited were placed into an individual jar.

2.- Hot brine solution (1.5 M NaCl, 0.2 Acetic Acid, and 4 mM Sodium bisulphate) at 82 C was used to fill to each jar to capacity. Jars were then passed through a steam exhaust tunnel line for 5 minutes to preheat and deaerate the solution prior to closure.

3.- Jars were capped, then processed in boiling water for 10 minutes, cooled and stored for 5 days at 3 C. They were then transferred to a 25 C room for 51 days storage. Following storage, pericarp and endocarp tissue, from 6 spears per treatment were analyzed for textural characteristics, using the Kramer Shear Press.

Experiment 3.

A nutrient solution culture greenhouse experiment was designed to study the influence of K^+ in the nutrient solution and water availability on leaf A rates, leaf osmolality and growth of pickling cucumber plants.

This controlled environment experiment was conducted at the Plant Science Greenhouse, Michigan State University, from May to July 1991. K^+ availability was controlled by culturing the plants in a hydroponic system using rock wool and modifying the concentration of K^+ within the nutrient solution.

Seeds of the pickling cucumber cultivar "Calypso", (Asgrow Seed Company, Kalamazoo, MI) were sown on May 4 in rock wool propagation blocks (Grodan SBS 36/77) with 77 cells (4.44Lx4.44Wx3.81D) per flat. Deionized water was used for watering during the first five days of germination.

Treatments and experimental design.

Five-day old seedlings were transplanted into 3.8 l plastic pots filled with granular (medium grade) horticultural rock wool (Pargro, Alabama). Modified Hoagland solution (Epstein, 1972) was applied during the first 26 days after planting (6th true leaf stage of development) to all treatments to ensure good initial growth. Approximately 0.8 l of solution was applied to each container at three days intervals when the plants were small. When the plants had developed 10 true leaves, nutrient solution was applied every other day. The nutrient solution contained: 3mM KNO_3, 6 mM $Ca(NO_3)_2.4H_2O$, 1mM NaH_2PO_4, 0.5 mM $MgSO_4.7H_2O$, 50 μM NaCl, 25 μM H_3BO_3, 2 μM $MnSO_4.H_2O$, 2 μM $ZnSO_4.7H_2O$, 0.5 μM $CuSO_4.5H_2O$, and 0.5 μM H_2MoO_4.(85% MoO_3). Iron was supplemented as sequestrine at a concentration of 3mM. It was necessary to acidify the nutrient solution with H_2SO_4 (1N) to maintain the pH between 6 and 7.

Treatments were factorial combinations of four potassium rates, 0.01, 0.1, 1 and 10 mM K^+, and two water regimes, regular daily irrigation and induced water deficit. Treatments were replicated three times in a complete randomized block design with four plants per plot. Water deficits were induced by withholding water during the fruit period (47 to 64 DAP).

K^+ treatment formulations were prepared in such a way that the other anions accompanying the nutrient solution remained nearly in balance (Table 3). Micronutrient and iron concentrations in solution were not modified (Epstein, 1972). All pots were covered with a styrofoam plate so as to avoid algae growth. In a separate experiment (not reported here), extensive algae growth occurred on the surface of the rock wool when a styrofoam plate was not used. In addition, plant growth was suppressed, possibly as the result of salt accumulation on the surface of the rock wool due to evaporative water loss.

Treatments were initiated when plants reached the 6th true

Ta

Ch

K
Ca
N
N
M
K
K
M
N

Table 3. Composition of treatment nutrient solutions varying in K^+ concentration.

Salt concentration in nutrient solutions (mM)

Chemicals	K^+ treatments (mM)			
	0.01	0.1	1	10
KNO_3	0.0	0.0	1.0	4.0
$Ca(NO_3)_2 \cdot 4H_2O$	4.0	4.0	4.0	4.0
NaH_2PO_4	1.0	1.0	1.0	0.0
$NH_4H_2PO_4$	0.0	0.0	0.0	1.0
$MgSO_4 \cdot 7H_2O$	0.5	0.5	0.5	1.0
KCl	0.0	0.0	0.0	2.0
K_2SO_4	0.01	0.1	0.0	2.0
$Mg(NO_3)_2$	0.5	0.5	0.5	0.0
NH_4NO_3	1.5	1.5	1.0	0.0

leaf stage of development. Nutrient solution (0.8 l) was added to each container on alternate days. As the plants reached anthesis (approximately 44 DAP), it was necessary to apply 1.2-1.6 l per container every day. Plants were watered twice a day when temperature and light intensities were high.

Drought-stressed treatments were induced by withholding water from plants for 12 to 24 hours. As the drought stressed plants became larger and the days sunny and warm, drought-stress treatments were imposed by applying only 1/4 to 1/2 the amount of solution given to non-stressed plants. The rock wool in the pots was flush-rinsed once every week with deionized water in order to prevent salt accumulation. Nutrient solutions were reapplied within 2 to 4 hours after rinsing.

Pistillate flowers were hand-pollinated between 10 A.M. and noon on the day they opened. Day/night temperatures were maintained at about 30/20 C ± 5 C and no supplemental lighting was provided.

Parameters measured.

a) Leaf gas exchange measurements.

A response to modified internal CO_2 concentration in the 6th leaf from the shoot apex was determined using an open gas exchange system described by Sams and Flore (1986). Each leaf was enclosed in a 0.260 dm^2 plexiglass chamber. Volume flow rate was 300 $ml.min^{-1}$, light intensity was kept at 600 PAR

μmoles.m^{-2}.sec^{-1}, and the chamber temperature was 19.3 C.

The CO_2 responses of leaves from differentially watered plants were determined by exposing the leaves to CO_2 levels ranging from 0 to 823 ppm (0, 80, 127, 190, 261, 415, 605 and 823 ppm.). Measurements were taken 60 days after planting. Linear and non linear functions were regressed through the data using PlotIt regression analysis programs.

In addition, net CO_2 assimilation rate, photosynthetically active radiation, relative humidity and leaf temperature determinations were made under greenhouse conditions using a portable open system LCA-2 infrared gas analyzer (IRGA, Analytical Development Corporation, Hodesdan, England). An air supply unit with a flow rate of 400 cm^3.min-1, and a Parkinson broadleaf chamber with a window area of 6.25 cm^2 were also used with the IRGA.

Measurements were taken on the 6th leaf from the shoot apex at 37, 41, 48, and 55 days after planting on four plants per treatment in two replications. Plants were positioned under a 400 W metal Halide lamp such that the measured PAR at the leaf surface was always greater than a 800 μmol m^{-2} sec^{-1}.

Assimilation rate, transpiration rate, stomatal conductance and water use efficiency were calculated using a computer program developed by Moon and Flore (1986).

b)

K

r

f

S

P

c

b) **Leaf and fruit samples.**

K^+ concentrations were determined in tissue sections from recently fully expanded leaves (6th node from the apex), and from mature leaves (2nd leaf from the base of the plant). Samples were collected at 43, 47, and 58 days after planting. Petiole and lamina tissue were dried at 60 C in a forced air oven for 3 days and then ground in a Wiley mill to pass a 20 mesh screen. Fruit samples also were taken, as fruit reached 4-4.5 cm in diameter, for K^+ concentration determination. Individual fruits were divided into pericarp and endocarp tissues, dried at 60 C in a forced air oven for 3 days, and ground in a Wiley mill to pass a 20-mesh screen. Pericarp and endocarp tissue dry weights were estimated from these samples.

c) **Determination of osmotic potential, and tissue K^+ concentration.**

Osmotic potential was determined 67 days after planting from a section of lamina tissue (1/6 of the leaf) from the 6th leaf from the shoot apex. Leaf sections were weighed, rehydrated by floating on distilled water for 4 hours at 4C, blotted dry, and then placed in plastic vials for storage at -20 C. After thawing, the lamina was inserted into the barrel of a 5 ml syringe and pressed for extraction of cell sap. A 10 μl aliquot of sap was used to determine solution osmotic potential using a Wescor 5000 Vapor pressure osmometer.

Dehydrated leaf and fruit tissues (0.1 g) were wet-ashed with hydrogen peroxide and perchloric acid after the method of Adler and Wilcox (1985). Potassium concentrations were analyzed by atomic emission spectrophotometry (IL VIDEO 12, Thermo-Jarrel Ash, Frankin, MA). Cesium chloride was added at concentration of 1000 μg/ml in all solutions, including the blank, to suppress the ionization in the air-acetylene flame.

RESULTS

Experiment 1.

Total leaf area increased in a sigmoidal manner during pickling cucumber ontogeny. By 40 days after planting (DAP), which corresponded to the onset of flowering, drought stressed plants had significantly lower leaf area than irrigated plants. Leaf area was 23, 28, 55 and 58 per cent lower at 35, 41, 48 and 56 DAP, respectively, in drought-stressed plants as compared with irrigated ones (Figure 1). Drought stress also affected vine length as early as 35 DAP. The largest differences occurred at 48 and 56 DAP when the vine length of drought stressed plants was 42.8 and 48.3 per cent lower as compared to irrigated plants (Table 4). Vine length was not affected by K^+ treatments (Figure 2).

Water-stressed plants wilted between 9:00-10:00 A.M. during dry hot days and did not regain turgidity until approximately 8:30 P.M. at 50 DAP.

Measurement of diurnal fluctuations of gas exchange at 42 DAP, during vegetative development (VD), and at 48 DAP, during reproductive development (RD), indicated that $\underline{A}$ declined during the day time. The diurnal decline was larger in leaves of vegetative plants than in fruiting plants. Mean daily $\underline{A}$ rates were higher during RD than VD (Figure 3). Irrigated plants showed similar diurnal trends in g_s and E rates during VD and RD (Figure 4 and 5). E in fully expanded

Figure 1. Total leaf area for irrigation treatments during the life cycle of pickling cucumber plants cultured in a rainout shelter. Significant F test (P = 0.05) indicated by a and b letters.

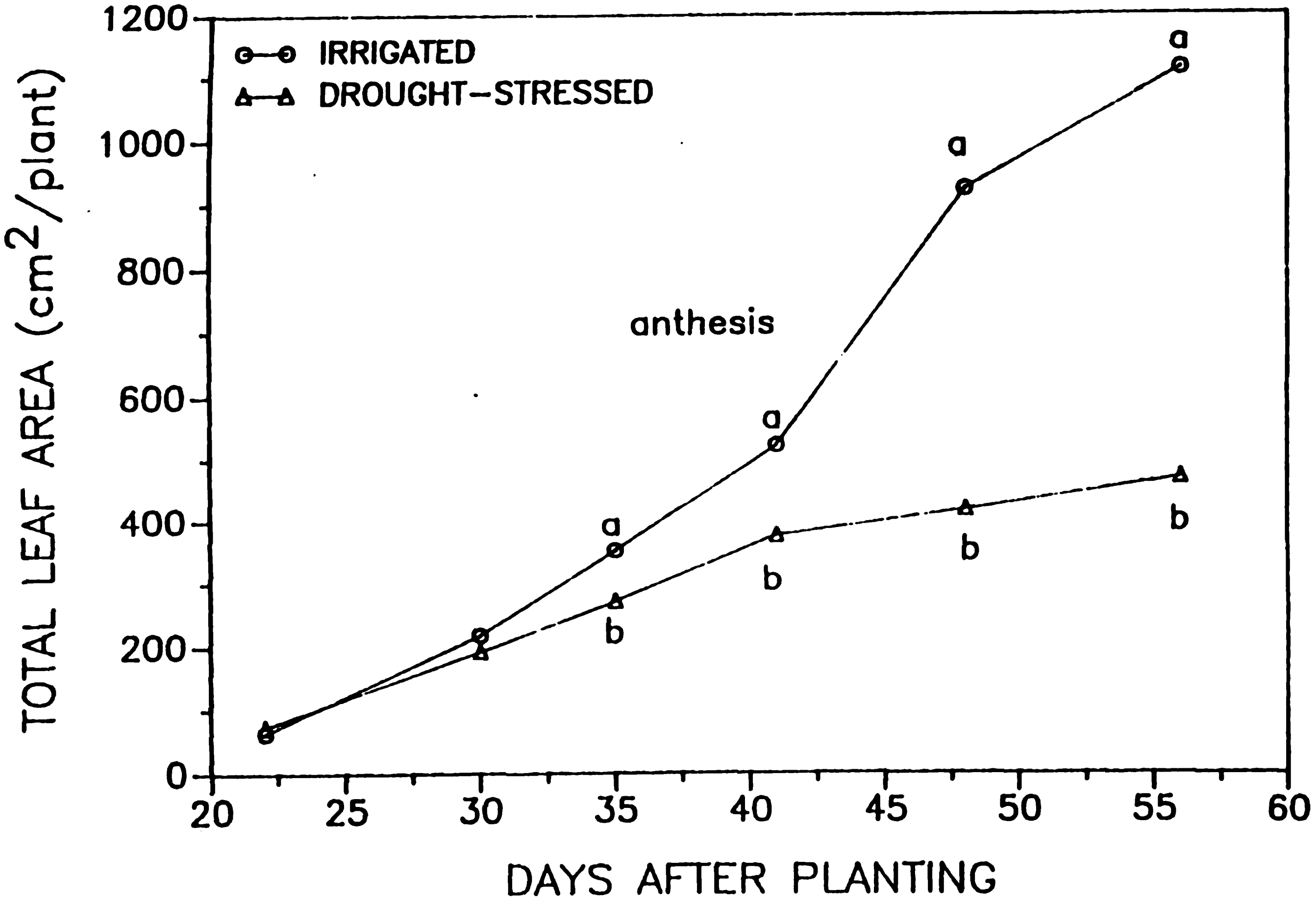
IRRIGATED
DROUGHT-STRESSED
anthesis
a
a
a
a
a
b
b
b
b
b
TOTAL LEAF AREA (cm2/plant)
0
200
400
600
800
1000
1200
DAYS AFTER PLANTING
20
25
30
35
40
45
50
55
60

Figure 1.

Table 4. Effect of irrigation on vine length of pickling cucumber plants cultured in a rainout shelter.

	Vine length (cm)		
Days after planting	Irrigated	D. stressed	F test sign
22	6.10	6.58	*
30	14.23	13.57	NS
35	27.89	24.81	**
41	47.38	37.93	***
48	83.44	47.72	***
56	98.89	51.08	***

NS, ***, **, * Non significant and significant at P = 0.0001, 0.01 and 0.05, respectively.

Figure 2. Vine length for K^+ fertilization treatments during the life cycle of pickling cucumber plants cultured in a rainout shelter.There were no significant differences due to K^+ fertilization treatments.

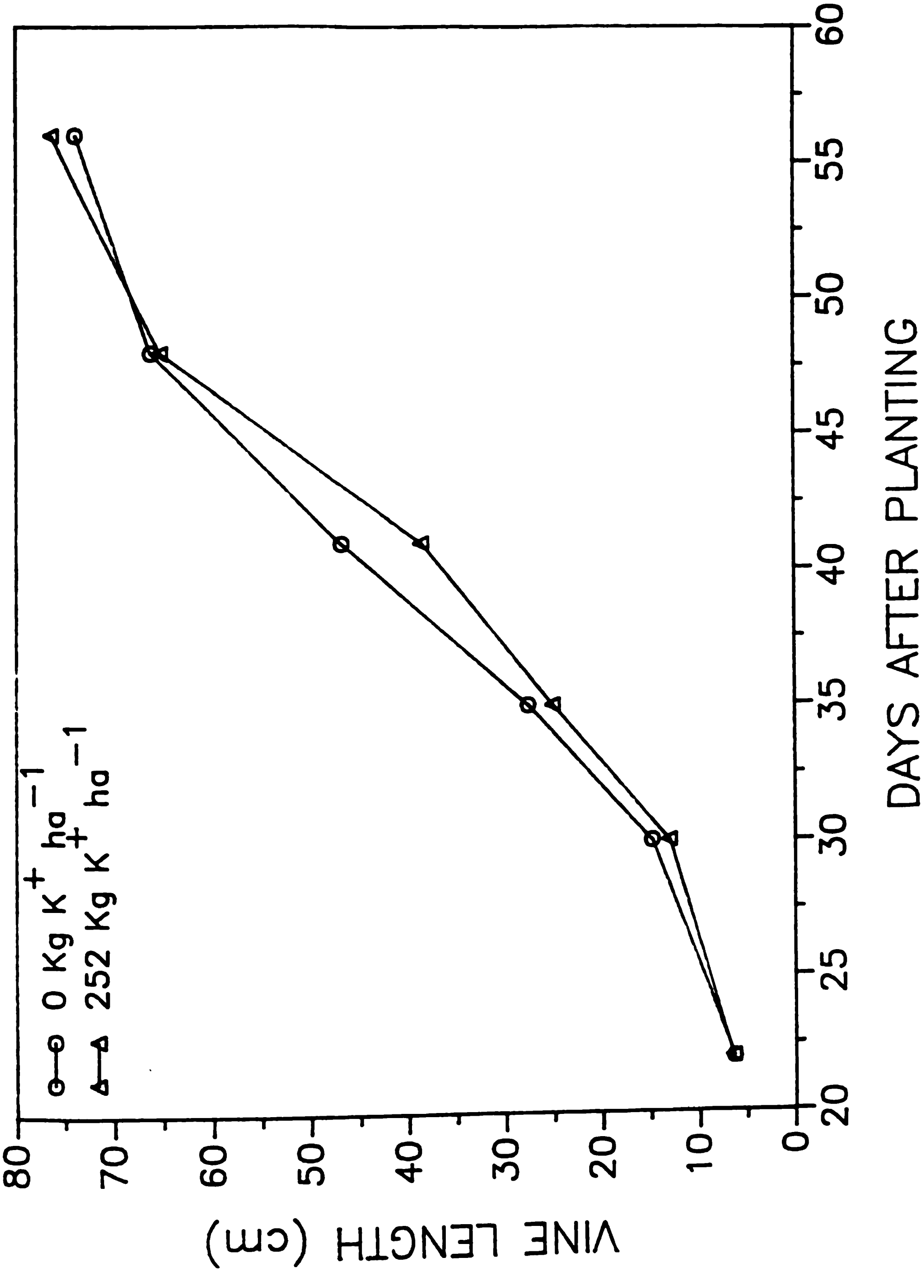
VINE LENGTH (cm)
DAYS AFTER PLANTING
0 Kg K^+ ha^{-1}
252 Kg K^+ ha^{-1}
0
10
20
30
40
50
60
70
80
20
25
30
35
40
45
50
55
60

Figure 2.

Figure 3. Diurnal changes of CO_2 assimilation rate of fully expanded leaves of field grown pickling cucumber plants during vegetative (VD) and reproductive development (RD), 42 and 48 days after planting respectively. LSD values for differences between time of the day. Significant F test (P = 0.05) for irrigation treatments indicated by a___and b letters.

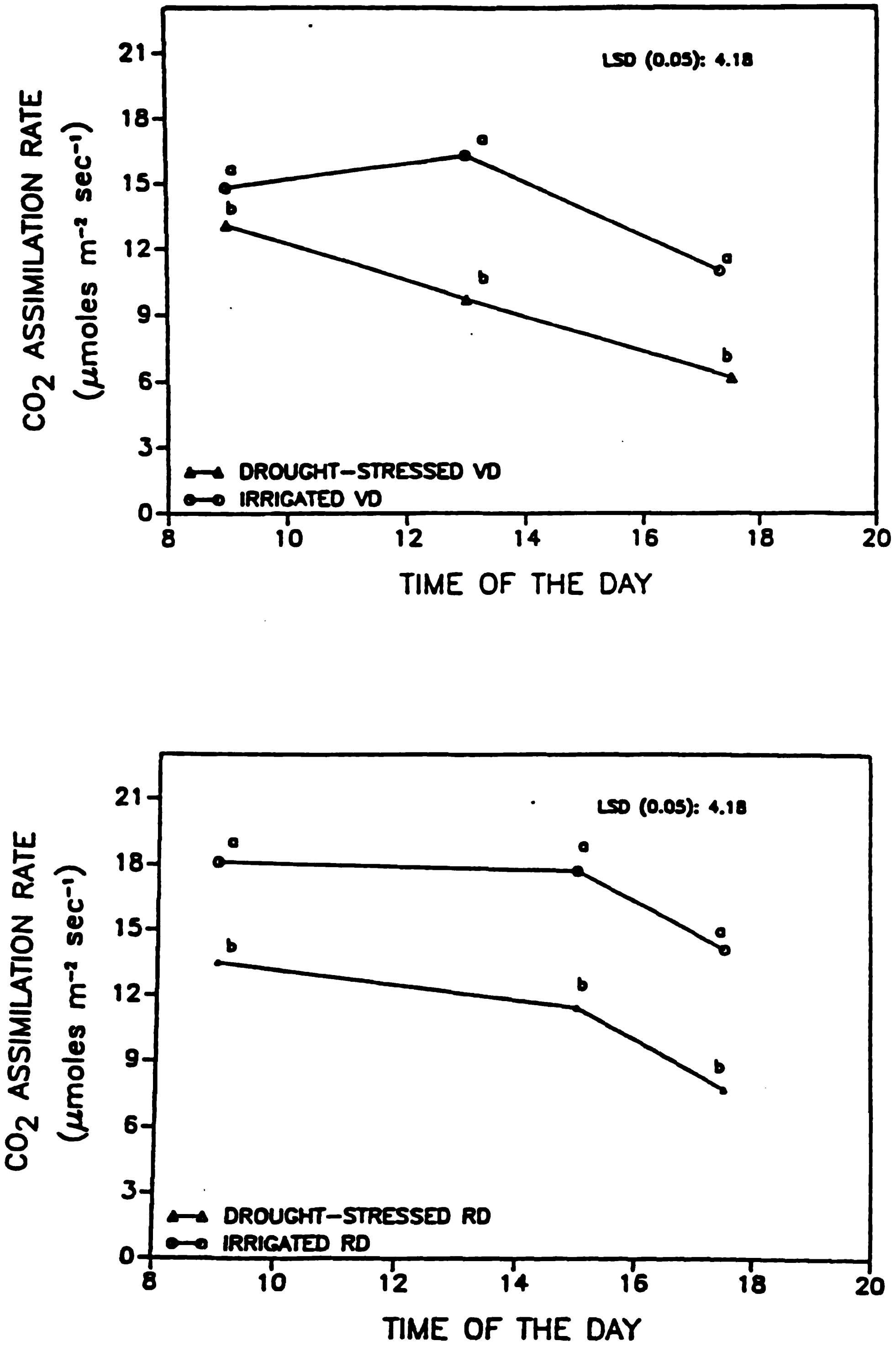
LSD (0.05): 4.18
CO2 ASSIMILATION RATE
(μmoles m-2 sec-1)
21
18
15
12
9
6
3
0
a
a
a
b
b
b
DROUGHT-STRESSED VD
IRRIGATED VD
8
10
12
14
16
18
20
TIME OF THE DAY
LSD (0.05): 4.18
CO2 ASSIMILATION RATE
(μmoles m-2 sec-1)
21
18
15
12
9
6
3
0
a
a
a
b
b
b
DROUGHT-STRESSED RD
IRRIGATED RD
8
10
12
14
16
18
20
TIME OF THE DAY

Figure 3.

le

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ge

4

2

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f

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5

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g

h

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s

s

leaves from drought-stressed plants declined through the day at VD.

Drought-stressed plants had lower A, E and g_s rates at all stages of ontogeny as compared to irrigated plants. In general, A rate was not affected by K^+ fertilization except at 41 DAP in no K^+ treatment (Table 5). Plants fertilized with 252 Kg $K^+.ha^{-1}$ exhibited a little higher A rate as compared with 0 Kg $K^+.ha^{-1}$. There were no interactions between irrigation and K^+ fertilization treatments on A rates. K^+ fertilization treatments did not affect g_s from 21 to 53 DAP. Higher g_s was found on plants fertilized with 252 Kg K^+ ha^{-1} at 55 DAP (Table 6). E was not influenced by K^+ fertilization treatments except at 53 DAP. Higher E was recorded on plants grown with 252 Kg $K^+.ha^{-1}$ (Table 7). Irrigated plants exhibited higher E than drought-stressed plants. Soil moisture content in irrigated plots was always higher as compared to drought-stressed plots (Table 8). Irrigated plots recorded volumetric soil moisture content between 9.8% and 11.9% at a 15 cm depth, while the water-stressed soils contained 1.4% to 4.4% at the same depth. At 30 cm, irrigated plots contained 16.2-18.0% while the drought-stressed had 9.7-11.8% moisture (Table 8). Soil saturation at 7, 15 and 40 cm depth corresponds to TDR readings of 39.5, 37 and 31 % (Dadun, 1991; personal communication).

Irrigated plants had 47% and 43.4% higher daily average fruit growth rates for length and diameter, respectively, than drought-stressed plants (Table 9). Daily average fruit growth

Figure 4. Diurnal changes in stomatal conductance of fully expanded leaf tissue of field cultured pickling cucumber plants during vegetative (VD) and reproductive development (RD), 42 and 48 days after planting respectively. LSD values for differences between time of the day. Significant F test (P = 0.05) for irrigation treatments indicated by a and b letters.

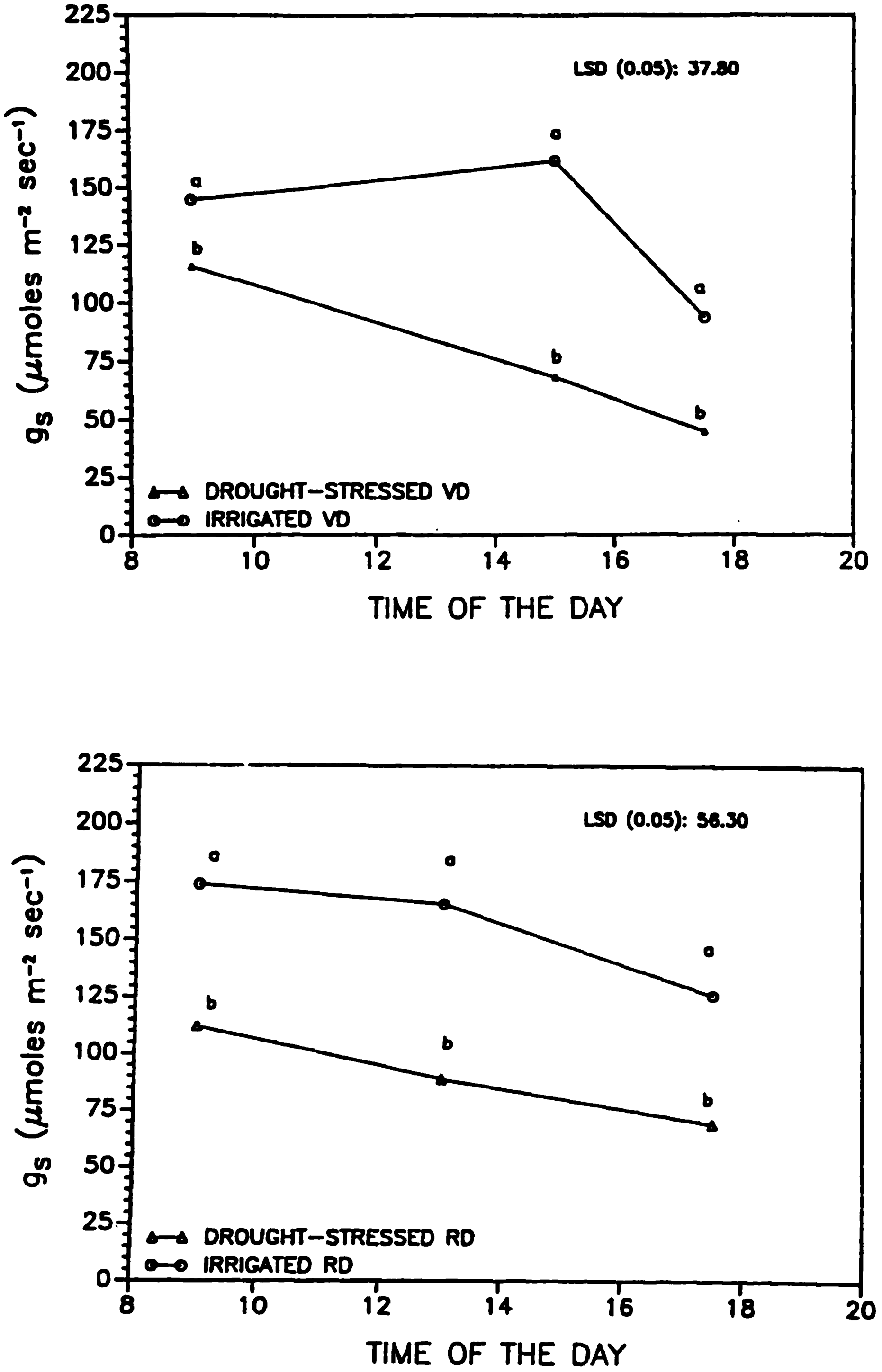

LSD (0.05): 37.80
a
a
a
b
b
b
g_s (μmoles m^{-2} sec^{-1})
225
200
175
150
125
100
75
50
25
0
DROUGHT-STRESSED VD
IRRIGATED VD
8
10
12
14
16
18
20
TIME OF THE DAY
LSD (0.05): 56.30
a
a
a
b
b
b
g_s (μmoles m^{-2} sec^{-1})
225
200
175
150
125
100
75
50
25
0
DROUGHT-STRESSED RD
IRRIGATED RD
8
10
12
14
16
18
20
TIME OF THE DAY

Figure 4.

Figure 5. Diurnal changes in transpiration rates of fully expanded leaves from field cultured cucumber plants during vegetative (VD), and reproductive development (RD), 42 and 48 days after planting respectively. LSD values for differences between time of the day. Significant F test (P = 0.05) for irrigation treatments indicated by a and b letters.

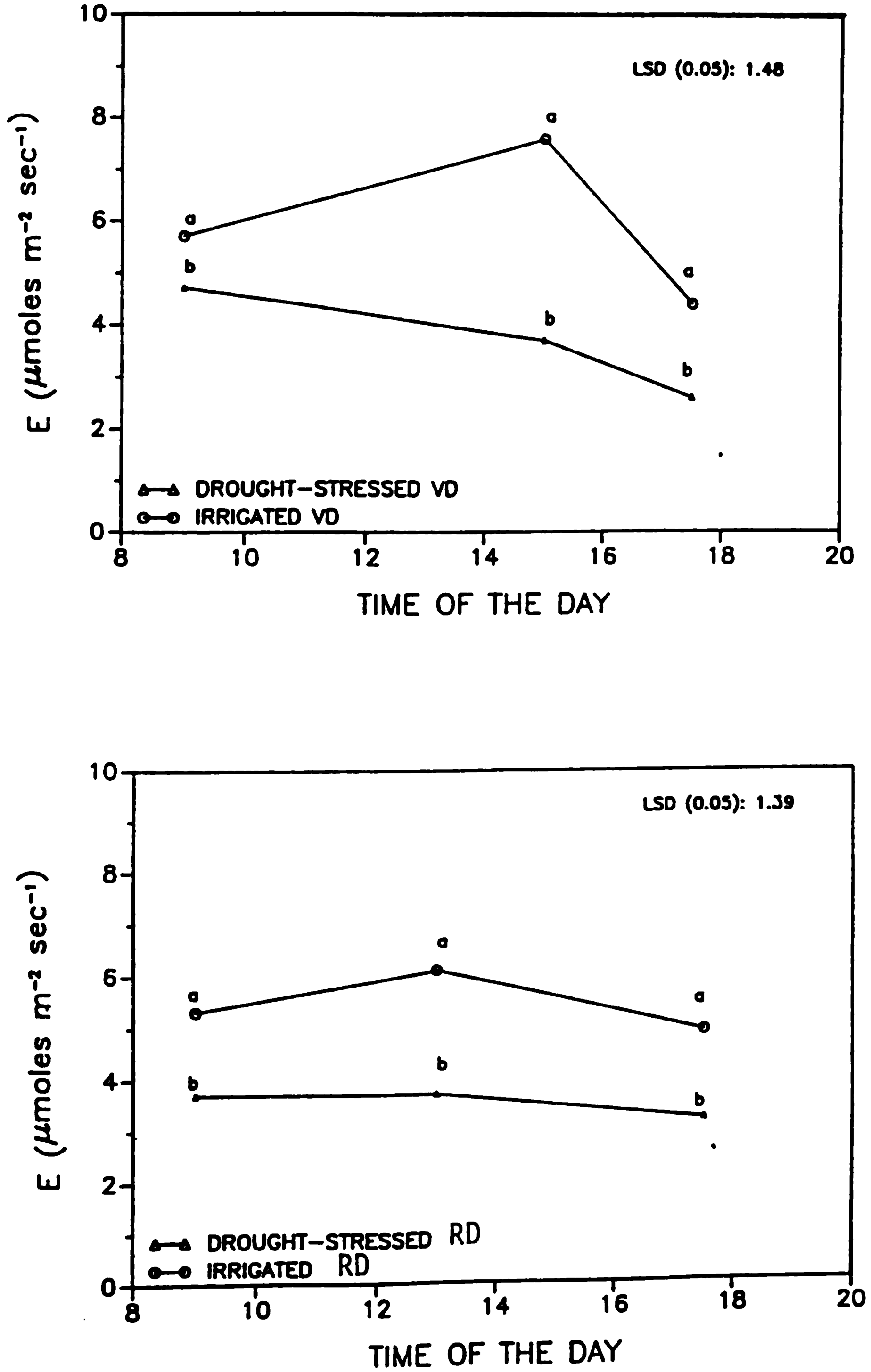

10
8
6
4
2
0
E (μmoles m-2 sec-1)
LSD (0.05): 1.48
a
a
a
b
b
b
DROUGHT-STRESSED VD
IRRIGATED VD
8
10
12
14
16
18
20
TIME OF THE DAY
10
8
6
4
2
0
E (μmoles m-2 sec-1)
LSD (0.05): 1.39
a
a
a
b
b
b
DROUGHT-STRESSED RD
IRRIGATED RD
8
10
12
14
16
18
20
TIME OF THE DAY

Figure 5.

Table 5. Effect of irrigation and K^+ fertilization treatments on **A** rates in fully expanded leaves from pickling cucumber plants cultured in a rainout shelter.

	CO_2 assimilation rate (μmoles m^{-2} sec^{-1})					
	Days after planting					
Treatments	29	41[z]	48	50	53	55
Irrigated	12.41	12.34	14.10	13.09	14.92	14.80
D.stressed	8.78	10.79	7.68	6.08	9.41	9.49
F test sig.	***	*	***	***	***	***
0 Kg $K^+.ha^{-1}$	11.05	10.46	10.63	9.45	11.63	11.44
252 Kg $K^+.ha^{-1}$	10.14	12.67	11.15	9.73	12.70	12.85
F test sign.	NS	*	NS	NS	NS	NS

NS, ***, * Non significant and significant at P = 0.0001 and 0.05, respectively.

No significant interaction between irrigation and K^+ fertilization treatments.

z = onset of anthesis.

Table 6. Effect of irrigation and K^+ fertilization rates on stomatal conductance in fully expanded leaves from pickling cucumbers plants cultured in a rainout shelter.

	Stomatal conductance (μmoles H_2O m^{-2} sec^{-1})					
	Days after planting					
Treatments	29	41[z]	48	50	53	55
Irrigated	185.2	148.8	125.9	117.6	121.6	140.6
D.stressed	140.6	103.7	69.3	53.9	98.0	71.9
F test sign	***	***	***	***	***	***
0 Kg $K^+.ha^{-1}$	173.3	123.0	96.8	83.7	122.1	99.4
252 Kg $K^+.ha^{-1}$	152.4	129.5	98.5	87.8	97.5	113.0
F test sign	**	NS	NS	NS	NS	*

NS, ***, **, * Nonsignificant and significant at P = 0.0001, 0.01 and 0.05, respectively.

No significant interaction between irrigation and K^+ fertilization treatments.

z: onset of anthesis.

Table 7. Effect of irrigation and K^+ fertilization treatments on transpiration rate in fully expanded leaves from pickling cucumber plants cultured in a rainout shelter.

	Transpiration rate (μmoles m^{-2} sec^{-1})					
	Days after planting					
Treatments	29	41^z	48	50	53	55
Irrigation	5.56	6.95	4.99	5.98	4.28	5.85
D. stressed	4.70	5.56	3.21	3.34	2.93	3.65
F test sign.	**	***	***	***	***	***
0 Kg $K^+.ha^{-1}$	5.23	6.10	4.17	4.44	3.47	4.63
252 Kg $K^+.ha^{-1}$	5.04	6.41	4.03	4.88	3.73	4.87
F test sign.	NS	NS	NS	NS	*	NS

^{NS}, ***, **, * Nonsignificant and significant at P = 0.001, 0.01 and 0.05, respectively.

No significant interaction between irrigation and K^+ fertilization treatments.

Table 8. Volumetric soil moisture (%) estimated with TDR in pickling cucumber treatment plots cultured in a rainout shelter.

	Soil moisture content (%)		
	Days after planting		
Treatments	44	49	53
		15 cm deep	
Irrigated	11.9	9.8	10.7
D. stressed	4.4	1.4	3.3
F test sign.	***	***	***
		30 cm deep	
Irrigation	17.8	16.2	18.0
D. stressed	11.8	10.1	9.7
F test sign.	**	*	***

***, **, * Significant at P = 0.0001, 0.01 and 0.05, respectively.

was unaffected by K^+ fertilization treatments.

Length:diameter ratio was lower for fruit from drought-stressed plants, 1.83 as compared to 2.34 for irrigated plants. Drought stressed plants also produced larger seeded fruit. K^+ fertilization did not have any effect on fruit quality parameters (Table 10).

Large differences between total and marketable yield were found between irrigated and drought-stressed plants. Approximately 95% more marketable fruits were harvested from irrigated plants (Table 11). Misshapen fruits in the water-stressed treatments constituted 97.22% of the total harvested fruit, while the non-stressed treatment had 16.92% misshapen fruit, even thought there were no significant differences in the net amount of misshapen fruit from both treatments (coefficient of variation = 38.2). Fruit yield was not affected by K^+ fertilization. The percentage of misshapen fruits was not influenced by K^+ fertilization.

Irrigation and K^+ fertilization regime did not affect K^+ concentration in the lamina tissue. K^+ concentration in petiole tissue was lower only at 44 DAP with 0 $kg.ha^{-1}$ K^+ applied (Table 2, appendix). Statistically higher K^+ concentrations were found in petiole tissue when time of sampling was a factor in the analysis of variance. Petiole tissue contained higher K^+ concentrations, 8-12% K^+ on a dry wt. basis, as compared to lamina tissue, 1-3.5% K^+. K^+ concentrations in lamina tissue increased from 25 DAP to 40 DAP and then declined as the fruit matured. K^+ concentrations

Table 9. Effect of irrigation and K^+ fertilization rates on fruit growth rate of pickling cucumbers in a rainout shelter.

	Fruit growth rate (mm/day)	
Treatments	Diameter	Length
Irrigated	21.5	6.33
D.stressed	11.9	3.58
F test sign.	*	**
0 Kg $K^+.ha^{-1}$	15.7	48.5
252 Kg $K^+.ha^{-1}$	17.6	50.5
F test sign	NS	NS

^{NS}, **, * Nonsignificant and significant at P = 0.01 and 0.05, respectively.
No significant interaction between irrigation and K^+ fertilization treatments.

Table 10. Effect of irrigation and K^+ fertilization on pickling cucumber fruit quality parameters (Rainout shelter, 1990).

Treatments	L/D^z	seed cavity (%)	seed size^y	seed set (%)
Irrigated	2.34	65.8	2.3	100
D. stressed	1.83	63.0	2.7	95
F test sign.	*	NS	*	NS
0 Kg $K^+.ha^{-1}$	2.16	64.9	2.5	95
252 Kg $K^+.ha^{-1}$	2.01	63.8	2.5	100
F test sign.	NS	NS	NS	NS

^{NS}, *, Nonsignificant and significant at P = 0.05.
z: length:diameter ratio.
y: seed size 1= small, 3= large.

Table 11. Effect of irrigation and K^+ fertilization on total and marketable, and oversize and misshapen fruit yields of field-grown pickling cucumber.

Treatments	Total yield (t/ha)	Marketable yield (t/ha)	Oversize (t/ha)	Misshapen (t/ha)
Irrigated	19.5	12.4	3.8	3.3
D. stressed	7.2	0.1	0.1	7.0
F test sign.	*	***	NS	NS
0 Kg $K^+.ha^{-1}$	14.5	6.5	2.2	5.8
252 Kg $K^+.ha^{-1}$	12.2	6.0	1.7	4.5
F test sign.	NS	NS	NS	NS
cv (%)	24.1	22.6	41.5	38.2

NS, ***, * Nonsignificant and significant at P = 0.001 and 0.05, respectively.

i

6

w

f

w

c

d

d

in petiole increased up to 48 DAP and then declined (Figure 6). Similarly endocarp and pericarp tissue K^+ concentrations were not affected by the treatments in either 17.7 mm or 50 mm fruit. The only exception was in large diameter fruit in which drought-stress was observed to reduce endocarp tissue K^+ concentration by 12.4 %, except in endocarp of 50 mm in diameter fruit where K^+ concentration was 12.4% lower in drought-stressed plants (tables 3, appendix).

Osmotic potential was lower, more negative, in rehydrated lamina tissue from drought stressed plants, but was not affected by K^+ fertilization treatments (Table 12).

Experiment 2.

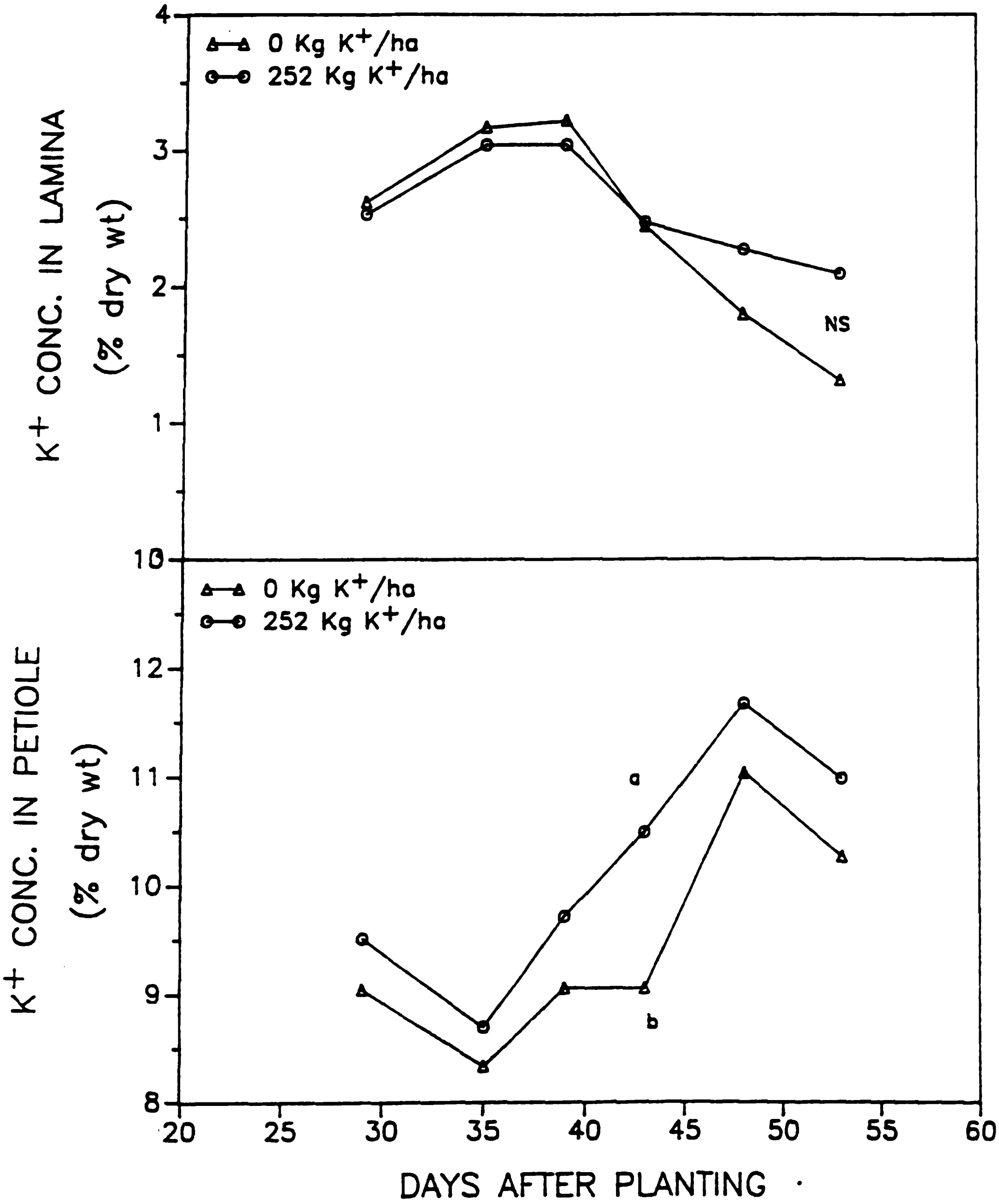
In HTRC field experiment significant amount (84 mm and 71 mm) rainfall was received in July and August. Thus volumetric soil moisture contents, estimated with TDR, were not different between irrigation treatments at either a 15 or 30 cm depth at 44, 49 and 53 DAP (Table 13).

Mean daily fruit growth rates, for fruit ranging in diameter from 1.5 to 4.5 cm, were not affected by irrigation, K^+ salt source, or K^+ fertilization rate (Table 14). Fruit elongation rate, however, was significantly higher under irrigated conditions.

Irrigation, K^+ sources and K^+ rates did not influence total shoot dry matter at harvest time (Table 6, appendix).

K^+ concentrations in lamina tissue ranged from 1.4 to 2.8

Figure 6. Changes in K^+ concentration in lamina and petiole tissues, from the 1^{st} fully expanded leaf during plant ontogeny, of pickling cucumber plants. There were significant differences in petiole K^+ concentration only at 44 days after planting. Significant F test ($P = 0.05$) indicated by a and b.



0 Kg K+/ha
252 Kg K+/ha
K+ CONC. IN LAMINA (% dry wt)
4
3
2
1
NS
0 Kg K+/ha
252 Kg K+/ha
K+ CONC. IN PETIOLE (% dry wt)
13
12
11
10
9
8
a
b
20
25
30
35
40
45
50
55
60
DAYS AFTER PLANTING

Figure 6.

Table 12. Effect of irrigation and K^+ fertilization on the osmotic potential of lamina tissue from rainout cultured pickling cucumber plants.

Treatments	Leaf osmotic potential (MPa)
Irrigated	-0.27
D. stressed	-0.64
F test sign.	***
0 Kg $K^+.ha^{-1}$	-0.43
252 Kg $K^+.ha^{-1}$	-0.48
F test sign	NS

NS, *** Nonsignificant or significant at P = 0.001.

Table 13. Volumetric soil moisture content (%) estimated by TDR from field cultured pickling cucumber plants.

	Volumetric soil moisture content (%)		
	Days after planting		
Treatments	44	49	53
	15 cm depth		
Irrigated	2.9	4.1	2.9
D. stressed	2.9	2.8	3.8
F test sign.	NS	NS	NS
	30 cm depth		
Irrigated	7.7	8.0	7.9
D. stressed	7.8	7.8	8.6
F test sign.	NS	NS	NS

NS No significant differences between treatments.

Table 14. Effect of irrigation, K^+ fertilization rate and K^+ salt source on the mean daily increase in length and diameter of pickling cucumber fruit.

	Growth rate ($mm.day^{-1}$)	
	diameter	length
Irrigated	5.11	11.1
Non-irrigated	4.91	10.2
F test sign.	NS	**
0 Kg $K^+.ha^{-1}$	4.87	10.5
84 Kg $K^+.ha^{-1}$	5.10	10.5
168 Kg $K^+.ha^{-1}$	4.97	10.5
252 Kg $K^+.ha^{-1}$	5.10	11.1
F test sign	NS	NS
KCl	5.11	10.8
K_2SO_4	4.91	10.5
F test sign	NS	NS

^{NS}, ** Nonsignificant and significant at P = 0.01.

% K^+ (Table 15). At 46 and 50 days, the lamina tissue K^+ concentration was highest in the 168 and 252 Kg K^+.ha fertilization treatments.

There was an increase of 71% and 73% in tissue K^+ concentration at 46 and 50 DAP as K^+ fertilization rate increased from 0 to 252 kg/ha. The treatment which did not receive K^+ always showed lower K^+ concentrations in leaf lamina (1.38 to 2.02 % dry weight) or in petiole tissues (5.93 to 6.83 % dry weight) than K^+ fertilized plants (2.04 to 2.34 in lamina and 7.00 to 9.43 % dry weight in petiole, Table 15). Similarly, fruit endocarp and pericarp K^+ levels were enhanced by increasing the rates of K^+ fertilization (Table 16). K^+ concentrations in endocarp tissue were more stable, 3.45 to 3.97% dry weight, as compared with pericarp tissue, 2.80 to 3.97. The differences in K^+ concentrations between pericarp and endocarp tissues dissapered with 168 and 252 Kg $K^+.ha^{-1}$ fertilization treatments.

Total fruit yield, with a once over harvest was approximately 21 to 22.3 t/ha. K^+ sources and K^+ fertilization rate had no effect on total, marketable,and oversize fruit yield. K^+ fertilization also did not effect the net amount or the percentage of misshapen fruit (data not presented).

Irrigation, K^+ sources and K^+ fertilization rates did not affect seed cavity and seed size (data not presented). Irrigation and K^+ fertilization treatments did not affect A, E and Gs (Figures 17, 18 and 19; appendix). KCl application resulted 5.3% in higher A rates at 49 DAP, as compared to

Table 15. Effect of K^+ fertilization treatments on lamina and petiole tissue K^+ concentrations from field-cultured pickling cucumber plants (HTRC, 1990).

Fertilization treatments (Kg $K^+.ha^{-1}$)	K^+ concentrations (% dry wt.)		
	Days after planting		
	40	46	50
		Lamina	
0	2.02	1.74	1.38
84	2.34	2.11	1.46
168	2.35	2.26	2.06
252	2.84	2.53	2.04
LSD (0.05)	0.76	0.23	0.39
		Petiole	
0	6.83	5.93	6.42
84	8.15	7.00	7.10
168	8.23	7.27	9.39
252	9.43	8.33	8.79
LSD (0.05)	1.50	0.81	1.73

Table 16. Effect of K^+ fertilization treatments on K^+ concentration in pericarp and endocarp fruit tissues in 4.5 cm diameter pickling cucumber fruits (HTRC, 1990).

Fertilization treatments (kg $K^+.ha^{-1}$)	K^+ concentrations (% dry wt.)	
	Pericarp	Endocarp
0	2.80	3.45
84	3.21	3.75
168	3.79	3.92
252	3.97	3.97
LSD (0.05)	0.42	0.25

application of K_2SO_4.

Experiment 3.

Plants cultured with nutrient solution containing 0.01 and 0.1 mM K^+ developed yellowish lesions on middle and lower leaves at 37 DAP. One week later, necrosis was observed on leaf margins and brownish spots appeared on the blade (Figures 7 and 8). By 50 DAP, leaves were generally chlorotic except around the midrib. The low K^+ treatments, 0.01 and 0.1 mM K^+, also produced smaller leaves than treatments receiving 1.0 and 10.0 mM K^+. K^+ concentrations in the lamina tissue of the 6th leaf from the shoot apex were 1.6 and 6.4 times lower in the 0.01 and 0.1 mM K^+ treatments as compared with the 1.0 and 10.0 mM K^+ treatments respectively, at 43 DAP (Table 17). No interactions between irrigation and K^+ fertilization treatments were found for K^+ concentration in lamina at any of the three sampling dates.

Lamina tissue K^+ concentrations in fully expanded mature leaves (2nd leaf from the bottom of the plant) showed the same response as in young fully expanded leaf. The 10 mM K^+ treatment resulted in the highest lamina tissue concentrations, 3.23, 3.48 and 2.91 % dry weight, at 43, 47 and 56 DAP, respectively. Nevertheless, K^+ concentrations in mature leaves were consistently always lower than in younger leaves.

Figure 7. Initial K^+ deficiency symptoms in leaves of pickling cucumber plants grown in solution culture medium, 37 days after planting.

Figure 7.

Figure 8. Foliar K$^+$ deficiency symptoms at 37 days after planting on greenhouse pickling cucumber plants growing in culture solution. 69

after
rowing

Figure 8.

Table 17. Effect of K^+ concentration in the nutrient solution on K^+ concentration in the 6th leaf from the shoot apex of pickling cucumber plants.

Nutrient solution K^+ conc. (mM)	Lamina K^+ conc. (% dry wt.) Days after planting 43	47	56
0.01	0.67	0.53	0.47
0.1	0.66	0.61	0.55
1.0	1.08	0.98	0.92
10	4.24	4.19	3.97
LSD (0.05)	0.24	0.63	0.52

K^+ concentrations declined from 43 to 56 DAP in both young fully expanded and mature leaves (Tables 17 and 18). While K^+ concentrations in young fully expanded lamina tissue from the of 10 mM K^+ treatment was 4.24% at 43 DAP it declined to 3.97% K^+ at 56 DAP, while the on 0.01 mM K^+ treatment only declined from 0.67 to 0.47%. In mature leaves, the K^+ concentrations changed from 0.48 to 0.27 % in 0.01 mM K^+ and from 3.23 to 2.91 in the 10 mM K^+ treatment solution.

The low K^+ treatment concentrations in the nutrient solution, 0.01 and 0.1 mM K^+, appeared to result in lower percentage leaf dry matter content as compared to the high K^+ treatment concentrations, 1 and 10 mM K^+ (Table 19).

K^+ treatments significantly affected $\underline{A}$ rates in cucumbers leaves (Table 20). The highest $\underline{A}$ rates were measured in leaves from plants cultured in 1 and 10 mM K^+. The lowest $\underline{A}$ rates were from the 0.1 mM K^+ treatment rather than from the 0.01 mM K^+ treatment. $\underline{A}$ rates at 55 days were extremely low, 1.8-4.0 μmoles CO_2 m^{-2} sec^{-1}, in all treatments.

$\underline{A}$ rates in drought stressed plants, 0.84 μmoles m^{-2} sec^{-1} were only approximately 16% of the rates measured in irrigated plants, 4.96 μmoles m^{-2} sec^{-1} (Figure 9). There was significant interaction between K^+ concentrations in the nutrient solution and irrigation on $\underline{A}$.

Nutrient solution K^+ treatments affected g_s in a manner similar to $\underline{A}$ rate. At 37 DAP, the lowest stomatal conductances were found in plants receiving 0.1 mM K^+, while at 48 DAP the 0.01 mM K^+ treatment was lower (Table 21). In general, maximum

Table 18. Effect of K^+ concentrations in the nutrient solution on K^+ concentration in lamina tissue of (2^{nd} node from base) from pickling cucumber plants.

Nutrient solution K^+ conc. (mM)	Lamina K^+ conc. (% dry wt)		
	Days after planting		
	43	47	56
0.01	0.48	0.37	0.27
0.1	0.47	0.35	0.33
1.0	0.74	0.56	0.39
10	3.23	3.48	2.91
LSD (0.05)	0.36	0.51	0.41
Irrigated	1.14	1.22	0.87
Withholding water	1.32	1.15	1.07
F test sign	*	NS	NS

^{NS}, * Nosignificant and significant at $P = 0.05$.

Table 19. Effect of K^+ concentration in the nutrient solution and irrigation on percent dry matter in mature leaf tissue at 56 days after planting.

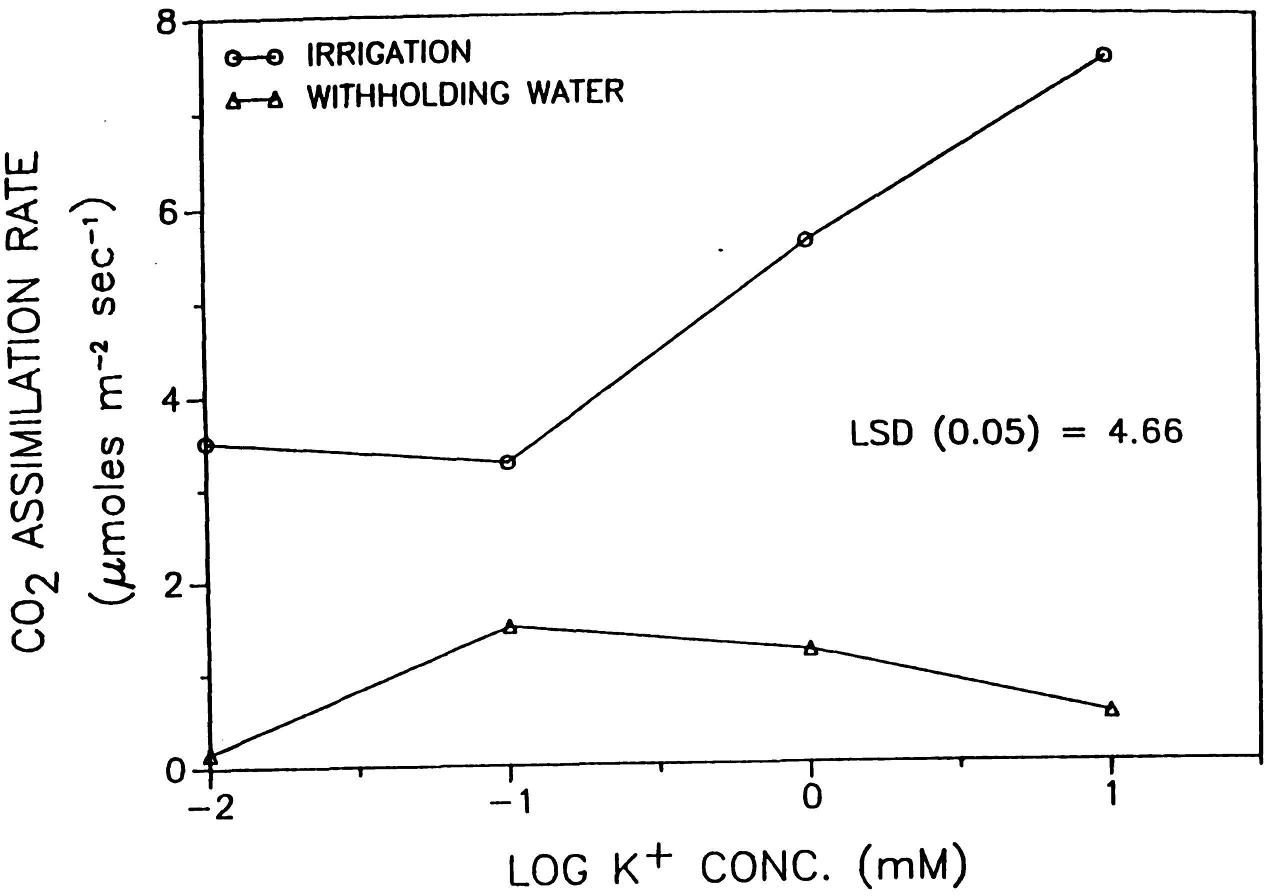
Nutrient solution K^+ conc. (mM)	Percent leaf dry matter
0.01	13.91
0.1	13.00
1.0	16.91
10	15.36
LSD (0.05)	2.51
Irrigated	14.76
Withholding water	14.83
F test sign	NS

^{NS} No significant differences between treatments.

Table 20. Effects of K^+ concentrations in the nutrient solution on A rates in fully expanded leaves from 37 to 48 DAP of pickling cucumber plants.

	A rates (μmoles CO_2 m^{-2} sec^{-1})		
Nutrient solution K^+ conc. (mM)	Days after planting		
	37	41	48
0.01	14.5	11.0	4.5
0.1	8.5	8.3	8.5
1.0	18.1	14.8	13.6
10	18.0	13.6	12.3
LSD (0.05)	7.3	6.8	7.7

Figure 9. Effects of irrigation and K^+ concentration in the nutrient solution on CO_2 assimilation rate in fully expanded leaves of pickling cucumber plants at 55 days after planting. Measurements made from 1:30 to 5:00 P.M. Points are means of 8 measurements.



IRRIGATION
WITHHOLDING WATER
LSD (0.05) = 4.66
CO_2 ASSIMILATION RATE
(μmoles m^{-2} sec^{-1})
8
6
4
2
0
−2
−1
0
1
LOG K^+ CONC. (mM)

Figure 9.

g_s occurred when plants were supplied with 1.0 and 10 mM K^+ in the nutrient solution. Drought stress reduced g_s by up to 80% as compared to irrigated conditions at 55 DAP (Fig. 10). There was a significant interaction between solution K^+ concentration and water regime on g_s. Stomatal conductance declined sharply as K^+ concentrations increased in water-stressed plants. Under continuous irrigation, g_s was lower in leaves cultured in 0.1 mM K^+ but higher in plants cultured in 1.0 and 10 mM K^+ within the nutrient solution.

E rates were also found to be lowest in the 0.1 mM K^+ treatment and highest when the plants were supplied with 1.0 or 10 mM K^+ at 37 and 48 DAP (Table 22). At 55 DAP there was a significant interaction between K^+ concentrations and water regime treatments on E. As K^+ concentration in the nutrient solution increased, the E became lower in drought-stressed plants. The lowest E under irrigation was found when plants were cultured in 0.1 mM K^+ nutrient solution with higher rates observed in the 1 and 10 mM K^+ treatments (Figure 11).

The effects of K^+ nutrition on CO_2 saturation of assimilation were examined in pickling cucumber plants. There was a significant interaction among K^+ treatments, irrigation and concentration of external CO_2. A rate increased as external CO_2 was increased (Fig. 12). Low solution K^+ concentrations, 0.01 and 0.1 mM K^+, resulted in lower A rates as compared with higher K^+ concentrations, 1 and 10 mM K^+ on irrigated plants (Fig. 12). The highest A rate on drought-stressed plants was recorded on 0.1 mM K^+ (Fig. 12).

Table 21. Effects of K^+ concentration in the nutrient solution on g_s in a young fully expanded leafduring reproductive development of pickling cucumber plants.

	g_s (μmoles CO_2 m^{-2} sec^{-1})			
	Days	after	planting	
Nutrient solution K^+ conc. (mM)	37	41	48	55
0.01	54.7	50.0	44.2	70.0
0.1	27.2	35.9	50.0	45.7
1.0	77.1	77.2	90.3	55.6
10	67.5	70.4	96.0	71.3
LSD (0.05)	43.2	NS	49.3	NS

Figure 10. Effects of irrigation and K^+ concentration in the nutrient solution on stomatal conductance (g^s) in mature leaves of pickling cucumber plants at 55 days after planting. Measurements made from 1:30 to 5:00 P.M. Points are means of 8 measurements.

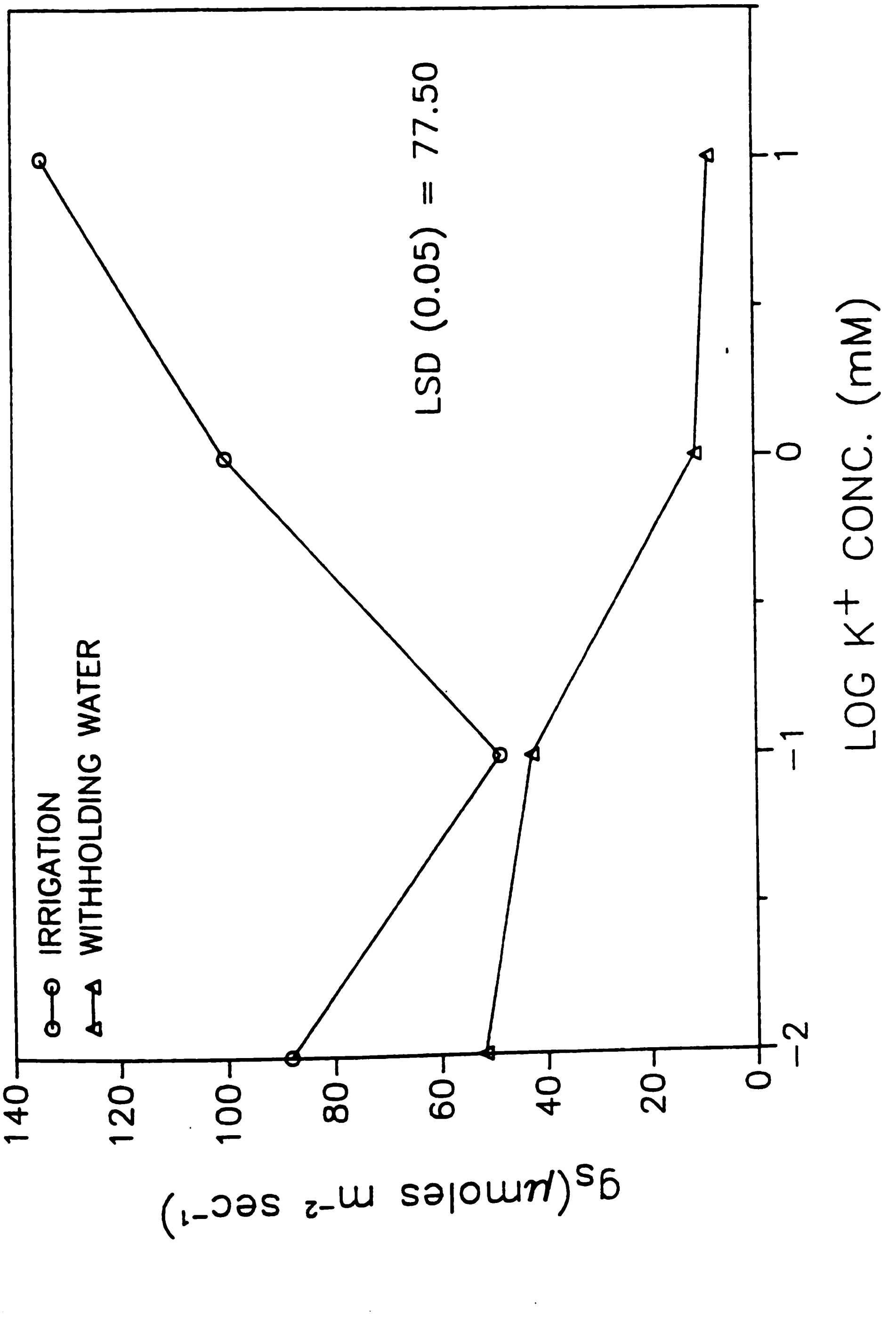

IRRIGATION
WITHHOLDING WATER
LSD (0.05) = 77.50
g_s(μmoles m^{-2} sec^{-1})
LOG K$^+$ CONC. (mM)
140
120
100
80
60
40
20
0
−2
−1
0
1

Figure 10.

Table 22. Effects of K^+ concentration in the nutrient solution on E rates during fruit development in pickling cucumber plants.

	E (μmoles H_2O m^{-2} sec^{-1})			
	Days after planting			
Nutrient solution K^+ conc. (mM)	37	41	48	55
0.01	2.90	8.16	3.03	3.57
0.1	1.43	2.37	3.62	2.74
1.0	3.73	4.29	6.03	2.60
10	3.50	3.90	5.86	2.90
LSD (0.05)	2.01	NS	2.82	2.44

[NS] No significant differences.

Figure 11. Effects of irrigation and K^+ concentration in the nutrient solution on transpiration rate (E) in fully expanded leaves of pickling cucumber plants. All measurements were made between 1:30 and 5:00 P.M., 55 days after planting. Points are means of 8 measurements.

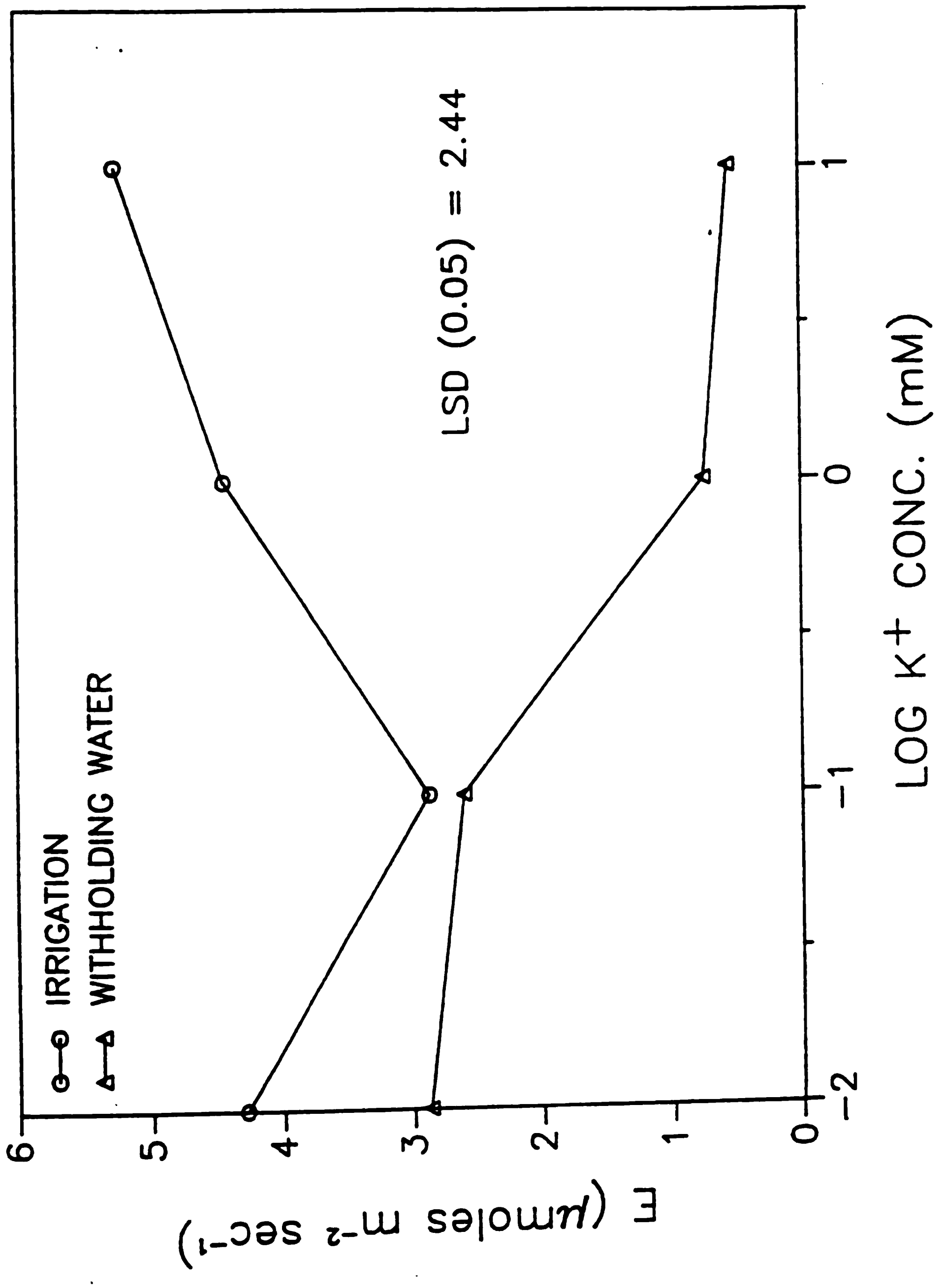

IRRIGATION
WITHHOLDING WATER
LSD (0.05) = 2.44
E (μmoles m-2 sec-1)
6
5
4
3
2
1
0
−2
−1
0
1
LOG K+ CONC. (mM)

Figure 11.

Figure 12. Effects of external CO_2 concentration and K^+ concentration in the nutrient solution, on CO_2 assimilation rate in fully expanded leaves of irrigated and water-stressed pickling cucumber plants. Measurements were conducted on fruiting plants, 60 days after planting.

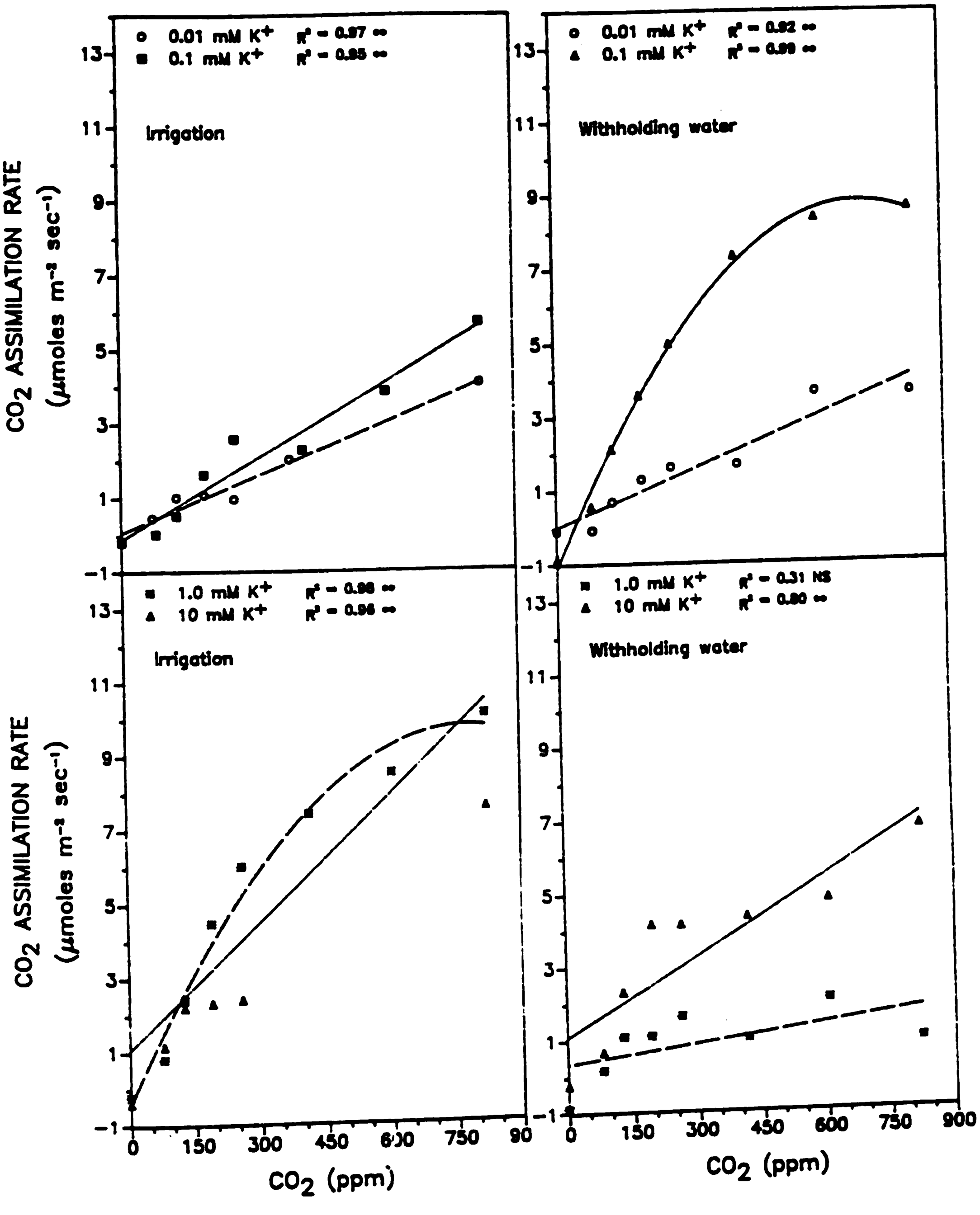

○ 0.01 mM K+ R² = 0.97 **
■ 0.1 mM K+ R² = 0.95 **
Irrigation
○ 0.01 mM K+ R² = 0.92 **
▲ 0.1 mM K+ R² = 0.99 **
Withholding water
■ 1.0 mM K+ R² = 0.98 **
▲ 10 mM K+ R² = 0.96 **
Irrigation
■ 1.0 mM K+ R² = 0.31 NS
▲ 10 mM K+ R² = 0.80 **
Withholding water
CO2 ASSIMILATION RATE (µmoles m-2 sec-1)
CO2 ASSIMILATION RATE (µmoles m-2 sec-1)
-1
1
3
5
7
9
11
13
0
150
300
450
600
750
900
CO2 (ppm)
CO2 (ppm)

Figure 12.

G_s declined with increasing ambient CO_2 concentrations. Minimum levels of g_s, 14.5 to 75.3 μmoles m^{-2} sec^{-1}, were measured at ambient CO_2 concentrations above 300 ppm. The F test indicated that there were no significant differences in g_s among either K^+ concentration or irrigation treatments (Fig. 13).

E rates were reduced in an exponential manner when ambient CO_2 concentration was increased experimentally. A significant interaction was found between K^+ treatments, irrigation, and external CO_2 concentration as they affected E (Fig. 14). Plants with 0.01 mM K^+ showed a stable E rate over a rrange of external CO_2 concentrations under water deficit conditions.

Analysis of variance (Table 7, appendix) indicated that there was a significant interaction between solution K^+ concentration, irrigation and intercellular CO_2 concentration treatments as they affected $\underline{A}$ rate (Fig. 15). $\underline{A}$ increased as intercellular CO_2 was increased. Under irrigated conditions, treatments in 1 and 10 mM K^+ in the nutrient solution had the highest $\underline{A}$ rates at intercellular CO_2 concentrations higher than 75 ppm. Slight wilting symptoms were observed during measurement in the laboratory of the 10 mM K^+ treatment plants even though they had been irrigated.

The affect of K^+ nutrition on assimilation was influenced by plant water status (Fig. 15). In plants under water deficit, the highest assimilation rates were observed in plants having been treated with 0.1 and 10 mM K^+. In contrast, the 1.0 mM K^+ treatment, which was an intermediate

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Figure 13. Effects of external CO_2 concentration and K^+ concentration within the nutrient solution, on stomatal conductance (g_s) of fully expanded leaves on irrigated and water-stressed pickling cucumber plants. Measurements made on fruiting plants, 60 days after planting.

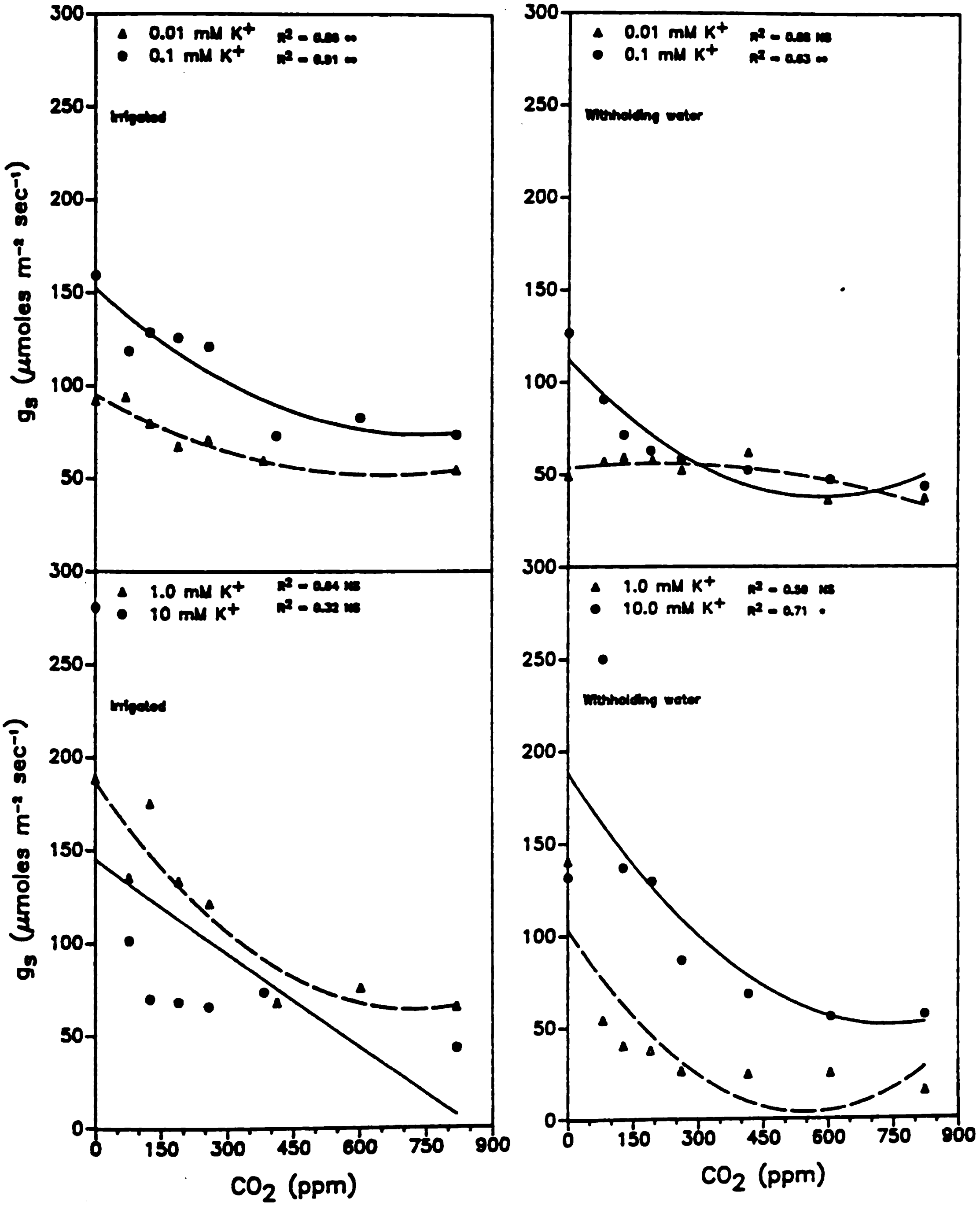
▲ 0.01 mM K^+ R^2 = 0.86 **
● 0.1 mM K^+ R^2 = 0.91 **
Irrigated
▲ 0.01 mM K^+ R^2 = 0.86 NS
● 0.1 mM K^+ R^2 = 0.63 **
Withholding water
▲ 1.0 mM K^+ R^2 = 0.84 NS
● 10 mM K^+ R^2 = 0.32 NS
Irrigated
▲ 1.0 mM K^+ R^2 = 0.58 NS
● 10.0 mM K^+ R^2 = 0.71 *
Withholding water
g_s (μmoles m^{-2} sec^{-1})
0
50
100
150
200
250
300
CO_2 (ppm)
0
150
300
450
600
750
900

Figure 13.

Figure 14. Effects of external CO_2 concentrations and K^+ concentrations within the nutrient solution, on transpiration rate (E) in fully expanded leaves of irrigated and drought-stressed pickling cucumber plants. Measurements made on fruiting plants, 60 days after planting.

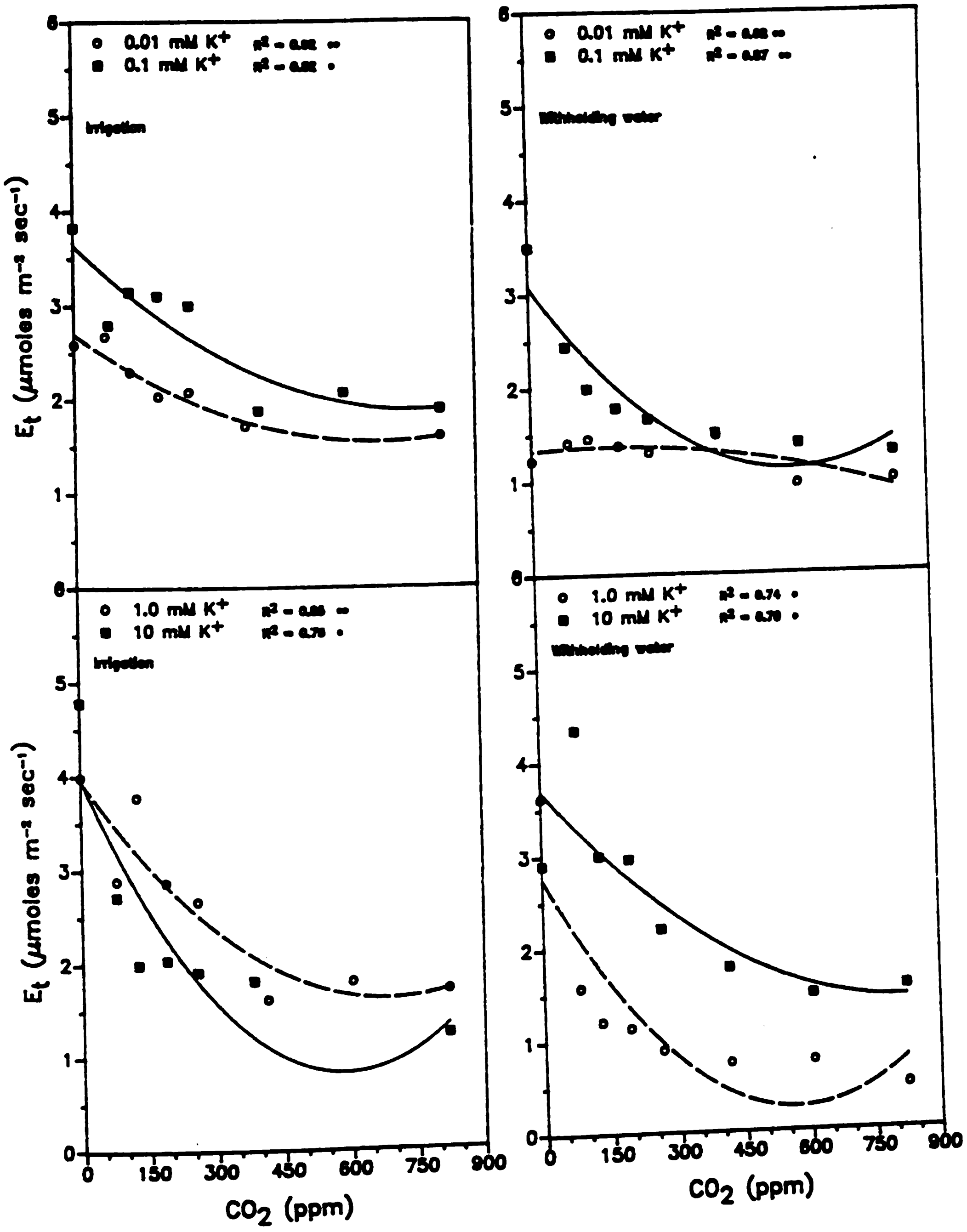
○ 0.01 mM K+ R² = 0.92
■ 0.1 mM K+ R² = 0.92
Irrigation
○ 0.01 mM K+ R² = 0.88
■ 0.1 mM K+ R² = 0.87
Withholding water
○ 1.0 mM K+ R² = 0.86
■ 10 mM K+ R² = 0.75
Irrigation
○ 1.0 mM K+ R² = 0.74
■ 10 mM K+ R² = 0.70
Withholding water
Et (µmoles m-2 sec-1)
Et (µmoles m-2 sec-1)
0
1
2
3
4
5
6
0
150
300
450
600
750
900
CO2 (ppm)
CO2 (ppm)

Figure 14.

Figure 15. Effects of intercellular CO_2 concentration and K^+ concentration in the nutrient solution on CO_2 assimilation rate in fully expanded leaves of irrigated and water-stressed pickling cucumber plants. Measurements were made on fruiting plants, 60 days after planting.

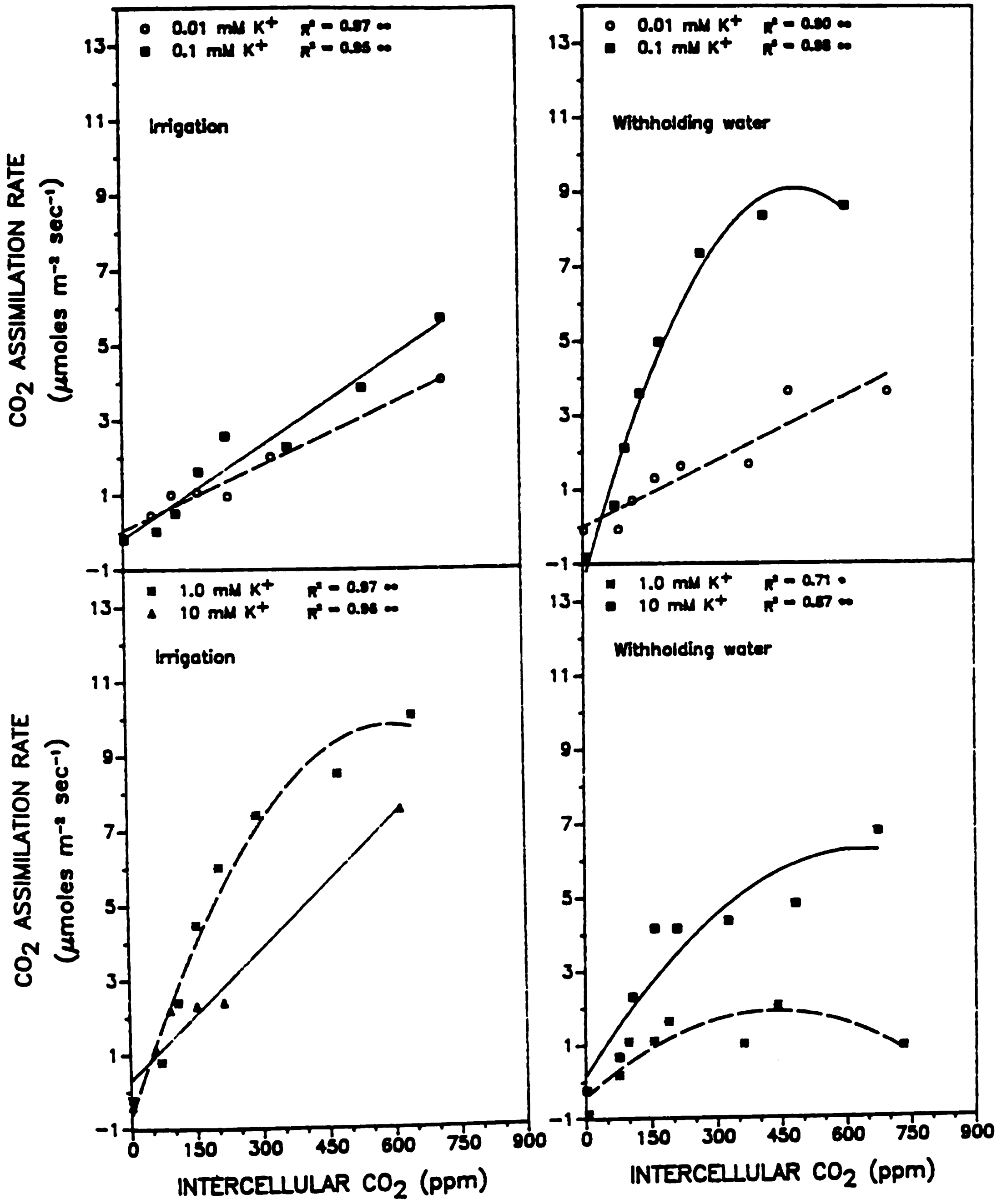
○ 0.01 mM K^+ R^2 = 0.97 **
■ 0.1 mM K^+ R^2 = 0.96 **
Irrigation
○ 0.01 mM K^+ R^2 = 0.90 **
■ 0.1 mM K^+ R^2 = 0.98 **
Withholding water
■ 1.0 mM K^+ R^2 = 0.97 **
▲ 10 mM K^+ R^2 = 0.96 **
Irrigation
■ 1.0 mM K^+ R^2 = 0.71 *
■ 10 mM K^+ R^2 = 0.87 **
Withholding water
CO_2 ASSIMILATION RATE (μmoles m^{-2} sec^{-1})
CO_2 ASSIMILATION RATE (μmoles m^{-2} sec^{-1})
-1
1
3
5
7
9
11
13
0
150
300
450
600
750
900
INTERCELLULAR CO_2 (ppm)
INTERCELLULAR CO_2 (ppm)

Figure 15.

concentration, resulted in the lowest assimilation rates.

When the relationship between lamina tissue K^+ concentration (6th leaf from apex) and assimilation rate was examined, a low correlation was obtained (Fig. 16). At any specific K^+ concentration within the tissue, a large amount of variability in A was observed.

K^+ concentrations in fruit tissue, pericarp and endocarp, were enhanced, 0.44 to 4.79 % dry weight in pericarp and 1.43 to 4.55 % dry weight in endocarp when nutrient solution K^+ concentrations were increased from 0.01 to 10 mM K^+ (Table 23). The differences in K^+ concentrations between pericarp and endocarp tissues were larger at low K^+ concentration s in the nutrient solution. No differences in K^+ in fruit tissues at 10 mM K^+. There was no interaction between irrigation and K^+ nutrient solution concentrations on K^+ concentration in fruit tissues.

K^+ nutrition affected significantly leaf osmolality of pickling cucumber plants grown in a culture medium. Expressed sap from leaves grown with 0.01 and 0.1 mM K^+ had relatively low osmolality, 152.5 and 135.1 mmolal, respectively, as compared to plants grown in 1.0 and 10 mM K^+ nutrient solution, 187.0 and 214.3 mmolal, respectively (Table 24).

Figure 16. Relationship between lamina tissue K^+ concentration (6th leaf from apex) and CO_2 assimilation rate at ambient CO_2 on pickling cucumber plants.

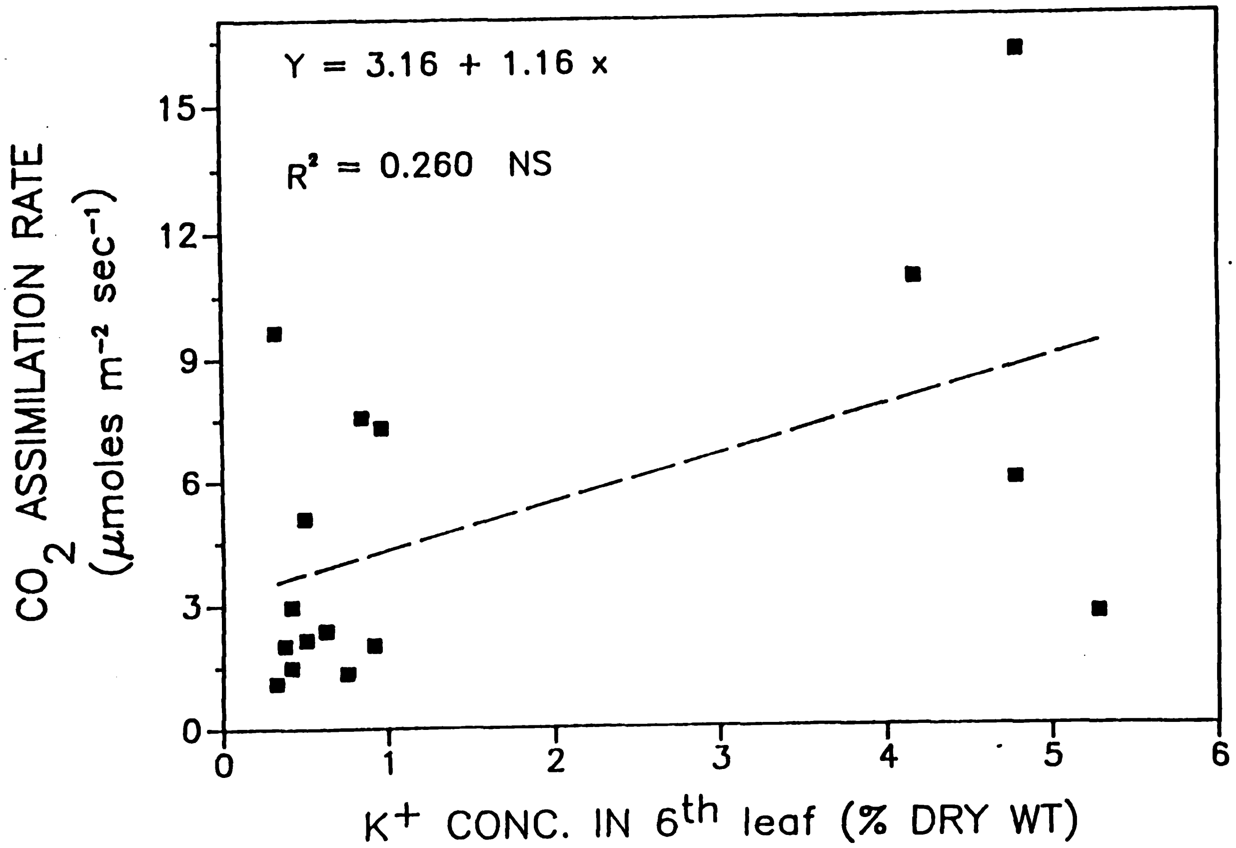
Y = 3.16 + 1.16 x
R² = 0.260 NS
CO2 ASSIMILATION RATE (µmoles m⁻² sec⁻¹)
0
3
6
9
12
15
K+ CONC. IN 6th leaf (% DRY WT)
0
1
2
3
4
5
6

Figure 16.

Table 23. Effect of K^+ concentration in the nutrient solution on K^+ levels in pickling cucumber fruit tissue (4-4.5 cm in diameter).

Nutrient solution K^+ conc. (mM)	K^+ conc. (% dry wt) pericarp	endocarp
0.01	0.44	1.43
0.1	0.52	1.86
1.0	1.34	2.83
10	4.79	4.55
LSD (0.05)	0.43	0.63
Irrigated	1.74	2.65
Withholding water	1.80	2.69
F test sign	NS	NS

NS No significant differences.

Table 24. Effect of K^+ concentration in the nutrient solution on leaf osmolality (6th leaf from apex) of pickling cucumber grown in a culture solution.

Nutrient solution K^+ conc. (mM)	Leaf osmolality (mmolal)
0.01	152.5
0.1	135.1
1.0	187.0
10	214.3
LSD (0.05)	23.6

DISCUSSION

According to these results, there is insufficient evidence to support the hypothesis that low K^+ availability leads to a high incidence of misshapen fruits.

K^+ fertilization did not affect vegetative plant growth on pickling cucumbers grown in a rainout shelter under field conditions. The lack of significant differences in total plant leaf area and vine length (Table 1 and Figure 2) in a rainout shelter experiment support this statement. Field cultured pickling cucumber plants also did not show any differences among K^+ fertilization treatments or between K^+ salt sources on total shoot dry matter at harvest time (Table 4, appendix). Nevertheless, leaf size on pickling cucumber plants grown with 0.01 and 0.1 mM K^+ in the nutrient solution was observably smaller than that from the 1.0 and 10 mM K^+ treatments, which agrees with the results of Pike and Jones (1989). These smaller leaves contained 0.47-0.67 % K^+ on a dry weight basis in lamina tissue (6th leaf from the shoot apex). Leaf lamina K^+ concentrations in the rainout shelter experiment and in the HRC experiment contained 1.31-3.29 and 1.38-2.84 % K, respectively. These differences in K^+ concentrations in leaf lamina between field and solution culture experiments could explain the differences in vegetative growth response of pickling cucumber plants grown with different K^+ fertilization rates.

Assimilation rates were not affected by K^+ fertilization treatments on fully expanded leaves of pickling cucumber grown in a rainout shelter. The high content of native K^+ in the soil, 557 Kg K^+/ha, might explain this lack of response to K^+ fertilization treatments. Nevertheless, in the experiment at the HTRC where pickling cucumber plants were grown on a soil considered to be low-medium in K^+, 99 Kg K^+/ha, A rates were also not affected by K^+ fertilization treatments. Source K^+ salt also did not affect A rates in fully expanded leaves in this experiment.

A rates of pickling cucumber plants grown in a nutrient culture medium were significantly influenced by the K^+ concentrations in the nutrient solution. Pickling cucumber plants cultured with 0.01 and 0.1 mM K^+ in the nutrient solution, exhibited lower A rates as compared with plants grown with 1.0 and 10 mM K^+ (Table 20). Even though solution K^+ concentration treatments result in significant differences in A rates, the lack of differences in K^+ concentration in leaf lamina tissue between 0.01 and 0.1 mM K^+, 0.5-0.7 to 0.6-0.7, respectively, suggest that probably other factors might be contributing to differences in A.

According to the results of these study, K^+ concentrations in lamina tissue, of fully expanded leaves from plants grown in these three experiment, were not limiting of photosynthetic activity. The only exception was the 0.1 mM K^+ nutrient solution treatment in Experiment 3. In this case, A rate was lower than in the other three treatments. Under the conditions of this study, K^+ nutrition did not enhance A rates of pickling cucumber plants experiencing a water deficit.

There are two major requirements for cell extension, an increase in cell wall extensibility and solute accumulation to create an internal osmotic potential (Marschner, 1986). No differences in osmotic potentials of expressed sap from fully expanded leaves were found between K^+ fertilization treatments from pickling cucumber plants grown in a rainout shelter. Fruit osmolality was also not affected by K^+ fertilization treatments in this experiment. K^+ nutrition affected leaf osmolality in pickling cucumber plants grown in a culture solution (Table 23). Leaf osmolality increased from 153 to 214 mmolal as K^+ concentration in the nutrient solution increased from 0.01 to 10 mM K^+. This would suggest that the high native K^+ content in the soil, in the rainout shelter experiment resulted in luxury uptake and accumulation of K^+ by the cucumber plants thus precluding any metabolic response which might modulate leaf or fruit osmolality.

Drought stressed pickling cucumber plants within the rainout shelter had 54% lower vine length as compared with well watered plants. This finding is consistent with the results of Ortega and Kretchman (1982) who reported significantly lower vine length seven days after water was withheld from field cultured pickling cucumbers. The wilt symptoms in water-stressed treatments were in response to high evapotranspirative conditions under low soil moisture conditions. Loss in turgidity caused the stomata to close, as evidenced by the lower g_s (Figure 4). Similar results were reported by other researchers like Hall and Schulze (1980) and Rao and Bhatt (1980).

Fruit yield was not affected by K^+ fertilization rates even though K^+ fertilization treatments increased K^+ concentrations in lamina, petiole and fruit tissues of pickling cucumber plants grown on moderately low K^+ soils. This agrees with the results of Bishop et al (1969).

The lack of significant affects of K^+ nutrition on the incidence of misshapen fruit found in this study, probably is related to the fact that K^+ nutrition does not have a major affect on A rates. In addition, K^+ fertilization treatments did not influenced daily average fruit growth rates as evaluated by increases in fruit length and diameter. Treatments receiving no K^+ were able to support a normal fruit set and expansive fruit growth in a once-over harvest system. Even at the low K^+ concentrations in the nutrient solution, 0.01 and 0.1 mM K^+, no misshapen fruits were observed.

Irrigation treatments, on the other hand, had a large affect on expansive fruit growth. Daily average fruit growth rates for length and diameter were reduced 43% and 55%, respectively, in drought-stressed plants (11.9 and 3.58 $mm.day^{-1}$) as compared with well watered plants (21.5 and 6.33 $mm.day^{-1}$).

A K^+ fertilization rate of 90 Kg K^+/ha should be adequate for maximum growth and fruit yield of pickling cucumber under conditions similar to our field experiments.

In a multiple harvest system, pickling cucumber plants might have a tendency to develop a physiological K^+ deficiency condition even under high levels of K^+ availability. Vine growth must be maintained for a longer period of time in order to support continued fruit productivity. However, vegetative growth and new leaf initiation slows down during reproductive to competition for assimilates by developing fruit. As a consequence, the mean age and maturity of leaves on a cucumber plant is much greater after several harvests of fruit that at the initial harvest time.

Since K^+ concentrations decline typically with leaf age due to remobilization to developing fruits, it is highly probable that K^+ deficiencies might develop in a multiple harvest system.

As pickling cucumber plants continue to set fruit over an extended period of time in a multiple harvest system, there will be a higher proportion of mature leaves in each plant. This could influence productivity since older leaves have lower photosynthetic capacity than fully expanded leaves. In addition, the older leaves would be more depleted of K^+ due to K^+ remobilization to rapidly growing organs within the plant.

CONCLUSIONS

K^+ application rates did not affect vegetative plant growth of pickling cucumber plants under field conditions. When plants were cultured in nutrient solutins containing 0.01 and 0.1 mM K^+, K^+ became limiting of growth and deficiency symptoms appeared.

A rates were not affected by K^+ fertilization rates in field experiments, but A rates were lower when pickling cucumber plants were cultured hydroponically in 0.1 mM K^+. K^+ nutrition did not enhance A rates of pickling cucumber plants experiencing water stress.

K^+ fertilization did not affect pickling cucumber fruit growth and the incidence of misshapen fruit. Even when pericarp and endocarp tissue K^+ concentrations were relatively low, due to culture in low K^+ fertility soils or in 0.01 and 0.1 mM K^+ nutrient solutions, malformation of developing fruit was not observed.

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APPENDIX

APPENDIX

TABLE 1. K^+ concentration in lamina tissue of pickling cucumber (% dry weight basis). Rainout shelter experiment, KBS, 1990.

TREATMENTS	DAYS	AFTER	PLANTING			
	29	35	39	44	49	55
IRRIGATION	2.99	3.32	3.29	2.59	2.08	1.87
DROUGHT STRESS	2.15	2.88	2.97	2.31	1.97	1.53
F TEST SIGN	NS	NS	NS	NS	NS	NS
0 Kg $K^+.ha^{-1}$	2.62	3.17	3.22	2.44	1.80	1.31
252 Kg $K^+.ha^{-1}$	2.53	3.04	3.04	2.47	2.27	2.09
F TEST SIGN	NS	NS	NS	NS	NS	NS

^{NS} No significant differences.

APPENDIX

TABLE 2. K^+ concentration in petiole of pickling cucumber (% dry weight basis). Rainout shelter experiment, KBS, 1990.

TREATMENTS	DAYS AFTER PLANTING					
	29	35	39	44	49	55
IRRIGATION	9.27	8.45	9.84	9.45	11.34	10.01
DROUGHT STRESS	9.27	8.57	8.92	10.10	11.37	11.22
F TEST SIGN	NS	NS	NS	NS	NS	NS
0 Kg $K^+.ha^{-1}$	9.04	8.33	9.05	9.05	11.03	10.26
252 Kg $K^+.ha^{-1}$	9.51	8.69	9.71	10.49	11.67	10.98
F TEST SIGN	NS	NS	NS	*	NS	NS

NS No significant differences.

APPENDIX

TABLE 3. K^+ concentration in pickling cucumber fruit at harvest time (% dry weight basis). Rainout shelter experiment KBS,1990.

	Pericarp		Endocarp		Small[x]
Treatments	Large[z] fruit	Medium[y] fruit	Large fruit	Medium fruit	Fruit (per+end.)
IRRIGATION	2.92	3.43	4.61	4.61	4.84
D. STRESS	3.20	3.72	4.04	4.84	5.07
F TEST SIGN	NS	NS	*	NS	NS
0 Kg $K^+.ha^{-1}$	2.80	3.55	4.15	4.96	4.61
252 Kg $K^+.ha^{-1}$	3.32	3.60	4.50	4.50	5.30
F TEST SIGN	NS	NS	NS	NS	NS

[NS] No significant differences.
[x] Fruit 17.7 mm in diameter.
[y] Fruit 30.0 mm in diameter.
[z] Fruit 50.0 mm in diameter.

APPENDIX

Table 4. Effects of irrigation and drought-stress on leaf temperature, stomatal conductance (g_s) and transpiration rate (E) as measure at various times of the day on pickling cucumber plants growing in a rainout shelter.

Time of the day	Treatment		Mean	Standard Error
	D. stressed	Irrigated		
	Leaf temperature (C)			
10:50 A.M.	26.8	22.2		
12:00 P.M.	26.6	23.4		
2:40 P.M.	33.6	26.8		
5:10 P.M.	31.0	26.1	27.1	0.634
	g_s (μmoles cm^{-2} sec^{-1})			
10:50 A.M.	0.53	2.08		
12:00 P.M.	0.22	1.72		
2:40 P.M.	0.25	2.12		
5:10 P.M.	0.19	2.24	1.19	0.84
	E (μmoles m^{-2} sec^{-1})			
10:50 A.M.	8.93	16.68		
12:00 P.M.	2.77	12.09		
2:40 P.M.	6.22	24.18		
5:10 P.M.	3.74	21.24		

APPENDIX

Table 5. Effect of irrigation and K^+ fertilization rates on leaf and fruit osmolality of pickling cucumber. Rainout shelter experiment, KBS, 1990.

Treatment	leaf osmolality (mmolal)	fruit osmolality (mmolal)
Irrigated	222.8	209.9
Drought stressed	222.2	249.1
F test sign	NS	***
0 Kg $K^+.ha^{-1}$	217.5	234.8
252 Kg $K^+.ha^{-1}$	227.4	224.3
F test sign	NS	NS

^{NS}, *** No significant and significant at $P = 0.001$.
*** = significant differences between treatments at 0.001 level.

APPENDIX

Table 6. Effect of irrigation, K^+ sources and K^+ fertilization rates on dry weight of shoot at harvest time on field cultured pickling cucumbers. HTRC experiment, 1990.

Treatments	Shoot dry weight (Kg/ha)
Irrigated	386
Non irrigated	401
F test sign	NS
0 Kg $K^+.ha^{-1}$	385
84 Kg $K^+.ha^{-1}$	387
168 Kg $K^+.ha^{-1}$	374
252 Kg $K^+.ha^{-1}$	428
F test sign	NS
KCl	379
K_2SO_4	407
F test sign	NS

^{NS} No significant differences.

APPENDIX

Table 7. Analysis of variance for the effect of K^+ concentrations in the nutrient solution, irrigation and intercellular CO_2 concentration on A rates of pickling cucumber plants grown in a nutrient culture experiment, 1991.

Source	D. of freedom	Sum of squares	Mean squares	F value	Prob
Replication	1	6505.65	6506.6	14.48	0.0004
K^+ fert.(A)	3	13064.49	4354.83	9.69	0.0000
Irrigation (B)	1	71.07	71.07	0.16	
AB	3	28509.21	9503.07	21.15	0.0000
Intercellular CO^2 (C)	6	4870237.85	811706.31	1806.60	0.0000
AC	18	21426.24	1190.35	2.65	0.0029
BC	6	8877.66	1479.61	3.29	0.0077
ABC	18	34003.15	1889.06	4.20	0.0000
ERROR	55	24711.55	449.30		
TOTAL	111	5007406.87			

APPENDIX

Table 8. Effect of irrigation, K^+ sources and K^+ fertilization rates on textural firmness of fresh pickling cucumber fruit tissue (4.5 cm diameter). HTRC experiment, 1990.

Treatment	Fruit tissue firmness (N)[z]	
	pericarp	endocarp
Irrigated	14.49	4.18
Non-irrigated	14.75	4.04
F test sign	NS	NS
0 Kg $K^+.ha^{-1}$	14.44	4.02
252 Kg $K^+.ha^{-1}$	14.80	4.20
F test sign	NS	NS
KCl	14.53	4.09
K^2SO^4	14.71	4.13
F test sign	NS	NS

[NS] No significant differences.

[z] Textural firmness measured on 0.6 cm thick slices using a Kramer Shear Press.

APPENDIX

Table 9. Effects of irrigation, K^+ sources and K^+ fertilization rates on pickling cucumber fruit firmness after processing and storage for 50 days.

Treatment	Fruit tissue firmness $(N)^z$ pericarp	endocarp
Irrigated	11.41	1.94
Non-irrigated	11.14	1.92
F tets sign	NS	NS
0 Kg $K^+.ha^{-1}$	11.50	2.00
252 Kg $K^+.ha^{-1}$	11.02	1.96
F test sign	NS	NS
KCl	11.53	2.00
K_2SO_4	11.02	1.87
F test sign	NS	NS

[NS] No significant differences.

[z] Textural firmness measured on 0.6 cm thick slices using a Kramer stear press.

Figure 17. Effect of K^+ fertilization rates on CO_2 assimilation rates. HTRC experiment, 1990. There were no significant differences between treatments.

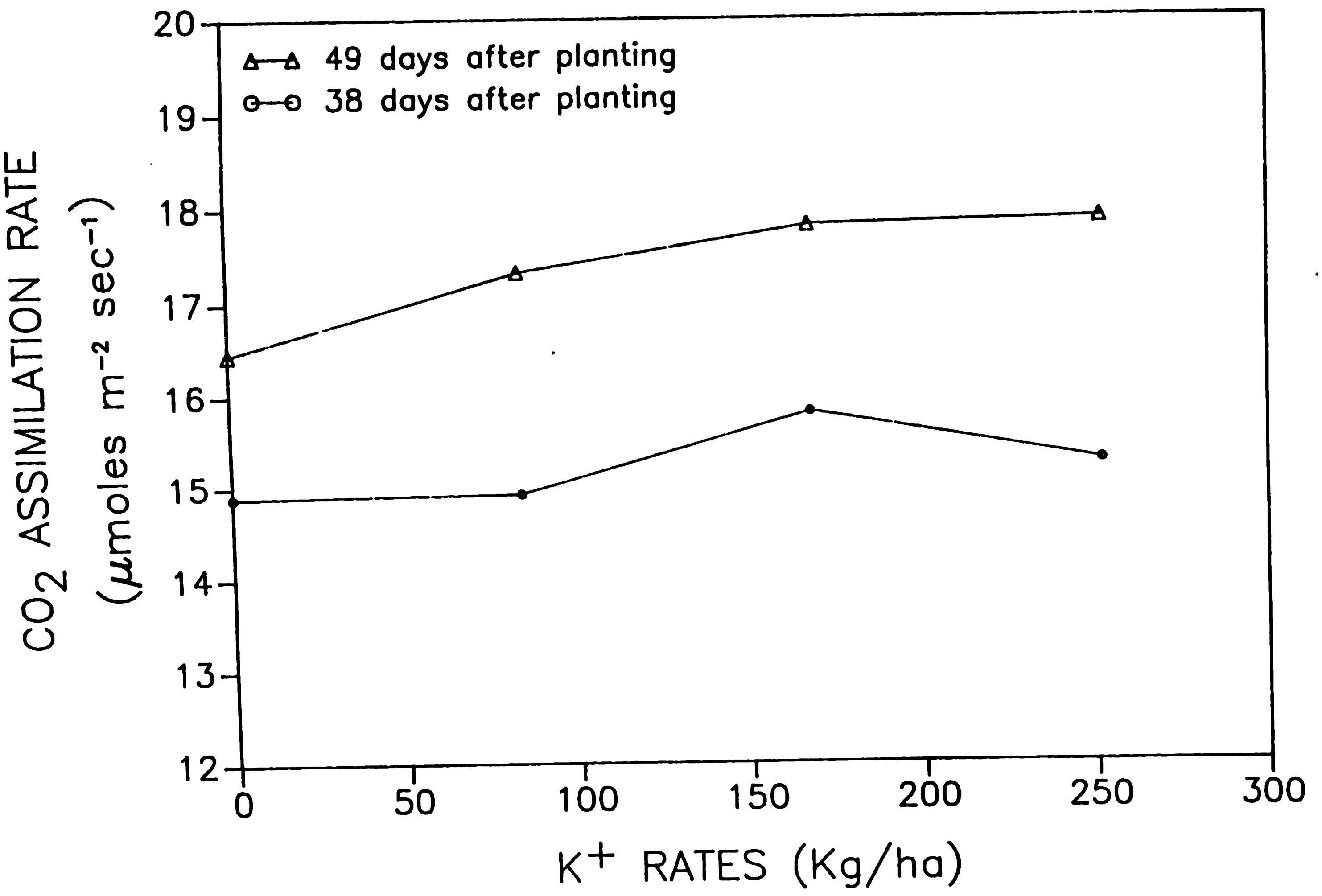
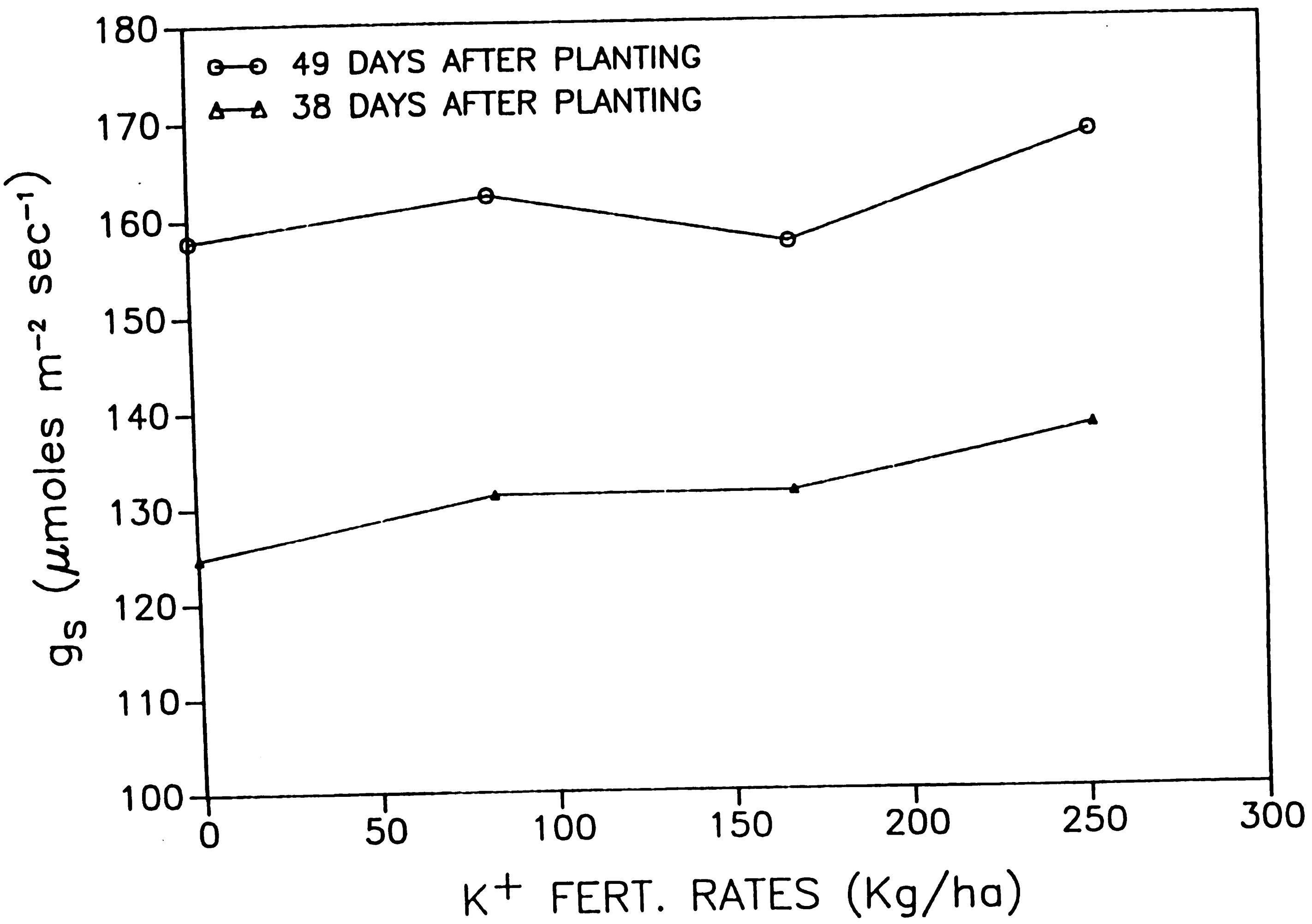

49 days after planting
38 days after planting
CO_2 ASSIMILATION RATE
(μmoles m^{-2} sec^{-1})
20
19
18
17
16
15
14
13
12
0
50
100
150
200
250
300
K^+ RATES (Kg/ha)

Figure 17.

Figure 18. Effect of K^+ fertiliation rates on stomatal conductance (g_s). HTRC experiment, 1990. There were no significant differences between treatments.



49 DAYS AFTER PLANTING
38 DAYS AFTER PLANTING
g_s (μmoles m^{-2} sec^{-1})
180
170
160
150
140
130
120
110
100
0
50
100
150
200
250
300
K$^+$ FERT. RATES (Kg/ha)

Figure 18.

Figure 19. Effect of potassium fertilization rates on transpiration rates (E). HTRC experiment, 1990. There were no differences between treatments.

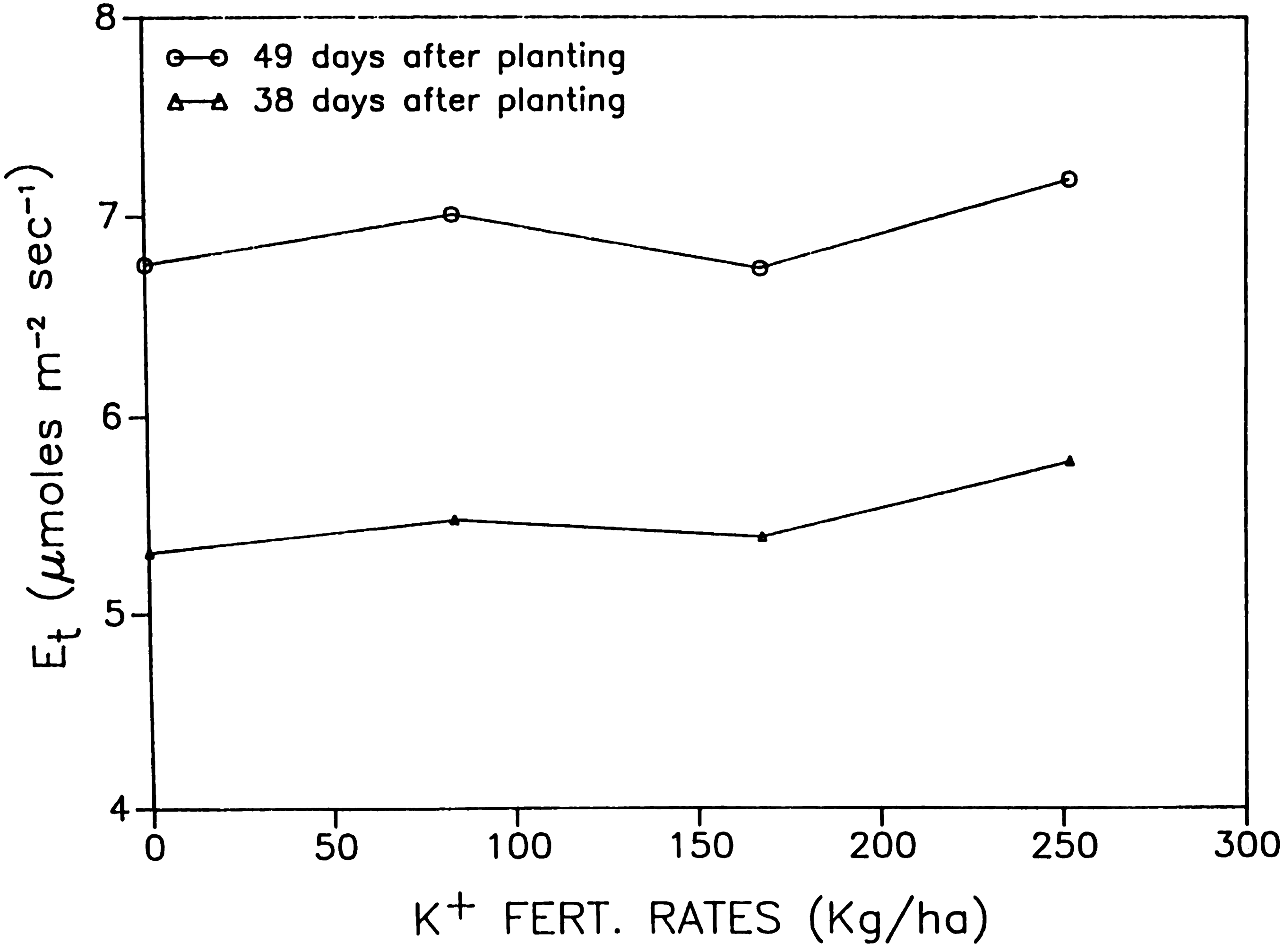

49 days after planting
38 days after planting
E_t (μmoles m^{-2} sec^{-1})
8
7
6
5
4
0
50
100
150
200
250
300
K^+ FERT. RATES (Kg/ha)

Figure 19.