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Influence of sodium chloride on transpiration and plant growth of two tomato cultivars

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The University of Arizona, 1987

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INFLUENCE OF SODIUM CHLORIDE ON TRANSPIRATION AND PLANT GROWTH OF TWO TOMATO CULTIVARS

by

Nabeel Younis Slail

A Thesis Submitted to the Faculty of the

DEPARTMENT OF PLANT SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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Norman F. Oebker — June 29, 1987

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ABSTRACT

Seedlings were grown at five salinity levels in Hoagland's solution for 4 weeks. Transpiration, leaf diffusive resistance, leaf temperature and plant growth of the tomato (Lycopersicon esculentum Mill.) cultivars 'VF 145B' and 'VF 10' were examined at different levels of NaCl ranging from 0 to -12 bars. Salinity-reduced transpiration increased leaf diffusive resistance and increased leaf temperature for both cultivars.

Shoot length, root length, shoot and root weight and leaf area were all lower for the two cultivars at increasing salinity levels. However, the two cultivars responded differently to salinity, with VF 10 showing better growth at the control and the -4 bar treatment than VF 145 B. At -9 and -12 bar treatment, the reverse was true.

Selection of tomato for salt resistance should not be based on vigorous growth at non-saline conditions because different genes may control the salt tolerance ability of the plants at high salinity levels.

CHAPTER 1

INTRODUCTION

Soil salinity, whether natural or artificially induced by irrigation and fertilization, poses a problem for agriculture. The source of this soil salinity is either from rocks that contain salts or from irrigation water that contains additional salts and fertilizers. Salinity is a very old problem. Raloff (1984) reported that the Sumerian culture of the Tigris-Euphrates was affected by salinity when the fertile land had been changed into desert as a result of salinity, and the region became a food importer, even though it has only half the population it used to support.

Salinity problems still exist today, especially in arid and semi-arid regions because of inadequate leaching, high evaporation rate, restricted drainage, and the dependence on irrigation to provide the water needed for crops, which will add more salt to the soil. Thus, salinity may be the ultimate limitation to irrigated agriculture (Rains, 1979). Such a possibility is based both on the effect of sodium salts on the physical characteristics of the soil and on the plants through toxicity, specific ion effects, or changing the water balance of the plants.

Flowers et al. (1977) reported that there are about 400 million hectares of saline-affected land in the world. Also, several tens of thousands of hectares are lost every year due to the effect of salt. As the world demand for food increases, exploiting marginal areas such as arid lands becomes a necessity. Such areas are characterized by high salinity in both the soil and the water resources (Epstein, 1972).

The problem of salinity could be solved in either one of two ways: removing the salt from the soil itself by soil management, through adequate drainage and leaching programs, which are very expensive, or by using salt-tolerant plants that can maintain normal growth and metabolism in non-optimal conditions of salinity. The latter method seems to be more promising (Greenway and Munns, 1980).

Understanding of physiological changes occurring in plants subjected to salinity as well as salt-tolerance mechanisms at the cell and whole plant level is important to all programs trying to establish salt-tolerant crop species. Overcoming salinity problems could be accomplished if such understanding is established and provided to plant breeders.

The objectives of this research on salt tolerance in tomato (Lycopersicon esculentum Mill.) seedlings were: (1) to evaluate the response of two different tomato cultivars to salinity; (2) to investigate the effect of

salinity on the growth of major parts of tomato plants; and (3) to study the effect of salinity on transpiration.

CHAPTER 2

LITERATURE REVIEW

Salinity can affect plant growth in three main ways. First, salinity tends to affect plant growth by reducing water availability (Rains, 1979). Second, excess of potentially toxic ions like sodium and chloride tend to affect plant metabolism (Lagerwerff and Eagle, 1961). Lastly, the predominance of salt ions in the soil solution potentially lowers the uptake of nutrient ions (Nanawati and Maliwal, 1973).

Plants in nature have evolved several adaptive mechanisms to deal with the presence of salt in their environment. Three strategies are possible and have been identified among plants growing in saline environments. First, avoidance of salinity. Basically it allows a glycophyte to grow at a particular time and/or place and survive when one would normally expect only halophytes. Secondly, exclusion of salts, which can occur at a whole plant or cellular level. This can be done by not allowing ions into the cell in the first place or by pumping them out once they are in. Lastly, physiological tolerance, which is the most significant mechanism for dealing with salt (Stavarek and Rains, 1983).

Any of these mechanisms of salt tolerance is expensive in terms of energy for the plant. Plants have to spend energy in accumulating and producing osmotica to lower water potential, transporting extra ions, and respiring more. That spending of energy will result in a reduced growth and therefore reduced yield (Yeo, 1983).

Salinity and Water Balance of the Plant

Salinity tends to lower the water potential of the soil, and thus for the plant to obtain water, it has to maintain negative water potential between the roots and the growth media. Plants can achieve the reduction in water potential by producing organic osmotica (e.g., organic and amino acids) or accumulating ions from the external media, which leads to the build-up of internal solute sufficient to maintain water flow into the plant. Such methods, however, are very expensive in terms of energy for the plant. It consumes significant amounts of carbon that would otherwise be used for growth (Rains, 1979).

A reduction in either pressure potential or osmotic potential has to be done, in order to lower the water potential of the plants (Bernstein, 1961). Hsiao (1973), however, classifies water stress into 3 categories. He considers lowering the water potential by several bars from a well-watered level to be a mild stress, and lowering the water potential by more than several but less than -12 to

-15 bars to be moderate stress. In both of these cases, plants tend to lower their osmotic potential due to the increase in solute concentration within the cell. The third category is severe stress, which he described to occur by lowering the water potential by more than -15 bars. Greenway and Munns (1980) discussed the effect of highly saline soil which is low in moisture on water potential of plants. They concluded that those will lose their turgor pressure, decrease their growth, and possibly die.

O'Leary (1969) found that increasing the salinity of the growth solution by addition of NaCl reduces the permeability of kidney bean (Phaseolus vulgaris L.) roots to water flow. Very little water could be forced through the roots under pressure as compared to roots from plants grown in non-salinized solutions. The author also found that relative water content of the leaves decreased with increasing salinity. Leaf resistance to water vapor diffusion was considerably higher in plants grown in salinized solutions; therefore, he suggested that physiological drought will take place even if osmotic adjustment occurs because of the increase in resistance in the water flow pathway from external solution.

Hayward and Spurr (1943) conducted an experiment to see the effect of salinity on the entry of water into corn

(Zea mays L.) roots. They found a reduction in water entry into the roots.

Boyer (1965) investigated the effect of salinity on water potential of cotton (Gossypium hirsutum L.) plants subjected to salinity. Change in water potential of leaf tissue followed changes in the water potential of the root medium. Changes in the osmotic potential of leaf tissue exceeded those of the root medium by a factor of 1.2 to 1.5. It was concluded that they resulted from nontransient concentrations of solutes in the tissues.

The effect of salinity on water balance of three wild relatives of the cultivated tomato and two tomato (Lycopersicon esculentum Mill.) cultivars was studied. Unlike bean and corn, salinity has induced succulence in all cultivars, especially in stem and leaf of wild cultivars (Tal and Shannon, 1983).

Findings of Milford et al. (1977) also seem to contradict those of O'Leary (1969) and Hayward and Spurr (1943). Milford et al., in their experiment on sugar beet (Beta vulgaris L.) found that sodium chloride increased plant dry weight and the area, thickness, and succulence of the leaves. It increased the water capacity of the plant, mainly the shoot.

Such conflict in the results between O'Leary (1969), Hayward (1943), Tall and Shannon (1983), and Milford et al.

(1977) about whether sodium chloride induces or reduces the water permeability of the roots may explain why some of the wild cultivars of tomato and sugar beet are relatively salt tolerant. Perhaps their root permeability to water under salinity conditions increases or at least is unaffected; however, even in this case, salinity would change the water balance of the plant.

Flowers et al. (1977) indicated that halophyte plants require salt for optimum growth. The optimal concentrations of salt for optimal halophyte growth ranges from 20 to 500 mM, depending on species and age. Growth of Atriplex nummularia Lindl was optimal at 100 to 200 meq/L where leaf and stem water content (expressed as percentage of dry weight) generally increased with salinity.

Some reports also suggest that salinity increases water potential in glycophytes. Tal and Shannon (1983) and Milford et al. (1977) reported an increase in water potential for tomato and sugar beet, respectively, when subjected to salinity.

Abel and Mackenzie (1964) investigated salt tolerance of soybean (Glycine max L.) varieties. They found that osmotic adjustment occurred in salt-tolerant rather than salt-sensitive species in order to maintain favorable water potential in the plants. With 9.6 mmhos/cm, leaves of the salt-sensitive plants accumulated 27,300 ppm in the leaves,

which was 6.5 times that of the control. In a comparative study between cultivated tomato and two wild tomato species, fruit size decreased in the cultivated species and remained unchanged in the wild species, while water content decreased under salinity in both cultivated and wild plants (Tal, 1971).

The osmotic pressure of roots as well as the osmotic pressure of above-ground parts of cotton and pepper (Capsicum annum L.) plants decreased with increases in the medium salinity over as wide a range of salinity as would permit any growth. Since osmotic pressure differentials between plant parts and root media are maintained, turgor does not decrease, and growth inhibition by salinity can not be attributed to water stress in the sense of lowered plant turgor. The osmotic adjustment process is indicated as a likely limiting factor for growth under saline conditions (Bernstein, 1961). In another study by Meiri and Plojakoff-Mayber (1969), it was stated that increasing salinity in the substrate affected the water balance of the leaf tissue. A lag in adjustment was noted, resulting from the fact that reduction in osmotic potential of the leaf tissue was lower than reduction in water potential. A reduction in the relative water content and in turgor pressure consequently occurred. It was also found that cell sap increased proportionally with salinity because of the increase of inorganic

and organic constituents, but when plants were transferred to non-saline media, turgor was maintained and cell sap was diluted.

Gale et al. (1967) studied the water balance of onion (Allium cepa L.), bean (Phaseolus vulgaris L.), and cotton plants grown under various salinity levels. Osmotic potential of onion leaf sap did not adjust to chloride salinity, and consequently water potential and turgor were reduced. Osmotic concentration of bean and cotton leaf sap did adjust to a saline root medium, and turgor was no less in the salinized plants than in the controls. It was concluded that chloride salinity does affect water balance of plants, and that the nature and degree of the effect will depend upon climatic conditions and may be very different between plant species and in the same species at different periods.

A reduction in water uptake in bean plants grown in saline medium resulted in retardation of leaf growth, expressed as a reduction in leaf expansion. Osmotic adjustment, however, had taken place in the leaf tissue (Meiri and Poljakoff-Mayber, 1967).

Tomato plants grown at 2 and 17 mS were different regarding water balance. Total rate of water uptake in detached berries was less in fruit grown at 17 mS than at 2 mS. Both water and osmotic potential were lower in the

17 mS than in the 2 mS, and turgor was similar in both of them (Ehret and Ho, 1986a).

In another experiment, tomato plants were grown under various salinity conditions (2, 12, and 17 mS). The increase in fruit fresh weight was markedly reduced by high solution conductivity (12 and 17 mS, and the fresh weight of mature fruit grown at 17 mS was less than that of fruit grown at 2 mS (Ehret and Ho, 1986b).

Tomato and pepper (Capsicum frutescens L.) plants were grown in saline soil under various irrigation regimes. Average soil water potential increased with amount of water and frequency of irrigation regime (Russo, 1981).

Slatyer (1961) investigated the water balance of tomato plants subjected to different salinity levels. At the beginning, water was lost from the plants associated with wilting, although recovery took place in all treatments after 28 hours of subjecting to salinity. This recovery of water content and maintenance of turgor was associated with the rapid increase in internal osmotic potential. When the osmotic substrate was removed, osmotic potential declined rapidly due to the increase in plant water content.

Water potential of seeds is also affected by salinity. McDonough (1976) studied the water potential of bromegrass (Bromus inermis Leyss) and alfalfa (Medicago

sativa L.) seeds imbibed on media of various osmotic potential (-2 to -16 bars). Seed water potentials were lower for higher concentrations because of greater restrictions in water uptake during imbibition. Over a 72-hour period, seed water potentials were lower than osmotic potentials of the media. Kurth et al. (1986) found similar results with tomato seeds imbibed at very high salinity. The osmotic potential of the seeds was reduced sharply after 4 hours of transferring from nutrient solution to 100% sea water, and it continued to decline during the next 3 days, but rose sharply soon after the seeds were returned to non-saline medium.

From previous experiments, it is well documented that salinity in some way will affect the water balance of plants. Greenway (1973) stated that salt accumulates in the environment and lowers its water potential, with an almost inevitable decrease in water potential of the plant tissues. Plants grown in saline conditions could act in one of the following ways. One, with no salt uptake by the plant, consequences will be the same as for plants grown on dry soil. Such plants may be of low turgor and hydration. Two, plants accumulate organic solutes. This accumulation also may be induced by salt uptake, which restores turgor and hydration of osmotic adjustment.

O'Leary (1971) suggested that high humidity level and foliar applications of plant growth hormones like cytokinins might overcome the reductions in the water content of plants due to salinity. Papadopoulos et al. (1985) tried to find a solution for the reduction of water content in tomato due to salinity. The root system was divided, and each of four quadrants allowed to grow in separate compartments containing different salinity levels. Root growth was reduced more in the compartments containing more salt, and about 63% of the total water taken up per plant was drawn from the compartment with the lowest salinity. Therefore, they concluded that tomato plants do not respond to the average soil salinity of the root zone, and that plants can tolerate high salinities in part of the root zone if the remaining roots are exposed to low salinities.

Salinity and Transpiration

Water supply to and water loss from leaves of plants subjected to salinity will be disturbed. As a result, water content of leaves could be reduced, and with it turgor (Meiri and Poljakoff-Mayber, 1969). Stomatal closure could follow and eventually transpiration would be reduced (Brouwer, 1963). Meiri and Poljakoff-Mayber (1970) studied the effects of various fluctuating regimes of NaCl on transpiration of bean plants. They found that transpiration was reduced in proportion to salinity. When plants were

transferred to non-saline medium, transpiration increased, but not to the level of non-salinized control plants. They also found a considerable similarity between the effects of salinity on leaf expansion and on transpiration rate. Water consumption of salinity affected plants is lower than in control plants. This may be due to lower transpiration rate and leaf area than that of the control.

Tomato plants were subjected to different salinity levels. At the beginning, water loss from the plants was associated with a rapid reduction in transpiration. Recovery in the plant water content in all treatments took place after 28 hours of subjecting to salinity, but for transpiration, subsequent recovery to values close to control happened after 28 hours (Slayter, 1961). Brouwer (1963) raised the section tension of bean root medium by the addition of sodium chloride. Transpiration rate decreased rapidly as salinity increased. This rapid decrease was due to partial closure of stomata. It was also concluded that plant growth is more sensitive than transpiration when plants are subjected to salinity.

When dwarf kidney beans were grown in various salinity levels, transpiration rate decreased with growth. When expressing the transpiration on the basis of the unshaded leaf surface area, transpiration rate seemed to be independent of the growth stage of the plant and influenced

by solution treatments. That is, transpiration increased as a result of increasing ion ratios of the solution at higher salt levels (Lagerwerff and Eagle, 1962).

Boyer (1965) investigated the effect of osmotic water stress on metabolic rates in cotton plants. He subjected cotton plants to salinity for a long period of time. It was noted that mesophyll cell resistance to diffusion of CO_2 did not increase at high solute concentration.

Gale et al. (1967) studied changes in water balance of onion, bean, and cotton. Osmotic potential of onion leaf sap did not adjust to salinity, and therefore stomatal aperture and transpiration were reduced. In bean and cotton, osmotic adjustment took place but the stomata of the salinized plants remained only partly open and transpiration was reduced. Plant and Hener (1985) subjected sugar beet to salinity and found that transpiration rate as well as leaf diffusive conductance were reduced. Eaton (1942) exposed tomato, cotton, and alfalfa to salinity. He reported that less water was lost by transpiration and evaporation per unit of dry matter produced in the salinity-treated beds than in the control. It was also indicated that water needs for the plants grown on saline soils tended to be lower than those of plants grown in non-saline soils.

Gale and Poljakoff-Mayber (1970) grew plants of Atriplex halimus L. in culture solutions to which NaCl was

added at different concentrations. At low salinity levels, an increase in leaf area and succulence was observed. This resulted in an increase of the leaf area available for transpiration, but the increase in stomatal resistance to water vapor loss and CO_2 uptake tended to reduce transpiration per unit leaf area. Riley (1984) indicated that as a result of water stress, transpiration was reduced but leaf diffusive resistance was increased. Leaf temperature and diffusive resistance were higher and transpiration was lower when less irrigation water was applied. In two alfalfa cultivars, leaf diffusive resistance increased and transpiration rates decreased as salinity increased (Sanchez-Diaz et al., 1982).

Hoffman et al. (1971) studied water relations and growth of cotton as influenced by salinity under 25, 40, 65 and 90% relative humidity. They observed an increased in transpiration per unit leaf area for the entire experiment, with an average of 80% for all salinity levels as the relative humidity decreased from 90 to 25%. A slight reduction in transpiration was noted as salinity increased in all humidity treatments.

Ehret and Ho (1986a) examined the effect of osmotic potential in nutrient solution on transpiration of tomato fruits. They grow tomato plants under 2 and 17 mS, and they noted that transpiration rate of fruits on plants grown at

2 and 17 mS was similar. In the 2 mS treatment, transpiration rate of the fruit calyx was greater than that of the berry on both an organ and unit area basis.

Salinity and Plant Growth

The effect of salinity on plants may vary depending on the stage of development. Sensitivity may be quite different during germination than at the later stages, and fruiting of some crops may be more or less affected than vegetative growth (Bernstein and Hayward, 1958). Lunin et al. (1963) conducted an experiment to determine the effect of salinization at various growth stages on yield of several vegetable crops. Yield was reduced significantly for all crops with an increasing salinity. With the exception of beet tops and broccoli (Brassica oleracea L.) tops, reduction in yields were significantly less when salinized at more mature growth stages. Tomato tops and pepper tops were the only crops tested which showed a significant interaction between growth stage and salinity. Such a significant interaction was not found for beet, broccoli, spinach (Spinacia oleracea L.), and onion.

Dumbroff and Cooper (1974) found that the early seedling stage of tomato was the stage in the plant life which was most affected by salinity. Growth rates remain severely restricted following removal of stress during this period, but plants stressed at later times resumed growth similar to

the control value soon after they were returned to base nutrient solution. Pearson and Bernstein (1959) investigated the effect of soil salinity at three stages of development of rice (Oryza sativa L.). It was indicated that salinity inhibited growth more severely at earlier stages of growth than at later stages. Salinity during the tillering stage inhibited growth twice as much as during heading.

Bernstein and Hayward (1958) stated that because salinity retards vegetative growth, it may be expected to delay flowering. Dumbroff and Cooper (1974) also observed that bud and flower formation in tomato were delayed due to the salt treatment. In other experiments, however, it was found that salinity did not affect the setting or time to flowering and first harvest of tomato plants grown at different salinity levels (Hall, 1983).

The salt tolerance of four varieties of barley (Hordeum vulgare L.) and two of wheat (Triticum aestivum L.) was tested on artificially salinized field plots. The intensity of the saline stress was varied for different stages of growth. Adding salinity during the last stage of growth, grain development and maturation appeared to have virtually no effect on the yield of these grains (Ayers, et al., 1952). It does not seem that all investigators agree that the early seedling stage is the most sensitive

stage for salinity. Stroganov (1964) reported that tomato plants are more sensitive to salinity during the flowering stage. Stroganov's results, however, could not be attributed totally to the stage of the plant growth. The length of the period at which plants were subjected to salinity is more than that of other individuals working with the early vegetative stages like Dumbroff and Cooper (1974).

Greenway (1965) imposed salinity in two varieties of Hordeum vulgare during early tillering and continued until grain formation. Relative growth rates did not support the notation that salt tolerance increases during plant development. Grain formation, however, was not affected by the treatment with NaCl. Salinity, however, differs in its effect on plant growth according to plant species. Nieman (1962) studied the response of 12 crop species grown in a range of NaCl treatments. He measured the growth as fresh weight increased, and found a big difference between salt sensitive ones, which responded to salinity either by severe depression or death, and salt tolerant ones, which were stimulated by salinity.

Milford et al. (1977) reported that sodium chloride increased plant dry weight and the area, thickness, and succulence of leaves of sugar beets, which is relatively salt tolerant. Acosta-Nunes and Ashton (1981) reported a stimulation effect of salinity at 0.23 and 0.3 MPa in the

fresh weight and shoot length of lettuce (Lactuca sativa L.). They suggested that stimulation happened because high Cl levels in tissues induced high turgor pressure and enzyme stimulation. Jennings (1976) stated that C_4 plants require sodium in trace amounts for photosynthetic carbon fixation. He also added that tomato responded to Na at trace amounts for increased carbon fixation. In bean plants subjected to sodium chloride, it was reported that chloride ions led to more succulent leaves (Gauch and Wadleigh, 1944). Smith (1975) reported that high application of KCl fertilizers to alfalfa caused burning of the leaflets and shoot death. This was thought to be due to the chloride ions. So, salinity stimulated growth at low concentration but reduced growth at high concentration. Attenburrow and Waller (1980) exposed tomato plants to different salinity levels induced by the addition of NaCl. It was shown that 200 mg/L NaCl in the water reduced yield significantly compared to the control. Increasing salinity to 800 mg/L resulted in further decline in yield and a reduction of water uptake. Hayward and Long (1941) grew tomato plants in salt solution containing different concentrations of soluble salts. They reported a depression in seedling growth, plant height, stem diameter, total fresh and dry weight, and flower bud formation in the high concentration of salt relative to the control.

Brown and Hayward (1956) examined the effect of salinity on the yield of six alfalfa varieties. They grew these varieties in plots that were artificially salinized by irrigating with water containing 0, 3000, 6000, and 9000 ppm of a 50:50 mixture of NaCl and $CaCl_2$. The average yield for all varieties was reduced to 79% of the control by the low-salt treatment, 60% by the intermediate treatment, and 42% by the high-salt treatment.

Papadopoulos and Rendig (1983a) indicated that growth of tomato roots was reduced to a less extent than the stems when subjected to high salinity. Salama et al. (1981) applied sand culture technique to investigate the effect of salinity on tomato and rocket (Hesperis matronalis L.) growth. Salinity significantly reduced the shoot growth of both of them. Similar results were obtained by Tompkins and Hung (1981), where tomato and sugar beet were grown in salt solution. Growth of both of them was significantly reduced as described by dry matter production.

High level of salinity inhibits growth in tomato and lettuce. In general, as osmotic pressure was increased from 0.30 to 0.96 MPa, fresh weight, root length, and shoot length were reduced in both species. At the lowest level used, 0.23 MPa, growth was not inhibited in either species. At the highest level used, 0.96 MPa, root and shoot elongation were essentially blocked and fresh weight reduced to 28

and 13% of the control for tomato and lettuce, respectively (Acosta-Nunes and Ashton, 1981). When bean plants were grown under saline conditions, growth depression was reported and was expressed in lower dry weight yields. The shoot, especially the leaves, were more affected than roots by salinity (Meiri and Poljakoff-Mayber, 1970).

Ehert and Ho (1986b) studied the effects of salinity on dry matter partitioning and fruit growth in tomatoes grown from three successive sowings in nutrient film culture at different salinities. When the electrical conductivity of the nutrient solution was in the range of 2,4, and 6 mS, neither the total plant dry weight nor the proportional distribution of dry matter into fruit (52%), vegetative shoot (44%), and root (4%) was affected. When the conductivity was 10 mS, however, total plant dry weight was reduced by 19% of that at 2 mS. The proportional partitioning of dry matter into various organs, however, was still unaffected. The proportion of total plant weight in fruit was only reduced slightly at 17 mS. The increase in fruit fresh weight was markedly reduced by high solution conductivity (12 and 17 mS), and the fresh weight of mature fruit grown at 17 mS was 40% less than that of fruit grown at 2 mS. In contrast, the dry matter of individual fruit was not affected by salinity and therefore the percentage dry matter of fruit was markedly increased by high salinity.

Many reports indicate a reduction in yield due to salinity, but lower yield was offset by higher fruit quality and consequently higher value (Mizrahi and Pasternak, 1985; Attenburrow and Waller, 1980; Papadopoulos and Rendig, 1983b). Also, salinity shortened the time of fruit development by 4 to 15% (Mizrahi, 1982).

The effect of uniform and nonuniform salinity on root distribution and water uptake by tomato roots was investigated. The root system was divided and each of four quadrants allowed to grow in separate compartments containing different salinity levels. Root growth was reduced more in the compartment containing more salt, and about 63% of the total water taken up per plant was drawn from the compartment with the lowest salinity. For the plants that were grown in the uniform salinity level of 5.5 ds/m in all four quadrants of the root, it was noticed that fruit yields and shoot weights were significantly lower. So tomato plants do not respond to the average soil salinity of the root zone, and plants can tolerate high salinities in part of the root zone if the remaining roots are exposed to low salinities (Papadopoulos et al., 1985). Applying salt (NaCl) through a drip irrigation system to irrigated tomato plants resulted in restriction of the root growth into the areas with minimal salt concentration, below the drip outlet (West et al., 1979).

Hayward and Long (1943) reported an increase in osmotic concentration of vegetative and fruit juices of tomato plants when subjected to salinity. They also noticed a reduction in cambial activities, maturation of cells of smaller size, and relatively thicker walls in xylem elements and mechanical cells. They suggested that the primary factor in growth inhibition seems to be the concentration of the substrate.

Not all tomato cultivars respond the same to salinity. Tal (1971) studied how cultivated tomato differs in its responses to salinity from two wild tomato species. Fruit size decreased in the cultivated species, but remained unchanged in the wild varieties. It was also found that plant growth, shoot/root dry weight ratio, relative water content, and potassium concentration decreased under salinity in cultivated and wild plants. In all instances except for potassium, the decrease was smaller in the wild plants. Chloride and sodium concentrations and leaf succulence, however, increased in all plants, with all being higher in the wild plants. Rush and Epstein (1981) obtained similar results with wild tomato species (Lycopersicon cheesmanii) and domestic cultivars. They indicated that the wild species resists salinity more than 200 mmol, and responded to salt stress in much the same way that many other halophytes do, that is by salt accumulation. Tal and Shannon

(1983) in their study further confirmed the idea that the wild relatives of tomato are more resistant than the domestic ones.

Reduced ion uptake is one aspect in which salinity will affect plants. Nanawati and Maliwal (1973) conducted an experiment to select varieties suitable for salt-affected areas. Tomato plants were grown under different salinity levels. The uptake of N, P, K, Ca, and Mg decreased with an increase in salt concentration. Papadopoulos and Rendig (1983b) found positive response of plants to increasing levels of N at the lowest initial salinity level of 1 ds/m. At the higher initial salinity levels of 5 and 9 ds/m, increasing N was ineffective in counteracting adverse effects on growth and yield of tomato plant which were reduced due to salinity. It was noticed that high salinity masked effects of P fertility, but less so with sudangrass (Sorghum sudanense L.) than with the other two crops (Patel and Wallace, 1976).

Scanlon and Morgan (1982) reported a development of blue green color in tomato plants grown in nutrient solution when subjected to salinity. In Atriplex nummularia grown at salinity levels above 10 meq/L, leaf color changed from dark green to light green (Greenway, 1968). Chlorosis was reported in bean plants grown under various salinity levels (Gauch and Wadleigh, 1944).

In an attempt to overcome growth inhibition due to salinity, O'Leary (1971) suggested growing plants in enclosures to maintain high humidity and foliar application of plant hormones like cytokinins. Application of hormones is to offset the lack of delivery of hormones from the root to leaves when plants are subjected to salinity. Results of Hoffman, et al. (1971) support O'Leary's suggestion. Growing cotton plants under high salinity level and 90% relative humidity resulted in 40% increase in growth. When at low humidity levels (25, 40, and 65%) such results were not obtained.

Salinity and Leaf Anatomy

The growth processes of leaf initiation, unfolding, and expansion, are expressions of the cellular processes of division, expansion, and differentiation. All these processes continue through the life cycle of the leaf, and therefore, all of these processes may be affected by salinity.

Bernstein (1961) found that osmotic potential of both the above and below-ground plant parts decreased in cotton and pepper plants over as wide a range of salinity as would permit plant growth. Leaf enlargement is highly sensitive to water stress. It is one of the first growth processes affected by a decrease in leaf water potential. For example, leaf enlargement in corn has been shown to

cease at a leaf water potential of -0.7 MPa (Acevedo et al., 1971).

A period of water or salinity stress will first cause reduction in the rate of leaf surface additions, followed by a cessation of expansion as the stress intensifies, and lastly cell division is affected by severe stress. If the stress is not too severe, growth resumption is rapid, suggesting a physical process (Terry et al., 1983). Jennings (1976) stated that salinity suppresses leaf expansion. Such suppression occurs even with halophytes at high salt concentrations. In their study on bean plants, Meiri and Poljakoff-Mayber (1970) reported that leaf expansion was retarded immediately at the beginning of salinization. The retardation was proportional to the rate of salinzation. Water deficiency causes a rapid cessation of the initiation of new primordia on the cereal apex at very low potential (Barlow et al., 1977).

Wignarajah et al., (1975) in their study on bean noticed a reduction in cell division as a result of being exposed to salinity. Cell division ceases with the onset of increased stress and DNA replication, which is closely coupled to cell division which also stops. At apparently severe levels of deficit, with 50% or more loss of tissue water content, most cells show a reversible aggregation of chromatin (Crevecous, et al., 1976) which presumably would

prevent both DNA replication and transcription. Protein synthesis is inhibited by osmotic stress imposed on excised plant parts. Inhibition of protein synthesis has been demonstrated in leaf discs cut from plants subjected to salinity stress (Ben-Zion et al., 1967). Boyer (1968), however, found that cell expansion is determined by the extensibility of the cell wall, so he concluded that cell wall extensibility is the primary site that will be influenced by water stress. Here the important question is whether leaf expansion ceases due to the inhibition of protein synthesis or whether the reverse is true. Which of the cellular responses to stress is primary is open to question.

Exposure of the leaves of bean to salt containing media decreased chlorophyll content, increased the rate of respiratory O_2 uptake, increased the number of mitochondria and led to abnormal chloroplast fine structure (Siew and Kelin, 1968).

In plants grown at high salinity, rapid rates of ion uptake could result in a build-up of high ion concentrations in the cell walls of leaves, particularly when cells reach flux equilibrium. This would cause adverse effects on the water relations of individual leaf cells (Oertli, 1968).

Longstreth and Nobel (1979) studied the effects of salinity on the leaf anatomy of cotton, bean and Atriplex

patula, L. They found that increasing salinity led to a higher ratio of mesophyll surface area to leaf area for cotton and bean and to a less extent for Atriplex patula L. (salt tolerant species). Photosynthesis did not increase as a response to the increase in the internal surface of CO_2 absorption because the mesophyll resistance to CO_2 exchange increased with increasing salinity.

Meiri and Poljakoff-Mayber (1967) investigated the effect of sodium chloride on growth of bean leaves in thickness and in area. They reported that salinity induced retardation of leaf growth. Growth in area ceases before growth in thickness. Leaves of salt affected plants are often thicker than leaves of non-saline control plants. Thickness of the cells in all leaf layers is affected by salinity except for the upper epidermis, but thickening of the leaf as a whole seems to be due mainly to enlargement of the palisade layer. Leaves of the salt affected plants are smaller than those of the control plants but there are more cells and stomata per unit area in them. The epidermal cells are therefore smaller in the salt affected plants than in the controls. Reduction of leaf area seems therefore to be a result of reduction in cell size.

In contrast to what Meiri and Poljakoff-Mayber (1967) stated, Hayward and Long (1941) found that palisade tissue in the leaves of tomato plants grown in high sodium

sulfate cultures was very compact. They also indicated that leaflets of plants grown at high salt concentrations were thicker and more succulent. This was correlated with the loose arrangement of mesophyll. Many other investigators have reported an increase in leaf succulence in glycophytes as a response to salinity. Chloride ions were claimed to be the reason for succulence. (Lagerwerff and Eagle, 1961; Scanlon and Morgan, 1982; Milford et al., 1977; Gauch and Wadleigh, 1944).

In halophytes, growth of Atriplex nummularia was optimum at 100 to 200 meq/L with leaf size being largest at 100 meq/L of NaCl. The leaf and stem water content (expressed as percentage of dry weight) generally increased with increasing chloride concentration, particularly in the NaCl treatment. It was concluded that Na had stimulated leaf growth and led to leaf succulence (Greenway, 1968). In Atriplex halimas salinity also led to increased leaf area and succulence. This resulted in an increase of leaf area available for transpiration and photosynthesis (Gale and Poljakoff-Mayber, 1970).

CHAPTER 3

MATERIALS AND METHODS

Two tomato (Lycopersicon esculentum Mill.) cultivars were used in this research. One of them is considered salt-tolerant 'VF-145B-7879' and the other cultivar 'VF10' is considered salt sensitive. Both are characterized by being open pollinated, having medium-large size fruit and being determinate. VF10 is also characterized by having higher yields than VF 145B. The source of the seed was from Petoseed Co., Inc. (Saticoy, CA). Experiments were conducted at the University of Arizona in a greenhouse from January to April 1987. Throughout the experiment, both the temperature and humidity were measured by a hygrometer. The temperature ranged from 18 to 32^{o}C, and the humidity ranged from 20% to 80%. At the beginning of the experiment the day length was 10 hours, and at the end of the experiment the day length became 12 hours.

Seed Germination

Polystyrene trays were washed with 10% Clorox solution to avoid any fungal or bacterial contamination, and then the trays were washed with water and filled with

vermiculite. Seeds of each of the tomato cultivars were sown in separate trays in a greenhouse. Adequate moisture for germination was provided by daily irrigation. Liquid fertilizer (20:20:20 Peter's fertilizer) was used for the seedlings at a rate of one teaspoon/8 liters of irrigation water, once a week.

Seedling Transplant

Four-week-old seedlings, with a shoot length of about 7 cm were transplanted into plastic tubs that contained Hoagland solution (see Appendix A). The tubs were wrapped with aluminum foil to avoid algae growth and to protect the roots from being exposed to light. Polystyrene sheets covered with aluminum foil were used to support the seedlings. Four holes were made in every sheet, and a piece of sponge was used to hold each seedling in the hole. Seedling roots were cleaned with water before transplanting and an air pump with an air stone was used to provide oxygen to the roots in the nutrient solution. There were four seedlings in a tub of 8 liters. Twenty tubs were arranged on a bench in a randomized complete block design with two replications.

For the first week, all plants were grown in the nutrient solution to allow the plants to modify to their new environment. After the first week, only control plants were allowed to continue growing in the original solution, which

consisted of tap water and the nutrient solution, while in the other tubs were the treated plants. Sodium chloride was added to give the following:

1. Four tubs with an osmotic potential of 0 bars.
2. Four tubs with an osmotic potential of -4 bars.
3. Four tubs with an osmotic potential of -6 bars.
4. Four tubs with an osmotic potential of -9 bars.
5. Four tubs with an osmotic potential of -12 bars.

The osmotic potentials of the solutions were confirmed by the use of Wescor model 5100C vapor pressure osmometer. The solutions in the tubs were kept at a constant level (8 liters) by the addition of tap water to make up for the transpiration losses. All solutions were changed every week.

Salinity and Transpiration

Transpiration, leaf diffusive resistance, and leaf temperature were measured by the use of a Licor Model LI 1600 steady state porometer with a 0.6 cm^2 aperture. The uppermost fully expanded leaf was used for the measurement to see the effect of the salt solution. Measurements were done once a week. Two plants were measured in each tub, one measurement per plant. The measurements were done at noon at the upper leaf surface.

Salinity and Plant Growth

The same plants used for the transpiration study with the same treatments were used for the plant growth studies. Plant height, shoot (fresh and dry) weights, root length, root (fresh and dry) weights, and leaf area were measured to see the effect of salt solution on plant growth. Except for plant height, which was measured every week, all the other measurements were done at the end of the experiment.

Plant height and root length were measured to the nearest mm. Leaf area was measured by the use of Licor LI-3100 area meter when the leaves were still fresh. The shoot and root (fresh and dry) weights were measured by the use of an ordinary balance of the Ohaus type. To determine the dry weights of the shoots and roots, each plant was placed in a marked paper bag in an oven at 65^{o}C for 48 hours to dry both shoots and roots.

Statistical Analysis

For all physiological characteristics measured (transpiration and plant growth tests), analysis of variance (ANOVA) and mean separation were used to see if there were any statistical differences among treatments and between cultivars.

CHAPTER 4

RESULTS

Physiological Responses

Physiological characteristics (transpiration rate, leaf diffusive resistance and leaf temperature) were measured for 4 weeks, on a weekly basis. For the measurements done on transpiration in the first week after treatment, mean separation for transpiration demonstrated that VF 145 B had a lower transpiration rate than VF 10 (Table 1). Transpiration rate decreased significantly for both cultivars as the salinity level in the treatment solution increased (Table 2). For VF 145 B, there was a reduction in transpiration rate of 19.4, 27.8, 33.3, and 39.1% at -4, -6, -9, and -12 bars, respectively, compared to the control, and for VF 10 a reduction of 20.9, 34.0, 42.4, and 49.4% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 1).

For the second seek of treatment, mean separation for transpiration rate demonstrated that VF 10 and VF 145 B were not significantly different (Table 1). Transpiration rate decreased as salinity level increased, but the difference between the different salinity levels was not as

significant as those for the first week (Table 2). For VF 145 B there was a reduction of 6.9, 22.4, 35.5, and 45.2% at -4, -6, -9, and -12 bars, respectively, compared to the control, and for VF 10 a reduction of 13.3, 28.8,. 43.5, and 51.8% was noticed at -4, -6, -9, and -12, respectively, compared to the control (Fig. 2).

For the third week, mean separation for transpiration rate showed no significant difference between the two cultivars (Table 1). Transpiration rate decreased as salinity increased for both cultivars (Table 2). For VF 145 B there was a reduction of 18.6, 30.9, 42.8, and 49.4% at -4, -6, -9, and -12 bars, respectively, compared to the control, for VF 10 a reduction in transpiration rate of 19.8, 36.2, 52.3, and 65.8% was noticed at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 3).

For the fourth week, mean separation for transpiration rate indicated no significant difference between the two cultivars (Table 1); however, as salinity increased, transpiration rate decreased for both cultivars (Table 2). For VF 145 B there was a reduction of 25.3, 30.7, 48.0, and 53.7% at -4, -6, -9, and -12 bars, respectively, compared to the control. With VF 10, transpiration rate was reduced by 17.7, 31.1, 66.4, and 72.9% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 4).

Table 1. Mean separation of transpiration rate ($\mu g\ cm^{-2}\ s^{-1}$) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Cultivars	First Week	Second Week	Third Week	Fourth Week
VF 10	32.82 b[z]	27.18 a	18.32 a	17.93 a
VF 145B	31.84 a	27.15 a	18.67 a	17.16 a

[z] Means within a column followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

Table 2. Transpiration rate (µg cm^{-2} s^{-1}) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Solution Conc. (bars)	First Week	Second Week	Third Week	Fourth Week
VF 10				
0	46.44 e[z]	37.30 d	28.12 e	27.50 d
-4	36.75 d	32.33 dc	22.54 d	22.63 c
-6	30.63 c	26.56 bc	17.95 c	18.96 b
-9	26.76 b	21.08 ab	13.40 b	9.23 a
-12	23.51 a	17.99 a	9.61 a	7.45 a
VF 145B				
0	41.85 e	34.71 c	25.21 e	26.19 c
-4	33.75 d	32.32 c	20.52 d	19.56 b
-6	30.20 c	26.94 b	17.42 c	18.16 b
-9	27.90 b	22.40 ab	14.42 b	13.61 a
-12	25.50 a	19.05 a	12.77 a	12.13 a

[z] Means within a column for a given cultivar followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

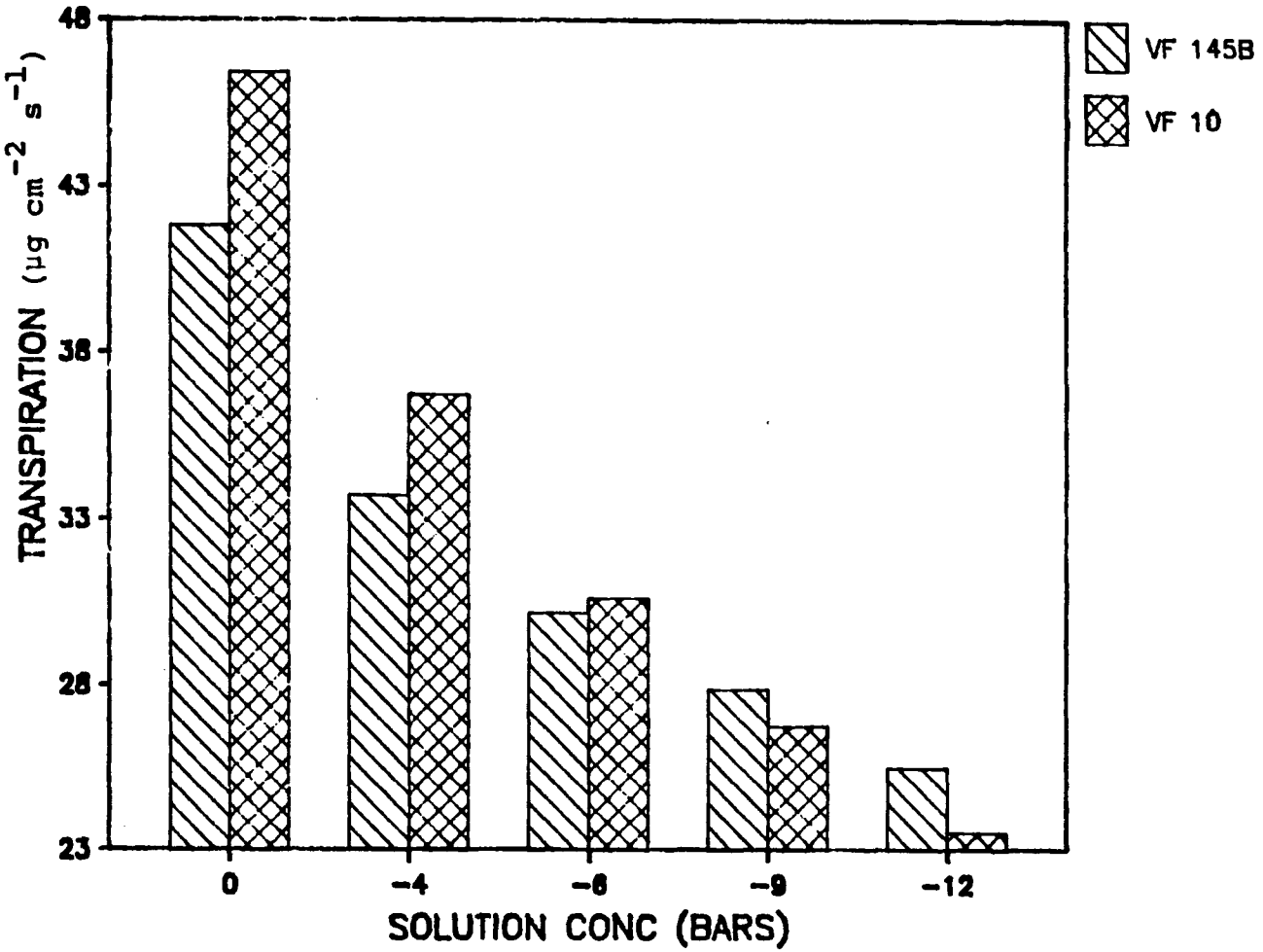

Fig. 1. Transpiration rate (µ.g cm^{-2} 5^{-1}) in two tomato cultivars after 1 week of treatment in various NaCl levels.

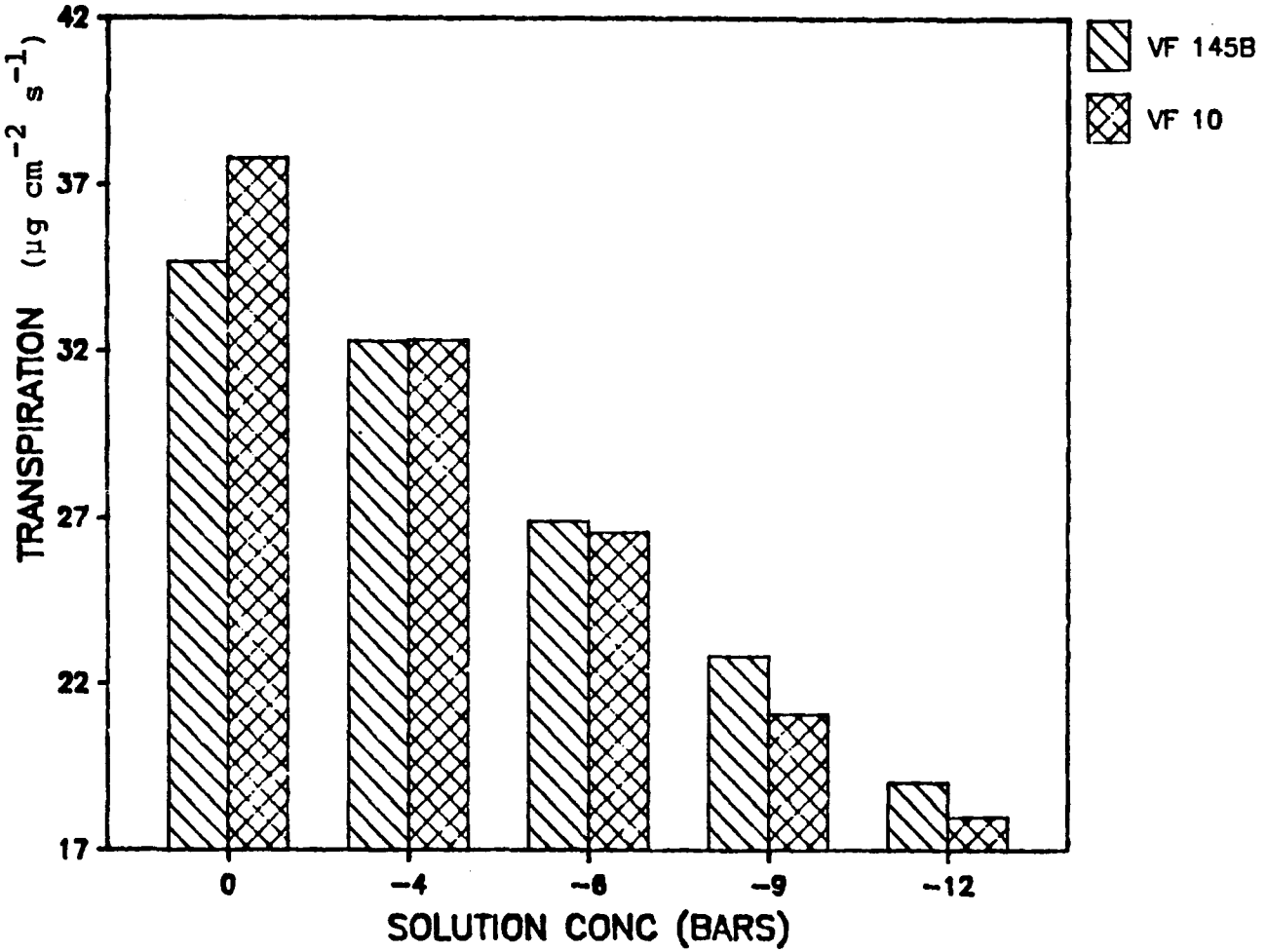

Fig. 2. Transpiration rate (μ g cm^{-2} 5^{-1}) in two tomato cultivars after 2 weeks of treatment in various NaCl levels.

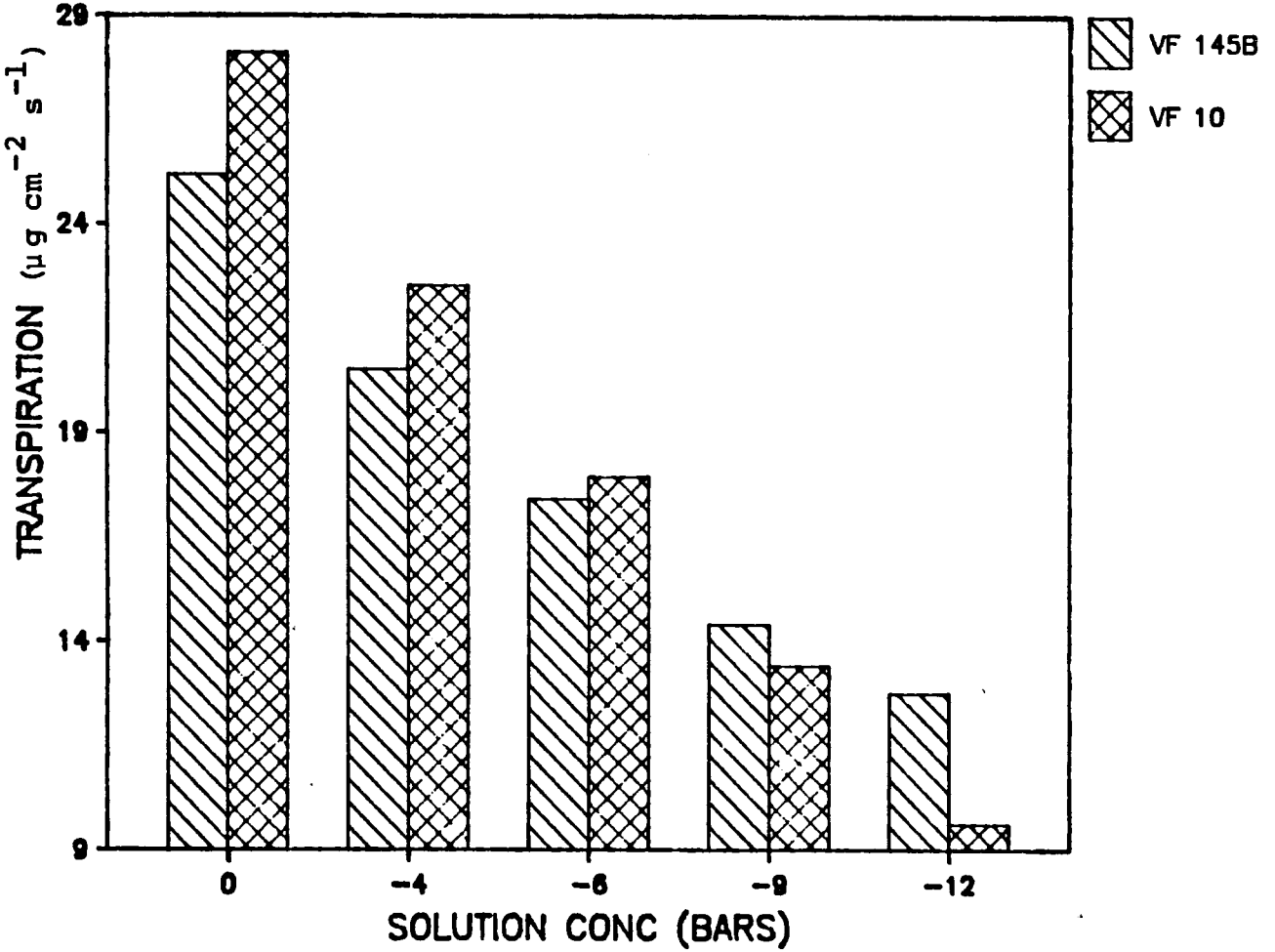

Fig. 3. Transpiration rate (µ.g cm^{-2} 5^{-1}) in two tomato cultivars after 3 weeks of treatment in various NaCl levels.

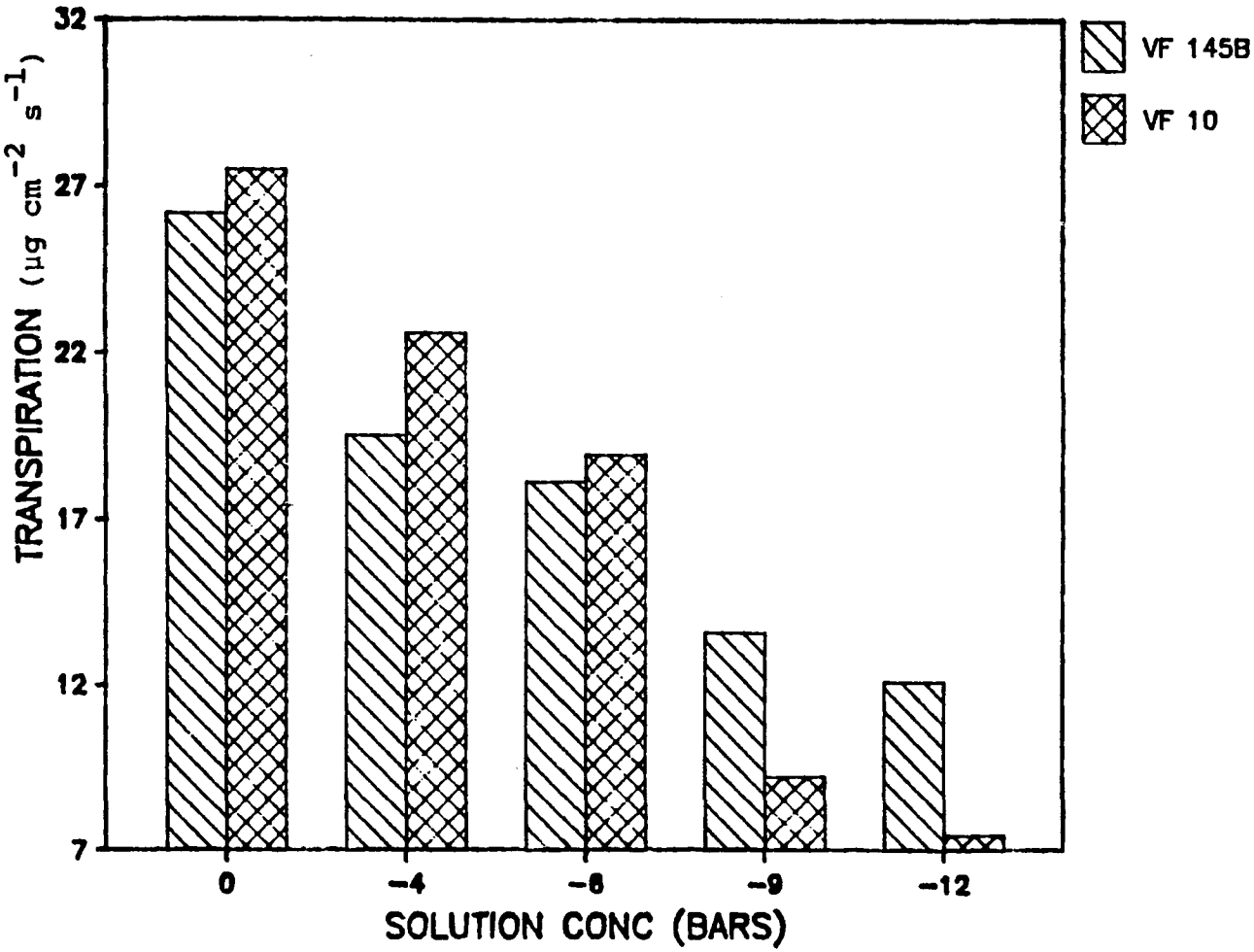

Fig. 4. Transpiration rate (μ g cm^{-2} 5^{-1}) in two tomato cultivars after 4 weeks of treatment in various NaCl levels.

For leaf diffusive resistance in the first week, mean separation showed that VF 10 had higher leaf diffusive resistance than VF 145 B (Table 3). Leaf diffusive resistance increased significantly for both cultivars as salinity increased (Table 4). For VF 10, there was an increase of 92.1, 142.3, 219.4, and 327.3% at -4, -6, -9, and -12 bars, respectively, compared to the control, and for VF 145 B an increase of 52.0, 103.1, 122.0, and 197.2% was observed at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 5).

In the second week, VF 145 B had lower leaf diffusive resistance than VF 10 (Table 3). Leaf diffusive resistance for both cultivars increased as salinity level increased (Table 4). For VF 145 B there was an increase of 11.9, 63.7, 105.4, and 125% at -4, -6, -9, and -12 bars, respectively, compared to the control, and for VF 10 there was an increase of 32.1, 135.8, 174.0 and 296.5% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 6).

In the third week. VF 145 B had lower leaf diffusion resistance than VF 10 (Table 3). As salinity level increased, leaf diffusive resistance increased too for the two cultivars (Table 4). For VF 145 B there was an increase of 28.4, 47.3, 71.6, and 208.6% at -4, -6, -9, and -12 bars, respectively, compared to the control; for VF 10 there was

Table 3. Mean separations of leaf diffusive resistance (s cm^{-1}) of two tomato cultivars at 4 weekly intervals.

Cultivars	First Week	Second Week	Third Week	Fourth Week
VF 10	0.582 b[z]	0.779 b	1.199 b	2.117 b
VF 145B	0.557 a	0.681 a	0.933 a	1.665 a

[z] Means within a column followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

Table 4. Leaf diffusive resistance (s cm^{-1}) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Solution Conc. (bars)	First Week	Second Week	Third Week	Fourth Week
VF 10				
0	0.227 a[z]	0.343 a	0.508 a	0.795 a
-4	0.436 b	0.453 a	0.688 b	1.050 a
-6	0.550 c	0.808 b	1.063 c	1.288 a
-9	0.725 d	0.935 b	1.513 d	3.030 b
-12	0.970 e	1.358 c	2.223 e	4.420 c
VF 145B				
0	0.286 a	0.420 a	0.545 a	0.900 a
-4	0.435 b	0.470 a	0.700 b	1.315 b
-6	0.581 c	0.688 b	0.803 c	1.520 b
-9	0.635 d	0.863 b	0.935 d	2.200 c
-12	0.850 e	0.945 c	1.680 e	2.390 c

[z] Means within a column for a given cultivar followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

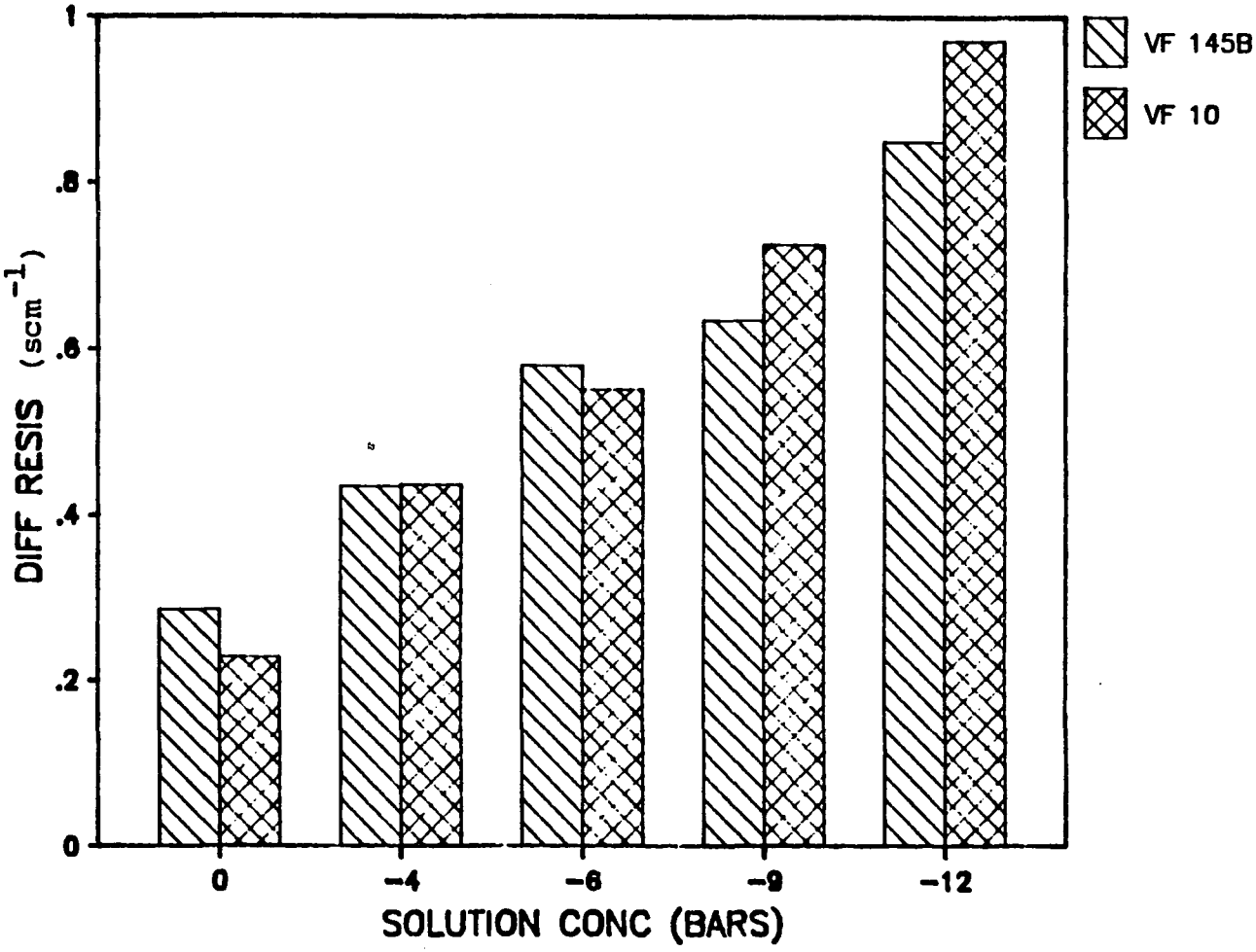

Fig. 5. Leaf diffusive resistance (scm^{-1}) in two tomato cultivars after 1 week of treatment in various NaCl levels.

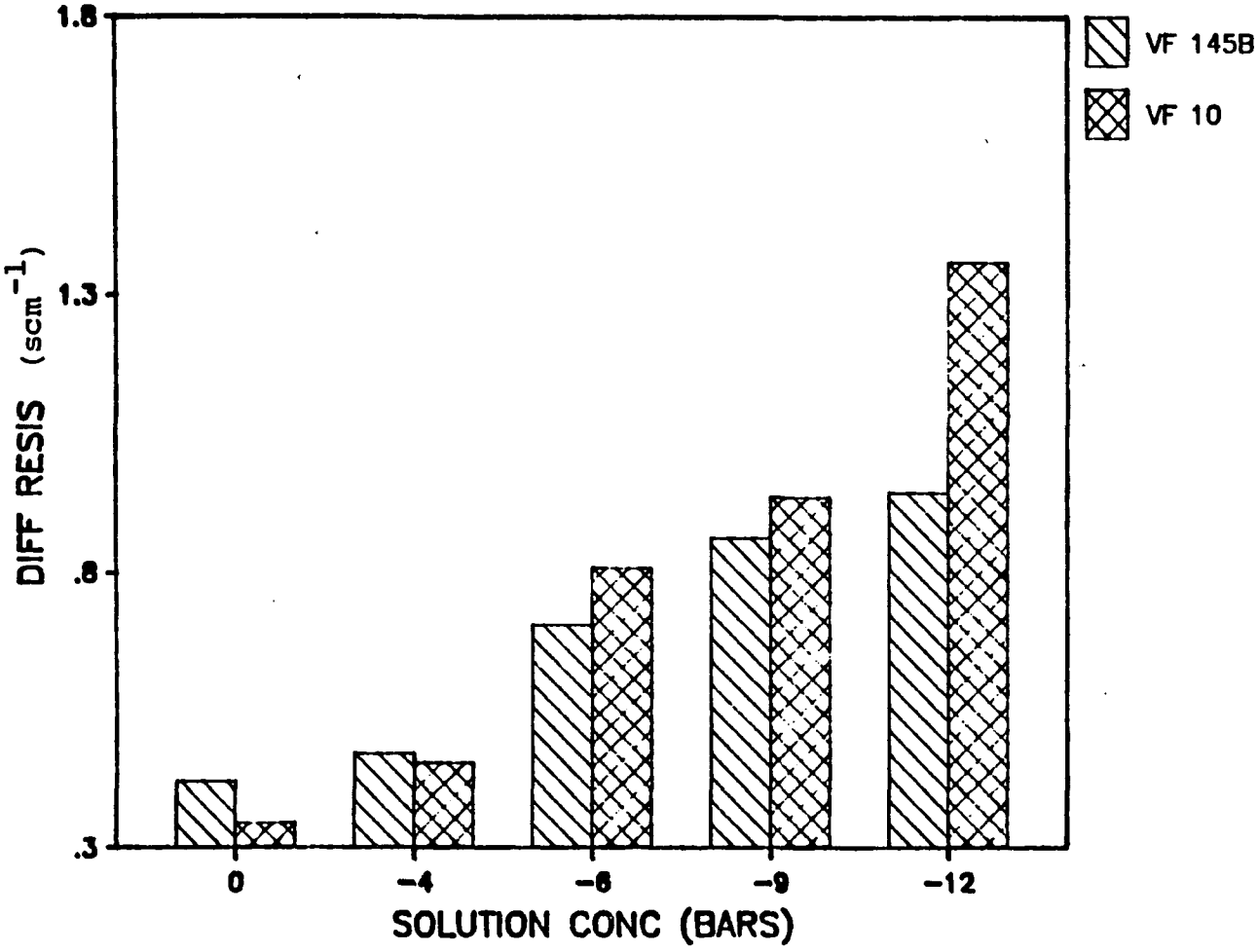

Fig. 6. Leaf diffusive resistance (scm^{-1}) in two tomato cultivars after 2 weeks of treatment in various NaCl levels.

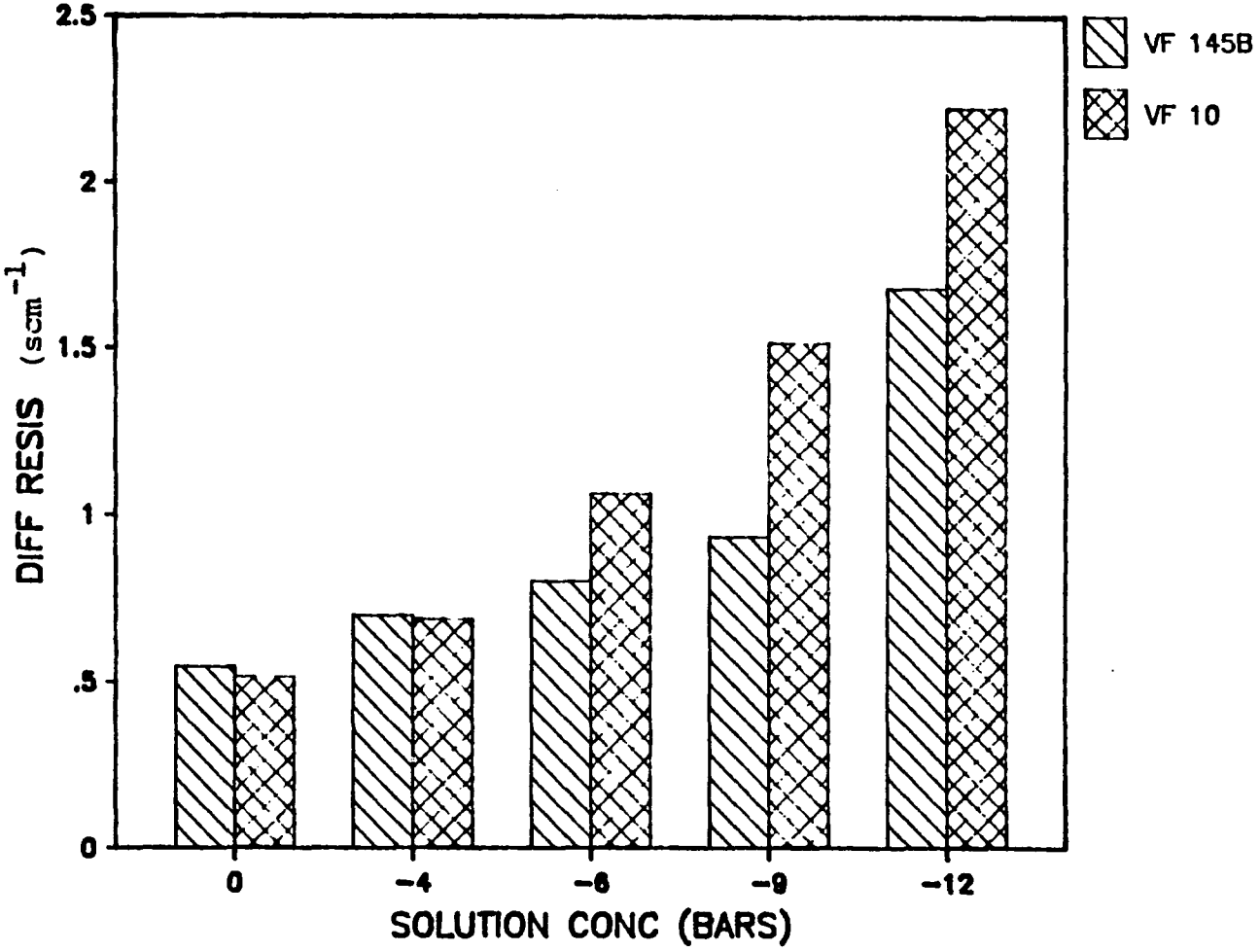

Fig. 7. Leaf diffusive resistance (scm^{-1}) in two tomato cultivars after 3 weeks of treatment in various NaCl levels.

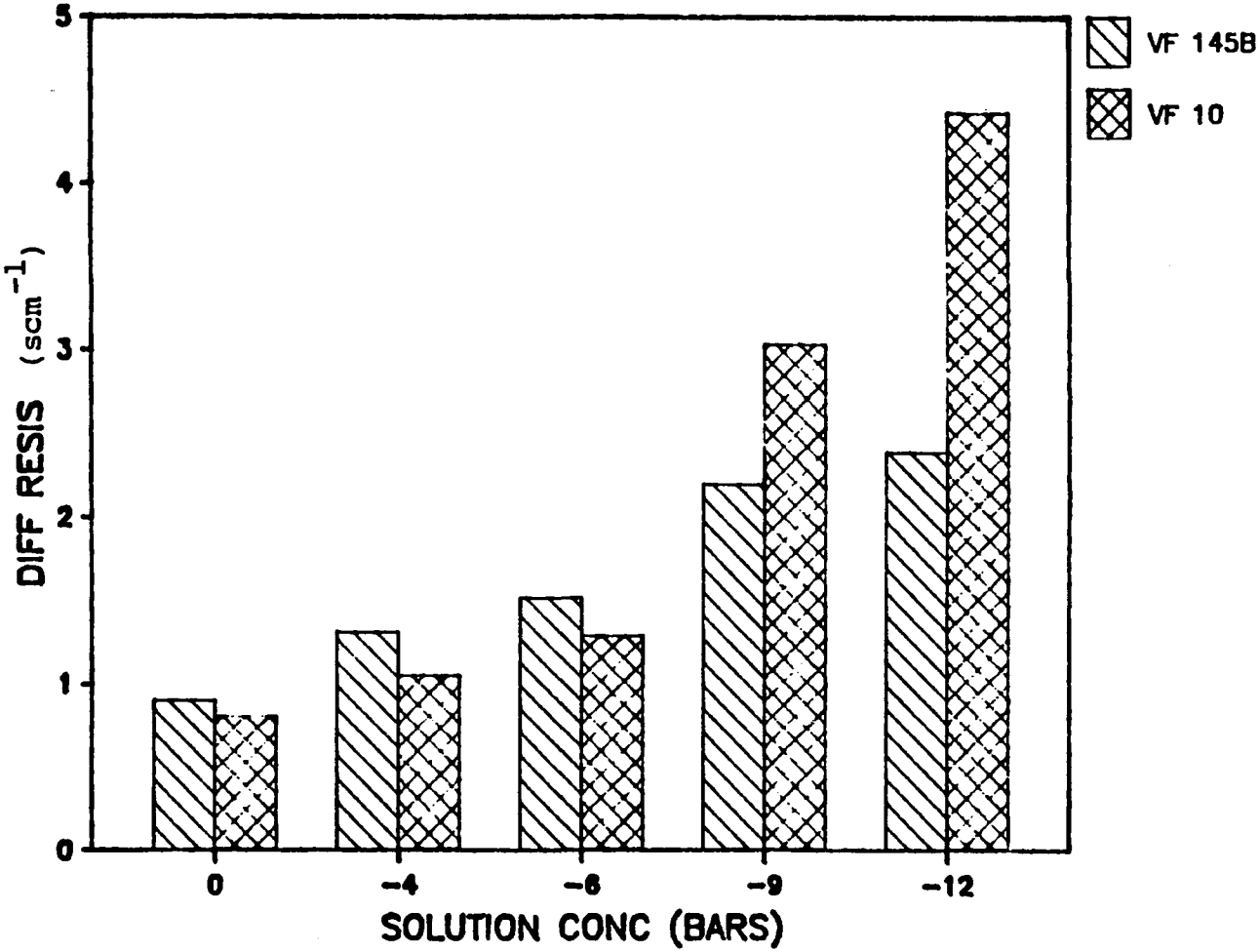

Fig. 8. Leaf diffusive resistance (scm^{-1}) in two tomato cultivars after 4 weeks of treatment in various NaCl levels.

an increase of 35.5, 109.5, 198.1, and 338.0% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig 7).

With regard to leaf diffusive resistance in the fourth week, VF 10 had leaf diffusive resistance significantly higher than VF 145 B (Table 3). For both cultivars, as salinity increased, leaf diffusion resistance increased also (Table 4). For VF 145 B the increase was 46.1, 68.9, 144.5, and 65.6% at -4, -6, -9, and -12 bars, respectively, compared to the control. Leaf diffusive resistance of VF 10 increased 32.1, 62.0, 281.1, and 456.0% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 8).

Mean separation for leaf temperature indicated that there was no significant difference between the two cultivars throughout the experiment (Table 5). Leaf temperature, however, for both cultivars in the first week increased as salinity level increased (Table 6). For VF 145 B there was an increase of 4.9, 10.9, 15.7, and 18.6% at -4, -6, -9, and -12 bars, respectively, compared to the control, and for VF 10 an increase of 4.3, 16.4, 18.6, and 22.4% was observed at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 9).

For the second week, as salinity increased leaf temperature for both cultivars increased (Table 6). For VF 145 B there was an increase of 8.5, 10.7, 11.5, and 11.5% at

-4, -6, -9, and -12 bars, respectively, compared to the control; for VF 10 an increase of 2.6, 13.2, 16.0, and 23.9% was observed at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 10).

In regard to temperature in the third week, leaf temperature increased significantly for both cultivars as salinity increased (Table 6). For VF 145 B there was an increase of 3.1, 6.3, 11.8, and 15.8% at -4, -6, -9, and -12 bars, respectively, compared to the control. For VF 10 an increase of 3.3, 8.2, 15.8, and 19.6% was found at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 11).

Leaf temperature in the fourth week increased as the salinity level increased for both cultivars (Table 6). For VF 145 B there was an increase of 3.3, 4.6, 5.8, and 7.8% at -4, -6, -9, and -12 bars, respectively, compared to the control; for VF 10 leaf temperature increased by 2.9, 4.0, 11.0, and 13.6% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 12).

When analysis of variance was calculated for each of the physiological characteristics, it was found that no significant differences existed between the two cultivars in regard to leaf temperature and transpiration in the second and third weeks. On the other hand, significant differences were found between the two cultivars in leaf diffusive

Table 5. Mean separation of leaf temperature (^{o}C) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Cultivars	First Week	Second Week	Third Week	Fourth Week
VF 10	25.05 a[z]	27.12 a	26.48 a	30.37 a
VF 145B	24.82 a	26.43 a	26.32 a	30.09 a

[z] Means within a column followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

Table 6. Leaf temperature (^{o}C) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Solution Conc. (bars)	First Week	Second Week	Third Week	Fourth Week
VF 10				
0	22.30 a[z]	24.40 a	24.21 a	28.56 a
-4	23.25 b	25.03 ab	25.00 b	29.40 ab
-6	25.95 c	27.63 bc	26.20 c	29.73 b
-9	26.45 cd	28.30 c	28.03 d	31.70 c
-12	27.30 d	30.23 c	28.95 e	32.45 c
VF 145B				
0	22.55 a	24.20 a	24.50 a	28.85 a
-4	23.65 a	26.25 ab	25.27 b	29.80 b
-6	25.00 b	26.80 ab	26.05 c	30.18 b
-9	26.10 cb	26.97 ab	27.39 d	30.52 cb
-12	26.80 c	27.95 b	28.36 e	31.10 c

[z] Means within a column for a given cultivar followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

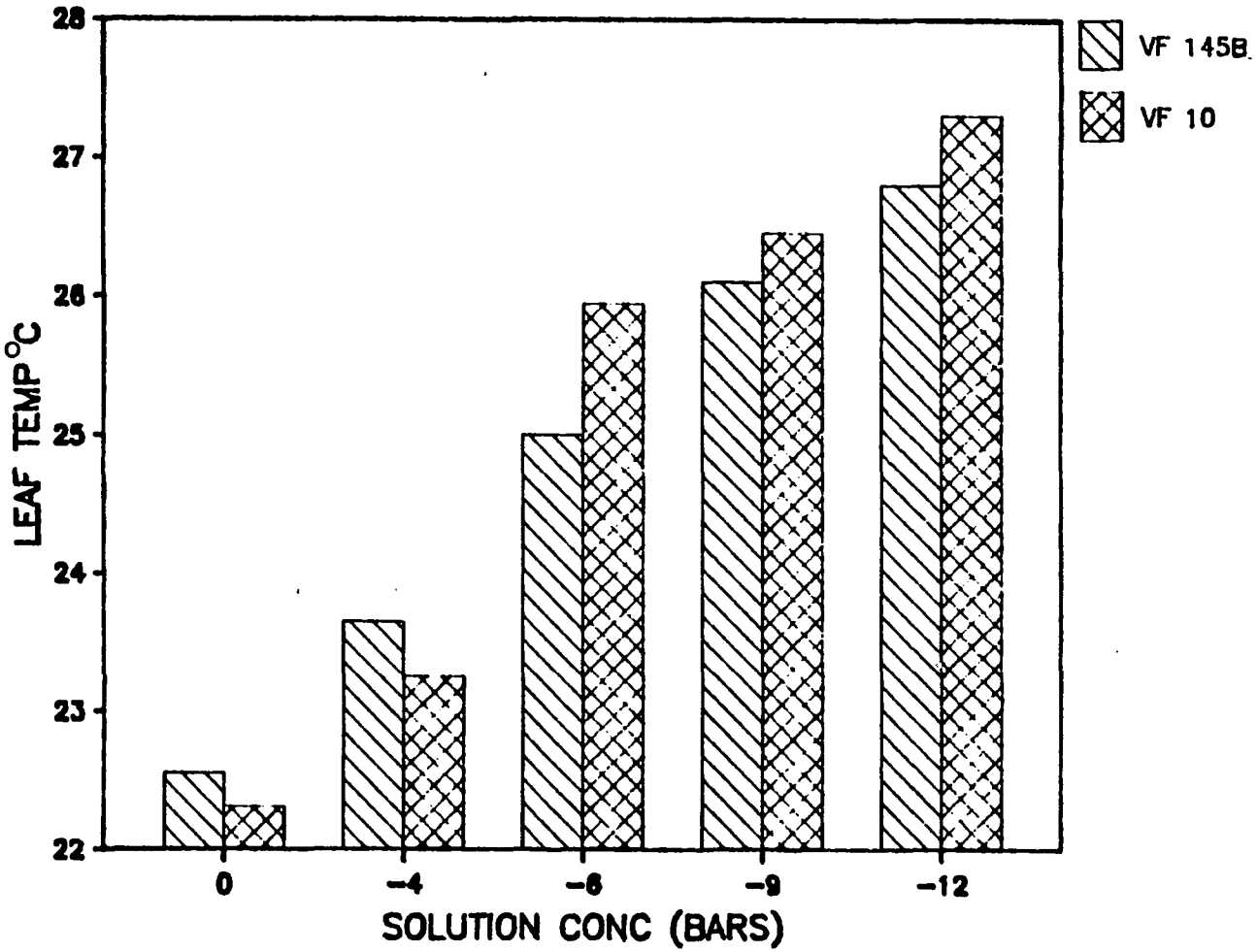

Fig. 9. Leaf temperature (^{o}C) in two tomato cultivars after 1 week of treatment in various NaCl levels.

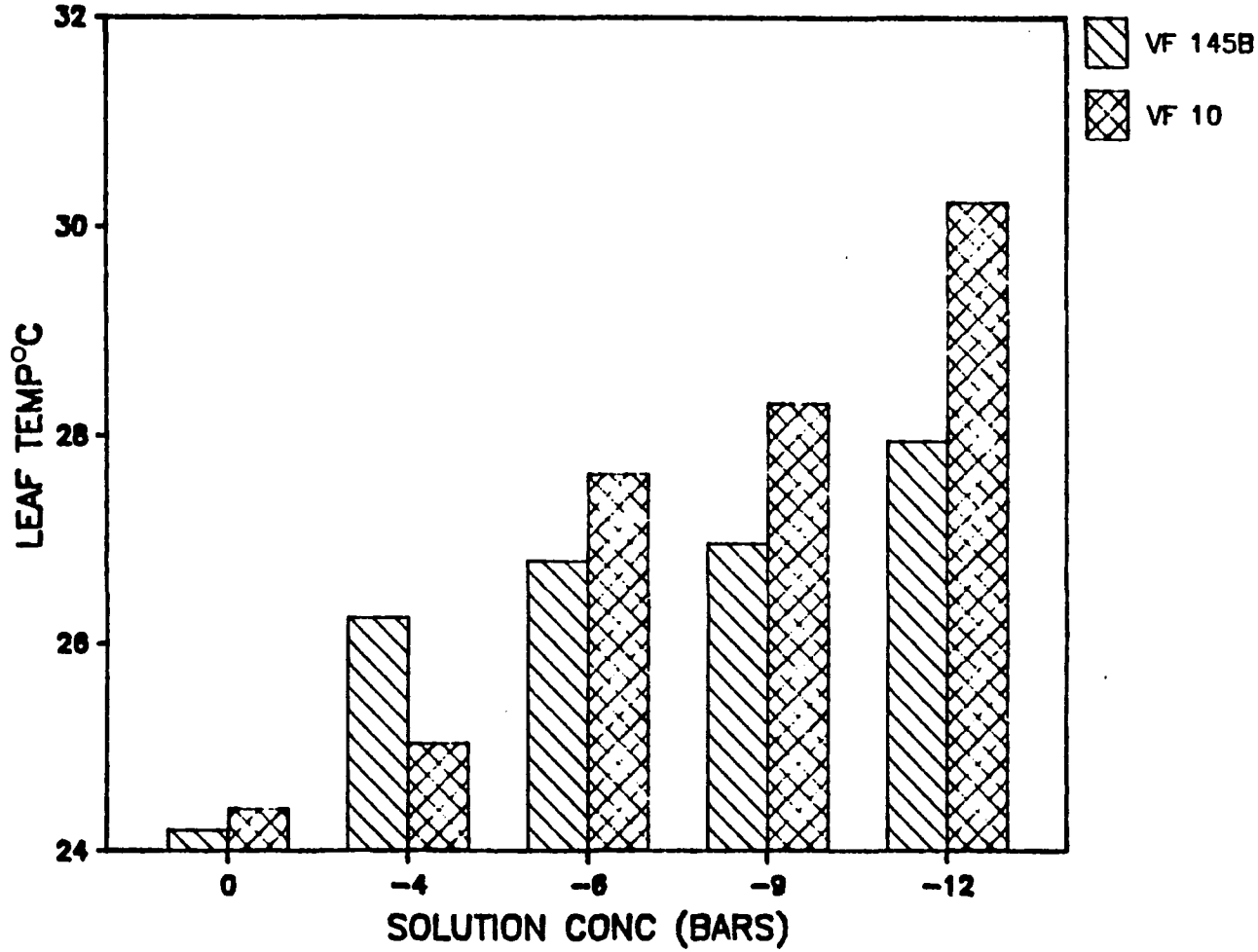

Fig. 10. Leaf temperature (^{o}C) in two tomato cultivars after 2 weeks of treatment in various NaCl levels.

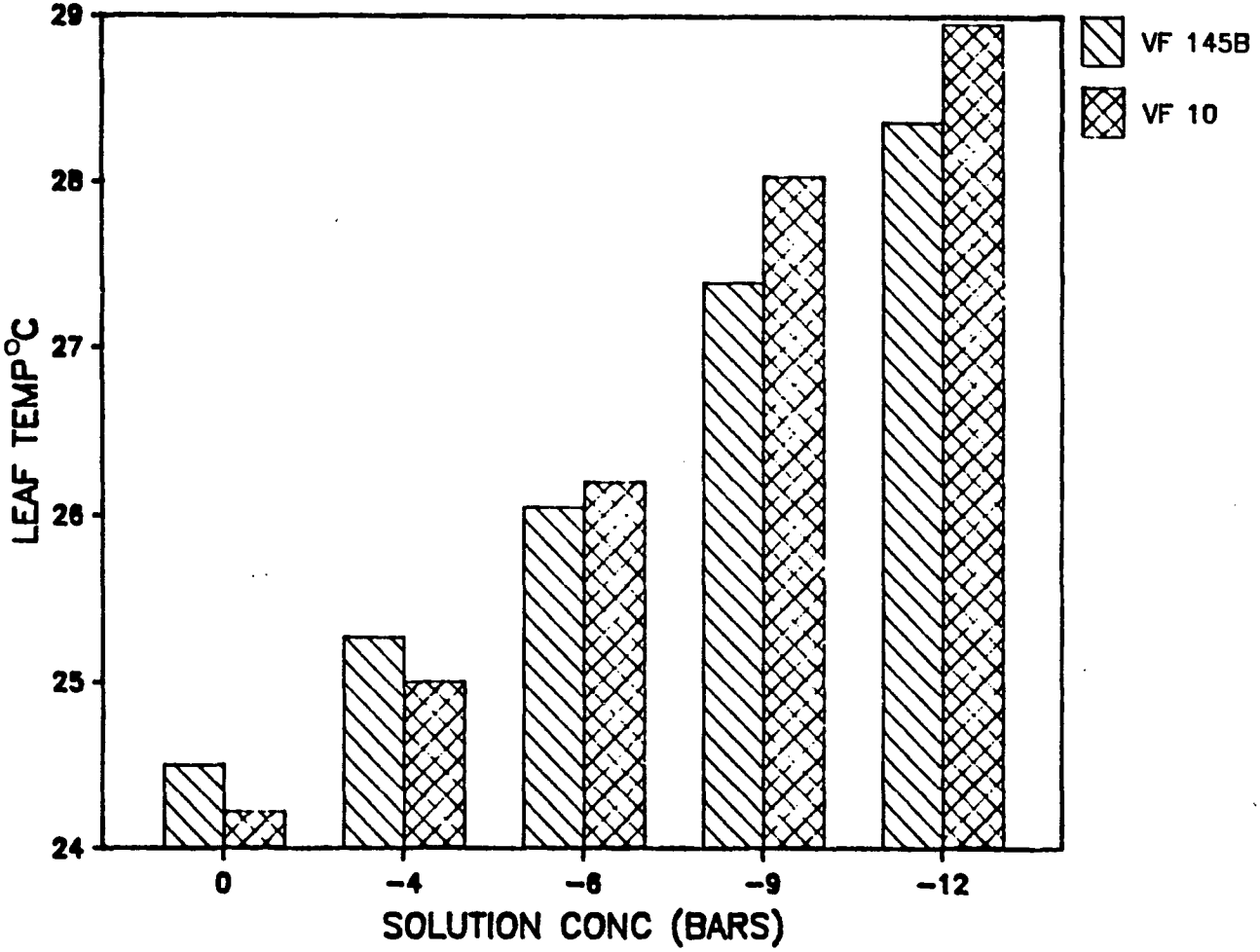

Fig. 11. Leaf temperature (^{o}C) in two tomato cultivars after 3 weeks of treatment in various NaCl levels.

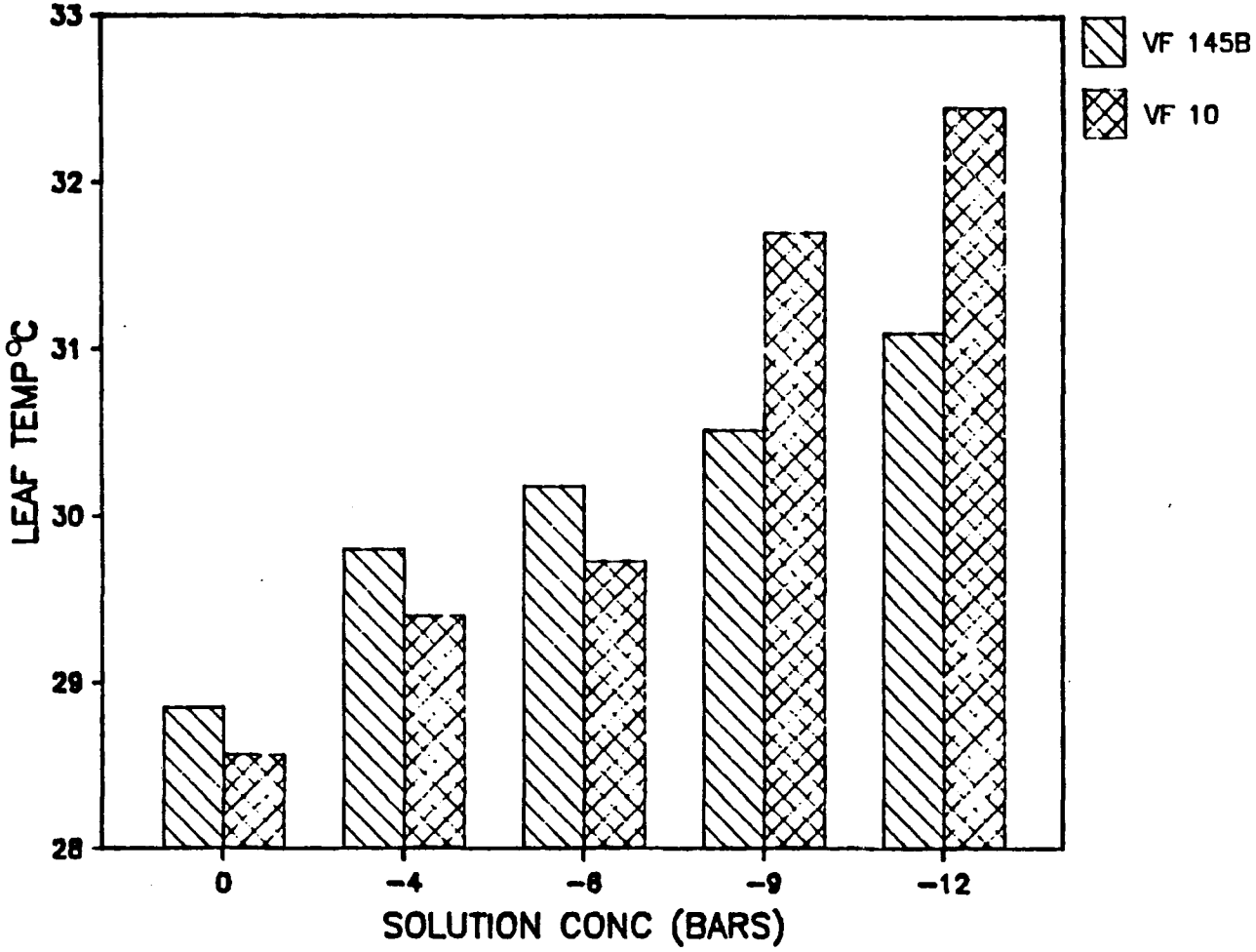

Fig. 12. Leaf temperature (^{o}C) in two tomato cultivars after 4 weeks of treatment in various NaCl levels.

resistance in the four weeks, and in transpiration in the first and fourth weeks of the experiment. Analysis of variance also was done for each cultivar, along with all of the physiological characteristics measured. Salinity level significantly affected all of the physiological characteristics measured. (For analysis of variance regarding this experiment, see Tables B.1 through B.36 in Appendix B.)

Plant Growth

After addition of NaCl, there was a permanent wilting for all treated plants. The next day all the plants recovered except for those of the VF 10 cultivar at -12 bars. Three plants died in one replication, and in the second replication two plants died. The surviving plants (at the -12 bars of the VF 10 cultivar) were stunted in growth. Shoot length, root length, shoot (fresh and dry) weights, root (fresh and dry weights) and leaf area were all affected by the salinity treatment in both cultivars.

Shoot length was measured every week. For the first week mean separation, a significant difference was found between the two cultivars as affected by salinity (Table 7); however, shoot length decreased as salinity level increased for both cultivars (Table 8). For VF 145 B there was a reduction of 4.7, 12.5, 16.2, and 21.1% at -4, -6, -9, and -12 bars, respectively, compared to the control. Shoot length was reduced for VF 10 by 6.8, 17.1, 31.3, and 41% at

Table 7. Mean separation of shoot length (cm) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Cultivars	First Week	Second Week	Third Week	Fourth Week
VF 10	8.28 a[z]	10.99 a	14.33 a	17.81 a
VF 145B	8.53 b	11.18 b	14.46 b	16.71 a

[z] Means within a column followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

Table 8. Shoot length (cm) of two tomato cultivars at 4 weekly intervals at different NaCl levels.

Solution Conc. (bars)	First Week	Second Week	Third Week	Fourth Week
VF 10				
0	10.26 e[z]	14.30 e	20.45 e	28.00 e
-4	9.56 d	13.46 d	18.33 d	24.27 d
-6	8.51 c	11.00 c	14.80 c	16.95 c
-9	7.05 b	9.07 b	10.49 b	12.19 b
-12	6.05 a	7.11 a	7.55 a	7.65 a
VF 145B				
0	9.58 e	13.05 d	18.33 c	21.97 d
-4	9.13 d	12.24 c	16.93 c	18.95 dc
-6	8.38 c	10.98 b	14.37 b	17.48 bc
-9	8.03 b	10.14 a	11.81 a	13.86 ab
-12	7.56 a	9.51 a	10.87 a	11.26 a

[z] Means within a column for a given cultivar followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

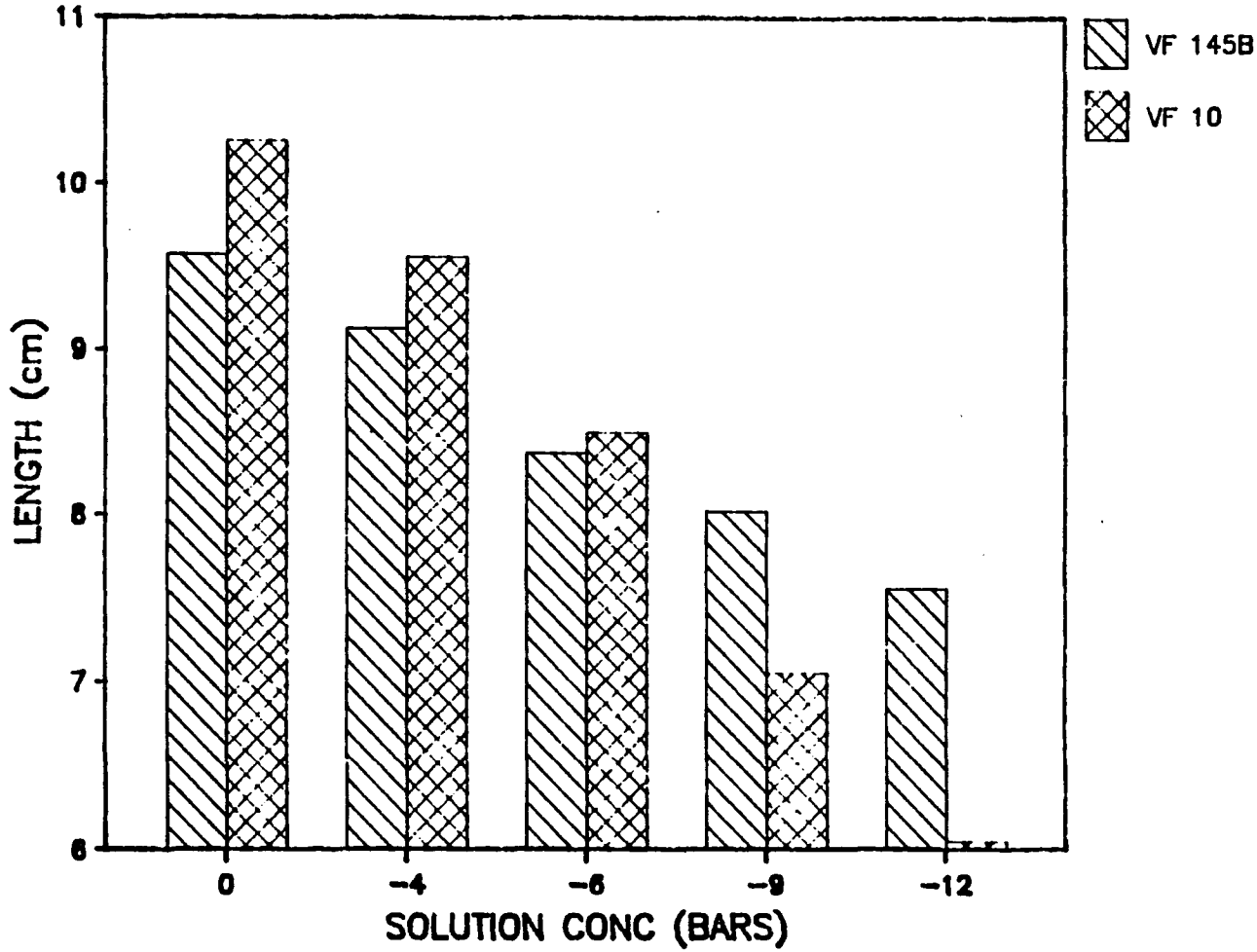

Fig. 13. Shoot length (cm) in tomato cultivars after 1 week of treatment in various NaCl levels.

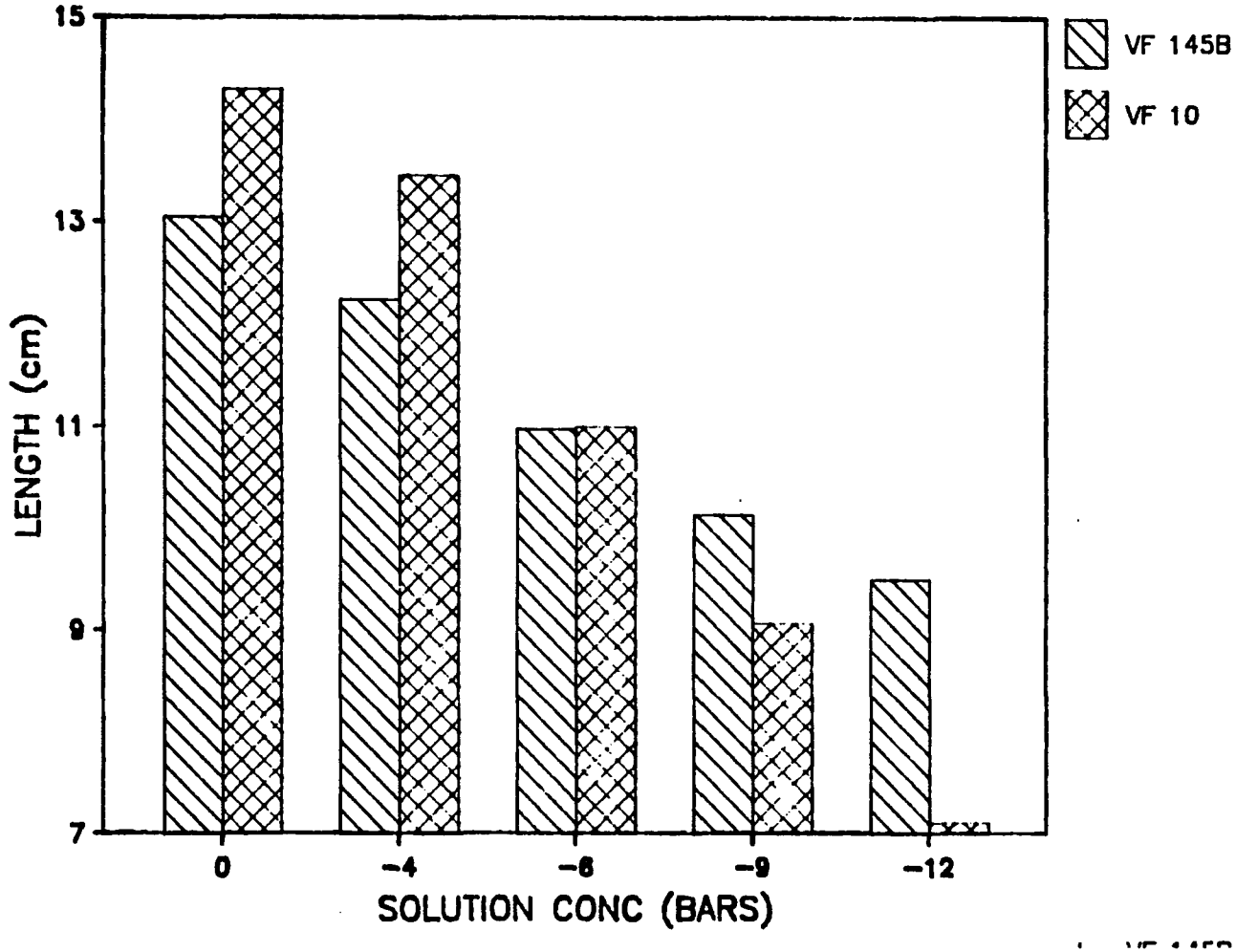

Fig. 14. Shoot length (cm) in two tomato cultivars after 2 weeks of treatment in various NaCl levels.

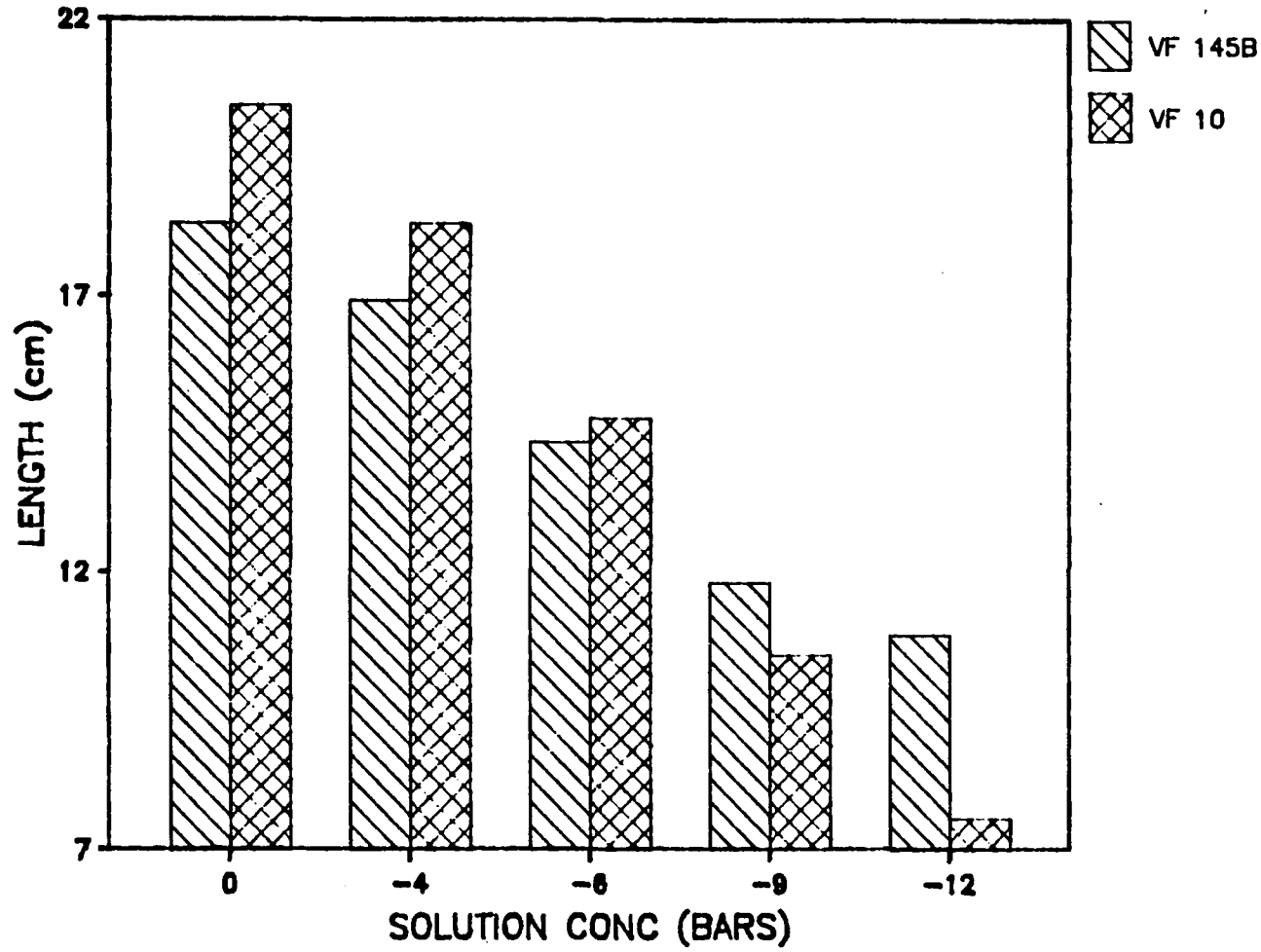

Fig. 15. Shoot length (cm) in two tomato cultivars after 3 weeks of treatment in various NaCl levels.

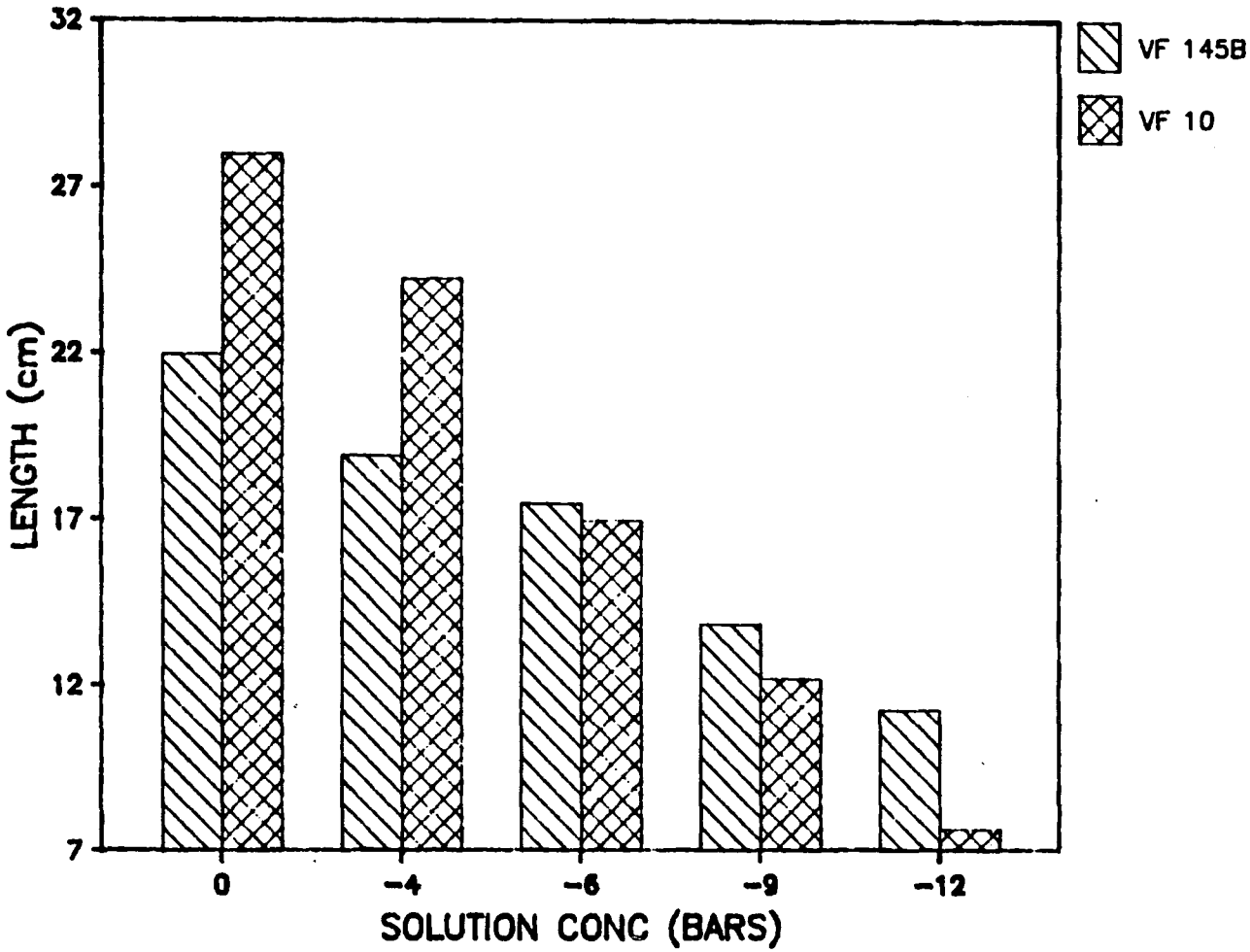

Fig. 16. Shoot length (cm) in two tomato cultivars after 4 weeks of treatment in various NaCl levels.

-4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 13).

In second week, mean separation demonstrated that VF 145 B had significantly higher shoot length than VF 10 (Table 7). Shoot length for both cultivars decreased as salinity level increased (Table 8). Shoot length for VF 145 B was reduced by 6.2, 15.9, 22.3, and 27.2% at -4, -6, -9, and -12 bars, respectively, compared to the control. A reduction of 5.9, 23.1, 36.6, and 50.3% was observed for VF 10 at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 14).

For the third week, shoot length of VF 145 B was significantly higher than VF 10 (Table 7). For both cultivars shoot length decreased as salinity increased (Table 8). For VF 145 B shoot length was reduced by 7.3, 21.6, 35.6, and 40.7% at -4, -6, -9, and -12 bars, respectively, compared to the control. A reduction of 10.4, 26.6, 48.7, and 63.1% was noticed for VF 10 at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 15).

In the fourth week, mean separation showed no significant differences between the two cultivars (Table 7); however shoot length for both cultivars decreased with increased salinity level (Table 8). For VF 145 B there was a reduction of 13.8, 20.4, 36.9, and 48.8% at -4, -6, -9,

and -12 bars, respectively, compared to the control. Shoot length for VF 10 was reduced by 13.3, 39.5, 56.5, and 72.7% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 16).

Root length of VF 145 B was significantly higher than VF 10 (Table 9); however, root length showed different responses to salinity than the other measured physiological characteristics. There was an increase in root length at -4 bars for both cultivars, for VF 145 B a 21.8% increase was noticed, while for VF 10 the increase was 17.6%. At higher salt concentration, root length decreased for both cultivars (Table 10). For VF 145 B a decrease of 13.2, 26.6, and 65.4% was noticed at -6, -9, and -12 bars, respectively, compared to the control. There was a reduction for VF 10 of 30.5, 43.0, and 78.8% at -6, -9 and -12 bars, respectively, compared to the control (Fig. 17).

Shoot (fresh and dry) weight were significantly different for the two cultivars (Table 9); however, shoot (fresh and dry) weight decreased as salinity increased for both cultivars (Table 10). For VF 145 B there was a reduction of shoot fresh weight of 33.6, 63.2, 73.3, and 80.9% at -4, -6, -9, and -12 bars, respectively, compared to the control. Shoot fresh weight for VF 10 was reduced by 20.1, 77.3, 90.0, and 95.1% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 18). In regard

Table 9. Mean separation of various plant growth parameters of two tomato cultivars at different NaCl levels.

Cultivars	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Leaf Area (cm^2)
VF 10	38.12 a[z]	38.49 b	3.83 b	15.86 a	0.79 b	40.26 b
VF 145B	40.04 b	29.49 a	2.68 a	15.90 a	0.73 a	34.34 a

[z] Means within a column followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

Table 10. Various plant growth parameters of two tomato cultivars at different NaCl levels.

Solution Conc. (bars)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Leaf Area (cm^2)
VF 10						
0	52.15 d[z]	88.43 d	9.79 e	26.30 d	1.88 d	80.05 e
-4	63.35 e	70.70 c	7.18 d	23.70 d	1.30 c	62.66 d
-6	36.25 c	20.09 b	1.18 c	19.12 c	0.64 b	36.14 c
-9	29.75 b	8.88 a	0.68 b	8.38 b	0.11 a	14.48 b
-12	11.05 a	4.36 a	0.23 a	1.80 a	0.04 a	0.00 a
VF 145B						
0	47.50 d	59.30 d	7.11 d	21.57 e	1.48 d	56.32 d
-4	57.50 e	39.35 c	3.46 c	20.08 d	1.07 c	42.13 c
-6	40.95 c	21.82 b	1.38 b	18.07 c	0.78 b	36.33 c
-9	34.65 b	15.85 a	0.83 a	11.60 b	0.24 a	21.57 b
-12	19.90 a	11.30 a	0.64 a	8.17 a	0.11 a	14.97 a

[z] Means within a column for a given cultivar followed by different letter are significantly different at the 0.05 level by least significant difference (LSD).

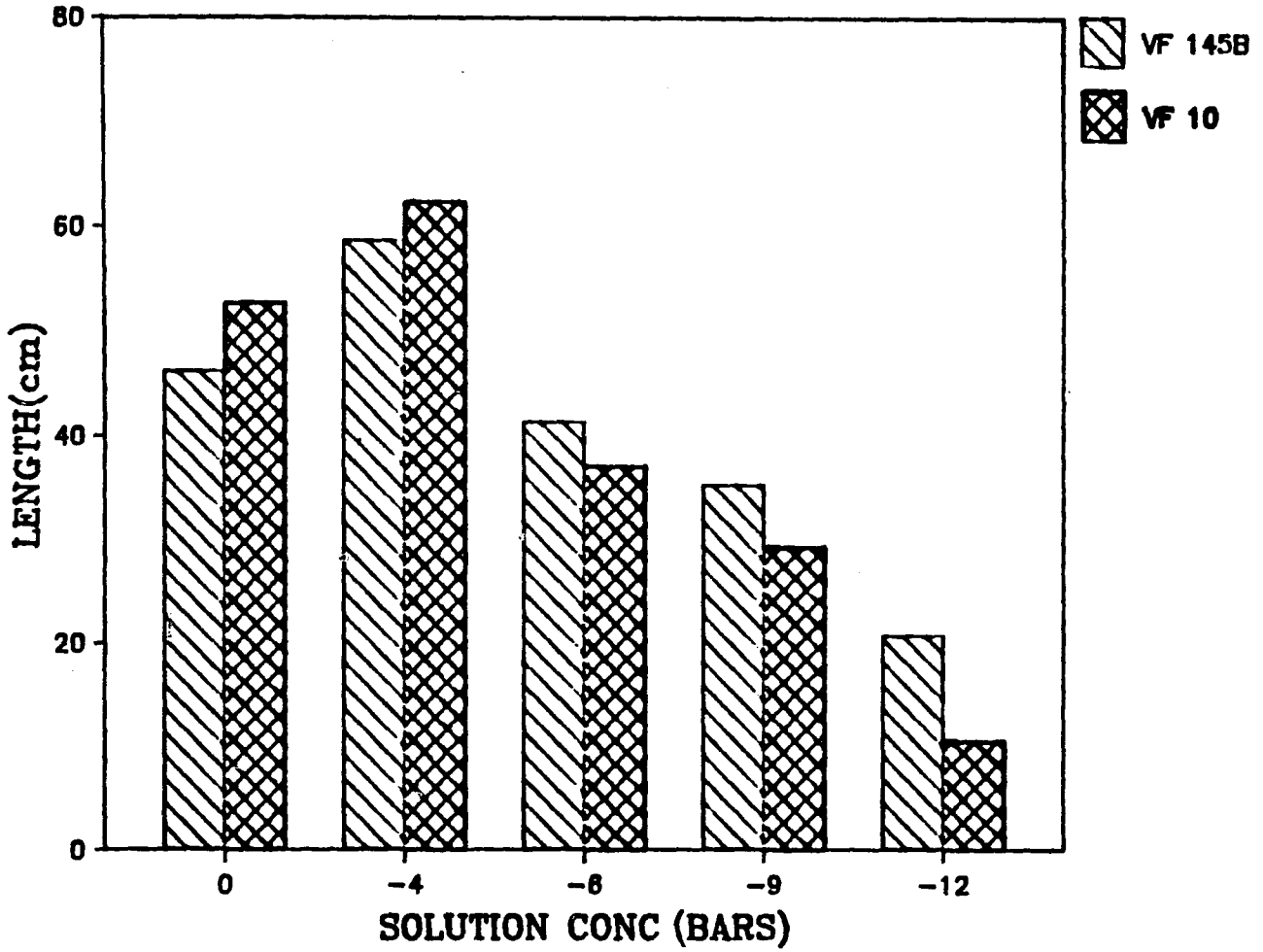

Fig. 17. Root length (cm) in two tomato cultivars as affected by various NaCl levels.

to shoot dry weight for VF 145 B, there was a reduction of 51.3, 80.6, 88.3, and 90.1% at -4, -6, -9, and -12 bars, respectively, compared to the control. Shoot dry weight of VF 10 was reduced by 26.6, 87.1, 93.1, and 97.6% at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 19).

Root fresh weight was not significantly different for both cultivars (Table 9); however, root dry weight of VF 10 was significantly higher than that of VF 145 B (Table 9). Salinity reduced root (fresh and dry) weight for both cultivars (Table 10). For root fresh weight, VF 145 B was reduced by 6.9, 16.2, 46.2, and 62.1% at -2, -4, -6, -9, and -12 bars, respectively, compared to the control. For VF 10, a reduction in root fresh weight of 9.9, 27.3, 68.2, and 93.2% was observed at -4, -6, -9, and -12 bars, respectively, compared to the control (Fig. 20). For root dry weight a reduction of 27.7, 47.6, 84.1, and 92.6% was noticed in VF 145 B at -4, -6, -9, and -12 bars. Root dry weight of VF 10 was reduced by 30.7, 66.1, 94.1, and 98.1% at -4, -6, -9, and -12 bars (Fig. 21).

For leaf area, there was a significant difference between the two cultivars as affected by salinity (Table 9). Leaf area for both cultivars was reduced as salinity level increased (Table 10); however, leaf area for VF 10 at the -12 bars was not measurable, because the leaves were dry.

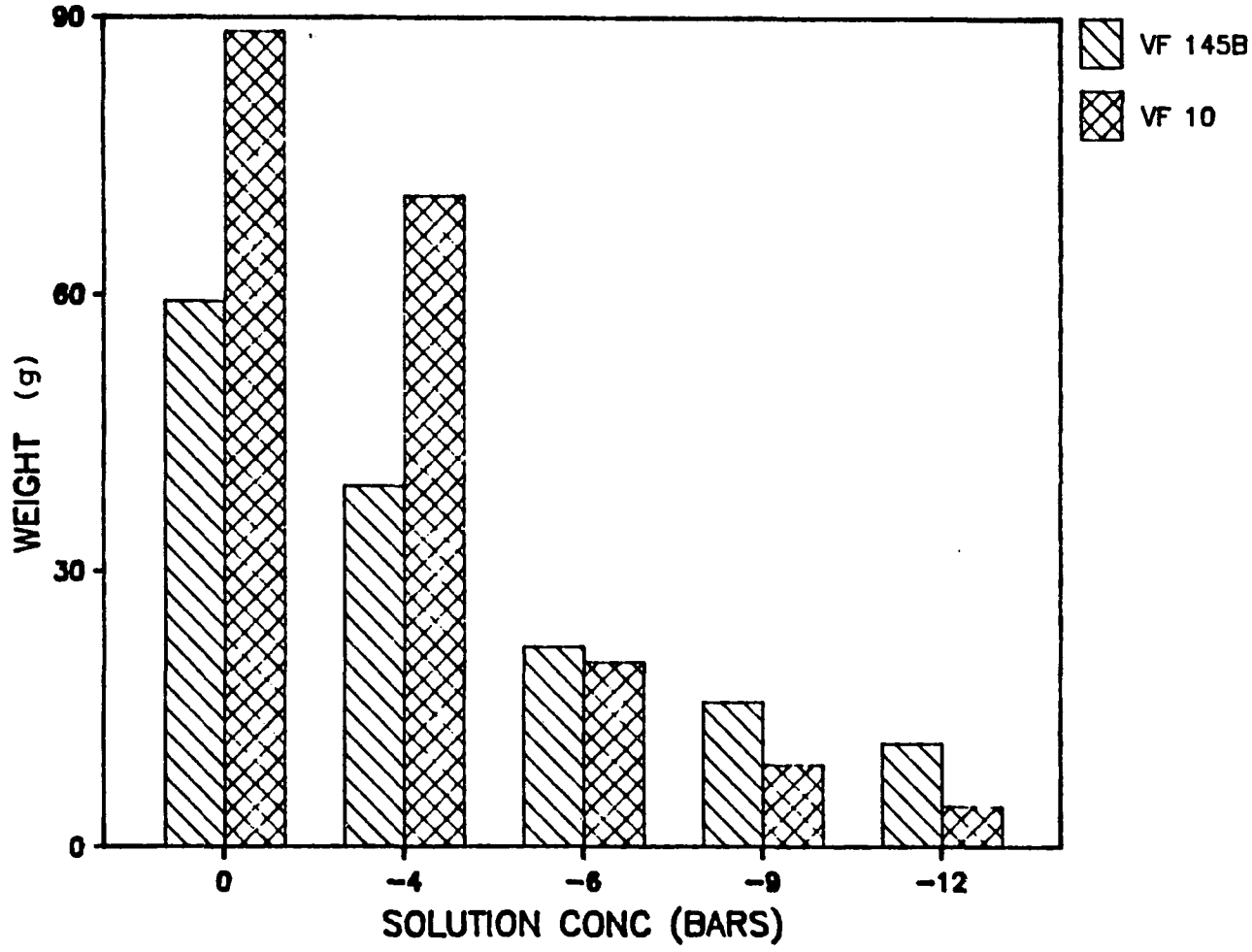

Fig. 18. Shoot fresh weight (g) in two tomato cultivars as affected by various NaCl levels.

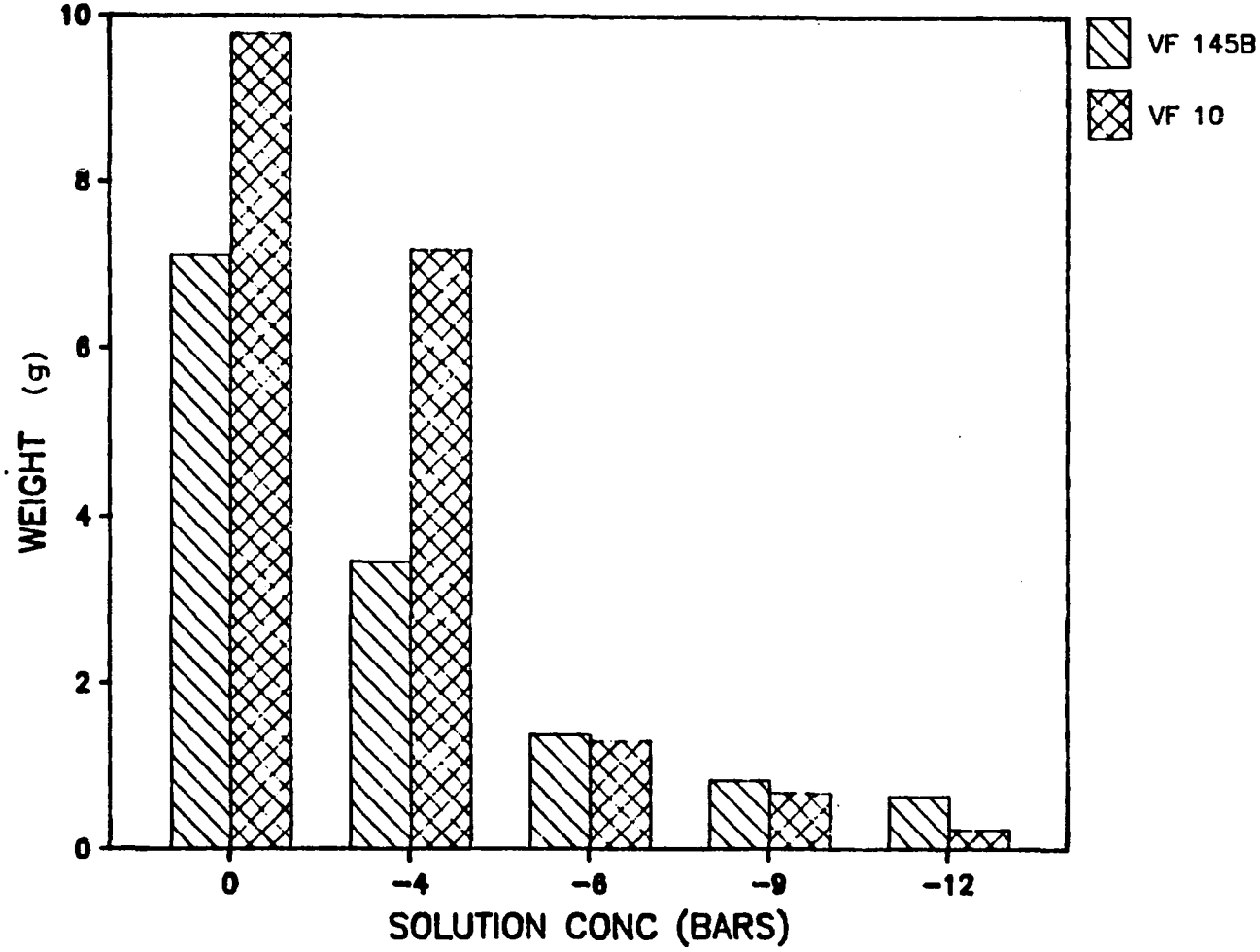

Fig. 19. Shoot dry weight (g) in two tomato cultivars as affected by various NaCl levels.

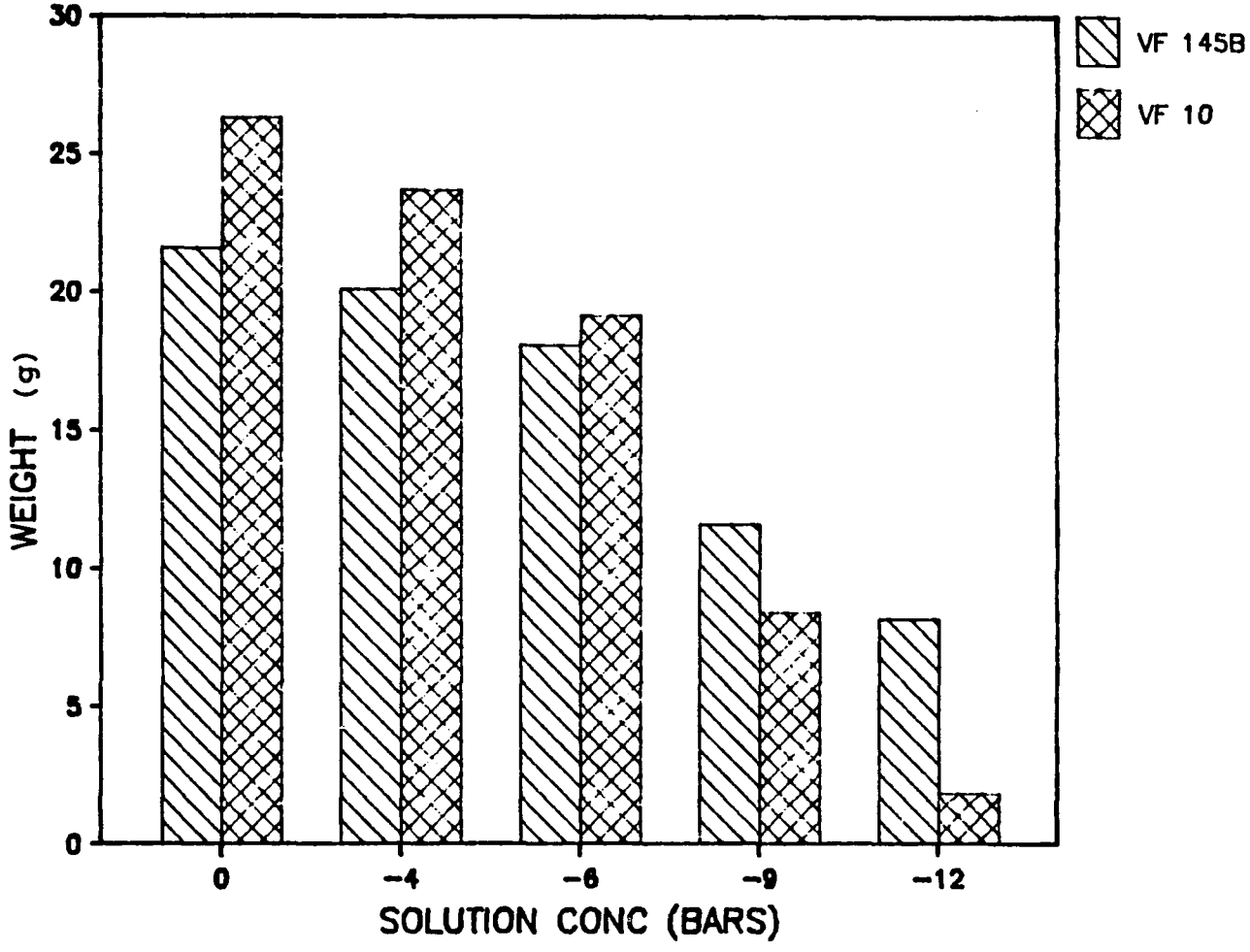

Fig. 20. Root fresh weight (g) in two tomato cultivars as affected by various NaCl levels.

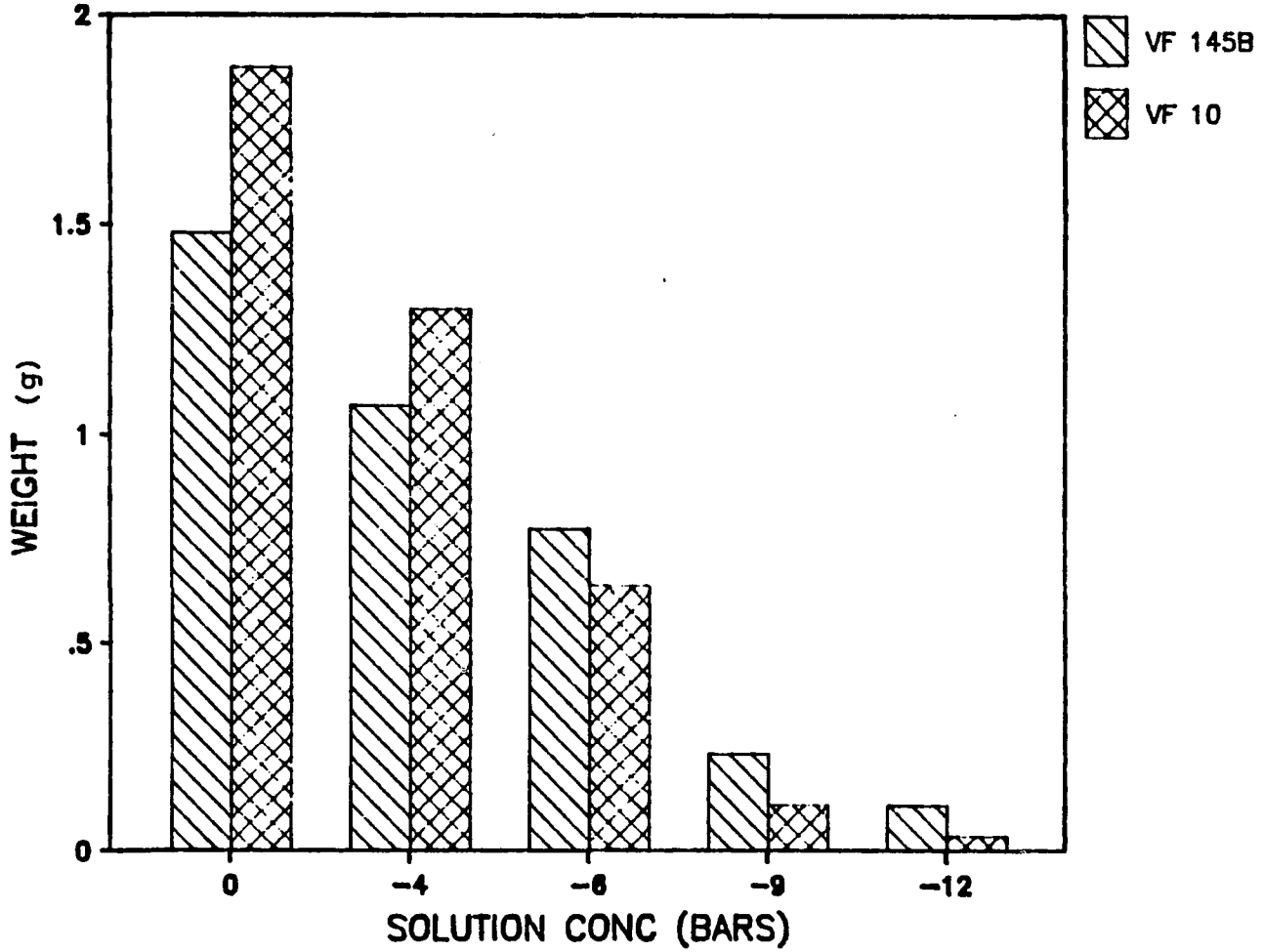

Fig. 21. Root dry weight (g) in two tomato cultivars as affected by various NaCl levels.

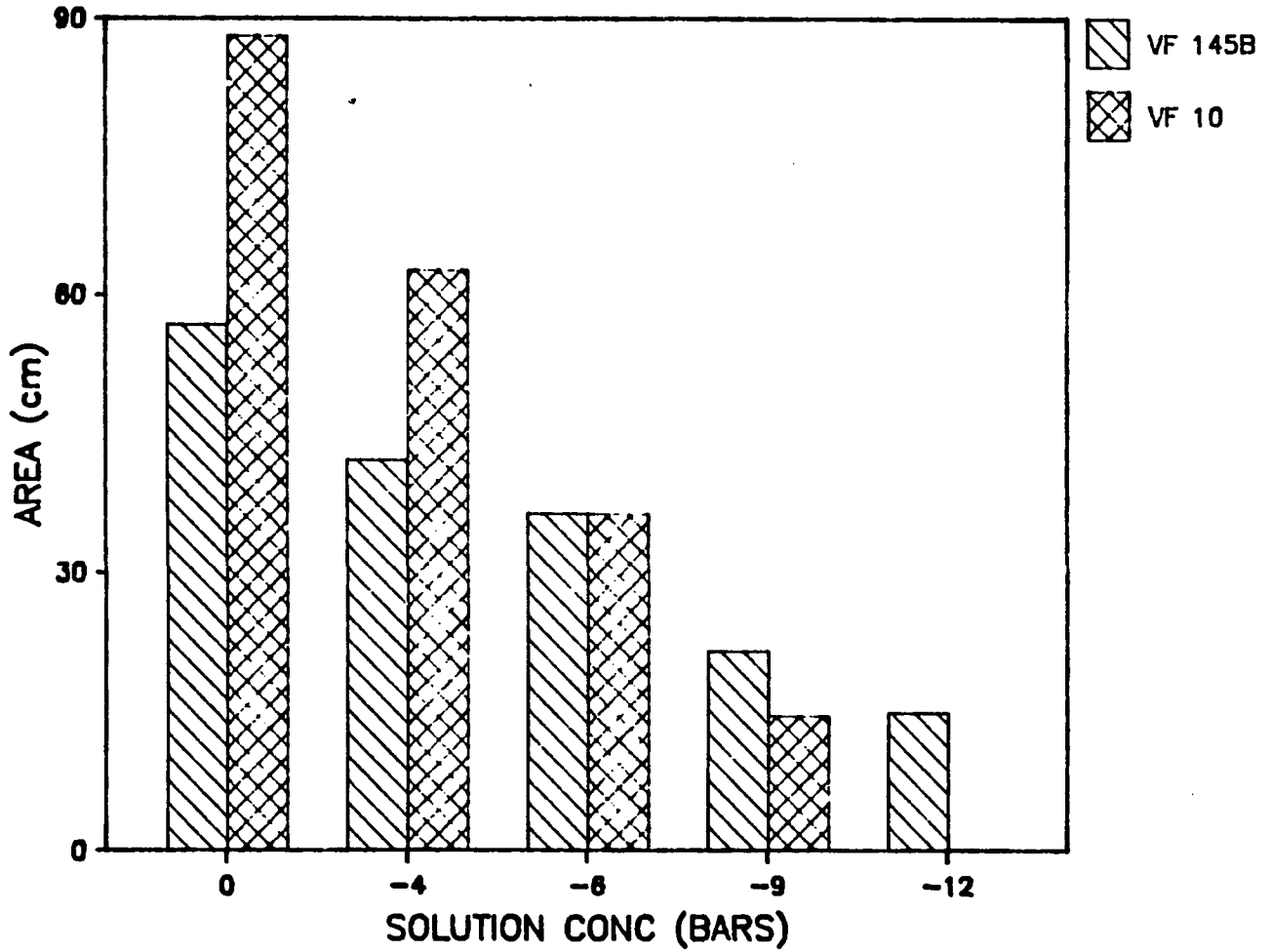

Fig. 22. Leaf area (cm^2) in two tomato cultivars as affected by various NaCl levels.

In VF 145 B leaf area was reduced by 25.7, 36.0, 62.0, and 73.6% at -4, -6, -9, and -12 bars, respectively compared to the control. A reduction of 21.7, 54.9, and 81.9%, in leaf area was noticed with VF 10 at -4, -6, and -9 bars, respectively, compared to the control (Fig. 22).

When analysis of variance was calculated for each of the physiological characteristics, significant difference were found between the cultivars in all the physiological characteristics measured. Analysis of variance was also conducted for each cultivar along with all the physiological characteristics measured, it was found that salinity level had significantly affected all of the physiological characteristics measured. (For analysis of variance regarding this experiment, see Tables B.37 through B.66 in Appendix B.)

CHAPTER 5

DISCUSSION AND CONCLUSIONS

The problem of salinity and its potential impact on plants could be solved in either one of two ways: either removing the salt from the soil itself by adequate drainage and leaching programs, which is very expensive, or by using salt tolerant plants that can maintain normal growth and metabolism in non-optimal conditions of salinity. The latter method seems to be more promising (Greenway and Munns, 1980). By the use of salt tolerant species, we can provide a way to overcome the detrimental effects of salinity on plants. Nieman (1962) studied the response of 12 crop species grown in a range of NaCl treatments and found a big difference between salt sensitive ones, which respond to salinity either by severe depression or death, and salt tolerant ones, which are stimulated by salinity.

Our results indicated that sodium chloride affected transpiration, leaf diffusive resistance and leaf temperature comparing the two tomato cultivars (Tables 1, 3, 5). For the whole experiment the trend was that VF 10 has higher transpiration, lower leaf diffusive resistance and lower temperature than VF 145B at the control and the -4 bars treatment. At

the higher salt concentrations, however, (-9 and -12 bars) VF 145B showed higher transpiration, lower leaf diffusive resistance and lower leaf temperature than VF 10 (Figs. 1-12).

The reduction in the transpiration rate may be due to less water uptake as a result of increasing salinity. O'Leary (1969) found that increasing the salinity of the growth solution by addition of NaCl reduced the permeability of kidney bean roots to water flow. Very little water could be forced through the roots under pressure as compared to roots from plants grown in non-salinized solutions.

Meiri and Poljakoff-Mayber (1969) reported a reduction in water content and turgor of bean plants when subjected to salinity. So the high leaf diffusive resistance that we found when the plants were subjected to salinity may be due to a decrease in stomatal aperture resulting from reduced turgor in the guard cells.

Higher leaf temperature under high salinity levels in the nutrient solution may be due to reduced transpiration. Reduction in transpiration rate means a reduction in the evaporative cooling system of the plant and will result in higher leaf temperature.

Tomato growth was drastically affected when plants were grown in nutrient solution in which salt was added. Shoot length, root length, shoot and root weights and leaf area were all significantly different from the control in the two cultivars. Shoot length, shoot and root weights and leaf

area for both cultivars decreased with increasing salinity level. Root length responded differently, at the -4 bars treatment, where root length increased, but at the -6, -9, and -12 bars treatment root length decreased. The increase in root length in the low salt concentration may be due to stimulation because Cl level in tissues induced high turgor pressure and enzyme stimulation (Acosta-Nunes and Ashton, 1981). Since root length increased at low salt concentration and decreased at high-salt concentration measurement of root volume may give us better indication to further understand the effect of salinity on root growth. Measuring root length alone may not be a reliable indication of the affect of salinity on root growth.

The two cultivars responded differently to all plant growth variables measured when subjected to salinity. VF 10 had higher values of the measured physiological characteristics at the control and the low salt concentration than VF 145B, at the high salt concentration VF 145B had higher values than VF 10 (Figs. 13-22).

Stavarek and Rains (1983) tried to explain the plant adaptive mechanism to deal with the presence of salt in their environment. Three strategies are possible and have been identified among plants growing in saline environments. First, avoidance of salinity. Basically it allows a glycophyte, by growing at a particular time and or/place, to survive when one would normally expect only halophytes.

Secondly, exclusion of salts, which can occur at a whole plant or cellular level. This can be done by not allowing ions into the cell in the first place or by pumping them out once they are in. Lastly, physiological tolerance by the plant to high level of salt within the tissue, which is the most significant mechanism for dealing with salt. It involves compartmentation and osmotic adjustment using inorganic and organic constituent.

Any of those mechanisms of salt tolerance are expensive in terms of energy for the plant. Plants have to spend more energy in accumulation and producing osmatica to lower water potential, transporting extra ions, and respiring more. That extra spent energy will result in a reduced growth and therefore reduced yield (Yeo, 1983).

In conclusion, results show that some genetic variability exists between the two cultivars in response to salinity. VF 10 showed better growth at the control and the low salt concentration than VF 145B. At the high salt concentration, however, VF 145B showed better growth than VF 10. So selection of tomato for salt resistance should not be based on vigorous growth under non-saline conditions. Different genes may control the salt tolerance ability of the plants at high salinity levels. Further study on the effects of salinity on yield is recommended. Also, field studies should be conducted to see the affect of salinity on plants in normal, non-controlled environments.

CHAPTER 6

SUMMARY

The effect of salinity (in the form of NaCl) on transpiration, leaf diffusive resistance, leaf temperature and plant growth was studied in VF 145B and VF 10 tomato cultivars. The experiments were done under greenhouse conditions. Seedlings were grown in aerated Hoagland's solutions at 0, -4, -6, -9, and -12 bars in a hydroponic system.

Transpiration leaf diffusive resistance and leaf temperature were evaluated after the salt was added every week for four weeks. Salinity reduced transpiration, increased leaf diffusive resistance and increased leaf temperature for both cultivars; however, the two cultivars responded differently to salinity. For the whole experiment the trend was that VF 10 had higher transpiration rate, lower leaf diffusive resistance and lower leaf temperature than VF 145B at the control and the -4 bars treatment; however, the higher salt concentrations (-9, -12 bars) showed that VF 145B had higher transpiration, lower leaf diffusive resistance, and lower leaf temperature than VF 10.

The same plants used for the transpiration study were used for the plant growth study. Shoot length, root length, shoot and root weights and leaf area were measured to determine the effect of salinity on them. Except for shoot length, which was measured every week, all other variables were measured at the end of the experiment.

Except for root length, all the physiological characteristics measured responded negatively to increasing salt concentrations. The root length of both cultivars, however, increased at the -4 bars treatment compared to the control. At the higher salinity treatments (-6, -9, and -12 bars), root length was reduced. The two cultivars kept the same trend obtained in the transpiration study with the plant growth study.

In conclusion, this study shows that genetic variability existed between the two tomato cultivars in response to salinity. Selection of tomato for salt resistance should not be based on vigorous growth under non-saline conditions since different genes may control the salt tolerance ability of the plants at high salinity levels.

APPENDIX A

FORMULA FOR HOAGLAND SOLUTION

FORMULA FOR HOAGLAND SOLUTION

Prepare two flasks. The $Ca(NO_3)_2$ must be separated from ingredients in Flask II because it will cause the nutrients to precipitate.

Flask I:

		g
a.	$Ca(NO_3)_2 4H_2O$	268.8
b.	Fe 330 sequestrene	11.3

Add (b) to 800 ml of distilled water, dissolve, and then add (a); then dissolve both nutrients by stirring. Bring the solution to a volume of 1 liter.

Flask II:

		g
a.	KNO_3	90.1
b.	$MgSO_4$	112.4
c.	$KH_2PO_4.3H_2O$	60.8
d.	H_3BO_3	0.64
e	$MnCl_2 4H_2O$	0.50
f.	$CuCl_2 H_2O$	0.56
g	MOO_3	0.01
h.	$ZnSO_4.7H_2O$	0.27

Dissolve the nutrients in 800 ml, one at a time, then bring the solution to a volume of 1 liter.

Amounts of nutrient solution that will be added to 8 liter tube every week:

1. 10 ml of nutrient solution, Flask I.
2. 50 ml of nutrient solution, Flask II.

APPENDIX B

ANALYSIS OF VARIANCE

Table B.1. Analysis of variance for transpiration ($\mu g/ cm^{-2} s^{-1}$) after 1 week of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	1.824	1.824	
Cultivars	1	4.763	4.763	10.69
Salt levels	4	952.0	238.0	534.2
Cultivars x salt level	4	30.72	7.681	17.24
Residual	9	4.009	0.4455	

Table B.2. Analysis of variance for transpiration ($\mu g\ cm^{-2} s^{-1}$) after 1 week of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.576	0.570	
Salt level	4	324.5	81.13	239.7
Residual	4	1.354	0.3385	

Table B.3. Analysis of variance for transpiration ($\mu g\ cm^{-2} s^{-1}$) after 1 week of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	1.325	1.325	
Salt level	4	658.2	164.6	255.3
Residual	4	2.578	0.6445	

Table B.4. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 1 week of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.2888E -3	0.2888E -3	
Cultivars	1	0.2977E -2	0.2977E -2	8.524
Salt levels	4	0.9764	0.2441	698.9
Cultivars x salt level	4	0.2391E -1	0.5976E -2	17.11
Residual	9	0.3143E -2	0.3492E -3	

Table B.5. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 1 week of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4624E -3	0.4624E -3	
Salt level	4	0.3616	0.9039E -1	246.0
Residual	4	4.1470E -2	0.3674E -3	

Table B.6. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 1 week of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.6399E -5	0.6399E -5	
Salt level	4	0.6387	0.1597	427.6
Residual	4	0.1494E -2	0.3734E -3	

Table B.7. Analysis of variance for leaf temperature (^{o}C) after 1 week of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.8450E -1	0.8450E -1	
Cultivars	1	0.2645	0.2645	1.724
Salt levels	4	60.26	15.07	98.21
Cultivars x salt level	4	1.233	0.3083	2.009
Residual	9	1.381	0.1534	

Table B.8. Analysis of variance for leaf temperature (^{o}C) after 1 week of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.3999E -2	0.3999E -2	
Salt level	4	24.23	6.056	25.61
Residual	4	0.9460	0.2365	

Table B.9. Analysis of variance for leaf temperature (^{o}C) after 1 week of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1210	0.1210	
Salt level	4	37.27	9.317	94.58
Residual	4	0.3941	0.9852E -1	

Table B.10. Analysis of variance for transpiration ($\mu g\ cm^{-2}\ s^{-1}$) after 2 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1051E -2	0.151E -2	
Cultivars	1	0.3001E -2	0.3001E -2	0.8441E -3
Salt levels	4	844.9	211.2	59.41
Cultivars x salt level	4	13.97	3.493	0.9823
Residual	9	32.00	3.556	

Table B.11. Analysis of variance for transpiration ($\mu g\ cm^{-2}\ s^{-1}$) after 2 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.2031	0.2031	
Salt level	4	344.1	86.03	25.74
Residual	4	13.37	3.342	

Table B.12. Analysis of variance for transpiration ($\mu g\ cm^{-2}\ s^{-1}$) after 2 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	1.215	1.215	
Salt level	4	502.0	125.5	28.22
Residual	4	17.79	4.447	

Table B.13. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 2 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.2346E -1	0.2346E -1	
Cultivars	1	0.4851E -1	0.4851E -1	12.82
Salt levels	4	1.602	0.4005	105.8
Cultivars x salt level	4	0.1437	0.3593E -1	9.496
Residual	9	0.3405E -1	0.3784E -2	

Table B.14. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 2 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.5290E -2	0.5290E -2	
Salt level	4	0.4305	0.1076	21.98
Residual	4	0.1958E -1	0.4896E -2	

Table B.15. Analsis of variance for leaf diffusive resistance (s cm^{-1}) after 2 weeks of treatment for VF10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.2401E -1	0.2401E -1	
Salt level	4	1.314	0.3285	100.4
Residual	4	0.1309E -1	0.3272E -2	

Table B.16. Analysis of variance for leaf temperature (^{o}C) after 2 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	15.17	15.17	
Cultivars	1	2.326	2.326	1.380
Salt levels	4	54.78	13.69	8.125
Cultivars x salt level	4	6.853	1.713	1.017
Residual	9	15.17	1.685	

Table B.17. Analysis of variance for leaf temperature (^{o}C) after 2 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	19.8	19.8	
Salt level	4	15.48	3.869	10.733
Residual	4	1.442	0.3605	

Table B.18. Analysis of variance for leaf temperature (^{o}C) after 2 weeks of treatment for VF 10 under different salinity levels.

Source	DF	S.S.	M.S.	F-value
Block	1	1.122	1.122	
Salt level	4	46.15	11.54	9.265
Residual	4	4.981	1.245	

Table B.19. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 3 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.3992E -1	0.3992E -1	
Cultivars	1	0.3225	0.3225	0.5915
Salt levels	4	602.1	150.5	276.1
Cultivars x salt level	4	23.56	5.891	10.81
Residual	9	4.906	0.5452	

Table B.20. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 3 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1850	0.1850	
Salt level	4	197.5	49.38	367.9
Residual	4	0.5369	0.1342	

Table B.21. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 3 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.508	0.508	
Salt level	4	428.2	107.0	115.2
Residual	4	3.717	0.9292	

Table B.22. Analysis of variance for leaf diffusion resistance (s cm^{-1}) after 3 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.7031E -2	0.7031E -2	
Cultivars	1	0.3551	0.3551	167.5
Salt levels	4	5.020	1.255	591.9
Cultivars x salt level	4	0.3417	0.8542E -1	40.29
Residual	9	0.1o08E -1	0.2120E -2	

Table B.23. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 3 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	1.323E -2	1.323E -2	
Salt level	4	1.560	0.3899	466.9
Residual	4	0.3490E -2	0.8725E -3	

Table B.24. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 3 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.7022E -2	0.7022E -2	
Salt level	4	3.809	0.9521	263.8
Residual	4	0.1444E -1	0.3610E -2	

Table B.25. Analysis of variance for leaf temperature (^{o}C) after 3 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1248	0.1248	
Cultivars	1	0.1248	0.1280	2.930
Salt levels	4	50.58	12.64	289.4
Cultivars x salt level	4	0.8026	0.2006	4.592
Residual	9	0.3932	0.4396E -1	

Table B.26. Analysis of variance for leaf temperature (^{o}C) after 3 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4411E -2	0.4411E -2	
Salt level	4	19.57	4.892	63.89
Residual	4	0.3063	0.7656E -1	

Table B.27. Analysis of variance for leaf temperature (^{o}C) after 3 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1877	0.1877	
Salt level	4	31.82	7.954	1612
Residual	4	0.1974E -1	0.4934E -2	

Table B.28. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 4 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	8.488	8.488	
Cultivars	1	2.987	2.987	5.047
Salt levels	4	790.7	197.7	334.0
Cultivars x salt level	4	49.78	12.44	21.03
Residual	9	5.327	0.5919	

Table B.29. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 4 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	5.395	5.395	
Salt level	4	246.5	61.62	83.91
Residual	4	2.938	0.7344	

Table B.30. Analysis of variance for transpiration (μg cm^{-2} s^{-1}) after 4 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	3.231	3.231	
Salt level	4	594.0	148.5	263.9
Residual	4	2.251	0.5628	

Table B.31. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 4 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.2258	0.2258	
Cultivars	1	1.019	1.019	15.88
Salt levels	4	18.58	4.645	72.37
Cultivars x salt level	4	3.926	0.9815	15.29
Residual	9	0.5776	0.6418E -1	

Table B.32. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 4 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.6400E -3	0.6400E -3	
Salt level	4	3.081	0.7703	119.6
Residual	4	0.2576E -1	0.6440E -2	

Table B.33. Analysis of variance for leaf diffusive resistance (s cm^{-1}) after 4 weeks of treatment for VF10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4182	0.4182	
Salt level	4	19.42	4.856	54.14
Residual	4	0.3588	0.8969E -1	

Table B.34. Analysis of variance for leaf temperature (^{o}C) after 4 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.3528E -1	0.3528E -1	
Cultivars	1	0.3809	0.3809	3.339
Salt levels	4	23.9	5.974	52.38
Cultivars x salt level	4	3.272	0.8179	7.171
Residual	9	1.027	0.1141	

Table B.35. Analysis of variance for leaf temperature (^{o}C) after 4 weeks of treatment VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4900E -1	0.4900E -1	
Salt level	4	5.676	1.419	17.28
Residual	4	0.3285	0.8213E -1	

Table B.36. Analysis of variance for leaf temperature (^{o}C) after 4 weeks of treatment for VF10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.2372	0.2372	
Salt level	4	21.49	5.373	48.07
Residual	4	0.4472	0.1118	

Table B.37. Analysis of variance for shoot length (cm) after 1 week of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1105E -1	0.1105E -1	
Cultivars	1	0.3100	0.3100	22.69
Salt levels	4	25.89	6.473	473.7
Cultivars x salt level	4	3.588	0.8970	65.64
Residual	4	0.1230	0.1367E -1	

Table B.38. Analysis of variance for shoot length (cm) after 1 week of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1210E -2	0.1210E -2	
Salt level	4	5.329	1.332	95.95
Residual	4	0.554E -1	0.1388E -1	

Table B.39. Analysis of variance for shoot length (cm) after 1 week of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1296E -1	0.1296E -1	
Salt level	4	24.15	6.038	375.4
Residual	4	0.6434E -1	0.1608E -1	

Table B.40. Analysis of variance for shoot length (cm) after 2 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.5832E -1	0.5832E -1	
Cultivars	1	0.1882	0.1882	5.572
Salt levels	4	79.12	19.78	585.6
Cultivars x salt level	4	9.781	2.445	72.40
Residual	9	0.3040	0.3378E -1	

Table B.41. Analysis of variance for shoot length (cm) after 2 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.5329E -1	0.5329E -1	
Salt level	4	17.12	4.280	77.38
Residual	4	0.2212	0.5531E -1	

Table B.42. Analysis of variance for shoot length (cm) after 2 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1225E -1	0.1225E -1	
Salt level	4	71.78	17.94	950.9
Residual	4	0.7549E -1	0.1887E -1	

Table B.43. Analysis of variance for shoot length (cm) after 3 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1022	0.1022	
Cultivars	1	0.9385E -1	0.9385E -1	0.4774
Salt levels	4	291.3	72.83	370.4
Cultivars x salt level	4	19.31	4.829	24.56
Residual	9	1.769	0.1966	

Table B.44. Analysis of variance for shoot length (cm) after 3 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.6724E -1	0.6724E -1	
Salt level	4	81.91	20.48	59.18
Residual	4	1.384	0.3461	

Table B.45. Analysis of variance for shoot length (cm) after 3 weeks of treatment for VF10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.3721E -1	0.3721E -1	
Salt level	4	228.7	57.18	597.3
Residual	4	0.3829	0.9573E -1	

Table B.46. Analysis of variance for shoot length (cm) after 4 weeks of treatment for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.5152	0.5152	
Cultivars	1	6.127	6.127	4.714
Salt levels	4	629.9	157.5	121.2
Cultivars x salt level	4	74.67	18.67	14.36
Residual	9	11.70	1.30	

Table B.47. Analysis of variance for shoot length (cm) after 4 weeks of treatment for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.7840	0.7840	
Salt level	4	142.2	35.55	15.89
Residual	4	8.947	2.237	

Table B.48. Analysis of variance for shot length (cm) after 4 weeks of treatment for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1681E -1	0.1681E -1	
Salt level	4	562.4	140.6	228.1
Residual	4	2.465	0.6163	

Table B.49. Analysis of variance for root length (cm) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.7814E -1	0.7814E -1	
Cultivars	1	18.53	18.53	14.02
Salt levels	4	4525	1131	856.1
Cultivars x salt level	4	145.5	36.37	27.52
Residual	9	11.89	1.321	

Table B.50. Analysis of variance for root length (cm) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.400E -2	0.400E -2	
Salt level	4	1583	395.8	227.3
Residual	4	6.966	1.741	

Table B.51. Analysis of variance for root length (cm) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.2250	0.2250	
Salt level	4	3086	771.4	653.9
Residual	4	4.719	1.18	

Table B.52. Analysis of variance for shoot fresh weight (g) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	1.735	1.735	
Cultivars	1	401.9	401.9	70.25
Salt levels	4	1342E 5	3354	586.3
Cultivars x salt level	4	1529	382.3	66.82
Residual	9	51.49	5.721	

Table B.53. Analysis of variance for shoot fresh weight (g) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	4.754	4.754	
Salt level	4	312.3	780.8	180.2
Residual	4	17.33	4.333	

Table B.54. Analysis of variance for shoot fresh weight (g) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	16.33	16.33	
Salt level	4	11825E 5	2956	798.2
Residual	4	14.81	3.703	

Table B.55. Analysis of variance for shoot dry weight (g) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1311E -1	0.1311E -1	
Cultivars	1	6.603	6.603	1119
Salt levels	4	196.5	49.12	8324
Cultivars x salt level	4	14.59	3.647	618.2
Residual	9	0.5310E -1	0.5900E -2	

Table B.56. Analysis of variance for shoot dry weight (g) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.1440E -2	0.1440E -2	
Salt level	4	59.01	14.75	1257
Residual	4	0.4695E -1	0.1174E -1	

Table B.57. Analysis of variance for shoot dry weight (g) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.3994E -1	0.3994E -1	
Salt level	4	153.3	38.32	4626.0
Residual	4	0.3313E -1	0.8283E -2	

Table B.58. Analysis of variance for root fresh weight (g) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	10.92	10.92	
Cultivars	1	0.6480E -2	0.6480E -2	0.9401E -2
Salt levels	4	1047	261.8	379.8
Cultivars x salt level	4	87.62	21.9	31.78
Residual	9	6.204	0.6893	

Table B.59. Analysis of variance for root fresh weight (g) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	2.181	2.181	
Salt level	4	265.0	66.26	873.3
Residual	4	0.3035	0.7588E -1	

Table B.60. Analysis of variance for root fresh weight (g) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	10.24	10.24	
Salt level	4	869.7	217.4	196.2
Residual	4	4.433	1.108	

Table B.61. Analysis of variance for root dry weight (g) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	0.1125E -2	0.1125E -2	
Cultivars	1	0.1625E -1	0.1625E -1	5.236
Salt levels	4	7.373	1.843	594.1
Cultivars x salt level	4	0.2335	0.5838E -1	18.82
Residual	9	0.2792E -1	0.3102E -2	

Table B.62 Analysis of variance for root dry weight (g) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4840E -2	0.4840E -2	
Salt level	4	2.619	0.6547	167.2
Residual	4	0.1566E -1	0.3915E -2	

Table B.63. Analysis of variance for root dry weight (g) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	0.4900E -3	0.4900E -3	
Salt level	4	4.988	1.247	618.8
Residual	4	0.8060E -2	0.2015E -2	

Table B.64. Analysis of variance for leaf area (cm^2) for the two tomato cultivars under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Blocks	1	12.58	12.58	
Cultivars	1	175.4	175.4	27.25
Salt levels	4	1088E	2721	422.8
Cultivars x salt level	4	1501	375.3	58.31
Residual	9	57.92	6.435	

Table B.62. Analysis of variance for leaf area (cm^2) for VF 145B under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	7.604	7.604	
Salt level	4	2209	552.2	118.0
Residual	4	18.72	4.68	

Table B.66. Analysis of variance for leaf area (cm^2) for VF 10 under different NaCl levels.

Source	DF	S.S.	M.S.	F-value
Block	1	5.084	5.084	
Salt level	4	1018E 5	2544	260.4
Residual	4	39.07	9.768	

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