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Drip and Sprinkler Irrigation of Carrots and Onions

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DRIP AND SPRINKLER IRRIGATION OF CARROTS AND ONIONS

by

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JDM

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure | Page

Figure	Page

INTRODUCTION

Drip irrigation is a relatively recent innovation in irrigated agriculture. The early days of drip irrigation extend from the 1930's into the post-World War II years when the concept was applied to irrigation of greenhouse plants (Rawitz and Hillel, 1974). Drip irrigation as a field practice, however, probably had its real beginnings in Israel in the early 1960's where much success has been reported since then. In spite of its recent beginnings, drip irrigation is gaining acceptance and popularity as a valuable method of irrigation in many parts of the world. Gustafson, et al. (1974) pointed out that in 1974 more crops were being used in drip irrigation experiments than crops that were not. Drip irrigation was introduced to California as a field practice for commercial crops in 1969 and within five years land under drip irrigation amounted to some 16,200 hectares (40,000 acres). Estimates for future utilization of drip irrigation are optimistic for many parts of the world.

As the name implies, water is dripped onto the soil surface with drip irrigation. Distribution of water to the crop is normally accomplished by small diameter irrigation lines made of polyethylene plastic. These lines are equipped with emitters to drip water at predetermined locations and rates to suit the crop and soil situation. Another form of drip irrigation is the porous tube concept in which the line is porous and water drips from the line itself rather than from emitters. The diameters of these lines range fron 9.5 mm (3/8 in) to 19 mm (3/4 in) (Marsh, et al. 1975). Water pressure in the lines is

normally low, although pressures approaching those used in sprinkler irrigation are used with certain equipment and applications. Emitter flow rates range from 1.9 liters/hour (0.5 gallons/hour) to 7.6 l/hr (2 gal/hr) with 3.8 l/hr (1 gal/hr) the most common flow rate (Marsh, et al. 1975). Because of the typically small diameter of the emitter discharge openings, a high quality water is necessary to prevent excessive plugging of emitters. Since raw water quality is rarely adequate, filtration is often necessary to improve quality.

A practice commonly associated with drip irrigation is that of maintaining a high moisture content in the root zone by utilizing slow, frequent irrigation applications (Marsh, et al. 1975). Another association commonly made with drip irrigation is that less soil volume is wetted since theoretically more control can be exercised over the location and quantity of water applied than with other irrigation methods. Rawitz and Hillel (1974) pointed out that field experience shows drip irrigation to be most advantageous when conditions are marginal for other methods. An example cited was a combination of sandy soils and saline water where surface irrigation would be inefficient and sprinkler irrigation could cause damage to foliage.

Since it appears that drip irrigation is becoming an increasingly important part of irrigated agriculture, perhaps its particular advantages and disadvantages should be further discussed, especially as they relate to South Dakota. Brosz and Wiersma (1974) cited some of the most common advantages claimed by proponents of drip irrigation: 1. Less water is used. 2. Yields are increased. 3. Crop quality is

improved. 4. Plant growth is accelerated. 5. Poorer quality water can be used. The first advantage is claimed because of the idea that less water needs to be used if less soil volume is wetted. Proponents also claim that less water losses are likely since the water is not sprayed onto the soil surface as in sprinkler irrigation where wind and larger evaporative losses can occur nor is it flooded onto the soil surface as in furrow irrigation where larger evaporative losses are also likely to occur. In addition, deep percolation losses have been said to be less with drip irrigation since application depths are normally smaller than those associated with conventional sprinkler and furrow irrigation (Goldberg, et al. 1976). The second, third and fourth advantages are claimed because a constantly moist root zone regime generally provides for better crop response than a regime which alternates between wet and dry. The last advantage is claimed because a poorer quality saline water does not wet the foliage of salt-sensitive plants in drip irrigation as opposed to sprinkler irrigation where the foliage is wetted. Proponents also feel that salts in the root zone have a less detrimental effect on crop response since the salts are kept in a dilute state in the moist root zone under drip irrigation (Goldberg, et al. 1976). Other advantages commonly claimed are: 1. Less weed growth occurs because less surface area is wetted. 2. Fertilizer can be applied through the fertilizer lines. 3. Since less surface area is wetted, cultural operations and irrigation can often take place at the same time. These three factors lead to the additional claim that field operations are made easier when drip irrigation is used (Marsh, et al.

1975).

Some of the disadvantages commonly associated with drip irrigation are: 1. Drip irrigation systems generally are more complex than other systems and thus require a patient and knowledgeable operator. 2. The soil moisture status must be monitored carefully and irrigation requirements should be known under different conditions since application amounts are generally more controlled and more frequent under drip irrigation than under other methods. 3. If the filtration is inadequate or becomes inoperational, emitter plugging soon becomes a serious problem (DeBruyn, 1973). 4. Salts which may accumulate on the soil surface or at the periphery of the wetted zone may be leached or drawn into the root zone which may harm crop growth (Marsh, et al. 1975). Depending upon the particular application, the cost associated with a drip irrigation system may or may not be advantageous over other systems. Rawitz and Hillel (1974) commented that installation costs do vary considerably, but drip irrigation systems appear to be competitive with permanent sprinkler systems.

Of course, all the claimed advantages appear attractive. Some appear more attractive in some situations than in others. For instance, although irrigation water is a valuable commodity in South Dakota, it is even more precious in areas as California and Israel where efficient utilization of water is of utmost concern. However, South Dakota's irrigated acreage is experiencing considerable growth and possibilities for more efficient use of irrigation water should not be overlooked. Although activity associated with drip irrigation has been considerable

in the southwestern United States, a 1973 issue of Irrigation Age cited a lack of research in drip irrigation in the North Central part of the United States.

Drip irrigation is normally associated with the production of specialty crops. Specialty crops are presently not grown extensively in South Dakota, but the potential for such production appears promising with the close proximity of cities and agricultural production areas in eastern South Dakota. Martin (1966) pointed out numerous instances of successful commercial horticultural operations in South Dakota. Martin observed that possibilities appeared good for more South Dakotans to earn or supplement their income from production of horticultural crops. He also pointed out that local and distant markets offer possibilities for South Dakota growers and that processing plants could become located in South Dakota when it is exhibited that these specialty crops can be more extensively grown in the state.

Many specialty crops, especially vegetables, are shallow rooted and sensitive to periods of moisture stress. This makes irrigation of vegetables necessary to their production in South Dakota since summer rainfall is normally both inadequate and undependable. A study was initiated in conjunction with the South Dakota Agricultural Experiment Station and the Water Resources Institute to evaluate irrigation of specialty crops in eastern South Dakota. Drip and sprinkler irrigation were utilized for the irrigation of two specialty crops presently grown in South Dakota, carrots and onions. The study was initiated with the following objectives:

1. To compare carrot and onion yields under drip and sprinkler irrigation.
2. To study soil moisture distribution for carrots and onions in a shallow sandy loam soil.
3. To determine irrigation requirements for carrots and onions in eastern South Dakota.
4. To compare the economics of drip versus sprinkler irrigation of carrots and onions in eastern South Dakota.

LITERATURE REVIEW

Not all of the advantages associated with drip irrigation are applicable to this study; however, certain advantages offer possibilities for eastern South Dakota and deserve further investigation. Two of these advantages appear particularly applicable to this study and research related to these advantages will be discussed. These two advantages relate to crop response and water use efficiency under drip irrigation and to the root zone environment under drip irrigation. Also discussed in the Literature Review are carrot and onion production and irrigation requirements for carrots and onions.

Crop Response and Water Use Efficiency

One of the earliest drip irrigation research reports published was that of Shmueli and Goldberg (1969). The work was conducted during the years 1965 through 1968 in the arid Arava area of Israel with drip and sprinkler irrigation of muskmelon, tomatoes, cucumbers, sweet corn and peppers. The muskmelons were also grown under furrow irrigation. Soils in the experiment ranged from a sand to a loamy sand. For one phase of the study, both good and poor quality water were used to determine interaction among irrigation methods, water quality and crop yield. When saline water (electrical conductivity 3000 mmho/cm) was used, crop yields under drip irrigation ranged from 67 percent higher for tomatoes to 133 percent higher for peppers when compared to the corresponding crop yields under sprinkler irrigation even though the same gross amount of irrigation water was applied to both treatments. A drip yield of

43.9 metric tons/hectare (19.6 tons/acre) was recorded for cucumbers while cucumbers under sprinkler irrigation produced no yield. Drip yields were also 79 percent higher than the furrow yields in the musk-melon plots. When good quality water (electrical conductivity 400 mmho/cm) and the saline water were used to irrigate tomatoes, drip irrigated plots produced 28 percent and 66 percent greater yields than the sprinkler irrigated plots for the low and high-salinity waters, respectively. Again, the same gross amount of water was applied to the sprinkler and drip treatments. Drip irrigated tomatoes showed very comparable yields for both the low and high-salinity waters.

Research by Shumeli and Goldberg (1971a) was conducted in the Arava Valley in Israel utilizing drip, sprinkler and furrow irrigation on muskmelons grown in a sand to loamy sand soil. The intervals between irrigations and the gross amount of irrigation water applied per irrigation were identical for all three treatments. Irrigations were scheduled according to evaporation from a U.S. Weather Bureau Class A pan. Applications were every two to three days and the seasonal total amounted to 645 mm (25.4 in), including 15 mm (0.60 in) of rainfall. The irrigation water used was classified as C_4S_1 according to the U.S. Salinity Laboratory. It was found that the growth rates for muskmelon plants was greatest for the drip plots followed by the sprinkler and furrow irrigated plots, respectively. This was apparently due to the greater number of leaves per plant in the drip irrigated plots. The drip plots also displayed the fastest ripening of fruit and a 58 percent and 45 percent increase in total yield over the sprinkler and furrow

plots, respectively. This increase was attributed to a greater number of fruit per plant and a greater number of fruit reaching marketable size.

Shmueli and Goldberg (1971b) also conducted research on sprinkler and drip irrigated pepper plants grown at the site of the muskmelon research. Two sprinkler and two drip irrigation treatments were used in the study. One sprinkler and one drip treatment were irrigated daily while the other two treatments were irrigated every five days. Gross irrigation amounts were identical for all four treatments on a daily basis and were scheduled by the evaporation from a Class A pan. The water used was the same as that used for the irrigation of musk-melons. Both drip treatments showed better growths and earlier fruit maturity. Also, roots in the drip irrigated plots were concentrated near the drip nozzles. Pepper yields were greater in the drip irrigated plots than in the sprinkler irrigated plots but no differences were detected between drip treatment yields and between sprinkler treatment yields.

Emergence, early growth and soil salinity of five vegetable crops under drip and sprinkler irrigation were also studied by Shmueli and Goldberg (1971c). The site of the research and the irrigation water used were again the same as the muskmelon research. The five vegetable crops were cucumber, muskmelon, tomato, pepper and onion. Double-row beds were used with 30.5 cm (12 in) between the rows. The sprinkler system was designed to deliver water at an application rate of 5 mm/hr (0.2 in/hr). The drip laterals were placed between successive pairs of

rows so that each crop row was 15 cm (6 in) away from a lateral. All plots received the same gross amount of water, based on an evapotranspiration rate of 9 mm/day (0.35 in/day). Germination was more rapid and uniform for cucumber, tomato and pepper when drip irrigation was used. No differences in germination between the two irrigation methods were noted for muskmelon and onion. The final stands of plants for all crops were well established. No differences in early growth of seedlings were noted. Average values of electrical conductivities in the 0 - 3 cm (0 - 1.2 in) soil layer were determined from soil-water extracts and found to be significantly higher in the drip plots. Chloride contents in this layer were also highest for the drip plots, being significantly higher for muskmelon and tomato.

Bernstein and Francois (1972) utilized drip, furrow and sprinkler irrigation in research on the bell pepper. Two irrigation waters were used in the study, one a relatively low-salinity water (450 mg/l salts) and the other a relatively high-salinity water (2000 mg/l salts). In 1970 the three treatments received nearly the same amount of water. The drip irrigated plants exhibited accelerated early growth for both waters compared to the furrow and sprinkler irrigated plants. Peppers which were sprinkler irrigated with the high-salinity water showed signs of salt stress and damage to the foliage. After plant roots reached the 20 cm (8 in) depth, irrigations for the sprinkler and furrow plots were scheduled when tensiometers at the 20 cm (8 in) depth indicated a matric potential of 500 cm (197 in) of water. The drip plots were irrigated daily while the sprinkler and furrow plots

received water every 6 to 7 days. The furrow and sprinkler irrigated plants showed signs of moisture stress at the end of each irrigation cycle. The 1970 yields for the low-salinity water were greatest for the drip irrigated plots. The furrow plots yielded 3 percent less than the drip plots while the sprinkler plot yields were 11 percent less. The drip yields for the saline water were 13 percent less than the low-salinity water yields. Sprinkler and furrow yields were 28 and 36 percent less than respective yields for the low-salinity water. No differences were noted in fruit size, quality or maturity for the low-salinity water except at the first harvest when drip irrigated plots produced peppers larger in size. Fruit sizes were considerably smaller for all plots irrigated with saline water. Bernstein and Francois noted that the furrow and sprinkler irrigated plants appeared under-irrigated throughout the growing season while the drip irrigated plants received an excess of water, especially before roots reached the 20 cm (8 in) depth. In 1971, all treatments received water as it was needed. After plant roots reached the 15 cm (6 in) depth, irrigations for the sprinkler and furrow plots were scheduled when tensiometer readings at the 15 cm depth indicated a matric potential of 500 cm (197 in) of water. The drip irrigated plots again received water daily while sprinkler and furrow plots received water about every five days. No yield or plant growth differences were noted in 1971 for the low-salinity water but the furrow and sprinkler irrigated plots received 20 and 32 percent more water, respectively, than the drip irrigated plots. For the high-salinity water and the same relative water use, yields were reduced by

10 percent in the drip plots, 25 percent in the furrow plots and 20 percent in the sprinkler plots when compared to the low-salinity yields. Lower yields in the sprinkler plots irrigated with the high-salinity water were attributed to flushing of surface salts into the root zone rather than foliar absorption of salts. Bernstein and Francois believe that under actual field conditions, drip irrigation of an annual crop like pepper could result in a 50 percent water savings over furrow and sprinkler irrigation.

A study by Abrol and Dixit (1972) was conducted to compare drip irrigation and basin irrigation of onions and okra. The soil was a fine sandy loam and the irrigation water was a low salt content water with an electrical conductivity of 400 mmho/cm. One drip irrigation treatment and three basin irrigation treatments were used in the study. The daily drip irrigation treatment applied 80 percent of the previous day's loss from a Class A evaporation pan. The basin irrigation treatments applied 80 percent of the accumulated pan loss when the losses totaled 35, 60 and 85 mm (1.4, 2.4 and 3.3 in), respectively. Approximately the same amount of irrigation water was applied to all four treatments for the entire growing season. Yield and average diameter of drip irrigated onions was significantly greater than basin irrigated onions of the 60 and 85 mm treatments. The yield and average diameter of basin irrigated onions decreased with decreasing irrigation frequency. The drip irrigated okra showed significant increases in number of fingers, weight per finger, total yield and height and branching of plants. Yield again decreased for the basin irrigated

plots as the frequency of irrigation decreased. The decrease in water use efficiency for the basin irrigated plots was at least partially attributed to evaporative losses from the saturated soil surface. Root dry weight for okra was greatest for the drip irrigated plots and decreased in the basin irrigated plots as irrigation frequency decreased. Root length, however, was greatest for the basin irrigated plots with the lowest irrigation frequency and decreased as irrigation frequency increased.

Research by Hiler and Howell (1972) with grain sorghum grown in a field lysimeter showed yield and water use efficiencies to be significantly greater for drip irrigation than surface irrigation. In 1971, drip irrigated plants were larger than the surface irrigated plants, both in terms of height and leaf area. This difference was attributed to the more frequent drip irrigations which seemed to reduce crop water deficits. Drip irrigation studies in 1972 showed that the greatest water use efficiency was obtained by irrigating with frequent small amounts. Water use efficiency was 50 percent less when grain sorghum was drip irrigated with 110 percent of the measured soil moisture depletion than when irrigated with 40 percent of the depletion. Total yield was 27 percent greater in the 110 percent treatment than in the 40 percent treatment, however.

Gornat, et al. (1973) reported that sprinkler irrigation of tomatoes and cucumbers produced lower yields compared to drip irrigation when saline water (700 mg chloride/liter) was used. This difference in yield was largely attributed to the high salt concentration in the

foliage of the sprinkler irrigated plants. Drip irrigation avoided direct contact between the saline water and the foliage and provided a more favorable salt balance in the leaves. When pepper plants were drip and sprinkler irrigated with a water of lower salinity (95 mg chloride/l), no yield differences were recorded even though the sprinkled plants seemed to mature more rapidly.

Research by Brosz and Wiersma (1974) showed significantly greater yields for potatoes and corn under drip and subsurface irrigation than for yields under conventional and solid-set sprinkler irrigation. The study was conducted at the site of the field investigation for this thesis in a Fordville Sandy Loam. Irrigation on the solid-set sprinkler plots was scheduled to keep the soil moisture in the 60 to 80 percent range of available moisture. Water was applied to the drip and subsurface plots based on the amount and timing of water applied to the solid-set plots. The irrigation water application to the drip and subsurface plots was approximately 0.80 times the gross amount applied to the solid-set plots. In the conventional sprinkler plots, available moisture was allowed to deplete to about 50 percent of its total value before being irrigated back to field capacity. One conclusion of the study was that drip and subsurface irrigation could increase corn and potato yields 5 to 15 percent using 20 percent less water than sprinkler irrigation. Another conclusion was that drip and subsurface irrigation allowed more efficient utilization of water. Maturity and quality of potatoes were not affected by the particular irrigation treatment used, but black masses of spores were found on ears of corn plants irrigated

by the solid-set sprinklers.

Bucks,et al. (1974) studied drip, modified furrow and standard furrow irrigation of cabbage grown in a clay loam. All plants were grown on elevated beds with two rows to a bed. The drip treatment consisted of a lateral located in between these rows on each bed. The modified furrow treatment was irrigated by means of a channel, also located in between the rows on each bed. Standard furrow irrigation consisted of flooding water in between the beds. Twelve drip irrigation treatments and five modified-furrow treatments were used. In the drip irrigated plots, water was applied at 1.25, 1.0, 0.75 and 0.5 times the predicted actual evapotranspiration amount at 3, 6 and 12-day intervals. In the modified-furrow plots, water was applied at 1.25, 1.0, 0.75 and 0.5 times the predicted actual evapotranspiration amount every 6 days, and 1.0 times the predicted actual evapotranspiration amount was applied every 12 days. The standard furrow irrigated plots received water when the available moisture was depleted by 55 percent. The same yield was achieved by all three methods of irrigation. The drip irrigated plots and modified-furrow irrigated plots had similar water use efficiencies but the standard furrow plots used 22 percent more water in producing a comparable yield. When water was applied at 1.25 times the predicted actual evapotranspiration rate, no yield differences were noted between 3, 6 and 12-day irrigation intervals for the drip irrigated plots. The three-day irrigation interval plots showed yield reductions when water was applied at 1.0, 0.75 and 0.5 times the consumptive use rate, however. This demonstrates that the concept of

frequent water application may not always be the best management plan for drip irrigation. Soil and crop considerations may dictate irrigation practices not commonly associated with drip irrigation.

Grimes, et al. (1976) reported approximately equivalent yields of tomatoes for plants irrigated at frequent (thrice weekly) intervals by drip irrigation and plants irrigated at less frequent (once weekly) intervals by furrow irrigation. No significant differences were noted for tomato sizes between the two treatments. When tomatoes were drip irrigated less frequently (once weekly) lower yields resulted. This treatment was expected to have induced considerable drought stress, however. The duration of each irrigation application was the same for all treatments regardless of irrigation frequency. However, total water use data were not reported.

Hall (1974) also studied drip and furrow irrigation of tomatoes. For sandy soils in particular, Hall found that drip irrigation resulted in comparable or significantly greater yields along with a water savings. In heavier soils, however, Hall believed that water savings may not be quite so pronounced.

Drip irrigation offers promising potential for orchard applications as well as for row crops. Black and Mitchell (1974) showed that the root systems of mature pear trees previously irrigated by sprinkler irrigation adapted to drip irrigation without problems. In less than two seasons the extensive root systems of the eighteen-year old trees changed to a concentrated root system in the drip irrigated zone. No signs of water stress or changes in fruiting were observed.

Similar results were obtained by Willoughby and Cockroft (1974). Extensive root systems of mature pear trees changed to an intensive root system when drip irrigation was initiated. Roots outside the wetted area ceased to function while roots in the saturated zone died. The proliferation of new roots occurred in the soil between these extremes. Again, no changes in fruiting were noted. Drip irrigation of young peach trees was also investigated. It was found that the young trees would quickly establish an extensive root system in the soil zone between the saturated area and the dry area.

Research conducted on avocados by Gustafson, et al. (1974) indicated that drip irrigated trees could achieve growth equivalent to that of sprinkler irrigated trees while using only half as much water. Similar results were reported by Aljibury, et al. (1974) for orange and plum trees. Significant water savings under drip irrigation were noted for both crops, yet the yields obtained were very comparable for the two irrigation methods.

With the advent and growing utilization of drip irrigation, more research is becoming available to study its possibilities. Much of the work being done reports increased yields and water use efficiencies by drip irrigation over more conventional methods. This is true of both row crops and orchard crops, particularly in arid areas where saline water is used for irrigation.

The Root Zone Environment Under Drip Irrigation

Under conditions of low moisture stress, soil moisture is not a limiting factor in plant growth and yield. DeBruyn (1973) stated that

drip irrigation is based upon the principle of better plant response under conditions of low moisture stress. This is because drip irrigation systems are normally designed to keep soil moisture in the vicinity of the root zone at or near field capacity. DeBruyn also noted that water distribution is more uniform and controlled because the drip laterals are close to the plant rows and that application rates can be adjusted for the particular plant and soil.

Hoare, et al. (1974) also referred to some of the characteristics of drip irrigation as related to crop moisture use. One of the purposes of drip irrigation is to match the application rate with the evapotranspiration rate while maintaining low moisture stress in the root zone. In sandy or porous soils, this often means daily irrigation. For finer soils, less frequent applications can be adequate although application rates must not exceed the infiltration rate. The wetted zone under drip irrigation is normally "pear-shaped" or "cone shaped" according to Hoare. The size of this zone depends upon the discharge and locations of the outlets, conductivity of the soil and moisture use by the irrigated crop. This wetted zone encourages root development within its boundaries and thus limits the volume of soil which requires irrigation.

Shmueli and Goldberg (1971b) reported higher soil moisture contents with drip than with sprinkler irrigation of peppers on the day after water application. This was because the same amount of water was applied for each treatment but the drip laterals wet only a narrow strip rather than the entire soil surface. It was noted, however, that

the decrease in soil moisture content after five days was greater in the drip irrigated plots than in the sprinkler irrigated plots. This was attributed to a higher evapotranspiration rate with drip irrigation. The authors pointed out that the interval between irrigations is an important factor in determining the type of moisture stresses that plant roots will be exposed to during the growing season. Shmueli and Goldberg (1972) further emphasized this in their work with subjecting peppers to different water regimes. Hydraulic conductivity and thus the plant water supply in sandy soils vary considerably with changes in moisture content. Therefore it is important to extend the time that the soil moisture content does not limit plant water supply. This is particularly true when evapotranspiration rates begin to increase. To maintain an adequate plant water supply in a sandy soil, it would appear that frequent, small applications would give the best results.

S. D. Goldberg (1973) pointed out that differences in soil moisture status between sprinkler and drip irrigation are normally due to differing irrigation practices associated with the methods. A sprinkler system is often regarded as moveable, irrigating a given location only periodically. A drip system is stationary, which allows daily irrigation to restore evapotranspiration needs. However, both methods can also be utilized on a daily basis by changing the sprinkler system to a fixed or solid-set system. The disadvantage of the moveable sprinkler approach is that less frequent sprinkler applications result in a less favorable irrigation regime. The disadvantage of the solid-set sprinkler approach is that there are inherent problems associated

with this approach. For example, daily sprinkling would result in greater water losses than drip irrigation or less frequent sprinkling. Wiersma (1963) pointed out that more evaporation losses occur from soil or leaf surfaces than from the spray during irrigation. Since a given amount of water is required to wet the soil and plant surfaces, these losses would be a greater percentage of smaller applications than of larger applications.

Grimes et al. (1976) reported that frequent (thrice weekly) drip irrigation of tomatoes provided the most favorable moisture regime when compared to furrow irrigation and an infrequent (once weekly) drip treatment. Infrequent (once weekly) furrow irrigation also produced a favorable, although drier, moisture regime. Frequent (thrice weekly) furrow irrigation resulted in serious surface sealing problems which produced very high matric potentials below 15 cm (6 in). The infrequent drip treatment produced the worst moisture regime because not enough water was added to avoid serious moisture stresses.

Drip irrigation would appear to be the method best adaptable to light, frequent water applications when evaluated in terms of water savings, water distribution uniformity in the root zone and application control. Since drip irrigation is frequently used with saline waters, the root zone environment with respect to salinity is an important consideration.

Shmueli and Goldberg (1969) drip irrigated grapevines for 1.5 years with a saline water (electrical conductivity 3000 mmho/cm). Three zones of soil salinity concentration were found when salinity

measurements were taken. Roughly the top 30.5 cm (12 in) had salinity concentrations increasing in the direction of the drip orifice and soil surface. Low to medium salt concentrations were found in approximately the next 61 cm (24 in) of soil depth where plant roots tended to congregate. The lower zone showed an increase in salinity with depth. Salinity measurements taken in sweet corn plots at the end of the growing season showed similar salinity levels in the top 15 cm (6 in) for drip and sprinkler treatments. Below that, salinity in the drip plots decreased while salinity in the sprinkler plots increased. Furrow irrigated plots showed the highest salinity levels up to the 107 cm (42 in) depth where measurements were terminated. It appeared from these results that salts accumulated toward the edge of the wetted zone and on the soil surface when drip irrigation was used.

Similar results were noted by Shmueli and Goldberg (1971c) in a salinity study with five vegetable crops. As previously noted, electrical conductivity and chloride content were higher in drip plots than in sprinkler plots for the top 3 cm (1.2 in) of soil. Soil salinity profiles vary for different irrigation methods according to the authors. In sprinkler irrigation, salinity increases with depth due to downward leaching of salts. In drip irrigation, salinity increases with distance from the nozzle since water radiates from the nozzle with both horizontal and vertical components. It was pointed out that these general patterns change as more irrigations occur and as plant growth continues.

Bernstein and Francois (1973) also found salts to accumulate on

the soil surface and at the periphery of the wetted zone in drip irrigation. It was observed that these surface salts could easily leach into the root zone through the action of rainfall. Immediate irrigation would probably be required to leach these salts out of the root zone, although this effort may not always be successful.

In terms of root zone environment, soil moisture is not always the only factor which has a bearing on crop yield and quality. Abrol and Dixit (1972) reported lower soil strengths in a fine sandy loam for drip irrigation than for furrow irrigation. This was believed to be an important factor in obtaining greater onion yields and larger onions in the drip plots than in the furrow plots. Soil strengths in the furrow irrigated plots increased with decreasing irrigation frequency. It is logical to assume that a root or bulb crop has more potential for growth in a low strength medium than a high strength medium.

Certain crops are more sensitive to root zone temperature than others, e.g. potatoes. Singh,et al. (1974) reported comparable potato yields and quality for drip irrigation when compared to furrow irrigation. Maintaining a relatively cool soil temperature range is important in potato production. It was noted that drip irrigation offered good possibilities in this respect.

Drip irrigation appears capable of maintaining a constantly favorable root zone environment. One important reason for this is that daily irrigation provides a constant water supply at low matric potentials. This would appear to be true for saline and non-saline water supplies. Also, drip irrigation appears to lower soil strengths

providing for better root and bulb crop growth and has possibilities for providing healthy root zone environments for temperature sensitive crops.

Carrot and Onion Production

Carrots and onions are two commonly and extensively grown vegetable crops which offer potential for commercial production in South Dakota. According to Fogel and Ayres (1955), market gardening is an important business near the more populated areas of South Dakota. Successful production of vegetables and fruits requires irrigation since South Dakota rainfall is limited during the summer production months. Irrigation of these crops permits earlier maturity and improves appearance, quality and yield.

Campbell (1953) stated that vegetable crops are commonly more expensive to produce than general field crops, in spite of a shorter growing season. Initial costs of fertilizer, seed and plants, and labor are largely responsible. In terms of root depth, onions are classified as shallow-rooted and carrots as moderately deep-rooted. Campbell estimates that shallow-rooted crops require 3.8 cm (1.5 in) of water every week to ten days while moderately deep-rooted crops require 3.8 to 5.0 cm (1.5 to 2.0 in) for the same period.

Jones, et al. (1957) reported that onions grow best on slightly acid soil (pH 6.0 to 6.5). Sandy loams are generally best for onion production as the leaching of nutrients below the root zone is kept to a minimum. In terms of irrigation, Jones noted that a steady water supply is important to onion production because onions that suffer a

growth set-back may split into a double bulb when irrigation is resumed and thus reduce the percentage of fresh market quality bulbs. It may be difficult to determine if onions are suffering moisture stress, however, as the onion will still appear vigorous and healthy. Over-irrigation can also cause a yield reduction of onions. Shallow cultivations to prevent excessive weed growth are important in obtaining maximum yields.

Laver (1972) also stressed the importance of irrigation in obtaining maximum onion yields. Frequent irrigation is the best irrigation practice for onions according to Laver. But overwatering results in problems with onion shapes such as thick necks. Laver separated onion growth into three stages: 1. Top growth, no bulb development, 2. Rapid top and bulb growth and 3. Slower top growth, still quite rapid bulb growth. For irrigation practices, Laver recommended a few frequent applications after planting to assure good germination and establishment, less frequent applications during top growth and more frequent irrigation during rapid bulb development. Irrigation frequencies and amounts should steadily diminish late in the growing season to permit bulb maturation.

Van Eeden and Myburgh (1971) conducted research on furrow irrigation of onions. Soil moisture data indicated that 90 percent of the water consumed came from the top 30 cm of soil. This would indicate rooting depths of at least 30 cm. Narang and Dastane (1971) said that onion rooting depths were commonly 8 cm (3.2 in) or less with roots seldom deeper than 15 cm (6 in). Fogel and Ayres indicated that the

onion is a shallow-rooted crop with a rooting depth less than 46 cm (18 in).

A USDA leaflet by Boswell (1966) provided considerable information concerning carrot production. Boswell described the carrot as a cool season vegetable which produced best in mild climates free of temperature and precipitation extremes. Mean temperatures of 15.6°C to 21.2°C (60°F to 70°F) are best. Carrots are not tolerant to drought and require relatively large amounts of moisture. Good water distribution is essential to permit rapid, continuous growth. In warmer and drier areas, irrigation applications usually amount to more than an inch every week to ten days. Deep sandy loam or muck soils are best for carrot production as these soils are easy to work and permit good development. Poor soil structure or obstructions may cause poorly shaped carrots which is undesirable for fresh market carrots. Row widths for carrots range from 30.5 cm to 61 cm (12 in to 24 in) with 46 cm to 51 cm (18 in to 20 in) being the most common widths.

Irrigation Requirements for Carrots and Onions

Efforts to obtain crop coefficient curves for truck crops have not been very successful according to Robb (1966). A crop coefficient is the ratio of the actual to potential evapotranspiration for a particular crop during a specific time period. Plots of crop coefficients versus time of the growing season are useful in estimating irrigation requirements from potential evapotranspiration data. Crop coefficients greatly in excess of 1.0 have been obtained which indicates that deep percolation water may have been included in actual evapotranspiration

estimates. Because potential evapotranspiration is the maximum evapotranspiration that can occur under given climatic conditions, crop coefficients larger than 1.0 are in error.

Work on potential and actual evapotranspiration for onions was done in India by Narang and Dastane (1971). The work was done on three moisture regimes: (1) 0 - 0.3 atmosphere tension; (2) 0 - 0.6 atm. tension and (3) 0 - 0.8 atm. tension. Actual evapotranspiration rates were computed according to soil moisture depletions which were determined gravimetrically. Potential evapotranspiration values were found by utilizing the empirical formulae of Penman and Thornthwaite and by measuring daily pan-evaporation values from a U.S. standard open-pan evaporimeter. The authors believed that the Thornthwaite formula consistently underestimated potential evapotranspiration for the entire growing season. Basically, this was attributed to the formula ignoring some of the important weather parameters. The Penman formula appeared to give high values in the colder months of growth and low values during the warming and hotter months. The Penman formula was found to underestimate potential evapotranspiration most seriously in the wettest moisture regime because of the nearly unlimited moisture supply. The best correlation between actual evapotranspiration and potential evapotranspiration for all three moisture regimes was obtained using pan-evaporation data. The 0 - 0.6 atm. tension regime was found to be the best regime economically. Scheduling of irrigations for this regime using 0.7 times the pan evaporation was determined to be the best management plan.

Van Eeden and Myburgh (1971) also conducted research in South Africa on the feasibility of using pan-evaporation data to schedule irrigations for onions. Actual evapotranspiration rates were determined from soil moisture depletion measurements which were taken before each irrigation and analyzed gravimetrically. Evaporation was measured from a U.S. Weather Bureau Class A pan. Other work by the authors indicated that onions will seldom be subjected to high moisture stress if water is applied when 60 percent of the available moisture has been depleted. This favorable soil moisture regime could be achieved according to Van Eeden and Myburgh by using pan-factors of 0.3, 0.4, 0.5 and 0.6 for the first four two-week periods following transplanting. After this, a factor of 0.7 could be used until irrigation is halted. It was recommended that this data could be applied only to climates similar to the Transvaal Middleveld in South Africa where the research was conducted. Climatic information was not presented, however.

A bulletin published by the California Department of Water Resources listed measured monthly evapotranspiration for several principal crops. Evapotranspiration was measured using gravimetric sampling, lysimeters, and later neutron probes which replaced gravimetric sampling. The data were taken at Lompoc Station which is eight miles from the Santa Ynez Valley. The values given represent actual evapotranspiration in fields under well-managed conditions. Plots for the studies were located in large fields to assure uniform, realistic surroundings. The monthly evapotranspiration values for carrots for the months July, August, September and October were reported as 6.10 cm

(2.4 in), 9.65 cm (3.8 in), 9.65 cm (3.8 in) and 8.64 cm (3.4 in) respectively. This amounts to a total of 34.04 cm (13.4 in) for the growing season. The bulletin also published recommended monthly crop coefficients for the principal California irrigated crops. These values for carrots during the months July, August, September and October were 0.35, 0.62, 0.76 and 0.79 respectively. The low July value represents the water requirements of a young carrot crop planted in mid-July.

RESEARCH PROCEDURE

The field investigation portion of the study was conducted in 1974 and 1975 at the South Dakota State University Agricultural Engineering Research Farm located about 11 km (7 mi) southwest of Brookings. According to the Climatological Summary for Brookings (National Weather Service, 1971), the local climate is a continental type. The average annual precipitation is 52.3 cm (20.59 in) of which 80 percent normally falls in the months April through September. The average last frost date in spring is May 17 and the average first frost date in fall is September 21 for an average growing season of 127 days.

The author was not associated with the 1974 field investigation, which was preliminary in nature and provided useful information for the 1975 field investigation. The 1975 portion of the study will be discussed first in each Research Procedure subheading followed by the 1974 discussion because more extensive data were taken in 1975.

Experimental Plot Layouts and Irrigation Systems

Carrots and onions were grown in a Fordville sandy loam which is about 46 cm (18 in) deep underlain by sand and gravel. One sprinkler and three drip irrigation treatments, with four replications of each treatment, were used in the study. The location of the experimental area at the Farm is shown in Figure 1. Drip irrigated carrots, drip irrigated onions, sprinkler irrigated carrots and sprinkler irrigated onions were each grown in separate areas. The drip treatments were randomly assigned to the experimental plots for both crops. A plot

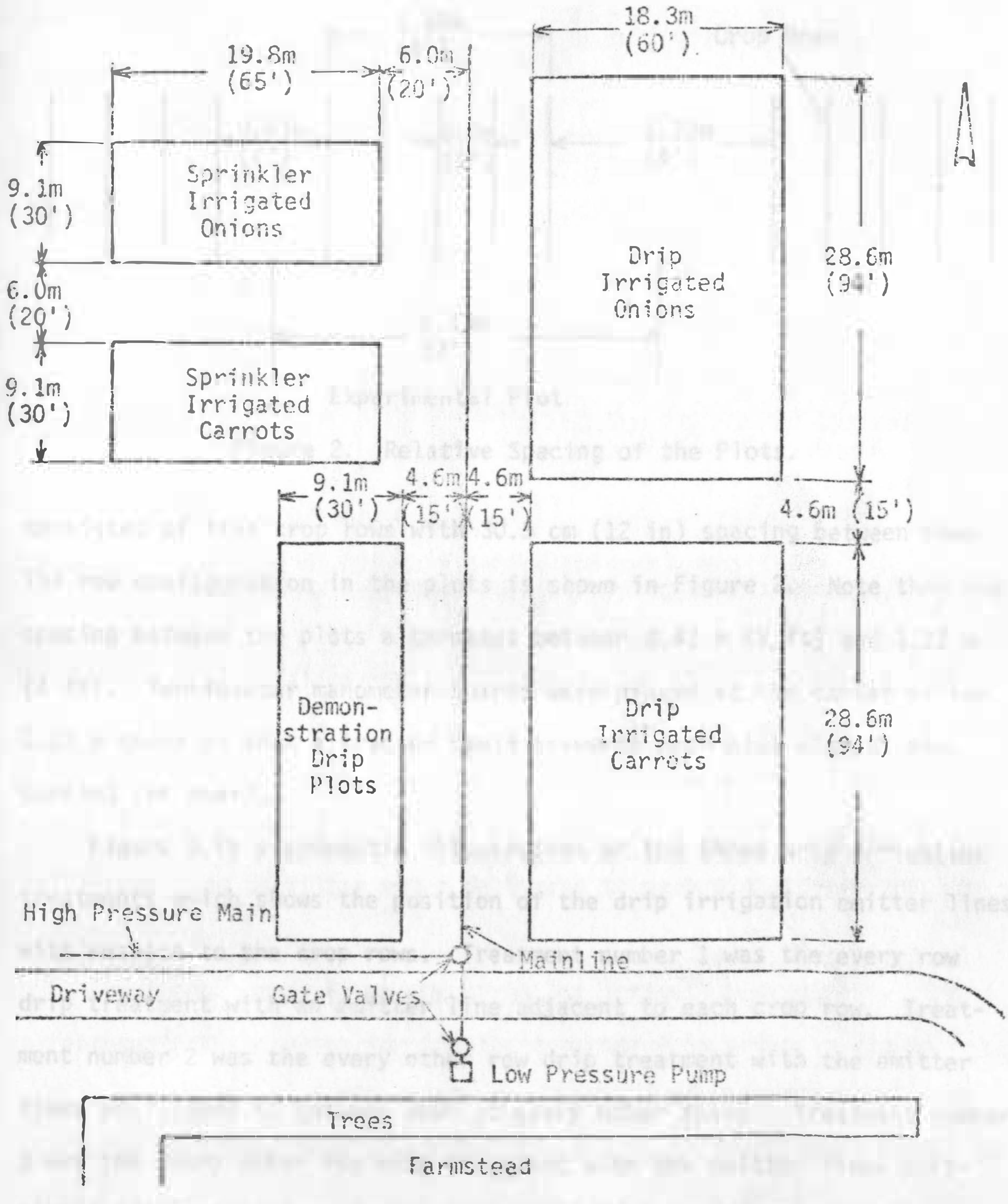


Figure 1. Carrot and Onion Plot Locations at the South Dakota State University Agricultural Engineering Research Farm, 1975.

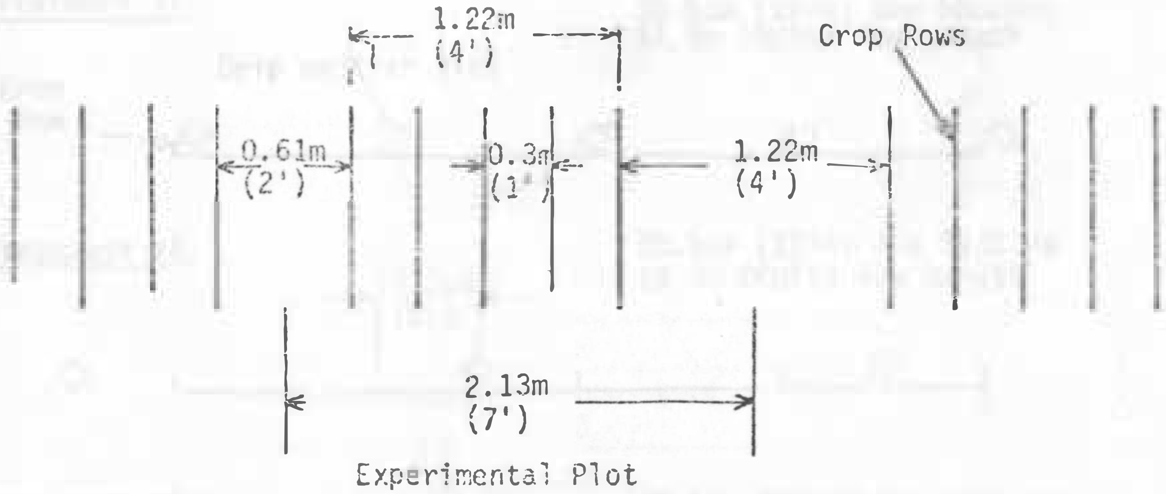


Figure 2. Relative Spacing of the Plots.

consisted of five crop rows with 30.5 cm (12 in) spacing between rows. The row configuration in the plots is shown in Figure 2. Note that the spacing between the plots alternates between 0.61 m (2 ft) and 1.22 m (4 ft). Tensiometer manometer boards were placed at the center of the 1.22 m space so that a tractor could traverse each plot without disturbing the board.

Figure 3 is a schematic illustration of the three drip irrigation treatments which shows the position of the drip irrigation emitter lines with respect to the crop rows. Treatment number 1 was the every row drip treatment with an emitter line adjacent to each crop row. Treatment number 2 was the every other row drip treatment with the emitter lines positioned in between rows at every other space. Treatment number 3 was the every other row drip treatment with the emitter lines positioned adjacent to every other crop row. Plot locations are shown in Figure 4 for the drip irrigated carrots and in Figure 5 for the drip irrigated onions. Figure 6 illustrates the arrangement of the drip

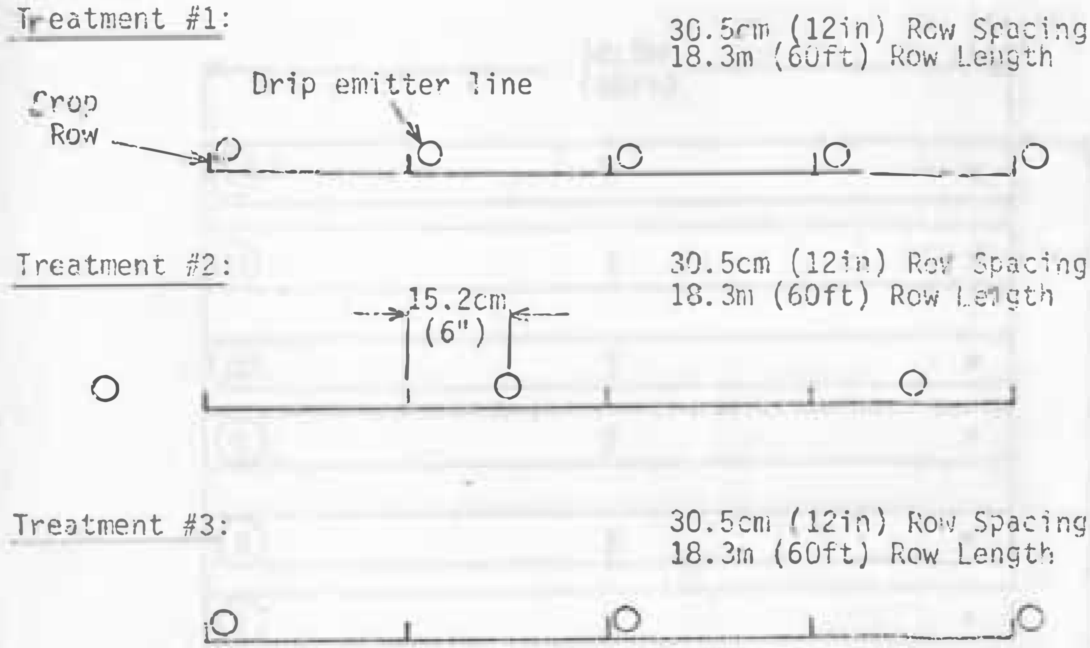
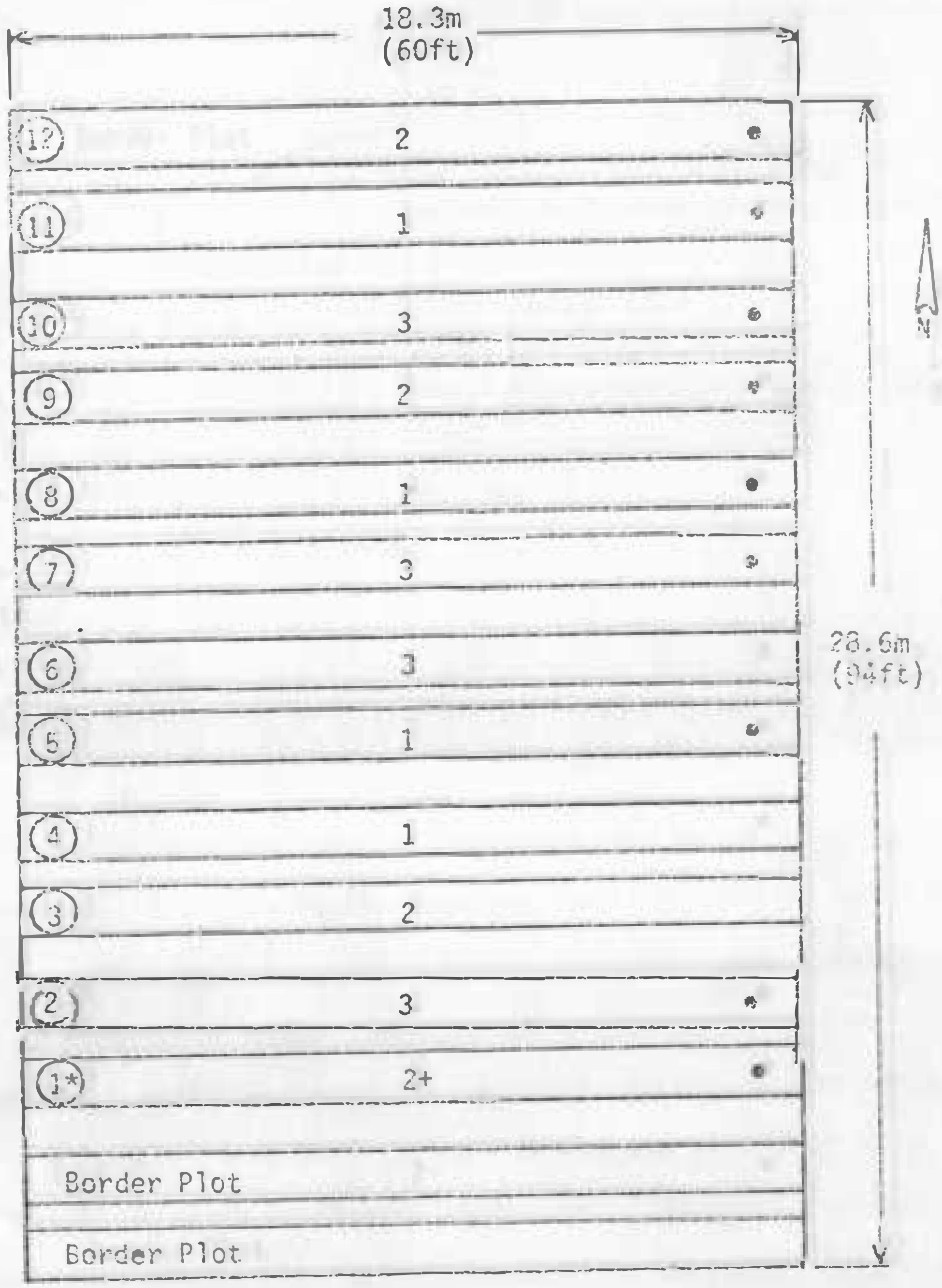


Figure 3. Position of Drip Irrigation Emitter Lines Relative to Crop Rows for Drip Irrigation Treatments.

irrigation emitter lines and appurtenances for the irrigation of one plot, in this case for treatment number 2. The drip emitter lines were 1.27 cm (0.5 in) inner diameter polyethylene plastic with Submatic 0.508 mm (0.020 in) emitters inserted every 22.9 cm (9 in). A 100 mesh filter was used to filter water delivered to each plot to prevent clogging of emitters.

Treatment number 4 was the sprinkler irrigation treatment. The arrangement of the plots for treatment number 4 is shown in Figure 7 and in Figure 8. Sprinkler heads were located at the corners of both sprinkler treatment plot areas and midway between these heads along the length of the plots. The sprinkler heads used were 23° Rainbird 25A heads with 0.28 cm (7/64 in) split-type nozzles. The heads were located on 1.25 cm (0.5 in) diameter risers 45 cm (18 in) in length.

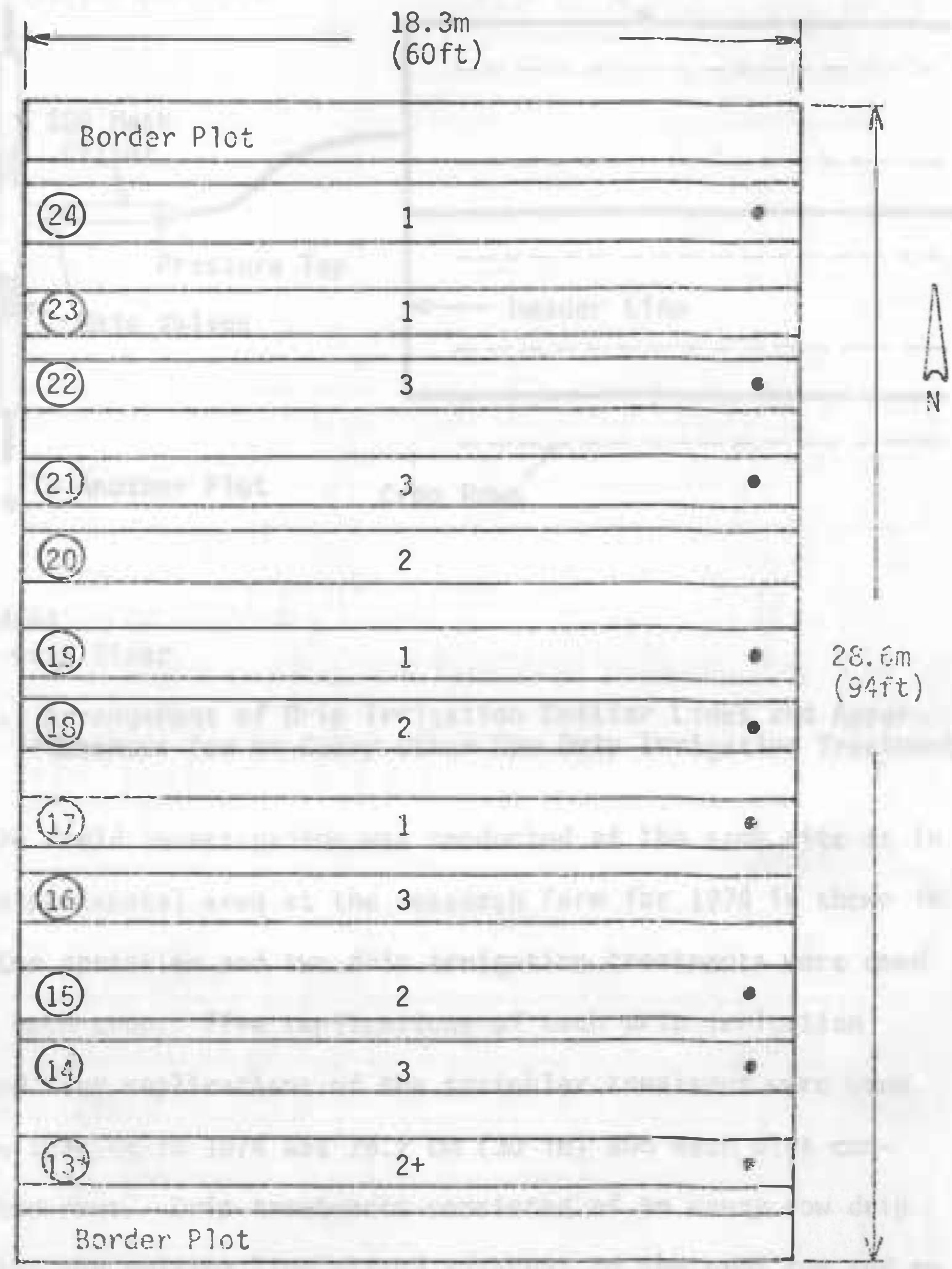


* Circled Number Represents Plot Number

• Denotes a Plot with a Tensiometer Bank

+ Number Represents Treatment Number

Figure 4. Plot Location for Drip Irrigated Carrots.



* Circled Number Represents Plot Number

● Denotes a Plot with a Tensiometer Bank

\+ Represents a Treatment Number

Figure 5. Plot Locations for Drip Irrigated Onions.

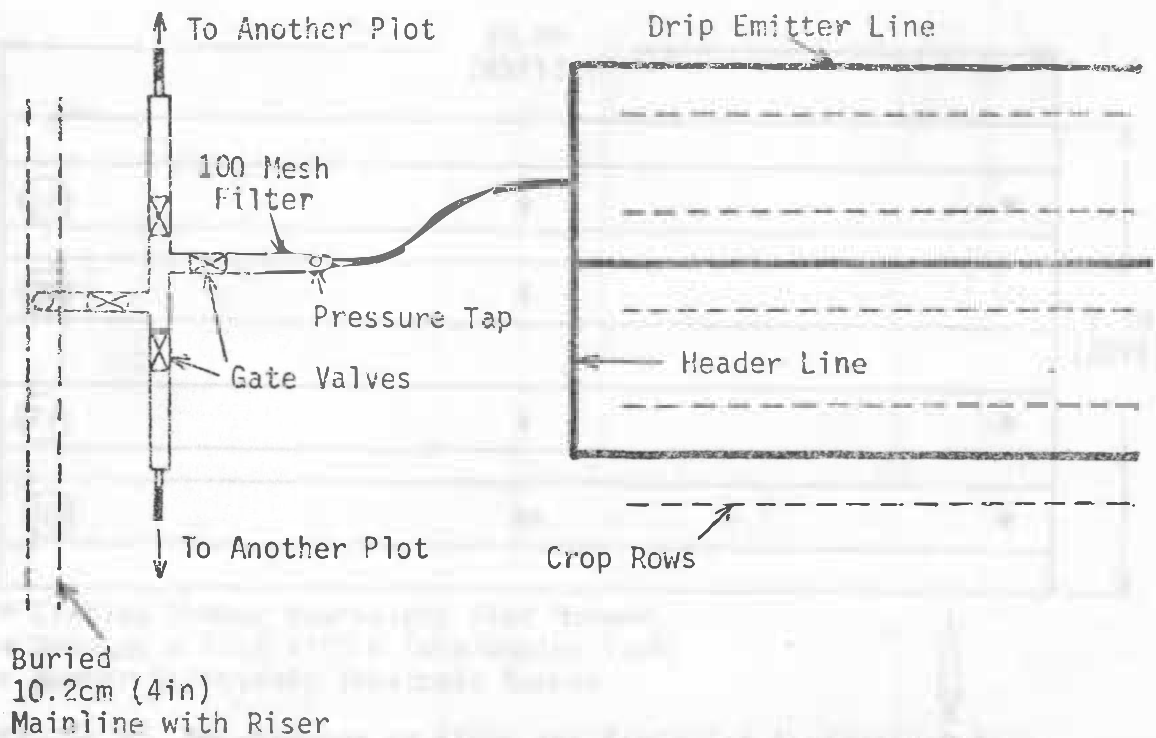
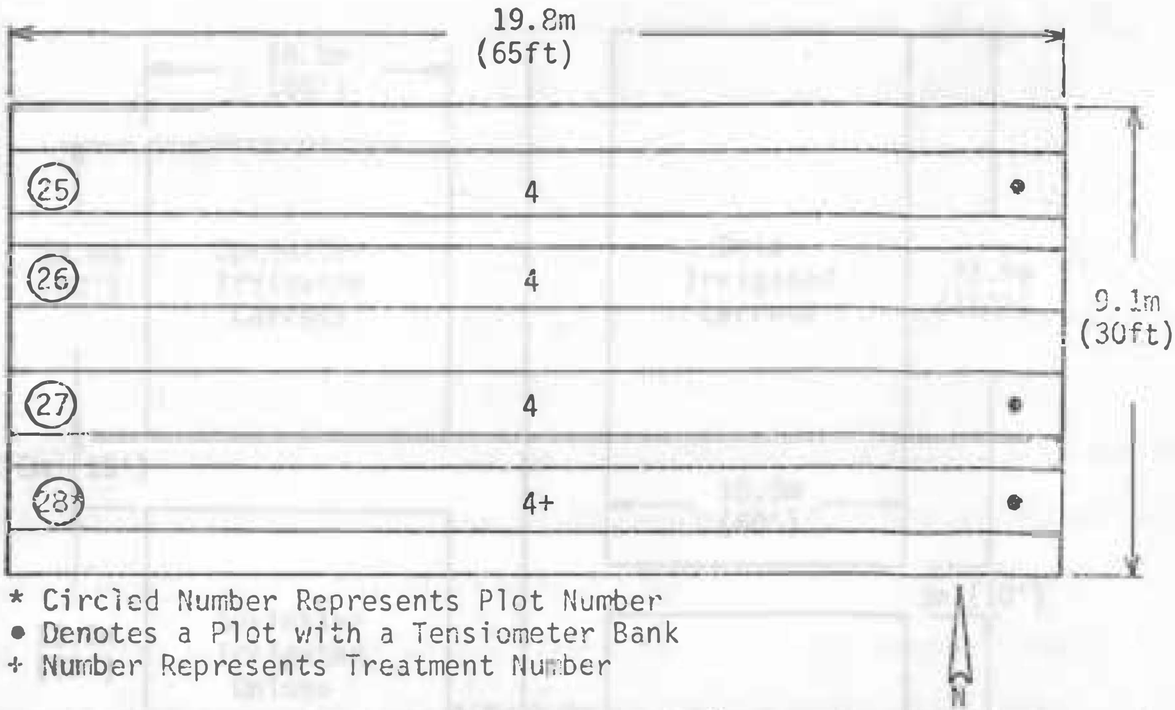


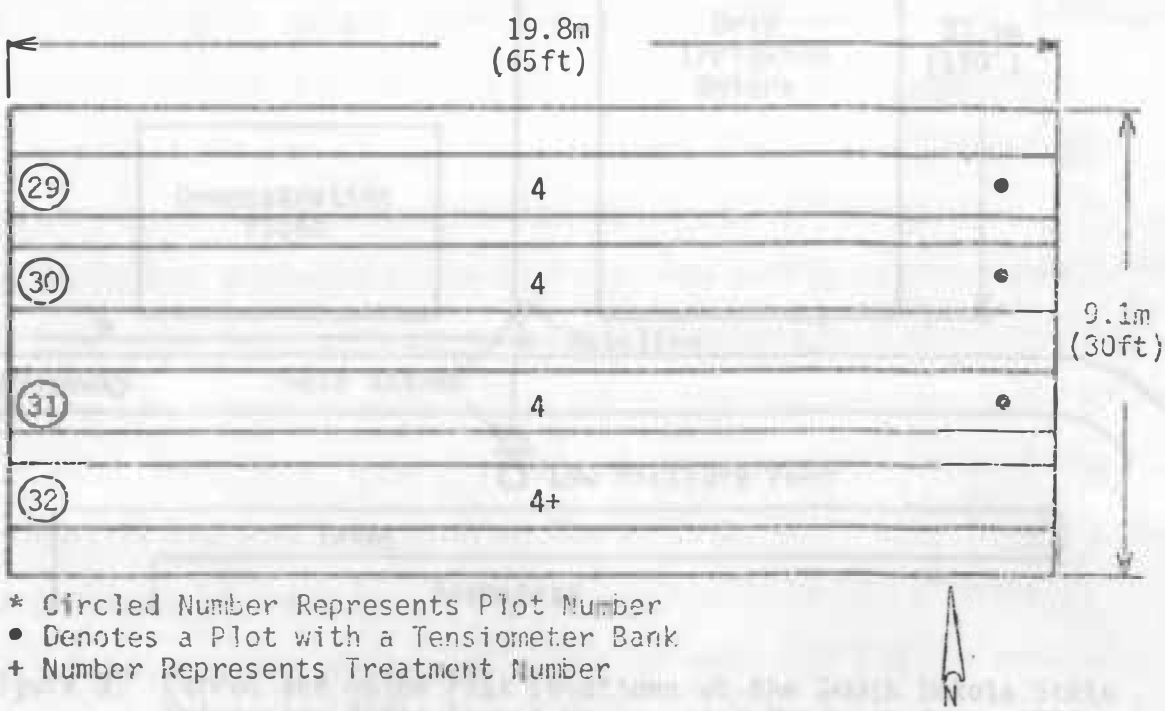
Figure 6. Arrangement of Drip Irrigation Emitter Lines and Appurtenances for an Every Other Row Drip Irrigation Treatment.

The 1974 field investigation was conducted at the same site as in 1975. The experimental area at the Research Farm for 1974 is shown in Figure 9. One sprinkler and two drip irrigation treatments were used to irrigate each crop. Five replications of each drip irrigation treatment and four replications of the sprinkler treatment were used. The crop row spacing in 1974 was 76.2 cm (30 in) and each plot consisted of four rows. Drip treatments consisted of an every row drip treatment with the emitter line placed adjacent to the crop row and an every other row drip treatment with the emitter line positioned between rows at every other space. The drip irrigation emitter lines and appurtenances were identical to those used in 1975. Sprinkler heads were located in both sprinkler treatment plot areas at the corners of



* Circled Number Represents Plot Number
• Denotes a Plot with a Tensiometer Bank
+ Number Represents Treatment Number

Figure 7. Arrangement of Plots for Sprinkler Irrigated Onions.



* Circled Number Represents Plot Number
• Denotes a Plot with a Tensiometer Bank
+ Number Represents Treatment Number

Figure 8. Arrangement of Plots for Sprinkler Irrigated Carrots.

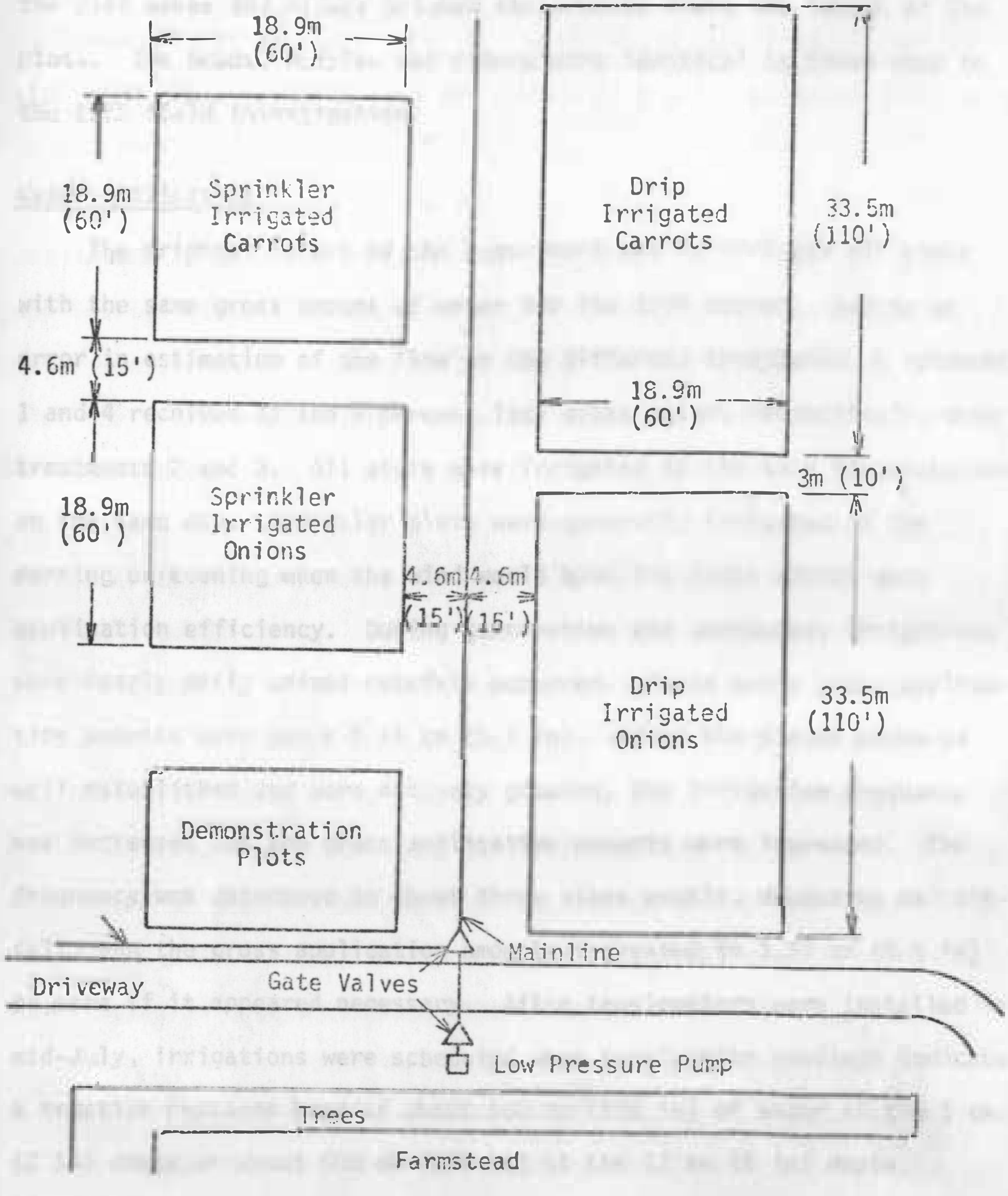


Figure 9. Carrot and Onion Plot Locations at the South Dakota State University Agricultural Engineering Research Farm, 1974.

the plot areas and midway between these heads along the length of the plots. The heads, nozzles and risers were identical to those used in the 1975 field investigation.

Water Application

The original intent of the experiment was to irrigate all plots with the same gross amount of water for the 1975 season. Due to an error in estimation of the flow to the different treatments, treatments 1 and 4 received 12 and 6 percent less gross water, respectively, than treatments 2 and 3. All plots were irrigated at the same frequency and on the same day. Sprinkler plots were generally irrigated in the morning or evening when the wind would have the least effect upon application efficiency. During germination and emergence, irrigations were nearly daily unless rainfall occurred. These early gross application amounts were about 0.75 cm (0.3 in). After the plants appeared well established and were actively growing, the irrigation frequency was decreased but the gross application amounts were increased. The frequency was decreased to about three times weekly, depending on rainfall, and the gross application amounts increased to 1.27 cm (0.5 in) or more if it appeared necessary. After tensiometers were installed in mid-July, irrigations were scheduled when tensiometer readings indicated a negative pressure head of about 600 cm (236 in) of water at the 5 cm (2 in) depth or about 500 cm (197 in) at the 13 cm (5 in) depth.

A low pressure centrifugal pump provided water for the drip plots. A high pressure turbine pump was used for irrigation of the sprinkler plots. Water samples from both wells were analyzed and both waters

were found to have an electrical conductivity of about 800 mmhos/cm and a sodium adsorption ratio of 0.48. Readings at the pressure taps of the every row drip plots averaged 34.5 kpa (5 psi) and gross application rates averaged 3.81 cm/hr (1.5 in/hr) according to water meter measurements. Readings at the pressure taps of the every other row drip plots (treatments 2 and 3) averaged 20.7 kpa (3 psi) and gross application rates averaged 2.16 cm/hr (0.85 in/hr) according to water meter measurements. Figure 11 shows the wetting pattern in an onion plot for treatment 2 after a gross application of 1.27 cm (0.5 in). Pressure at the sprinkler nozzles was 379 kpa (55 psi) giving a gross application rate of 1.32 cm/hr (0.5 in/hr) to the sprinkler plots. Sprinkler discharge rates were taken from the 1975 Rainbird Irrigation Equipment Catalog.

In 1974, all plots received the same net amount of water according to estimates made for water application efficiency. An 80 percent application efficiency was used in 1974 for the sprinkler treatment while the figure used for the drip treatments was 100 percent. Irrigation began in mid-June and similar application scheduling was used in 1974 as in 1975. Net application amounts were 1.27 cm (0.5 in) at each application for all treatments of both crops. Application rates averaged 0.65 cm/hr (0.26 in/hr) for the every row drip treatment and 0.43 cm/hr (0.17 in/hr) for the every other row drip treatment according to water meter measurements. Sprinkler application rates averaged 0.76 cm/hr (0.3 in/hr) according to discharge rates taken from the 1974 Rainbird Irrigation Equipment Catalog. Rainfall and irrigation data

for 1974 and 1975 are given in Appendix A.

Soil Moisture Status

Tensiometers were used to schedule irrigations according to readings at the 5 cm (2 in) and 13 cm (5 in) depths. The tensiometers were also used to measure negative pressure head, or soil moisture tension, and total hydraulic head. Figure 10 shows the arrangements of tensiometers in the soil for the four treatments. Figures 4, 5, 6 and 7 indicate the plots where tensiometers, or tensiometer banks, were located. The 46 cm (18 in) tensiometer depth was at or near the bottom of the sandy loam topsoil. In treatments 1 and 4, tensiometers were placed beneath the center crop row in the experimental area and also one-half row space away. In treatments 2 and 3, tensiometers were placed beneath the middle drip irrigation emitter line, one-half row space away and one row space away. Figure 12 shows a tensiometer bank in a sprinkler irrigated onion plot. The tensiometer banks were placed at random in three of the four replications for each treatment. A tensiometer manometer board provided readings for each tensiometer bank. Mercury having a specific gravity of 13.56 was used as the indicating fluid in the manometers. Tensiometer readings were taken from July 21 to September 6. If an irrigation was scheduled, the readings were taken immediately prior to the application of water.

Soil moisture release curves, Figure 13, for the sandy loam soil were determined in the laboratory for the four soil depths corresponding to the tensiometer depths. Utilizing these curves and the pressure head (soil moisture tension) values obtained from the tensiometers,

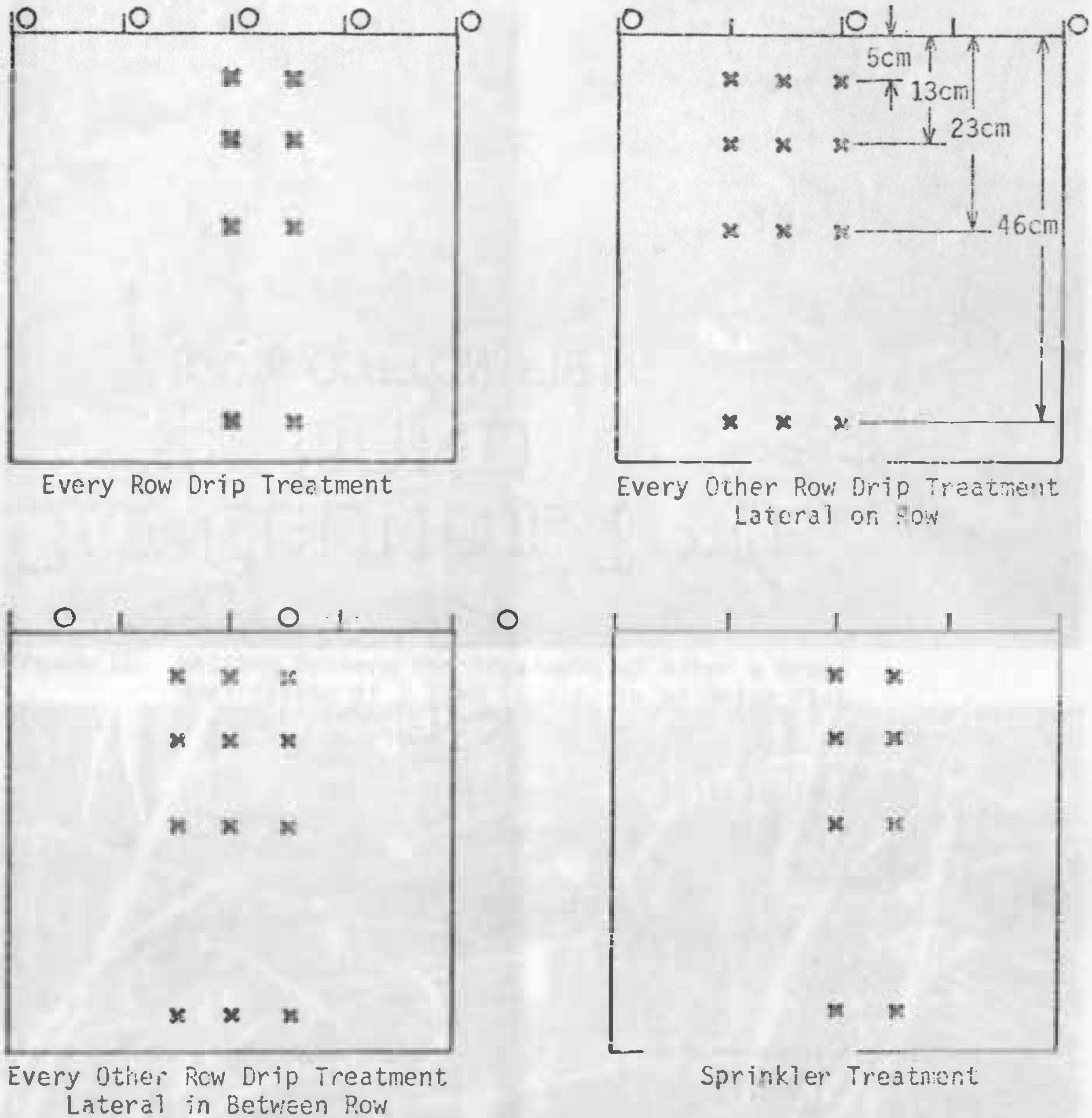
corresponding field volumetric moisture contents were determined. Thus, soil moisture status was monitored through the use of tensiometers. The replication averages of negative pressure head and volumetric moisture content from the 1975 tensiometer data are presented in Appendix B. The total hydraulic head values obtained from the tensiometer readings were used to calculate hydraulic gradients between the tensiometer depths.

Undisturbed soil core samples were taken from the plots at the 38 cm (15 in) depth for the determination of unsaturated hydraulic conductivity in the laboratory. The laboratory procedure followed was similar to that described in the American Society of Agronomy's Methods of Soil Analysis edited by Black, et al. (1965). The unsaturated hydraulic conductivity and hydraulic gradient values at this depth were utilized with Darcy's Law to estimate the amount of soil water moving out of the root zone as deep percolation or into the root zone from below. If these estimates proved to be too large a proportion of the estimated consumptive use for the particular time period in question, these data were not used for the determination of irrigation requirements. The unsaturated hydraulic conductivities determined in the laboratory are presented in Table 1 for various ranges of soil moisture tension. The values are averages of data taken from eleven core samples.

Table 1. Unsaturated Hydraulic Conductivities at the 38 cm (15 in) Depth for Various Ranges of Soil Moisture Tension

Soil Moisture Tension (cm of water)	20-50	50-100	100-200	200-300	300-500
Ku* (cm/day)	0.34	0.34	0.23	0.08	0.08

* Unsaturated Hydraulic Conductivity



× Denotes a Tensiometer Location
○ Represents a Drip Irrigation Lateral
⊥ Represents a Crop Row

Figure 10. Tensiometer Arrangements for Carrot and Onion Plots at the South Dakota State University Agricultural Engineering Research Farm, 1975.

Figure 11. Wetting Pattern for Treatment #2 After a Gross Application of 1.27cm (0.5in) in an Onion Plot.

Figure 12. Tensiometer Bank in a Sprinkler Irrigated Onion Plot.

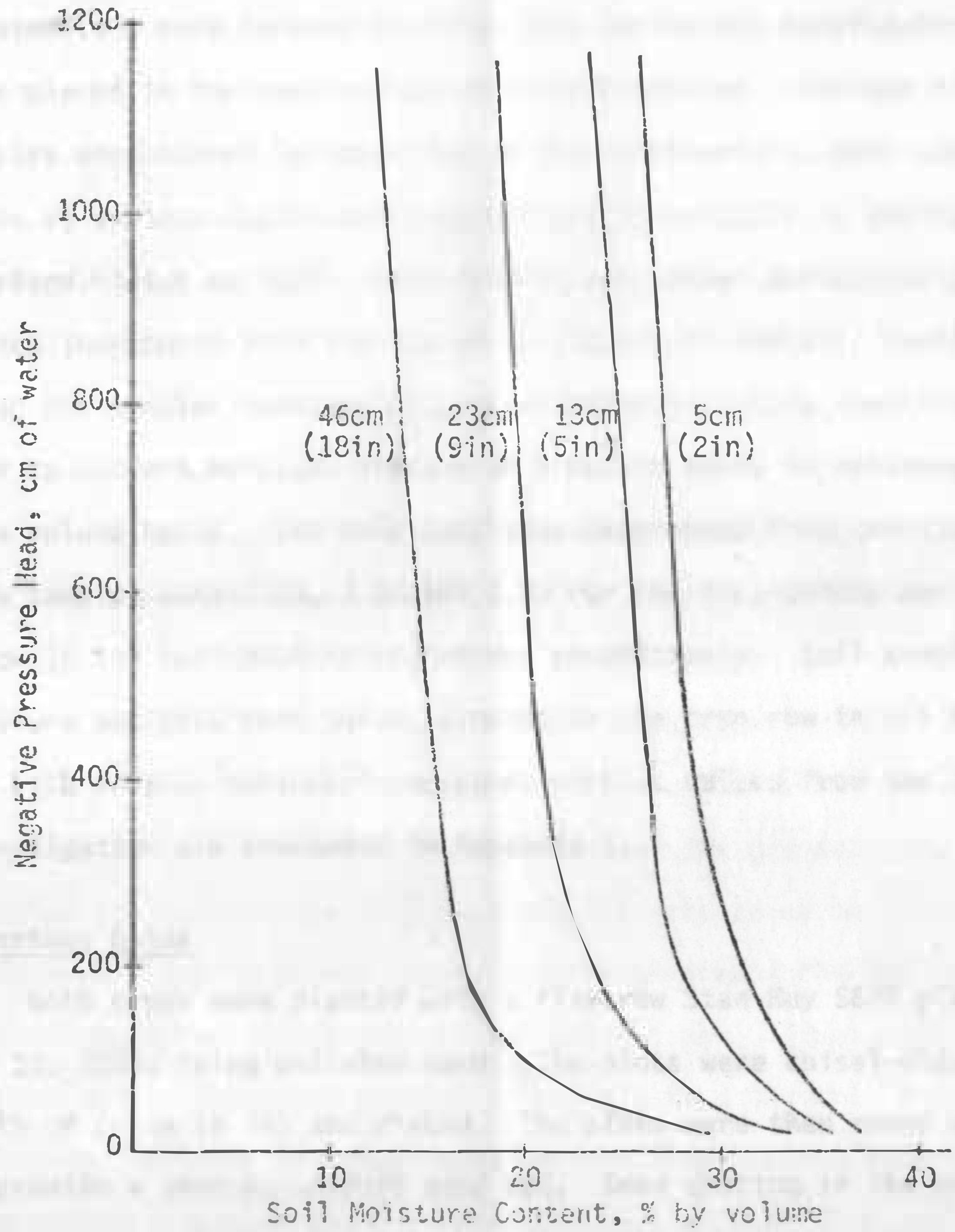


Figure 13. Soil Moisture Release Curves for Four Soil Depths in a Fordville Sandy Loam at the SDSU Agricultural Engineering Research Farm.

Tensiometers were also used in 1974 for irrigation scheduling. Tensiometers were located at three soil depths and tensiometer banks were placed in two replications of each treatment. Because of difficulties encountered in operation of the tensiometers, soil samples were taken at various depths and analyzed gravimetrically to monitor soil moisture status in 1974. Soil samples were taken periodically in 15 cm (6 in) increments from the top 46 cm (18 in) of the soil profile. After the samples were analyzed gravimetrically, bulk densities were used to convert moisture content on a weight basis to moisture content on a volume basis. The bulk densities determined from undisturbed soil core samples were 1.40, 1.50 and 1.55 for the top, middle and bottom 15 cm (6 in) soil profile increments respectively. Soil samples for moisture analysis were taken adjacent to the crop row in all treatments for both crops. Volumetric moisture content values from the 1974 field investigation are presented in Appendix G.

Important Dates

Both crops were planted with a five-row Stan-Hay S870 planter on May 11, 1975, using pelleted seed. The plots were chisel-plowed to a depth of 20 cm (8 in) and disked. The plots were then raked and dragged to provide a smooth, uniform seed bed. Seed spacing in the row was 3.81 cm (1.5 in) for carrots and 5.72 cm (2.25 in) for onions. The carrot variety was Scarlet Nantes and the onion variety was Pedro Sweet Spanish. Germination of both crops was about 85 percent. No intentional thinning of either crop was done at any time during the growing season. Fertilizer was applied to the plots prior to the planting at a

rate of 10 kg/ha (9 lb/acre) nitrogen, 77 kg/ha (69 lb/acre) phosphorus and 135 kg/ha (120 lb/acre) potassium. Nitrogen was applied through the irrigation systems on July 12 and August 7 for a total nitrogen application to the plots of 145 kg/ha (129 lb/acre).

All plots were mechanically cultivated on June 3. A post-emergence herbicide, TOK, was sprayed on all plots on June 13 and June 27. Dakthol, a pre-emergence herbicide was sprayed on all plots on June 25. Spraying did not alleviate the weed problem sufficiently and the plots were hand-weeded on July 7 and again on July 22.

Carrot plots were harvested for yield measurements and quality observation on September 29 and 30, 1975. Onion rows selected for harvest were pulled on September 16 and 17 and left in the field for 3 days to dry. The tops were then cut and the bulbs were spread on drying beds and dried for three weeks before being weighed for yield and examined for quality. Two rows from each plot of the carrots and onions were selected for harvest and the yield results were based on the data from these rows. For treatment number 3 for both crops, the two rows selected were the center row and an adjacent row. These rows were weighed and examined for quality separately to determine yield and quality differences that may exist between the crop row adjacent to a drip emitter line and the crop row 30.5 (12 in) away from the line. However, two of the carrot replications for this treatment were not weighed in this manner because of mixing problems that occurred during carrot harvest. The additional space between plots which was allowed to permit the installation of tensiometer manometer boards in 1975 was

ignored in calculating yields on a per unit basis.

In 1974, both crops were planted on April 24 with a planter identical to that used in 1975. Similar cultural operations were conducted in 1974 as in 1975 for seed bed preparation. The carrot variety was a Chantenay long and the onions were a mixture of White Globe and Yellow Sweet Spanish. Fertilizer was applied at a rate of 120 kg/ha (107 lb/acre) nitrogen, 134 kg/ha (120 lb/acre) phosphorous and 120 kg/ha (107 lb/acre) potassium prior to planting.

TOK was applied once early in the growing season. Weeds continued to be a problem and hand-weeding proceeded throughout the remainder of the growing season.

Both crops were harvested between September 6 and September 11, 1974. The carrots were weighed for yield measurements during harvest but the onions were spread on drying beds for three weeks before being weighed. Two rows from each plot for each crop were chosen for yield sampling and yield data were based on measurements from these rows.

PRESENTATION AND ANALYSIS OF DATA

Field data were collected in 1974 and 1975 from experimental plots of carrots and onions grown under drip and sprinkler irrigation. The field data consisted primarily of yield measurements and tensiometer readings. The 1974 field investigation was regarded as somewhat preliminary in nature and provided useful information for the 1975 portion of the experiment. The author was not associated with the experiment in 1974, however the author did conduct the analysis of the 1974 data. The first portion of the data to be presented is the yield data.

Yield Study

Carrot and onion yields for 1974 are presented in Tables 2 and 3, respectively. Corresponding 1975 yields are presented in Tables 4 and 5. Individual plot yields for both years of the study are presented in Appendix D. In 1974, all treatments for both crops received the same net amount of water. In 1975, the treatments for both crops received neither the same gross amount nor the same net amount of irrigation water. For this reason, the 1975 yields are also expressed in terms of water use efficiency. Water use efficiency is defined as the quantity of crop yield per unit quantity of water delivered to the crop.

The significant F-numbers obtained in the analyses of variance for 1974 crop yields, Tables 6 and 7, indicated that at least one yield mean was significantly different from the other yield means for both crops. Mean comparisons were then made using the method of contrasts (Ostle, 1963) as were all mean comparisons presented in this thesis.

Table 2. Carrot Yields for 1974.

Treatment	Average Yield	
	metric ton/hectare	bu*/acre
Every Row Drip	56.2	1003
Every Other Row Drip Line Between Rows	45.4	810
Sprinkler	51.7	922

* A bushel of carrots is considered to weigh 50 lb.

Table 3. Onion Yields for 1974.

Treatment	Average Yield	
	metric ton/hectare	bags*/acre
Every Row Drip	25.1	447
Every Other Row Drip Line Between Rows	18.2	325
Sprinkler	23.3	415

* A bag of onions is considered to weigh 50 lb.

Table 4. Carrot Yield Data for 1975*.

Treatment	Average Yield		Water Use Efficiency	
	metric ton/hectare	bu+/acre	kg/m^3 water	lb/ft^3 water
1	109.0	1946	35.5	2.22
2	99.8	1781	28.7	1.79
3	106.9	1907	30.8	1.92
4	84.9	1515	26.4	1.65

* 5% of the gross carrot yield weights were subtracted to account for dirt and any excess foliage.

+ A bushel of carrots is considered to weigh 50 lb.

Table 5. Onion Yield Data for 1975.

Treatment	Average Yield		Water Use Efficiency	
	metric ton/hectare	bags*/acre	kg/m^3 water	lb/ft^3 water
1	69.3	1236	22.6	1.41
2	59.3	1058	17.1	1.07
3	60.6	1081	17.4	1.09
4	54.7	977	16.9	1.06

* A bag of onions is considered to weigh 50 lb.

Table 6. Analysis of Variance of 1974 Carrot Yields.

Source	SS	df	MS	F
Treatments (between groups)	266.30	2	133.15	11.80*
Error	112.80	10	11.28	
Total	379.10	12		

* Significant at the 5% level. $F_{.05} = 4.10$.

Table 7. Analysis of Variance of 1974 Onion Yields.

Source	SS	df	MS	F
Treatments (between groups)	124.50	2	62.25	14.18*
Error (within groups)	48.30	11	4.39	
Total	172.80	13		

* Significant at the 5% level. $F_{.05} = 3.98$.

The carrot comparisons are presented in Table 8 and the onion comparisons in Table 9. The first comparison indicates that the sprinkler and average drip yields did not differ significantly for either crop. The second comparison indicates that the every row drip yields were greater than the every other row drip yields for both crops.

The analyses of variance for carrot and onion yields in 1975, Tables 10 and 11, gave significant F-numbers which indicated that at least one yield mean was significantly different from the other yield

Table 8. Non-Orthogonal Treatment Comparisons of 1974 Carrot Yields.

Treatment Comparison+	SS	MS	F
$\overline{1+2}$ vs. 3	5.99	5.99	0.53
1 vs. 2	260.16	260.16	23.01*

+ 1, 2 and 3 represent the every row drip treatment, the every other row drip treatment and the sprinkler treatment respectively for 1974.

* Significant at the 5% level. $F_{.05} = 4.96$.

Table 9. Orthogonal Treatment Comparisons of 1974 Onion Yields.

Treatment Comparison+	SS	MS	F
$\overline{1+2}$ vs. 3	7.54	7.54	1.71
1 vs. 2	116.96	116.96	26.42*

+ 1, 2 and 3 represent the every row drip treatment, the every other row drip treatment and the sprinkler treatment respectively for 1974.

* Significant at the 5% level. $F_{.05} = 4.84$.

Table 10. Analysis of Variance of 1975 Carrot Yields.

Source	SS	df	MS	F
Treatments (between groups)	1426.29	3	475.43	7.75*
Error (within groups)	336.07	12	28.01	
Totals	779.33	15		

* Significant at the 5% level. $F_{.05} = 3.49$.

Table 11. Analysis of Variance of 1975 Onion Yields.

Source	SS	df	MS	F
Treatments (between groups)	443.26	3	147.75	5.27*
Error (within groups)	336.07	12	28.01	
Totals	779.33	15		

* Significant at the 5% level. $F_{.05} = 3.49$.

means for both crops. Tables 12 and 13 present the mean comparisons that were then investigated. The first comparison for both crops indicated that the average of the yields for the drip irrigated treatments was significantly greater than the yields for the sprinkler irrigated treatment. The second comparison for carrots suggested that the yield for the every row drip treatment did not differ significantly from the average of the yields for the two every other row drip treatments. However, the same comparison for onions indicated that the every row drip yield was significantly greater than the average yield for the

Table 12. Orthogonal Treatment Comparisons of 1975 Carrot Yields.

Treatment Comparison	SS	MS	F
$\overline{1 + 2 + 3}$ vs. 4	1239.10	1239.10	20.20*
1 vs. $\overline{2 + 3}$	86.94	86.94	1.42
2 vs. 3	100.25	100.25	1.63

* Significant at the 5% level. $F_{.05} = 4.75$.

Table 13. Orthogonal Treatment Comparisons of 1975 Onion Yields.

Treatment Comparison	SS	MS	F
$\overline{1 + 2 + 3}$ vs. 4	206.22	206.22	7.36*
1 vs. $\overline{2 + 3}$	233.19	233.19	8.33*
2 vs. 3	3.85	3.85	0.13

* Significant at the 5% level. $F_{.05} = 4.75$.

every other row treatments. The yields for the two every other row drip treatments did not differ significantly for either crop according to the third comparison.

The analyses of variance for 1975 water use efficiencies again produced significant F-numbers for both crops as indicated in Tables 14 and 15. The treatment comparisons made were the same as those for the 1975 carrot and onion yields and are presented in Tables 16 and 17 with slightly different results than in the yield mean comparisons. The average of the drip water use efficiencies was significantly greater than the sprinkler water use efficiency for both crops. The second

Table 14. Analysis of Variance of 1975 Carrot Water Use Efficiencies.

Source	SS	df	MS	F
Treatments (between groups)	180.20	3	60.07	11.08*
Error (within groups)	65.06	12	5.42	
Totals	245.26	15		

* Significant at 5% level. $F_{.05} = 3.49$.

Table 15. Analysis of Variance of 1975 Onion Water Use Efficiencies.

Source	SS	df	MS	F
Treatments (between groups)	90.22	3	30.07	11.56*
Error (within groups)	31.23	12	2.60	
Totals	121.45	15		

* Significant at the 5% level. $F_{.05} = 3.49$.

comparison indicated that the every row drip water use efficiencies were significantly greater than the average of the every other row drip water use efficiencies for both crops. The third comparison indicated that no significant difference existed between water use efficiencies for the two every other row drip treatments for either crop.

For treatment 3 in 1975, the drip irrigation emitter line was located adjacent to every other crop row. The row yields in this treatment were analyzed to determine if yield differences existed

Table 16. Orthogonal Treatment Comparisons of 1975 Carrot Water Use Efficiencies.

Treatment Comparison	SS	MS	F
$\overline{1+2+3}$ vs. 4	83.21	83.21	15.35*
1 vs. $\overline{2+3}$	88.17	88.17	16.27*
2 vs. 3	8.82	8.82	1.63

* Significant at the 5% level. $F_{.05} = 4.75$.

Table 17. Orthogonal Treatment Comparisons of 1975 Onion Water Use Efficiencies.

Treatment Comparison	SS	MS	F
$\overline{1+2+3}$ vs. 4	14.06	14.06	5.44*
1 vs. $\overline{2+3}$	75.93	75.93	29.41*
2 vs. 3	0.23	0.23	0.07

* Significant at the 5% level. $F_{.05} = 4.75$.

between rows with emitter lines and those without emitter lines. The analyses of variance of these yields for both crops are shown in Tables 18 and 19 and significant F-numbers were recorded in both cases. The significant F-numbers thus indicated that the yield means for the crop rows with the emitter line were significantly greater than yield means for the crop row without the emitter line for both crops.

The 1975 carrot and onion yields were also inspected for grade and quality in addition to being weighed for yield measurement. The grading used for both crops was that used by the United States Department of Agriculture for fresh market vegetables.

Table 18. Analysis of Variance of Carrot Row Yields for Treatment #3.

Source	SS	df	MS	F
Treatments (between groups)	1.17	1	1.17	13.0*
Error (within groups)	0.35	4	0.09	
Totals	1.52	5		

* Significant at the 5% level. $F_{.05} = 7.71$.

Table 19. Analysis of Variance of Onion Row Yields for Treatment #3.

Source	SS	df	MS	F
Treatments (between groups)	3.22	1	3.30	41.25*
Error (within groups)	0.77	10	0.08	
Totals	3.99	11		

* Significant at the 5% level. $F_{.05} = 4.96$.

The USDA stipulates that carrots must be at least 12.7 cm (5 in) in length and 1.90 cm (0.75 in) to 3.8 cm (1.5 in) in diameter to be classified as a US Extra #1 carrot (Prashar, 1976). In addition, the carrot must be free from double roots and side shoots. Also, the dark spot on the top of the carrot root which results from the top of the carrot being above ground cannot be more than 0.32 cm (0.125 in) in depth. The purpose of the grading was to find the proportion of US Extra #1 carrots. In the drip plots, 45 percent of the carrots met these

requirements while 54 percent met the requirements in the sprinkler plots. A US Extra #1 percentage of 30 percent to 33 percent is considered average in the United States (Prashar, 1976). The drip irrigated carrots tended to be larger in diameter and crowding conditions were observed in these plots before harvest.

Onions were graded according to USDA requirements (Prashar, 1976) which stipulate that an onion must be between 5.1 cm (2 in) and 7.0 cm (2.75 in) to be classified as a medium-sized onion. Onions that met USDA requirements for a medium-sized onion or larger were then classified as fresh market onions. Onions that met size requirements were discarded if damaged or if double bulbs or soft tops were found. Seventy-two percent of the drip irrigated onions met all the size requirements for a medium-sized onion or larger while the figure for the sprinkler irrigated onions was 63 percent. It was noted during grading that the sprinkler irrigated onions were generally smaller in size. Serious weed problems encountered early in the growing season in parts of the sprinkler irrigated onion plots may account for some of the size difference. The areas where the most serious weed growth problems had occurred were avoided for yield sampling, however.

The onion rows with drip emitter lines for treatment 3 were graded and 74 percent of the onions in these rows met the requirements for a medium-sized onion or larger. This figure was 70 percent for the onion rows one row space away from the emitter lines for the same treatment. The onions in the rows without drip emitter lines were generally smaller, however.

Soil Moisture Study

In the 1974 field investigation, soil moisture status was monitored by gravimetric analysis of soil samples taken periodically from the experimental plots. Using the volumetric moisture content values from the 1974 field investigation in Appendix C, lines of volumetric moisture content versus time were drawn for all treatments for both crops. Figures 14, 15 and 16 show volumetric moisture content values at various soil depths beneath the crop row in the carrot plots for 1974. Since irrigations or rainfall occurred between all soil moisture sampling dates in 1974, the lines drawn between the data points do not represent the actual variation in volumetric moisture content. The every row drip treatment appears to have the wettest soil moisture regime for the carrot treatments in 1974. The sprinkler treatment appears to have the driest moisture regime. These differences in the soil moisture regime apparently had little effect on treatment yields because no significant differences were found between the sprinkler treatment yields and the average of the drip treatment yields in the carrot plots.

Figures 17, 18 and 19 are the corresponding illustrations for the onion plots in 1974. Again, the every row drip treatment appears to have the wettest soil moisture regime and the sprinkler treatment appears to have the driest soil moisture regime. Since no significant differences were found between the sprinkler treatment yields and the average of the drip treatment yields in the onion plots, the differences in soil moisture regime again apparently had little effect on

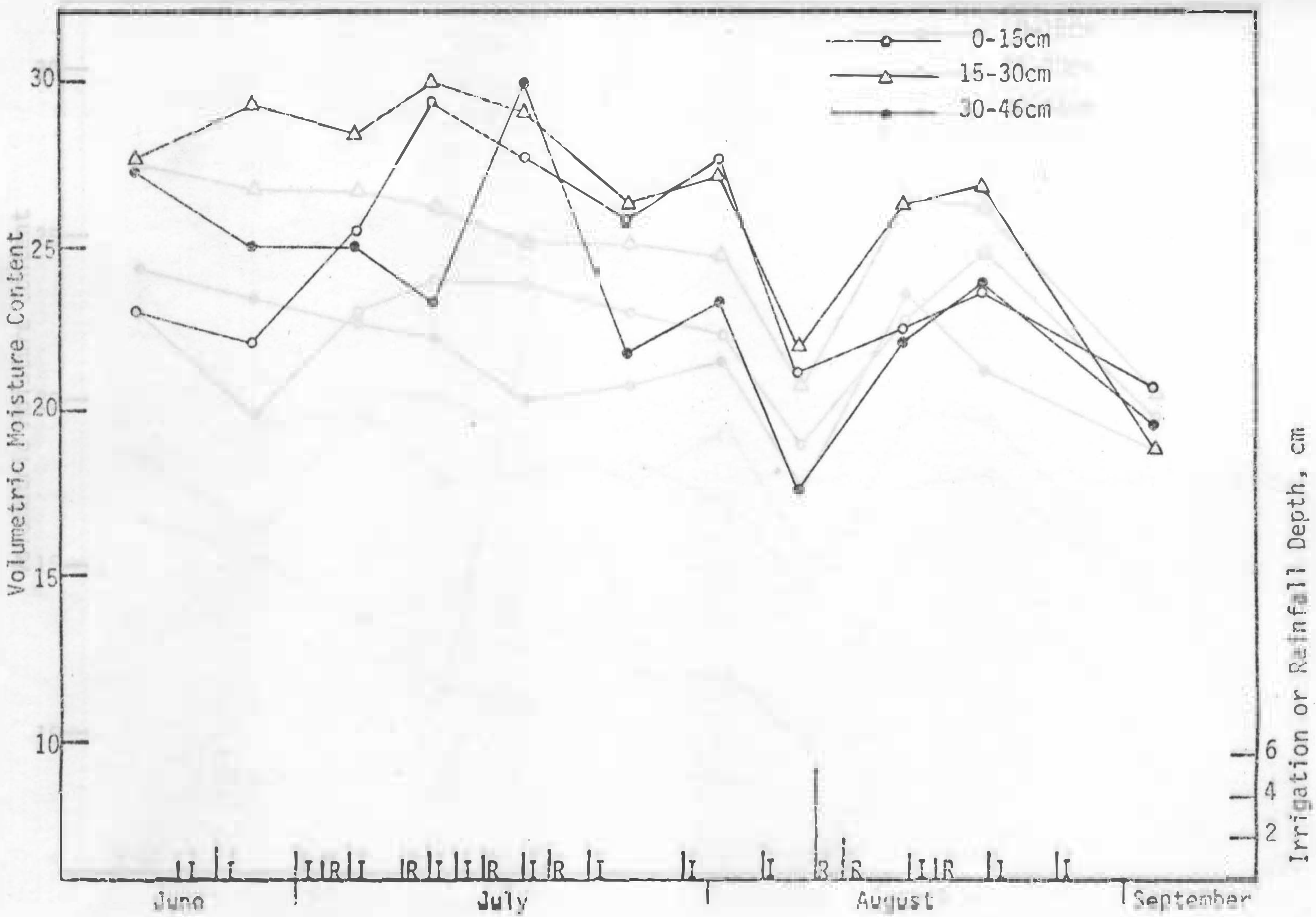


Figure 14. Volumetric Moisture Content at Various Depths for Carrots, Every Row Drip Treatment 1974.

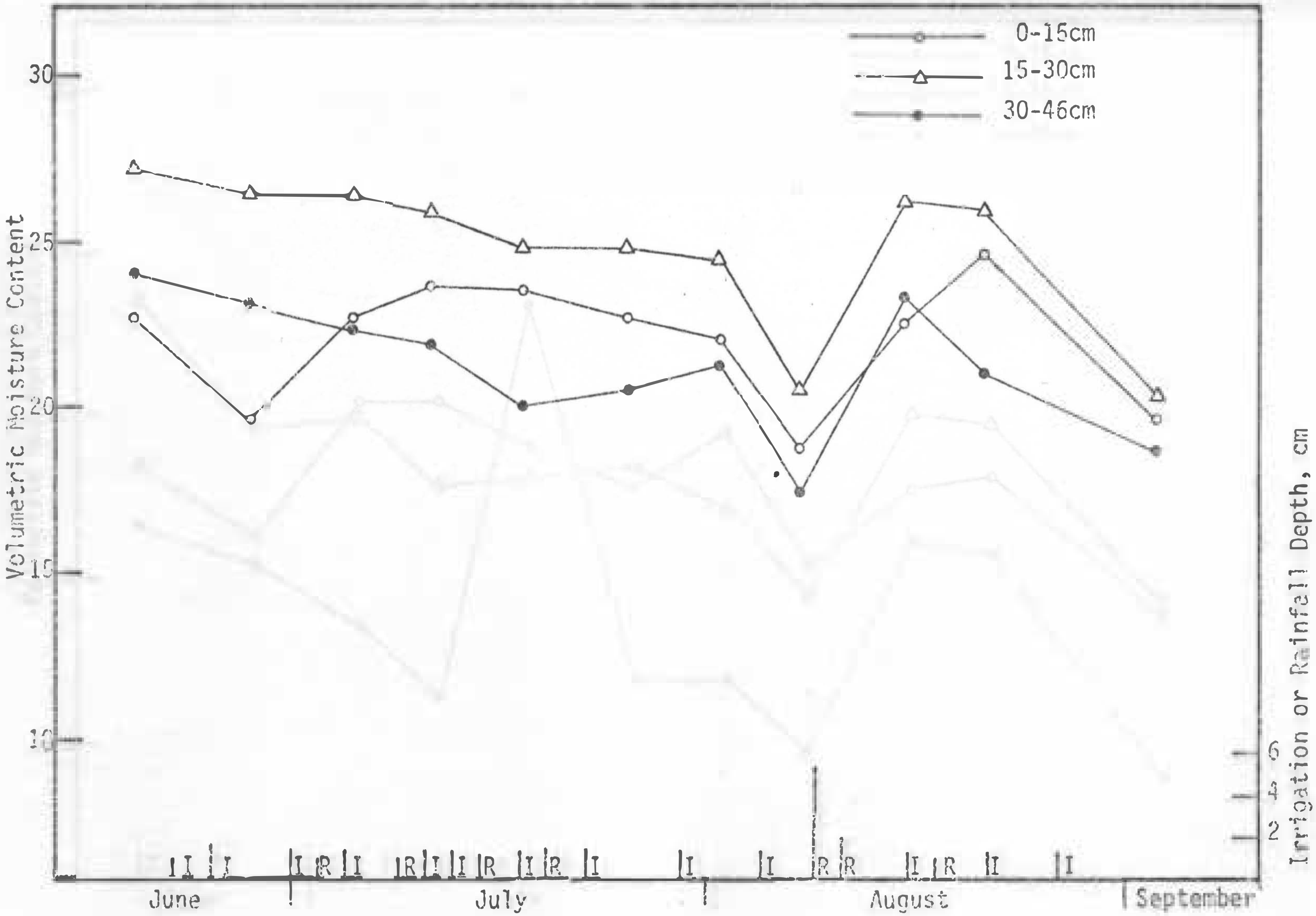


Figure 15. Volumetric Moisture Content at Various Depths for Carrots, Every Other Row Drip Treatment 1974.

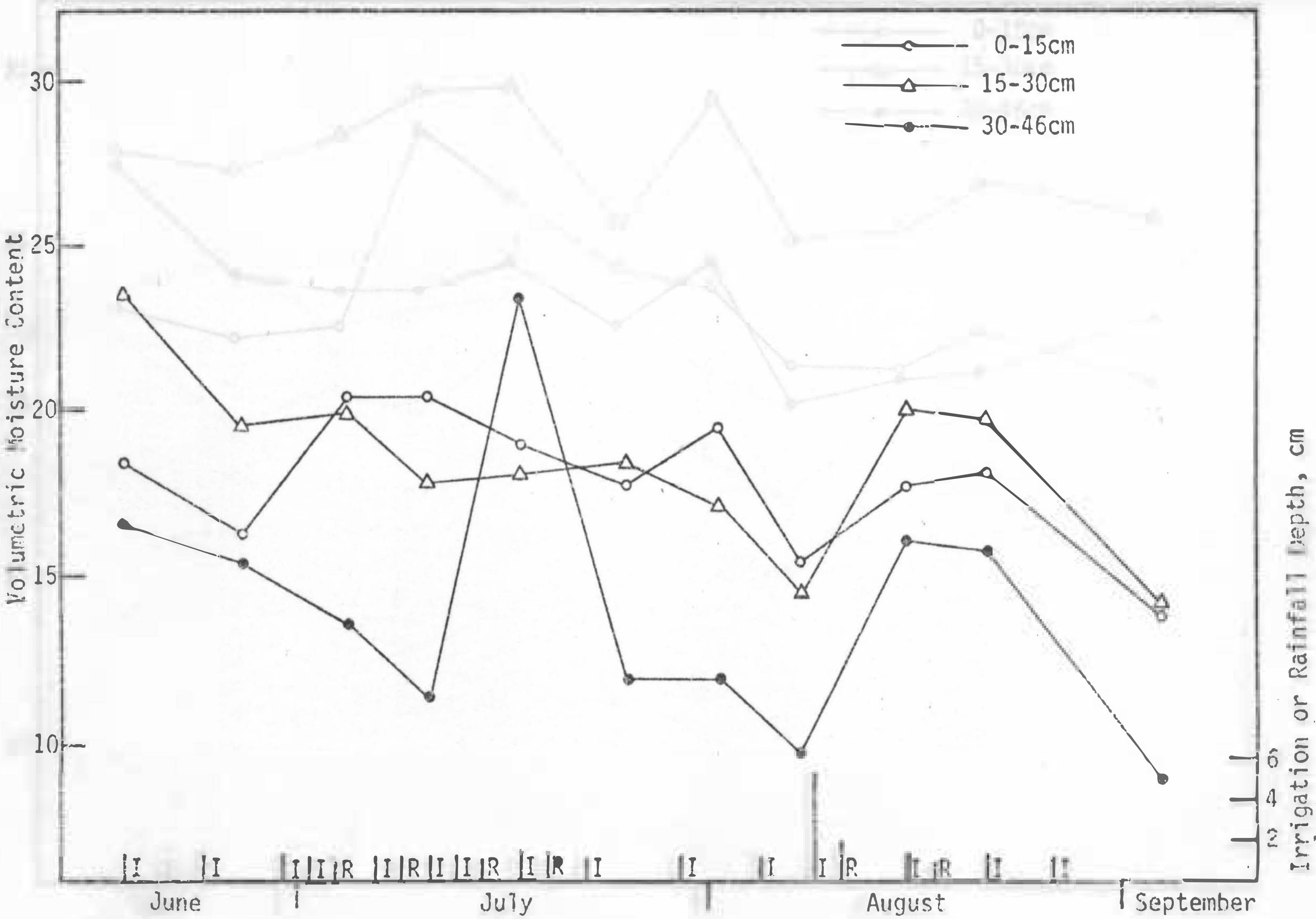


Figure 16. Volumetric Moisture Content at Various Depths for Carrots, Sprinkler Treatment 1974.

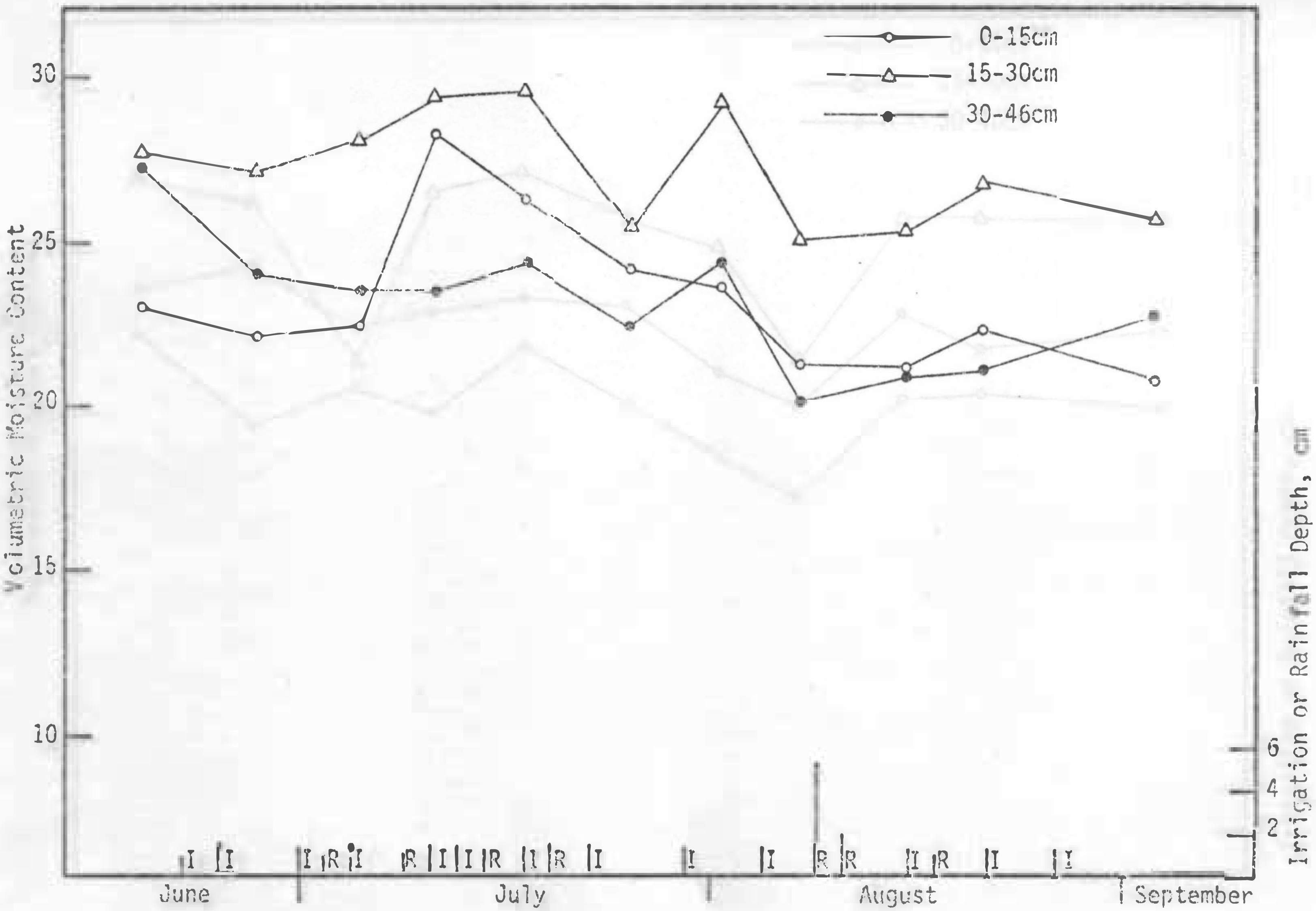


Figure 17. Volumetric Moisture Content at Various Depths for Onions, Every Row Drip Treatment 1974.

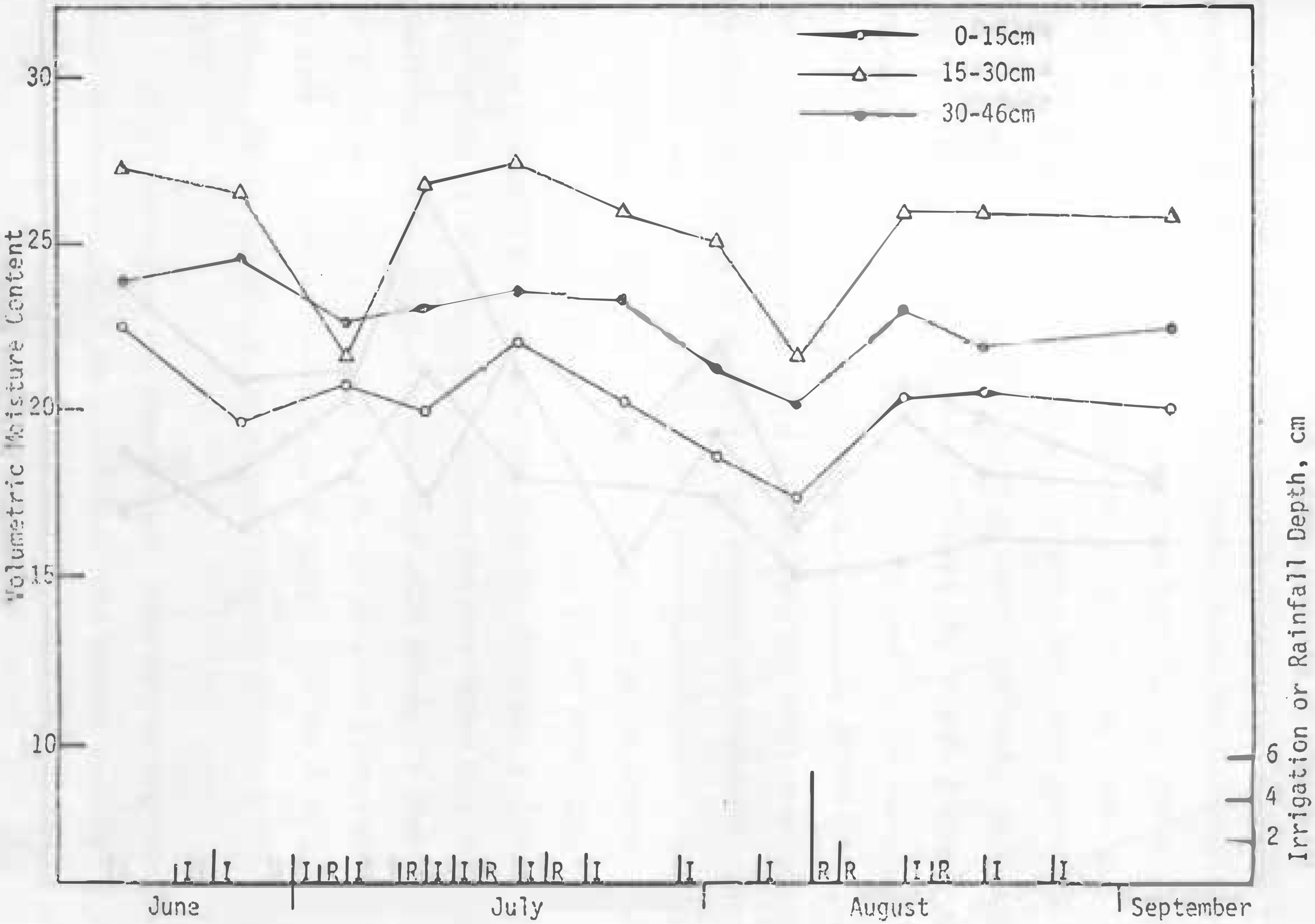


Figure 18. Volumetric Moisture Content at Various Depths for Onions, Every Other Row Drip Treatment 1974.

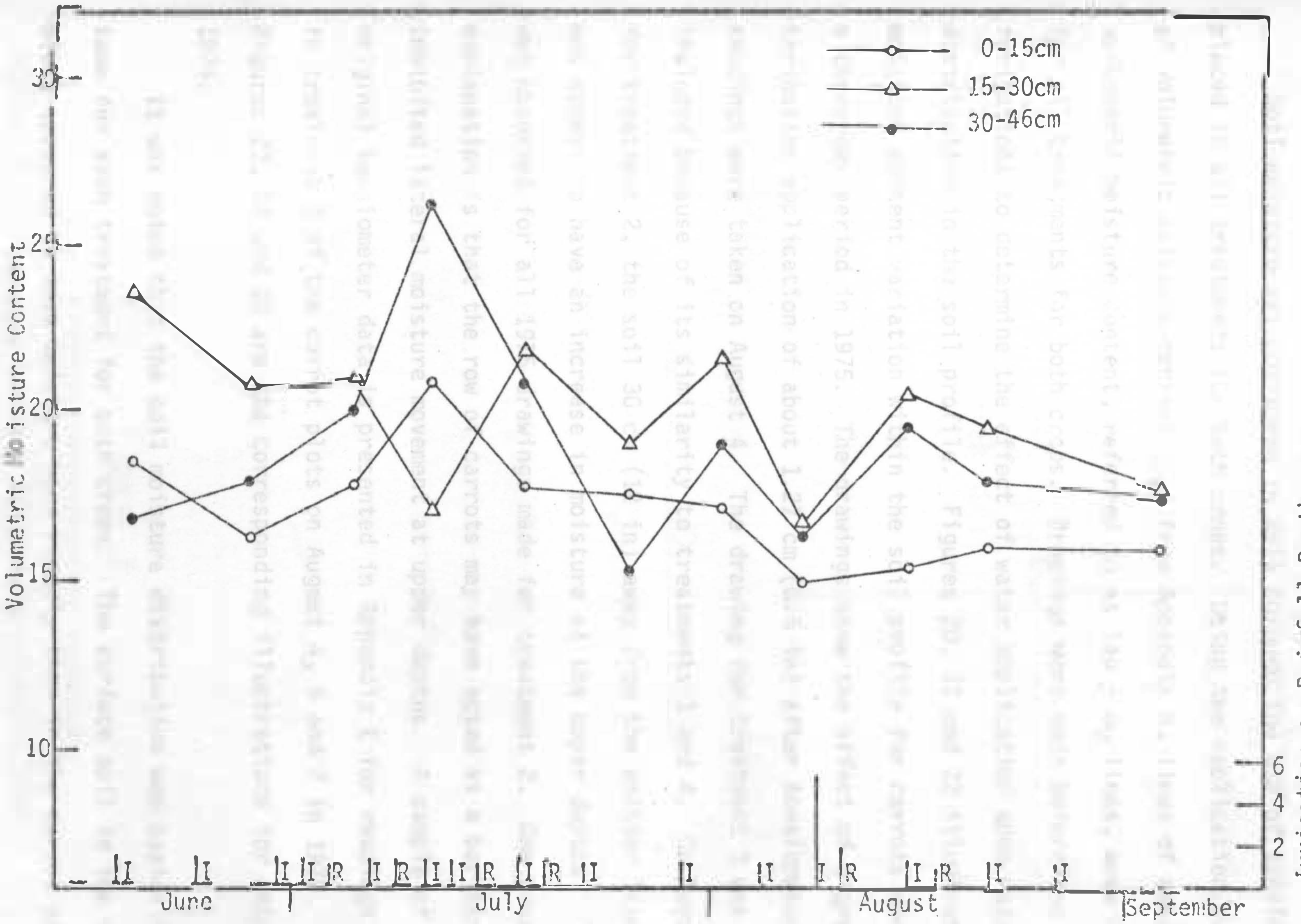
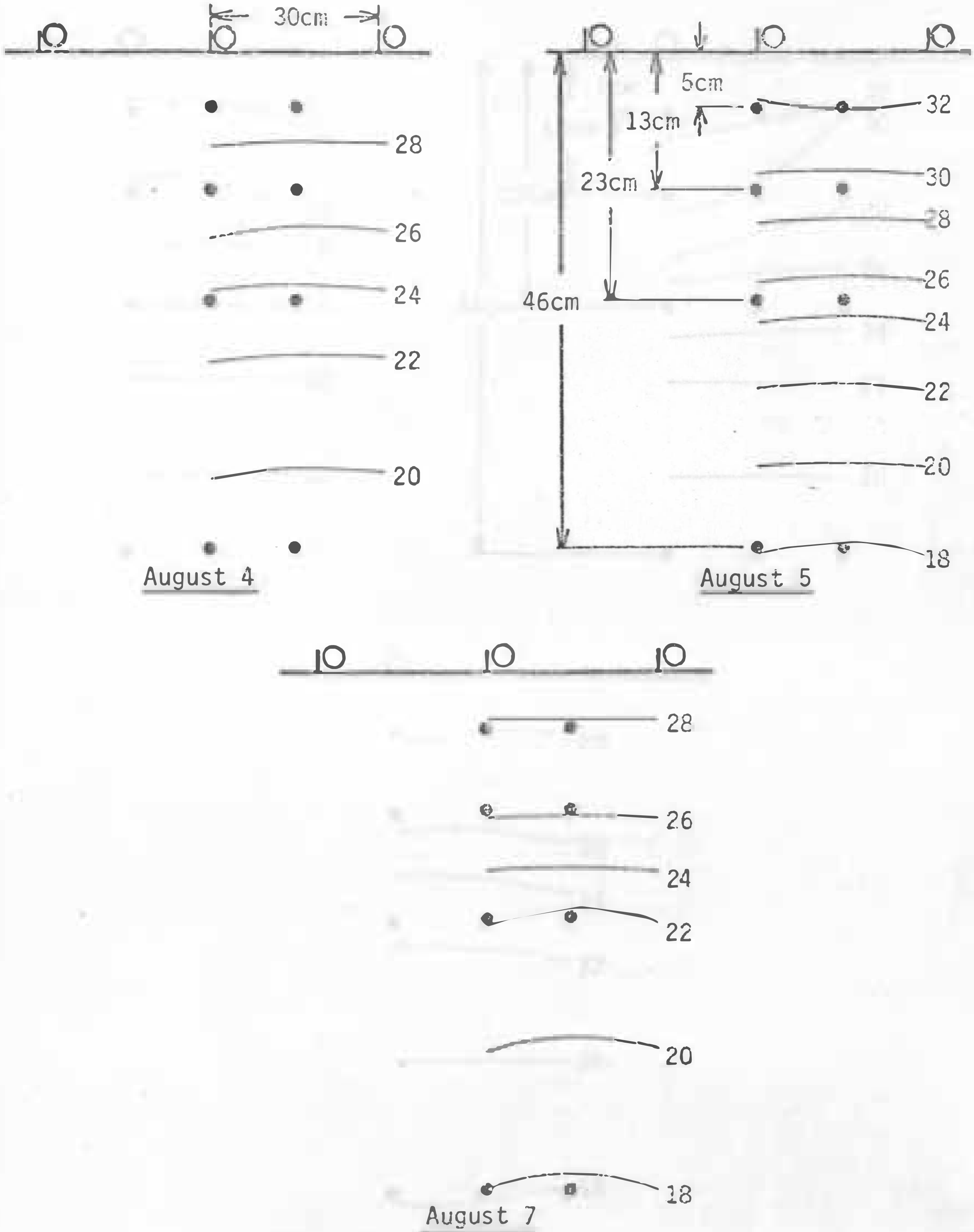


Figure 19. Volumetric Moisture Content at Various Depths for Onions, Sprinkler Treatment 1974.

treatment yields.

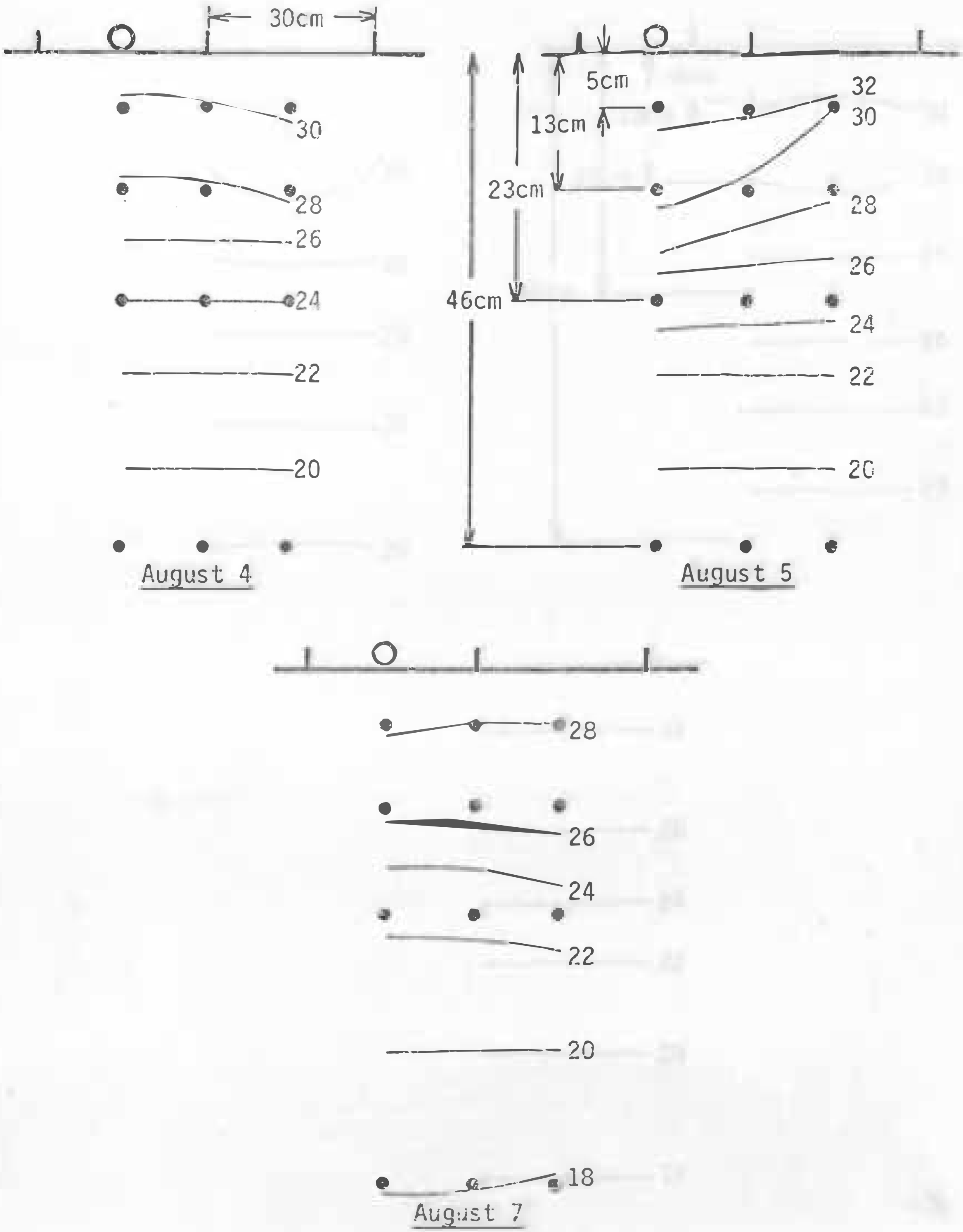
Soil moisture was monitored in 1975 through the use of tensiometers placed in all treatments for both crops. Using the replication averages of volumetric moisture content (Θ_V) from Appendix B, lines of constant volumetric moisture content, referred to as Iso - Θ_V lines, were drawn for all treatments for both crops. Drawings were made before and after irrigations to determine the effect of water application upon water distribution in the soil profile. Figures 20, 21 and 22 illustrate moisture content variation within the soil profile for carrots during a three-day period in 1975. The drawings show the effect of a gross irrigation application of about 1.27 cm (0.5 in) after tensiometer readings were taken on August 4. The drawing for treatment 3 was not included because of its similarity to treatments 1 and 4. On August 5 for treatment 2, the soil 30 cm (12 in) away from the emitter line does not appear to have an increase in moisture at the upper depths. This was observed for all 1975 drawings made for treatment 2. One possible explanation is that the row of carrots may have acted as a barrier and inhibited lateral moisture movement at upper depths. A sample of the original tensiometer data is presented in Appendix E for readings taken in treatment 2 of the carrot plots on August 4, 5 and 7 in 1975. Figures 23, 24 and 25 are the corresponding illustrations for onions in 1975.

It was noted that the soil moisture distribution was basically the same for each treatment for both crops. The surface soil in the onion plots appeared to lose moisture more rapidly than in the carrot plots



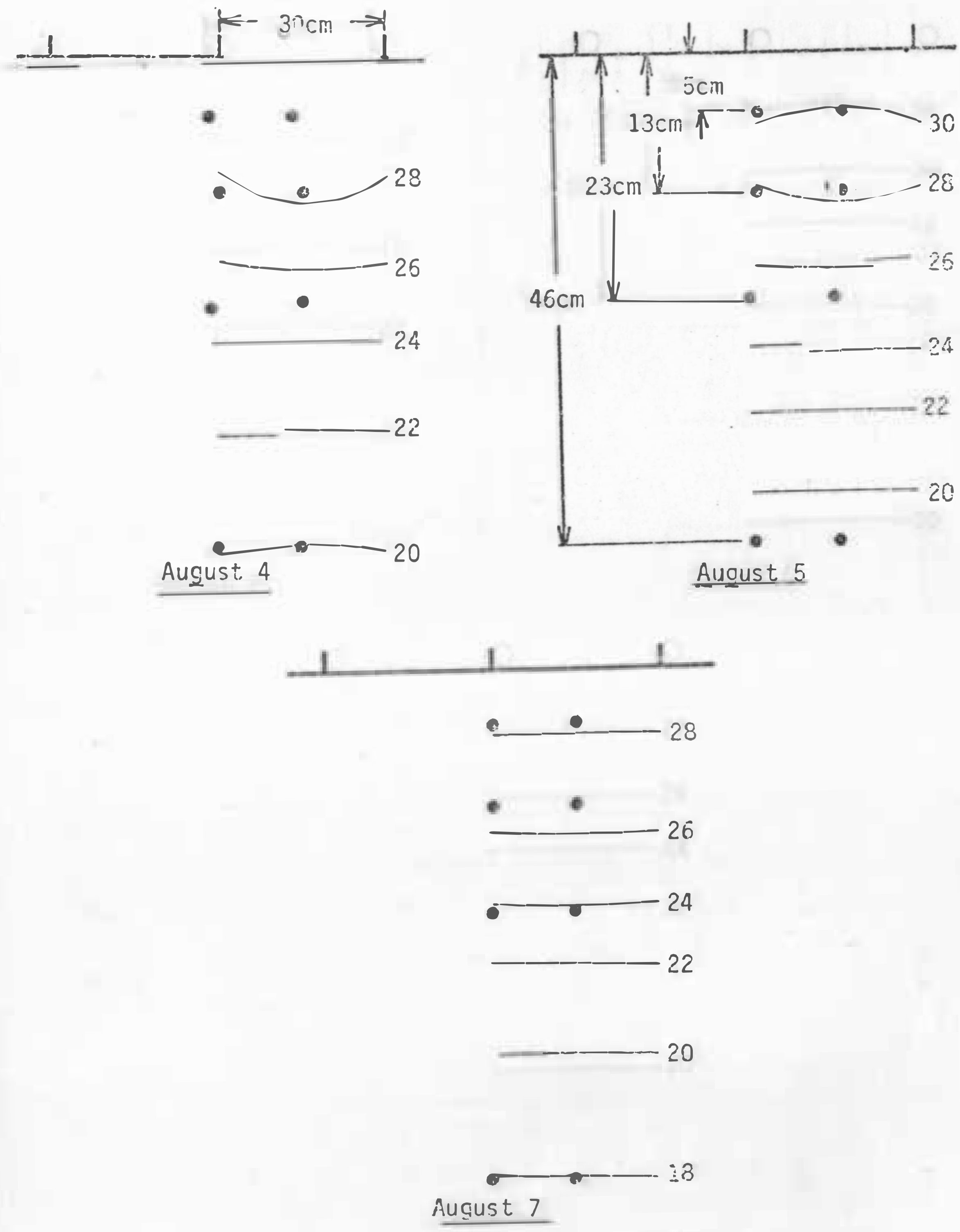
* Denotes a tensiometer location

Figure 20. Iso - θ_v Lines for Carrots, Treatment 1 1975.



• Denotes a Tensiometer Location

Figure 21. Iso - θ_v Lines for Carrots, Treatment 3 1975.



• Denotes a Tensiometer Location

Figure 22. Iso - θ_v Lines for Carrots, Treatment [illegible] 1975.

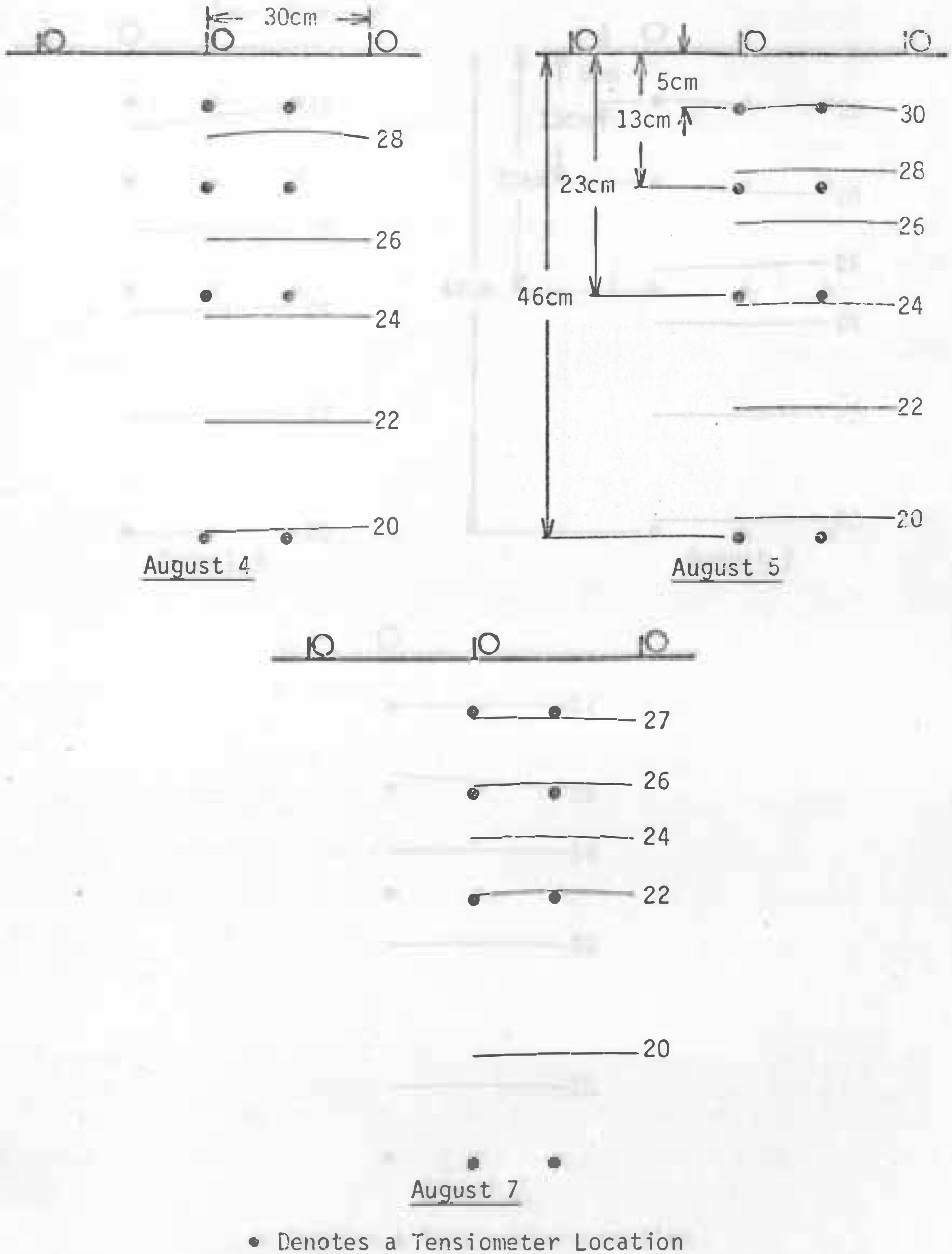
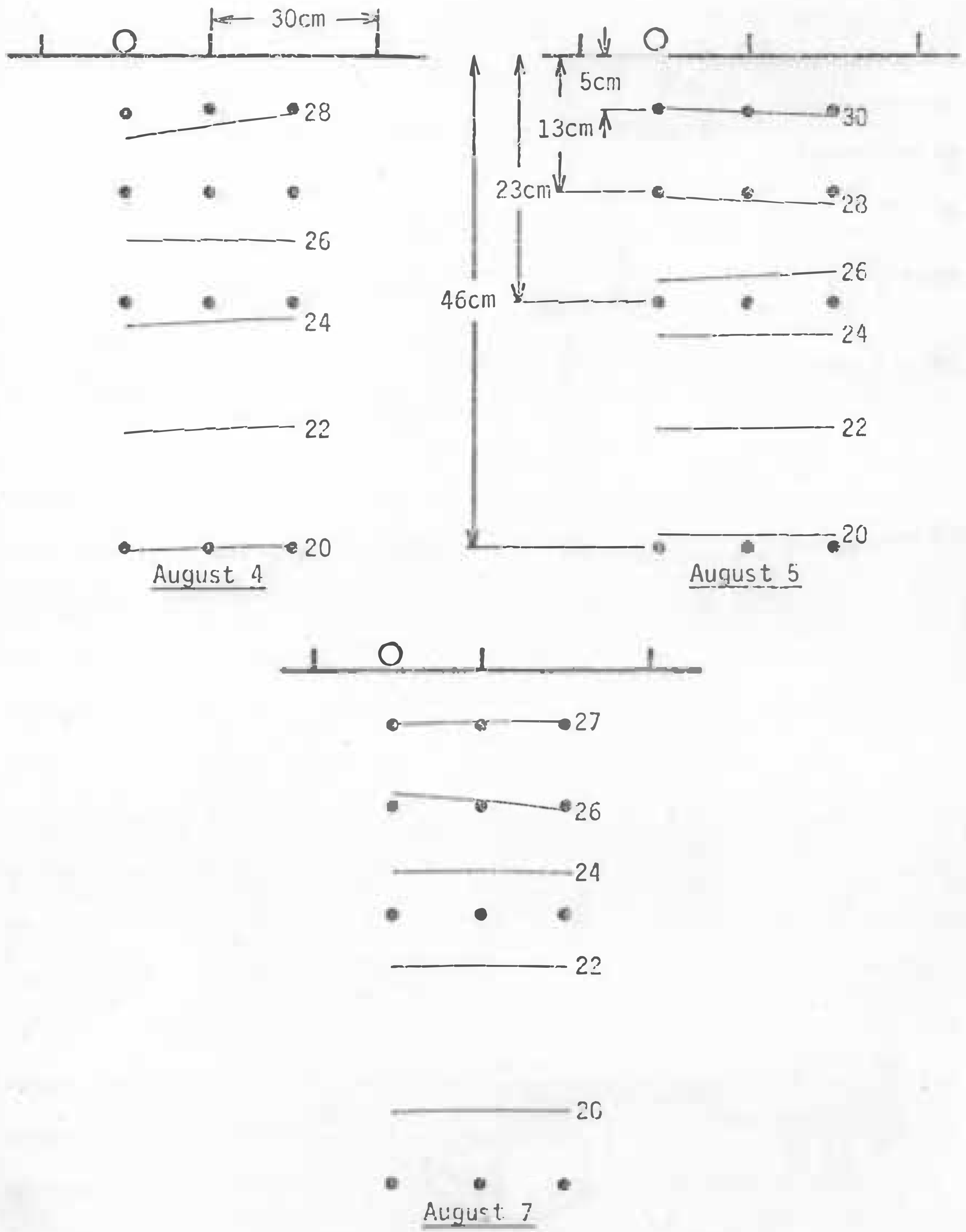
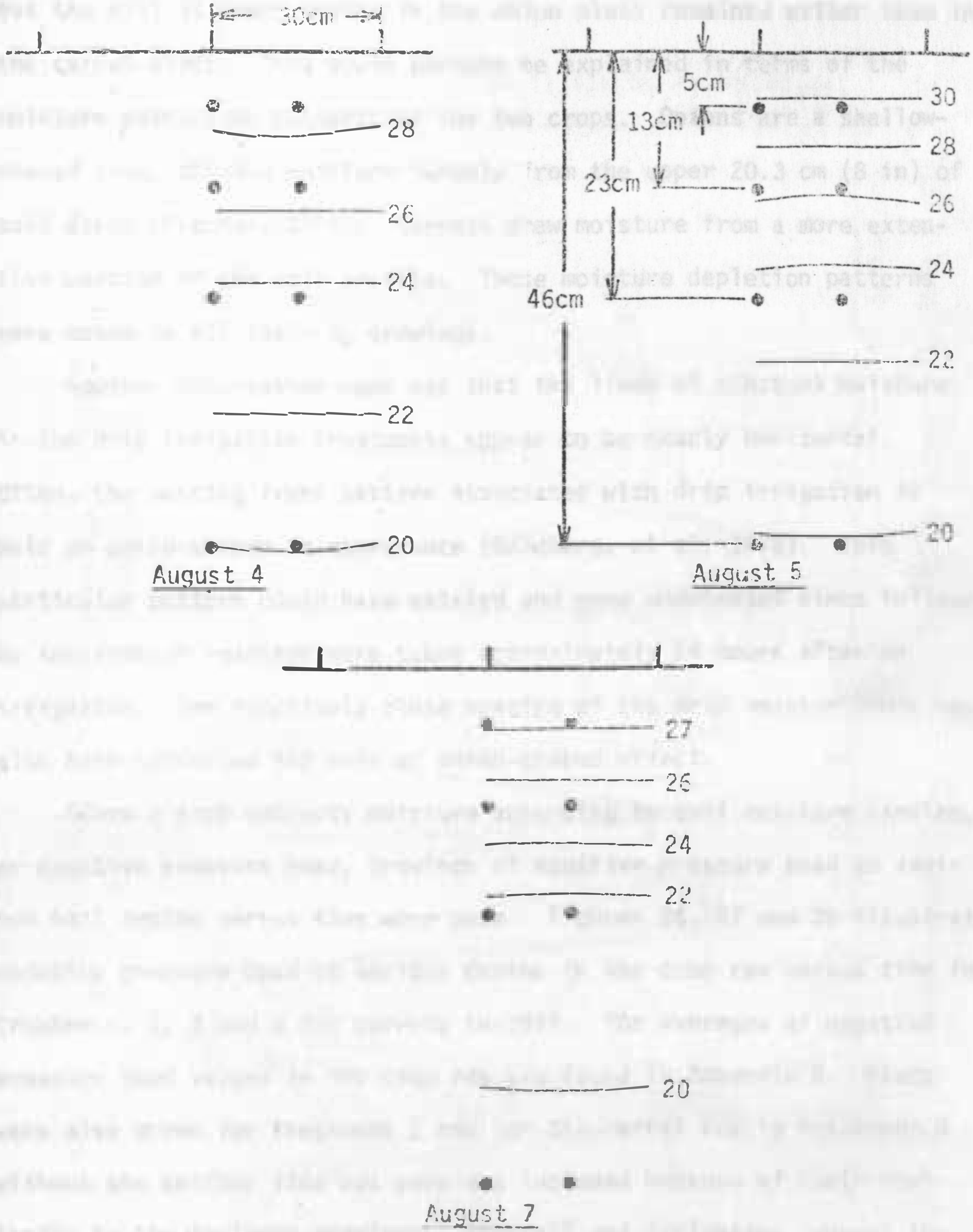


Figure 23. Iso - Θ_v Lines for Onions, Treatment 1 1975.



• Denotes a Tensiometer Location

Figure 24. Iso - θ_v Lines for Onions, Treatment 3 1975.



• Denotes a Tensiometer Location

Figure 25. Iso - θ_v Lines for Onions, Treatment 4 1975.

but the soil at lower depths in the onion plots remained wetter than in the carrot plots. This could perhaps be explained in terms of the moisture extraction patterns of the two crops. Onions are a shallow-rooted crop, drawing moisture largely from the upper 20.3 cm (8 in) of soil depth (Prashar, 1976). Carrots draw moisture from a more extensive portion of the soil profile. These moisture depletion patterns were noted in all Iso - Θ_V drawings.

Another observation made was that the lines of constant moisture in the drip irrigation treatments appear to be nearly horizontal. Often, the wetting front pattern associated with drip irrigation is bulb or onion-shaped in appearance (Goldberg, et al. 1976). This particular pattern could have existed and gone undetected since follow-up tensiometer readings were taken approximately 24 hours after an irrigation. The relatively close spacing of the drip emitter lines may also have cancelled the bulb or onion-shaped effect.

Since a crop extracts moisture according to soil moisture tension, or negative pressure head, drawings of negative pressure head at various soil depths versus time were made. Figures 26, 27 and 28 illustrate negative pressure head at various depths in the crop row versus time for treatments 1, 3 and 4 for carrots in 1975. The averages of negative pressure head values in the crop row are found in Appendix B. Plots were also drawn for treatment 2 and for the carrot row in treatment 3 without the emitter line but were not included because of their similarity to the included drawings. Rainfall and irrigation reduced the magnitude of the negative pressure head at the upper depths to values

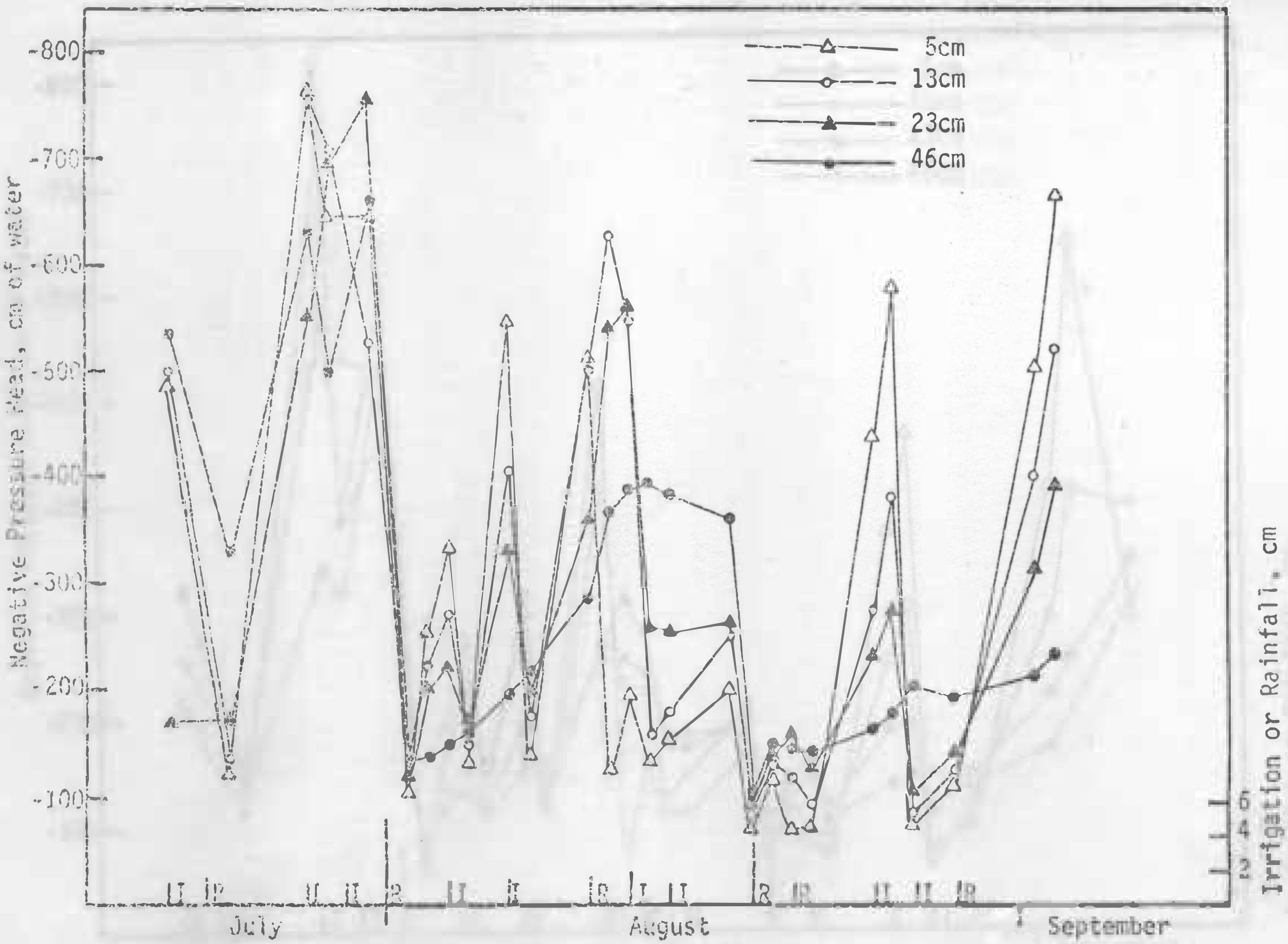


Figure 26. Negative Pressure Head at Various Depths for Carrots, Treatment 1 1975.

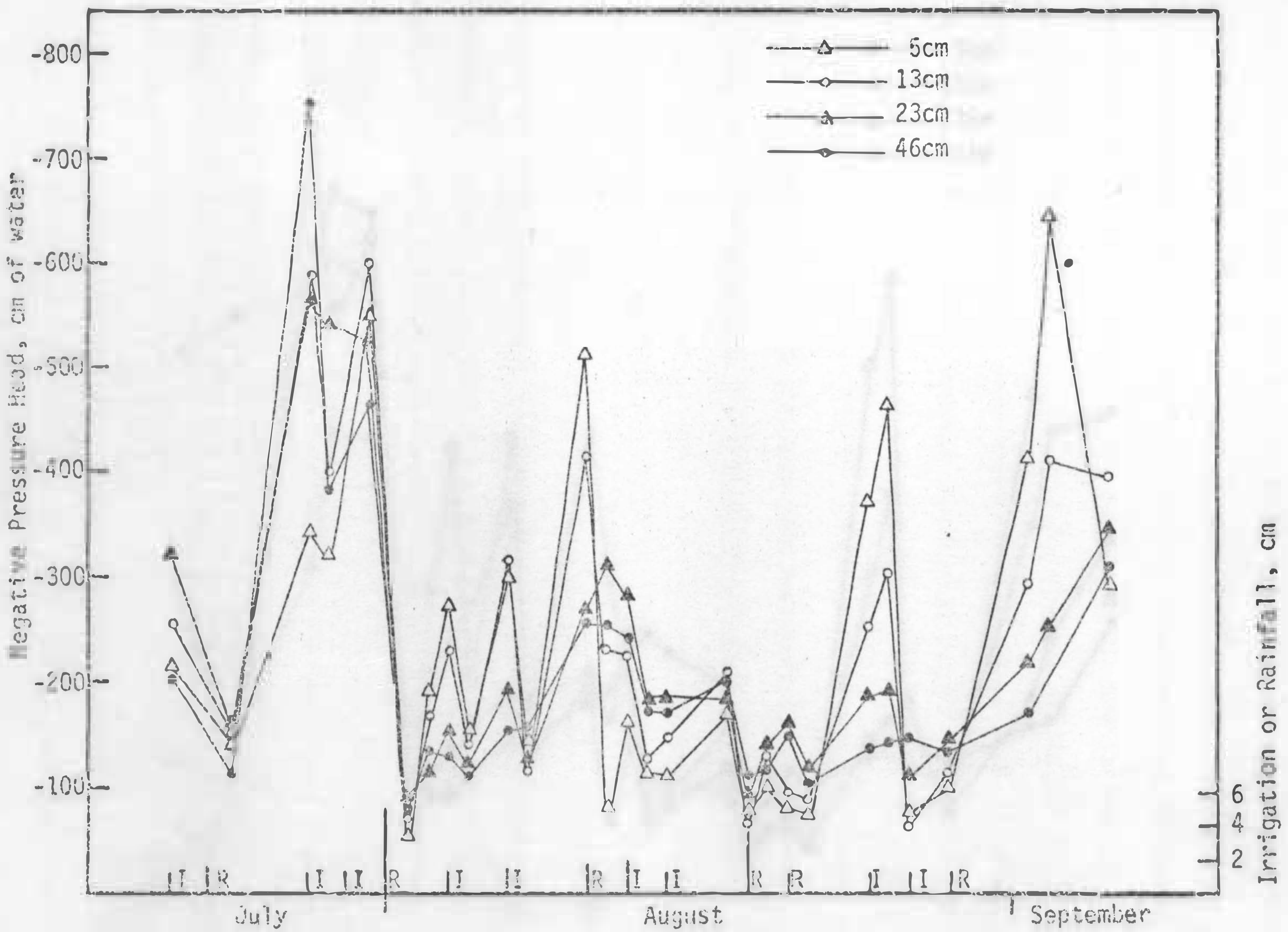


Figure 27. Negative Pressure Head at Various Depths for Carrots, Treatment 3 1975.

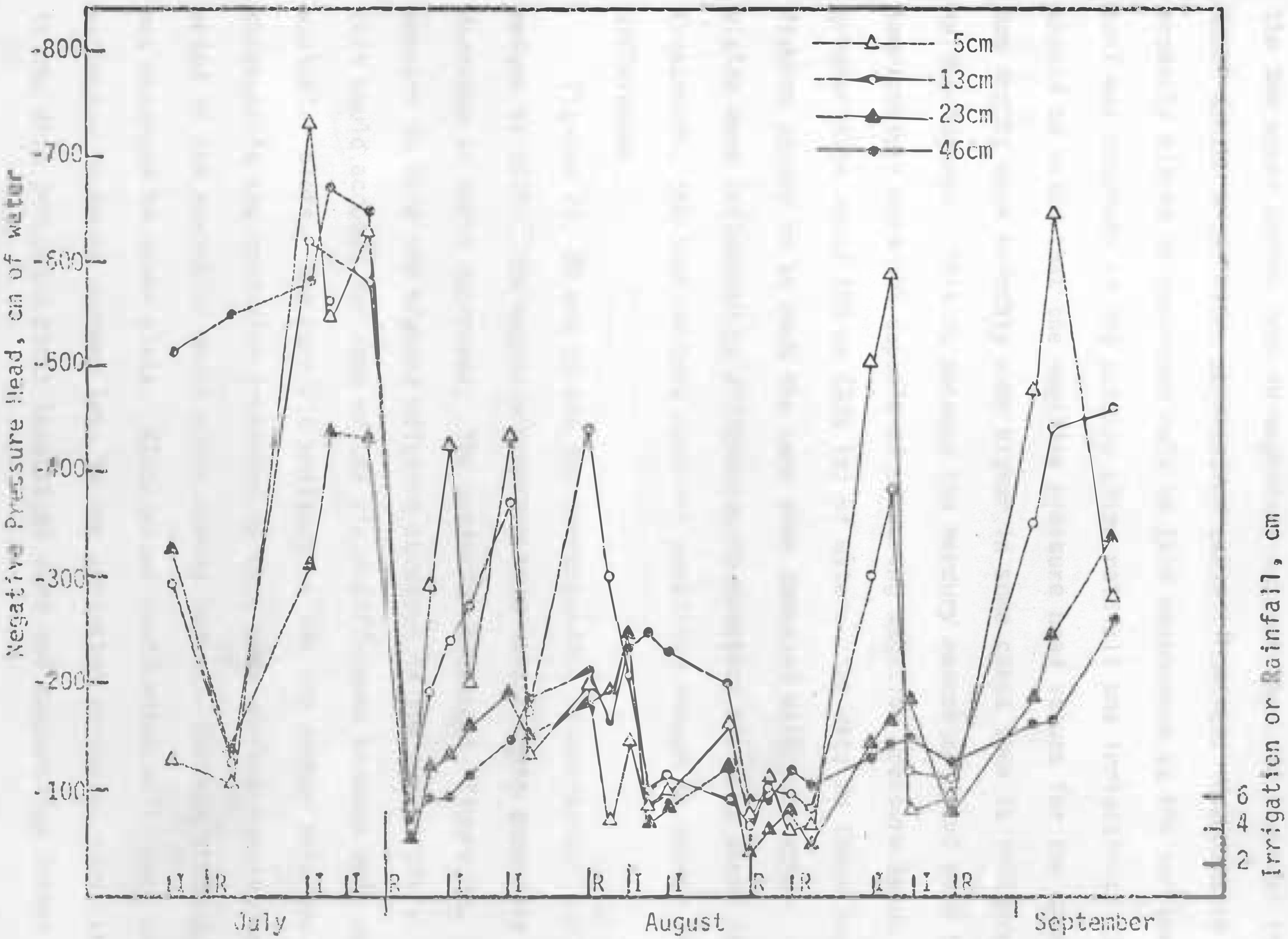


Figure 28. Negative Pressure Head at Various Depths for Carrots, Treatment 4 1975.

similar to those at the lower depths. Negative pressure head values at the two upper depths grew in magnitude quicker than did those at the two lower depths after water application ceased, however. Evaporation probably played an important role in this phenomenon as the surface soil was observed to dry quickly after rainfall and irrigations. It should be noted that the negative pressure head values for the upper two depths were probably even higher in some cases than is indicated in the figures. This is because the mercury manometers used with the tensiometers were not capable of measuring negative pressure heads greater than about 850 cm (335 in) of water. The data in these three figures appear to be much the same when compared with each other. If yields were influenced by differences in moisture stresses among these treatments, the tensiometers were not sensitive enough to detect the differences.

Figures 29, 30 and 31 are the corresponding illustrations for the onions in 1975. The negative pressure head values again generally decrease as depth decreases. The sprinkler treatment, Figure 31, appears to have the highest moisture stresses in the soil profile. This could account for some of the yield difference between drip and sprinkler plots. One possible explanation for the higher moisture stresses in the sprinkler treatment is that some surface sealing was noted in the sprinkler onion plots during August. Surface sealing was not observed in other plots. Also, water application efficiency was estimated to be 15 percent less in the sprinkler irrigated plots than in the drip irrigated plots because of wind and evaporation losses

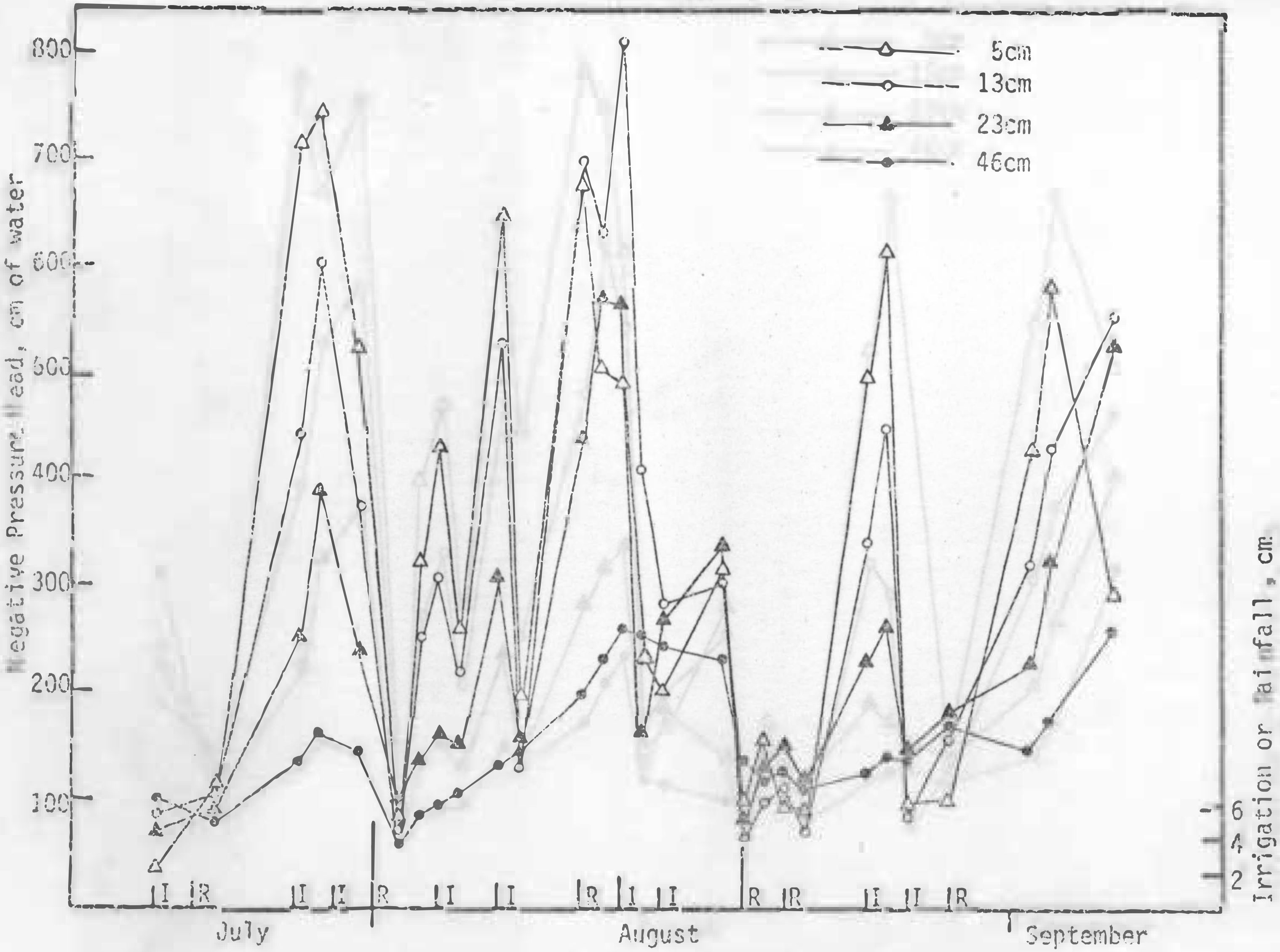


Figure 29. Negative Pressure Head at Various Depths for Onions, Treatment 1 1975.

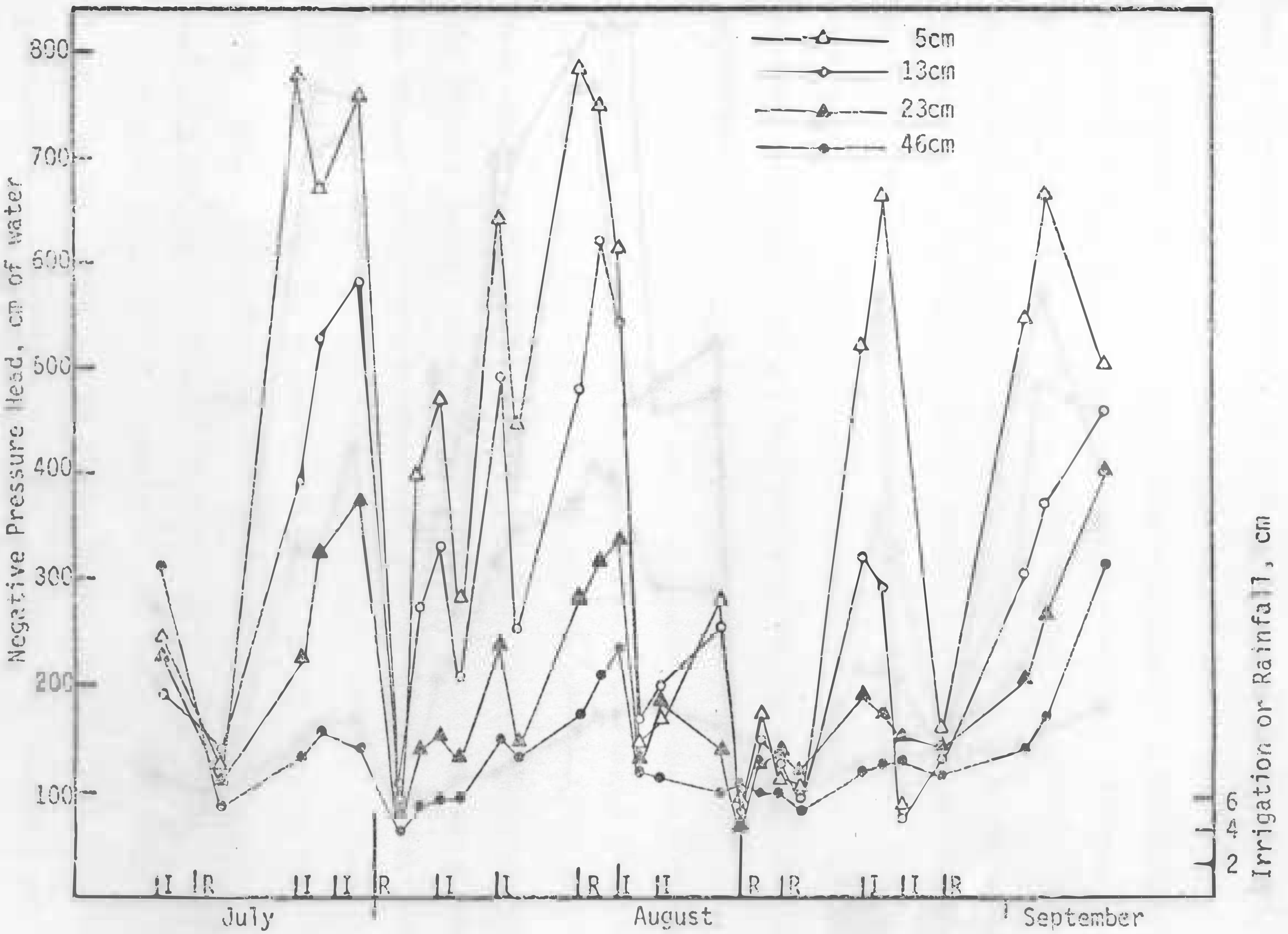


Figure 30. Negative Pressure Head at Various Depths for Onions, Treatment 3 1975.

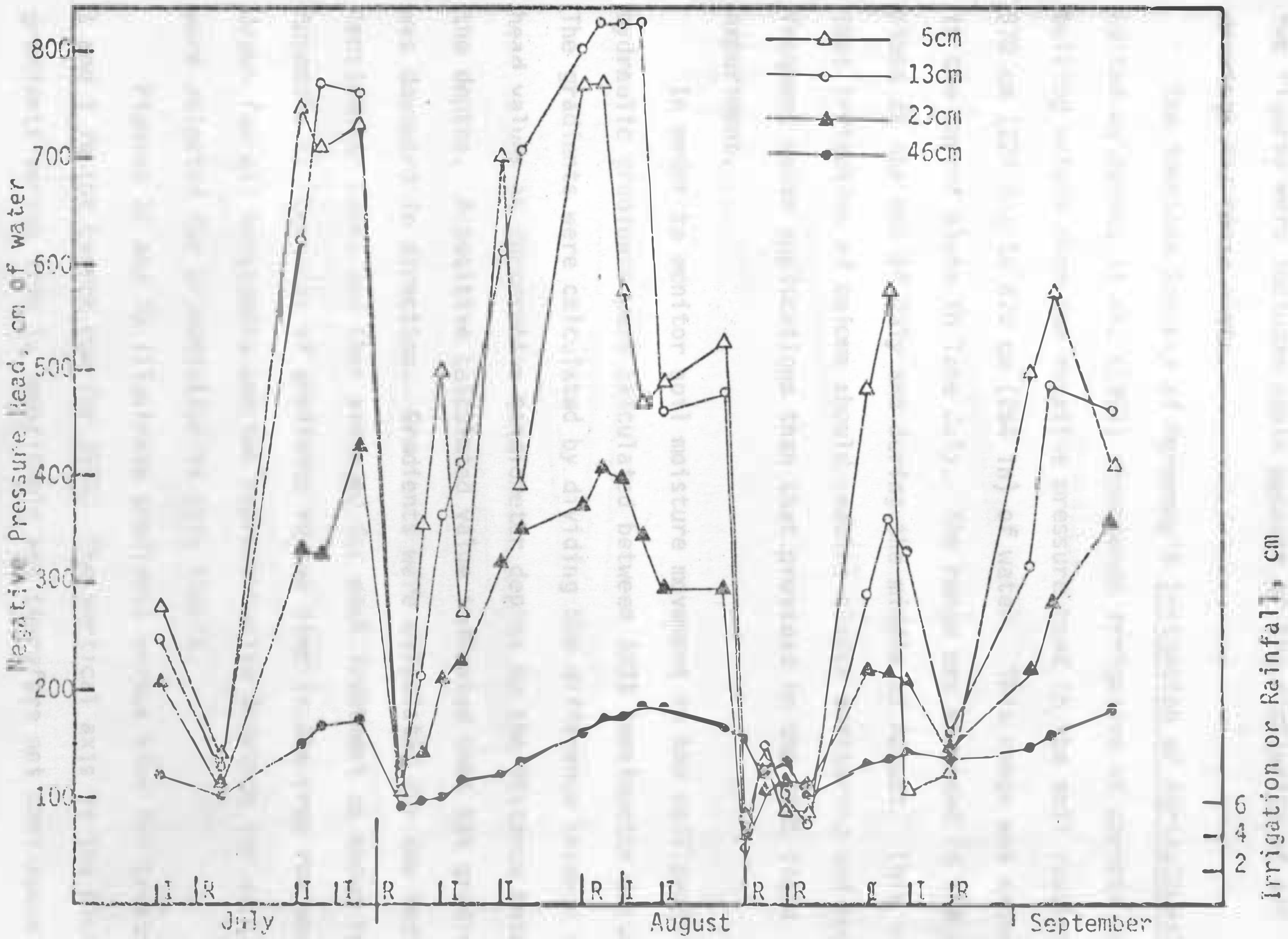


Figure 31. Negative Pressure Head at Various Depths for Onions, Treatment 4 1975.

associated with sprinkler irrigation. In the drip onion plots, only two figures were included again because of the similarity of all drawings for these plots.

The American Society of Agronomy's Irrigation of Agricultural Lands edited by Hagen, et al. (1969) recommends irrigation of carrots and bulbing onions when the negative pressure head in the soil reaches 570 cm (224 in) to 670 cm (264 in) of water. This range was exceeded in the carrot plots in late July. The range was exceeded in the onion plots at the end of July and during the middle of August. This suggests that irrigation of onions should require closer monitoring and more frequent water applications than that provided in the 1975 field experiment.

In order to monitor soil moisture movement in the soil profile, hydraulic gradients were calculated between 1975 tensiometer depths. The gradients were calculated by dividing the difference between total head values at consecutive tensiometer depths by the distance between the depths. A positive calculated value indicated that the gradient was downward in direction. Gradients were calculated for the individual tensiometer banks and then averaged for each treatment as shown in Appendix E. Drawings of gradients versus time in the crop row were drawn for all treatments and two representative drawings for each crop were selected for presentation in this thesis.

Figures 32 and 33 illustrate gradients versus time for treatments 1 and 2 in the carrot row for 1975. The vertical axis in the plots of gradients versus time is logarithmic and therefore not continuous

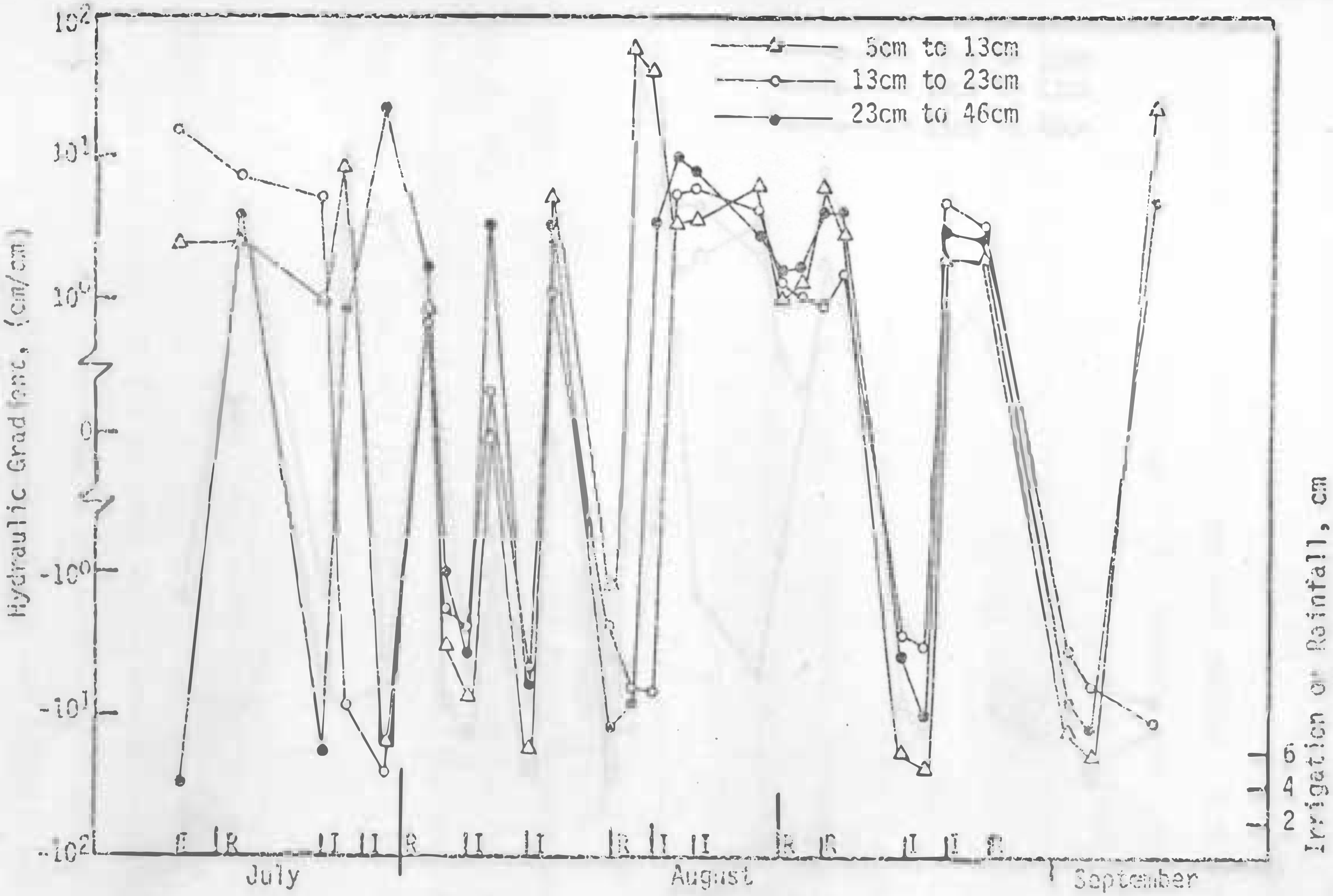


Figure 32. Hydraulic Gradients at Various Depths for Carrots, Treatment 1 1979.

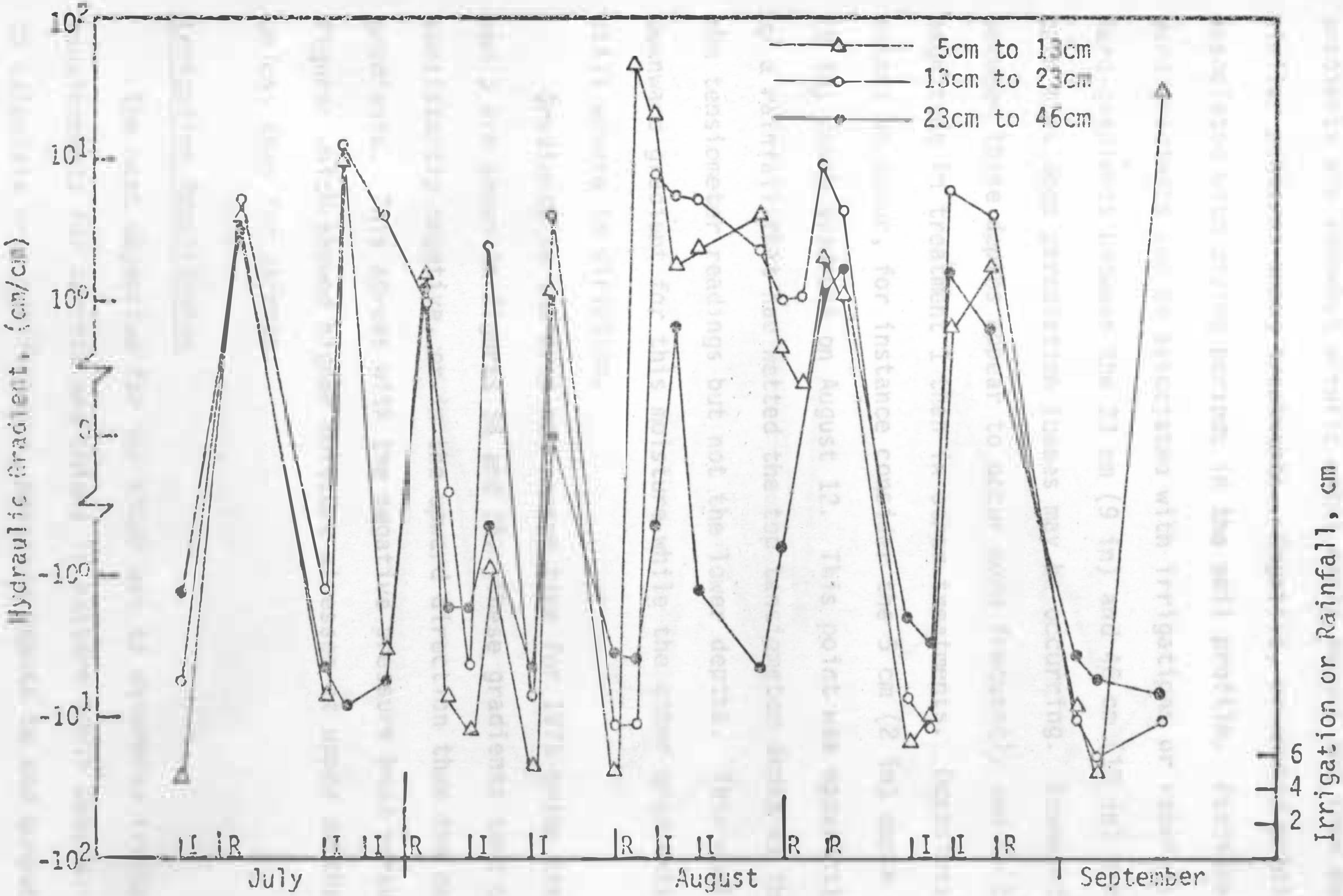


Figure 33. Hydraulic Gradients at Various Depths for Carrots, Treatment 2 1975.

between hydraulic conductivity values of -10^0 cm/cm and 10^0 cm/cm. The gradients are somewhat erratic until early August and then develop similar patterns among treatments. Negative, or upward gradients are associated with drying periods in the soil profile. Positive, or downward gradients can be associated with irrigations or rainfall. Downward gradients between the 23 cm (9 in) and 46 cm (18 in) depths indicate that deep percolation losses may be occurring. Downward gradients between these depths appear to occur more frequently and in larger magnitude in treatment 1 than in other treatments. Occasional erratic points do occur, for instance consider the 5 cm (2 in) depth to 13 cm (5 in) depth gradient on August 12. This point was apparently caused by a rainfall that had wetted the top tensiometer depth at the time of the tensiometer readings but not the lower depths. This would create a downward gradient for this moisture while the other gradients were still upward in direction.

Gradients in the crop row versus time for 1975 onion treatments 2 and 3 are shown in Figures 34 and 35. These gradients tend to be more consistently negative, or in the upward direction than the carrot gradients. This agrees with the negative pressure head versus time figures which showed higher moisture stresses at upper depths for onions than for carrots.

<u>Irrigation Requirements</u>

The next objective for the study was to determine irrigation requirements for carrots and onions in eastern South Dakota. In order to calculate crop coefficients, moisture inputs to and outputs from the

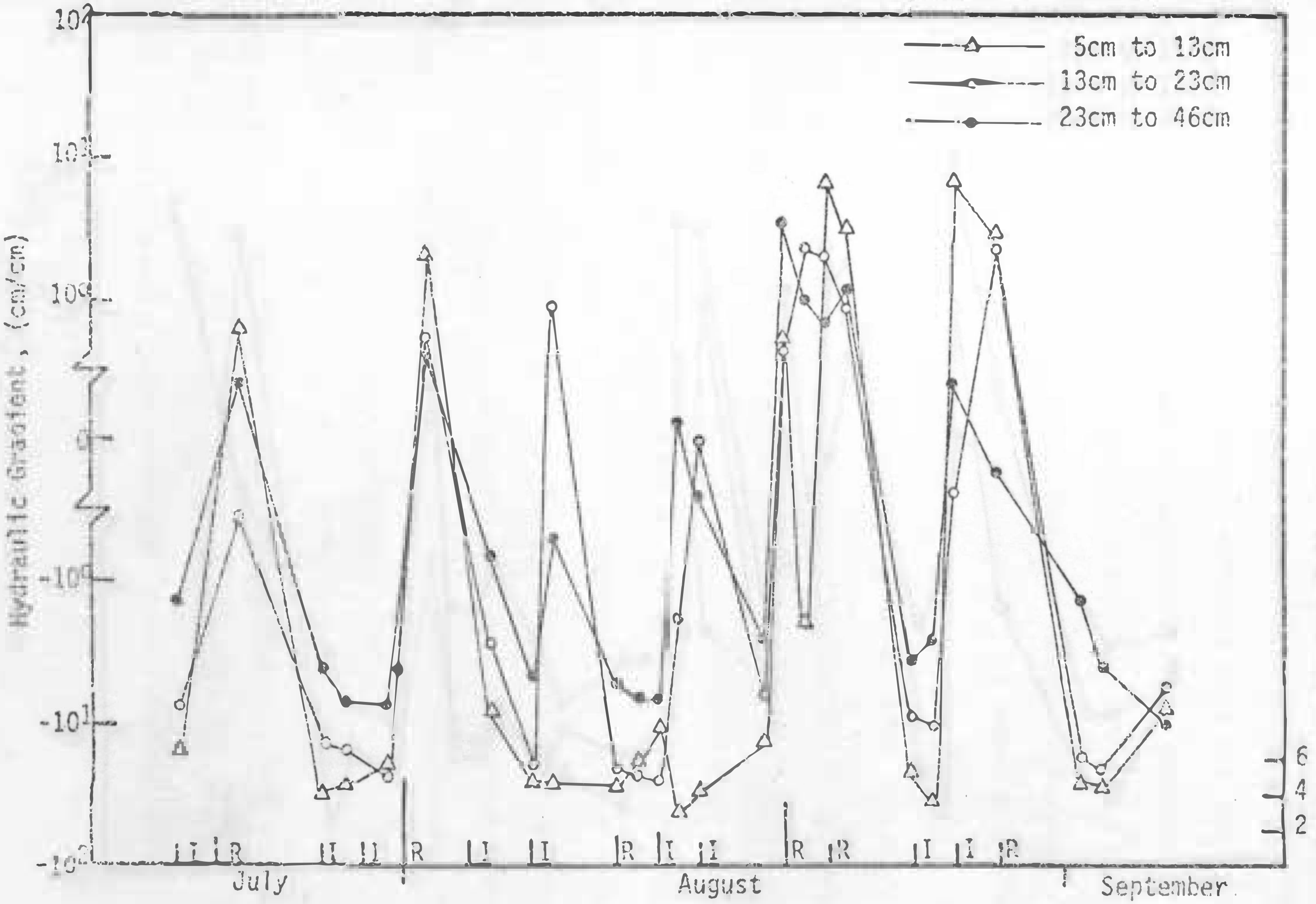


Figure 34. Hydraulic Gradients at Various Depths for Onions, Treatment 2 1975.

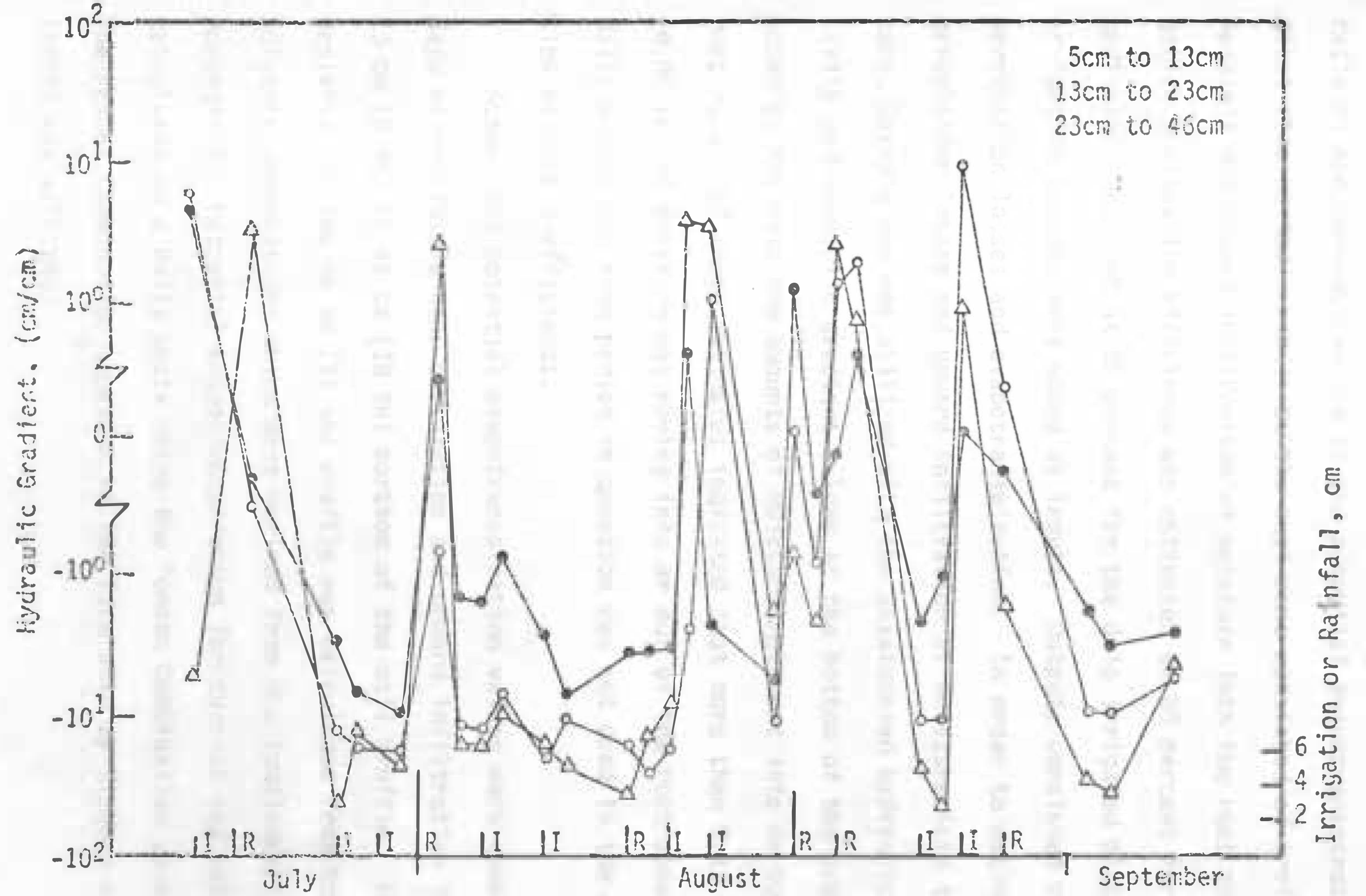


Figure 35. Hydraulic Gradients at Various Depths for Onions, Treatment 3 in the Onion Row with the Emitter Line, 1975.

root zone were monitored in 1975. A crop coefficient is defined as the ratio of the consumptive use to the potential evapotranspiration for a given time period. Inputs to the root zone consisted of irrigation, rainfall and upward infiltration of moisture into the root zone. Irrigation application efficiency was estimated at 80 percent for the sprinkler plots and at 95 percent for the drip irrigated plots when irrigation amounts were added as inputs. Outputs consisted of deep percolation losses and evapotranspiration. In order to estimate deep percolation losses and upward infiltration of moisture into the root zone, Darcy's Law was utilized with the unsaturated hydraulic conductivity and hydraulic gradient values at the bottom of the crop root zones to estimate the amounts of moisture-movement into or out of the root zone. If these estimates indicated that more than 0.13 cm (0.05 in) of moisture was moving into or out of the root zone on a daily basis, the time period in question was not used in the calculation of crop coefficients.

Actual and potential evapotranspiration values were computed for days of negligible deep percolation and upward infiltration in the 23 cm (9 in) to 46 cm (18 in) portion of the soil profile. Moisture depletion in the 46 cm (18 in) profile was calculated from total moisture computations which were derived from the tensiometer data, Appendix D. Potential evapotranspiration for carrots and onions was calculated on a daily basis using the Penman Combination Equation. The Penman Combination Equation of the form used by Stegman and Valer (1972) was utilized:

$$ET_p = \left[\Delta/(\Delta+\gamma)\right] R_n + \left[\gamma/(\Delta+\gamma)\right] 15.36\ (1 + .01w)\ (e_s - e_d)$$

where:

ET_p = potential evapotranspiration in inches per day.

Δ = a temperature dependent constant equal to the slope of the saturation vapor pressure curve at mean air temperature.

γ = a psychrometric constant.

R_n = net radiation in cal/cm^2 per day.

w = total wind run in miles per day at the two meter height.

e_s = saturation vapor pressure at mean air temperature in millibars.

e_d = saturation vapor pressure at mean dew point in millibars.

R_n was estimated by

$$R_n = (1 - \alpha)\ R_s - R_1$$

where:

R_n = net radiation in cal/cm^2 per day.

R_s = solar radiation in cal/cm^2 per day.

R_1 = net outgoing longwave radiation in cal/cm^2 per day.

α = mean daily shortwave reflectance or albedo, taken as 0.20 for carrots and 0.15 for onions.

R_1 was estimated by

$$R_1 = (1.35\ R_s/R_{so} - 0.35) R_{1o}$$

where:

R_{so} = solar radiation on a clear day in cal/cm^2 per day.

R_{lo} = net outgoing longwave radiation on a clear day in cal/cm^2 per day.

R_{lo} was estimated by

$$R_{lo} = \left[0.98 - (0.67 + 0.044\, e_d)\right] \sigma\, T_a^{\,4}$$

where:

σ = Stefan - Boltzman Constant (11.71×10^{-8} cal/cm^2 per day).

T_a = mean daily air temperature in degrees Kelvin.

e_d = saturation vapor pressure at mean dew point temperature in millibars.

A computer program was used to calculate values of ET_p using the Penman Combination Equation. The program required the following climatic data on a daily basis for inputs: 1. Minimum daily temperature in °F, 2. Maximum daily temperature in °F, 3. Mean daily dew point temperature in °F, 4. Albedo, 5. Total daily wind run in miles per day and 6. Daily solar radiation in cal/cm^2 per day.

Tensiometer data were eliminated for time periods in which estimates indicated that more than 0.13 cm (0.05 in) of moisture was moving into or out of the root zone on a daily basis. Actual evapotranspiration, potential evapotranspiration and the resulting crop coefficients were then calculated for both crops from the remaining tensiometer data. However, the calculated values of actual evapotranspiration for all treatments of both crops were consistently larger than the corresponding potential evapotranspiration values on days when irrigations occurred. This resulted in crop coefficient values larger than one in magnitude. Potential evapotranspiration is the evapotranspiration

which occurs when the stage of plant growth and soil moisture conditions are not limiting factors to the evapotranspiration process. Potential evapotranspiration is therefore the maximum evapotranspiration rate possible for a crop under given climatic conditions. The actual evapotranspiration rate cannot be larger than the potential evapotranspiration rate and thus crop coefficients larger than one are in error. A probable cause for the large actual evapotranspiration values is unmeasured deep percolation losses which may have occurred less than 24 hours after irrigations or rainfall. The shallow soil depth with good drainage is suspected as the cause of deep percolation losses. These losses would not have been indicated by the hydraulic gradients since tensiometers were not read for 24 hours following the irrigation. Table 20 presents the actual and potential evapotranspiration values and the resulting crop coefficients for carrots from the data which were not eliminated. Crop coefficients which were calculated to be slightly larger than one were reported as being equal to one. Because of consistent upward gradients and large actual evapotranspiration values, virtually all of the tensiometer data for onions were eliminated and consequently no crop coefficients for onions could be reported.

The actual evapotranspiration values for carrots reported in Table 20 were compared to estimates for actual evapotranspiration made from Figures 26 through Figure 28. During two periods in which tensiometer data were taken in 1975, negative pressure head values indicated that the available soil moisture was being readily utilized by carrots. Between July 24 and July 28, relatively high negative pressure head

Table 20. 1975 Carrot Crop Coefficients.

Date	Treatment Consumptive Use (cm)+				Potential	Treatment Crop Coefficients			
	1	2	3	4	Evapotranspiration (cm)*	1	2	3	4
7-24									
7-28	1.65	1.83	1.93	1.57	1.88	0.87	0.97	1.00	0.83
8-3					0.43				
8-4			0.20	0.25	0.46			0.43	0.54
8-5					0.46				
8-7			0.96	0.51	0.94			1.00	0.54
8-8					0.46				
8-11				0.61	1.30				0.47
8-12					0.41				
8-14					0.46				
8-15	0.20		0.08		0.20	1.00		0.40	
8-25					1.02				
8-26			0.18	0.23	0.48			0.37	0.48

+ The consumptive use values represent the consumptive use by carrots between the day where the amount is listed and the previously listed day.

* The value of albedo used for the calculation of ET_p for carrots was 0.20. The ET_p values listed represent the ET_p between the day where the amount is listed and the previously listed day.

values throughout the soil profile indicated that the carrots were utilizing most of the rainfall and irrigation amounts in the evapotranspiration process. Steadily increasing negative pressure head values throughout the soil profile between August 2 and August 14 also indicated that rainfall and irrigation amounts were being readily utilized. Actual evapotranspiration estimates from these two periods were made using the irrigation and rainfall records. These values averaged 0.47 cm/day (0.18 in/day) for the period in July and 0.42 cm/day (0.17 in/day) for the August period. From Table 20, consumptive use averaged 0.47 cm/day (0.18 in/day) between July 24 and July 28 and 0.29 cm/day (0.11 in/day) between August 2 and August 14. Climatic conditions during these two periods were more conducive to high evapotranspiration rates than at any other time in which tensiometer data were taken. Thus, from the available data, it would appear reasonable to expect actual evapotranspiration values approaching 0.50 cm/day (0.20 in/day) for carrots when climatic conditions are favorable to high evapotranspiration rates.

Estimates of actual evapotranspiration for onions were made from Figures 29 through Figure 31. The same two time periods were selected from these figures as were selected from Figures 26 through 28 for estimation of actual evapotranspiration. Since the water applied during these time periods in the onion plots was identical to that applied in the carrot plots, estimates of actual evapotranspiration were also identical. However, moisture stresses in the onion plots were generally greater than in the carrot plots, especially during the August 2 to

August 14 period. This suggests that the onions could have utilized more moisture than the carrots during these periods. It would therefore appear reasonable to expect actual evapotranspiration values of 0.50 cm/day (0.20 in/day) or greater for onions when climatic conditions are favorable to high evapotranspiration rates.

Evaporation pan data recorded 3.2 km (2 mi) northeast of Brookings from a US Class A pan was obtained for the two time periods from the Climatological Data publication for South Dakota (National Oceanic and Atmospheric Administration, 1975). Daily pan evaporation for the two periods averaged 0.85 cm (0.33 in). From the estimates made for actual evapotranspiration, an actual evapotranspiration to pan evaporation ratio was computed for carrots and onions. From the computed ratio (0.50 cm to 0.85 cm), it appears that irrigation application amounts approaching six-tenths (0.60) of the pan evaporation amounts are required for carrots and onions when climatic conditions are favorable to high evapotranspiration rates. This irrigation recommendation is for the period when the carrot root and onion bulb are undergoing rapid development. Since this irrigation recommendation was made largely from Figures 26 through 31 and not from actual and potential evapotranspiration calculations, it is noted that the recommendation is a rough estimate for irrigation application amounts. Research by Narang and Pastane (1971) in India and Van Eeden and Myburgh (1971) in South Africa recommended irrigation amounts for onions of seven-tenths (0.7) of the pan evaporation amounts for onions experiencing rapid bulb development. A bulletin published by the California Department of

Natural Resources (1975) recommended irrigation amounts for carrots ranging from 0.35 to 0.79 of the pan evaporation amounts, depending upon the stage of crop growth.

Economic Analysis

The economic analysis consists of comparing cost and return information associated with drip and sprinkler irrigation of carrots and onions. The costs presented in the study are irrigation equipment and operation costs and crop production costs. Returns consist of prices paid to the grower for carrot and onion crops based on national price averages. Some of the basic cost and return data are presented in Table 21.

The annual production costs associated with growing carrots and onions are presented in Table 22. The production costs for both crops are largely based on information from the University of Wisconsin for production of carrots and onions in a mechanized operation. Fertilizer costs were estimated according to application recommendations from Warnke, et al. (1976) and Prashar (1976). The annual labor costs for the irrigation systems include \$185/ha (\$75/acre) and \$124 ha (\$50/acre) for installation of the drip and sprinkler systems, respectively. Included as an annual production cost is the fixed machinery cost associated with the machinery used in the carrot and onion production. No land costs or charges were calculated for this analysis and thus the returns presented later are expressed as returns to land and management.

The design of the hypothetical irrigation systems was based upon the layout of the irrigation systems used in the 1975 field

Table 21. Cost and Price Information.

Item	Cost
Well and Casing+	$4190
Pump, Motor and Panel++	
Drip System	$2165
Sprinkler System	$2660
Irrigation Equipment	
Drip System	$1060/hectare ($430/acre)
Sprinkler System	$3440/hectare ($1390/acre)
Price of Carrots*	$110/metric ton ($5/cwt) US Extra #1 carrots $55/metric ton ($2.50/cwt) all other grades
Price of Onions*	$165/metric ton ($7.50/cwt) USDA Medium or larger onions $82/metric ton ($3.75/cwt) all other grades
Electric Costs**	$12.70/measured kw ($9.50/measured hp) for standby $0.019/kw-hr for service

+ A breakdown of items included in the well and casing costs is presented in Appendix F. The well and casing cost is for both the drip and sprinkler systems.

++ A breakdown of items included in the pump, motor and panel costs is presented in Appendix F.

* Prices obtained from Paul Prashar, Horticulture Department, South Dakota State University.

** Costs taken from "Crop Yield and Economic Analyses of Selected Multiple Pivot Irrigation Schemes" (unpublished M.S. thesis by Michael Otterby, South Dakota State University, 1976), p. 62.

Table 22. Annual Production Costs for Carrots and Onions*.

Item	Carrots		Onions	
	$/ha	$/acre	$/ha	$/acre
Fertilizer	188.00	76.00	188.00	76.00
Seed	30.00	12.00	77.00	31.00
Herbicide	203.00	82.00	114.00	46.00
Machine Operation	52.00	21.00	94.00	38.00
5% Capitol Charge on Above+	25.00	10.00	25.00	10.00
Labor				
Drip	403.00	163.00	519.00	210.00
Sprinkler	341.00	138.00	457.00	185.00
Transportation and Marketing	319.00	129.00	477.00	193.00
Harvesting	393.00	159.00	393.00	159.00
Fixed Machinery	430.00	174.00	413.00	167.00
Totals				
Drip	2043.00	826.00	2300.00	930.00
Sprinkler	1981.00	801.00	2238.00	905.00

* All costs are from the University of Wisconsin Horticulture Department for growing carrots and onions with largely mechanized field operations unless otherwise noted in the text. The costs are averages of data taken from commercial operations in Wisconsin in 1973. All of these costs were updated to 1976 using Agricultural Prices, USDA, and Survey of Current Business, U.S. Department of Commerce.

+ The 5% charge is based on an annual interest rate of 10% for 6 months.

investigation. Arrangement and spacing of crop rows were assumed to be similar to those used in the 1975 field investigation. All design considerations and cost estimates were based upon the assumption that the particular crop would be grown in a field 400 m (1320 ft) by 400 m or 16.2 ha (40 acres) in size. Design and cost information for the drip irrigation system were provided in part by Anjac Plastics of El Monte, California. Corresponding information for the sprinkler irrigation system was collected with the assistance of Cluever (1976). It was assumed that 1 hectare (2.5 acres) would be irrigated at one time for the sprinkler system and 2 hectares (5 acres) would be irrigated at one time for the drip system. A design pumping rate of 0.76 m^3/min (200 gpm) was calculated for the drip system which would produce a gross application rate of 0.23 cm/hr (0.09 in/hr). This would require an eleven-hour irrigation cycle for each 2 hectare (5 acre) area for a gross application of 2.54 cm (1 in). A design pumping rate of 1.04 m^3/min (275 gpm) was calculated for the sprinkler system and would produce a gross application rate of 0.64 cm/hr (0.25 in/hr). This would require a four-hour irrigation cycle for each 1 hectare (2.5 acre) area for a gross application of 2.54 cm (1 in). The drip irrigation system was designed similar to treatment 3 in 1974. It was assumed that the drip irrigation emitter line would be placed adjacent to every other crop row. Relatively close sprinkler spacing resulted from the design of the solid-set sprinkler system because of a design consideration made for winds in excess of 16.1 km/hr (10 mi/hr). The sprinkler irrigation lateral spacing along the mainline was calculated to be 12.2 m

(40 ft) with sprinklers spaced every 6.1 m (20 ft) along the laterals. The length of the 7.6 cm (3 in) diameter laterals was determined to be 195 m (640 ft).

The annual irrigation costs for the drip and sprinkler irrigation systems are presented in Table 23. Further cost breakdowns for the pump, panel and motor costs and the well and casing costs are presented in Appendix F. The drip irrigation emitter lines were assumed to have a one-year life while all drip irrigation plastic fittings were assumed to have a five-year life. All sprinkler irrigation equipment can be expected to have a fifteen-year life. The pump, motor and panel and the well and casing for each system were assumed to have twenty-year lives. The mainlines for both systems can be expected to have lives of thirty-five years. Information on the expected lives of these items was collected with the assistance of Cluever (1976) and Getting Industries, Sioux Falls, South Dakota (1976). Mainline costs for the drip irrigation system were approximately twice that of the sprinkler system because emitter line length was limited due to friction loss considerations. Annual costs for all items with a ten-year life or longer were based on a ten-year repayment plan at an annual interest rate of eight percent.

A summary of cost and return data is presented in Table 24. The yields used in calculating gross returns to land and management were estimated from the yields measured in the 1975 field investigation for treatments 3 and 4 of both crops. Because the carrots and onions in the 1975 field investigation were grown in relatively small plot areas

Table 23. Annual Irrigation Costs for Drip and Sprinkler Systems.

Item	Drip		Sprinkler	
	$/ha	$/acre	$/ha	$/acre
Well and Casing	39.00	16.00	39.00	16.00
Pump, Motor and Panel	20.00	8.00	25.00	10.00
Mainline**	47.00	19.00	19.00	8.00
Electric Costs	15.00	5.00	15.00	6.00
Irrigation Equipment+	954.00	386.00	604.00	244.00
Totals	1075.00	434.00	702.00	284.00

+ Irrigation costs for the drip system include bi-wall drip emitter lines spaced on every other row and all fittings. Sprinkler equipment costs include aluminum sprinkler pipe, risers and sprinkler heads and all fittings. Drip irrigation equipment prices were taken from information received from Anjac Plastics, El Monte, California. Sprinkler irrigation equipment prices were taken from the Heinzman Engineering, Inc. catalog. It was assumed that the drip emitter lines would be discarded after one year's use and thus had a one-year life. The drip fittings were assumed to have a five-year life. All other costs were figured on a ten-year repayment basis at 8%.

** Prices are for PVC mainline pipe taken from the Heinzman Engineering, Inc. catalog.

Table 24. Summary of Cost and Return Data.

Crop	Gross Return to Land and Management		Total Cost		Net Return to Land and Management	
	$/ha	$/acre	$/ha	$/acre	$/ha	$/acre
Drip Irrigated Onions	6454.00	2612.00	3375.00	1364.00	3079.00	1248.00
Sprinkler Irrigated Onions	5550.00	2246.00	2940.00	1189.00	2610.00	1057.00
Drip Irrigated Carrots	6414.00	2596.00	3118.00	1260.00	3296.00	1336.00
Sprinkler Irrigated Carrots	5105.00	2066.00	2683.00	1085.00	2422.00	981.00

under controlled experimental conditions, the yields used in the economic analysis were estimated at 75 percent of the yields recorded in the field investigation. The crop prices used to calculate gross returns to land and management were averages of recent monthly prices paid to United States growers (Table 21). These prices, and therefore the gross returns, vary considerably with the location and the time of year. Onion prices are particularly volatile and could produce considerably different results from those noted in Table 24. The net returns to land and management were calculated by subtracting the total annual costs from the gross returns to land and management. Total annual costs consisted of annual production costs for the particular crop and annual irrigation costs for the particular irrigation systems. Table 25 shows that under the crop price levels considered, drip irrigation will produce higher net returns to land and management than sprinkler irrigation for both crops. Table 24 also indicates that drip irrigation of carrots will produce the highest net returns to land and management of the four management plans considered.

SUMMARY AND CONCLUSIONS

Drip irrigation is becoming an increasingly important part of irrigated agriculture as evidenced by its growing acceptance in many parts of the world. The application of drip irrigation to specialty crops is exhibited in California where nuts, fruits and vegetables are all presently grown under drip irrigation. There has been little research done on drip irrigation in the North Central United States and thus information regarding the application of drip irrigation to this area is limited. Although specialty crops are not presently grown extensively in South Dakota, the possibilities for development of markets for these crops in the future appear attractive. A study was begun to evaluate the effects of drip and sprinkler irrigation on two vegetable crops presently grown in South Dakota, carrots and onions. The study was undertaken to provide more information on the irrigation of vegetables in South Dakota with particular emphasis on comparing drip and sprinkler irrigation crop yields and economics.

Data from the first two years of the study were reported and analyzed. The field experiment was conducted at the Agricultural Engineering Research Farm near Brookings, South Dakota, in a shallow sandy loam soil. During 1974, one sprinkler irrigation treatment and two drip irrigation treatments were used to irrigate both crops with a 76 cm (30 in) row spacing. The drip irrigation treatments consisted of placing an emitter line adjacent to every crop row and the placement of an emitter line at the center of alternate row spaces. The sprinkler treatment was designed to simulate a conventional solid-set

sprinkler system. Irrigation scheduling and net water applications were the same for all treatments. The 1974 carrot yields were 56.2 metric tons/hectare (1003 bushels/acre) in the every row drip irrigated plots, 45.4 mt/ha (810 bu/acre) in the every other row drip irrigated plots and 51.7 mt/ha (922 bu/acre) in the sprinkler irrigated plots. The corresponding 1974 onion yields were 25.1 mt/ha (447 bu/acre), 18.2 mt/ha (325 bu/acre) and 23.3 mt/ha (415 bu/acre). No statistically significant differences were found between the sprinkler treatment yield and the average of the drip treatment yields for carrots or onions. However, the every row drip treatment produced significantly greater carrot and onion yields than the every other row drip treatment.

During 1975, one sprinkler treatment and three drip irrigation treatments were used on 30.5 cm (12 in) row spacings. Again, one drip irrigation treatment consisted of placing the emitter line adjacent to every crop row. Another drip treatment consisted of placing the emitter line at the center of every other row space. In the third treatment, the emitter line was placed adjacent to every other crop row. The sprinkler treatment again was designed to simulate a conventional solid-set sprinkler irrigation system. Although irrigations were scheduled at the same time for all treatments in 1975, 12 percent and 6 percent less gross water was applied to the every row drip and sprinkler treatments, respectively, than was applied to the every other row drip treatments. The 1975 carrot yields were 109 mt/ha (1950 bu/acre) in the every row drip irrigated plots, 99.8 mt/ha (1780 bu/acre) in the every other row drip irrigated plots with the emitter line placed

at the center of alternate row spaces, 106.9 mt/ha (1910 bu/acre) in the every other row drip irrigated plots with the emitter line placed adjacent to every other crop row and 84.9 mt/ha (1520 bu/acre) in the sprinkler irrigated plots. The corresponding 1975 onion yields were 69.3 mt/ha (1240 bags/acre), 50.3 mt/ha (1060 bags/acre), 60.6 mt/ha (1080 bags/acre) and 54.7 mt/ha (980 bags/acre). For both crops in the 1975 field investigation, the drip treatments averaged a significantly greater yield than the sprinkler yield. The drip treatments also averaged a greater yield per unit of water applied than the sprinkler treatment. No significant yield differences were found between the every row drip treatment and the average of the every other row drip treatments for carrots. However, the every row drip yield for onions was found to be significantly greater than the average yield of the every other row drip treatments. For both carrots and onions in 1975, the every row drip treatment produced a significantly greater yield per unit of water applied than the average of the every other row drip treatments. No significant differences for carrots or onions were found between the every other row drip treatments in terms of yield or in terms of yield per unit of water applied.

Soil moisture status was monitored during both years of the study. Soil moisture distribution comparisons among the various treatments were then made using the field data. In 1974, the soil moisture distribution study consisted of comparing plots of volumetric moisture content versus time among the three treatments. The soil moisture distribution study in 1975 consisted of three portions: 1. Lines of constant volumetric moisture content (Θ_v), or Iso - Θ_v lines, were

compared among the various treatments. The Iso - Θ_V lines were compared before and after an irrigation to determine the effects of water application upon soil moisture distribution. 2. Soil moisture tension, or negative pressure head comparisons were made to study soil moisture stresses in the soil profile. 3. Hydraulic gradients in the soil profile were compared among treatments to study soil moisture movement in the soil profile, particularly into and out of the root zone.

Crop coefficients, the ratio between actual and potential evapotranspiration, were calculated for the 1975 treatments during periods of minimal moisture movement into and out of the root zone. Actual evapotranspiration was estimated during these periods using soil moisture data from the tensiometers and water input data from irrigation and rainfall records. Potential evapotranspiration was computed using the Penman Combination Equation. Crop coefficients for carrots and particularly onions were found to be largely in error because of consistently large actual evapotranspiration estimates that were believed to have been caused by unmeasured deep percolation. Consequently, estimates for irrigation requirements of carrots and onions were made from soil moisture tension and moisture input data and pan-evaporation data.

An economic analysis of drip and sprinkler irrigated carrots and onions was completed. The every other row drip treatment with the emitter line adjacent to alternate rows and the sprinkler treatment were used as the irrigation methods for comparison. Results of the 1975 field investigation were used as a basis for the analysis. Yields

used in the analysis were estimated at 75 percent of the 1975 field investigation yields because the experimental plots were relatively small and maintained under well-controlled conditions. Annual production costs for each crop were determined for a highly mechanized operation with low labor requirements. Irrigation costs were estimated from current prices for equipment and electricity. Gross annual returns to land and management were based on current averages of prices paid to growers for each crop. Net annual returns to land and management were then compared between treatments. In the analysis, drip irrigation of carrots and onions were found to produce higher net returns to land and management than sprinkler irrigation. Drip irrigation of carrots was found to produce the highest net returns to land and management, about \$3300/ha (\$1300/acre).

Conclusions

1. In the 1975 field investigation, the average water use efficiencies (yields per unit of gross water applied) for the drip irrigated treatments were significantly greater than the sprinkler treatment water use efficiencies for both carrots and onions. The every row drip treatment water use efficiencies were significantly greater than the average water use efficiencies of the every other row drip treatments for both crops.
2. Every row drip irrigated yields were 8 and 9 percent greater than the sprinkler irrigated yields for onions and carrots, respectively, in 1974 when a 76 cm (30 in) row spacing was

used. The averages of the drip irrigated yields were 15 and 24 percent greater than the sprinkler irrigated yields for onions and carrots, respectively, in 1975 when a 30.5 cm (12 in) row spacing was used.

3. Lines of constant volumetric moisture content (iso - θ_V lines) in the soil profile were generally horizontal in all 1975 treatments and not bulb or onion-shaped as reported in some research. Onions appeared to utilize moisture largely from the top 23 cm (9 in) of the soil profile in the 1975 field investigation while carrots extracted moisture from the entire 46 cm (18 in) soil profile.

4. Maximum carrot and onion moisture requirements approached 0.5 cm/day (0.20 in/day).

5. Drip irrigation of carrots and onions offers potentially greater net returns to land and management than sprinkler irrigation.

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APPENDIXES

APPENDIX A

IRRIGATION AND RAINFALL AMOUNTS (CM)

April 1974		
Date	Rain-fall	Net Irrigation
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12	1.80	
13	0.33	
14		
15		
16		
17		
18		
19		
20		
21	0.30	
22		
23		
24		
25		
26		
27	0.46	
28		
29		
30		
Totals	2.89	0.00

May 1974		
Date	Rain-fall	Net Irrigation
1		
2		
3		
4		
5	0.25	
6		
7		
8	0.61	
9		
10		
11	2.49	
12		
13	1.50	
14	0.66	
15		
16	0.79	
17		
18	1.91	
19		
20		
21	1.93	
22		
23		
24		
25		
26		
27		
28	0.20	
29		
30	1.47	
31	0.94	
Totals	12.75	0.00

June 1974				
		Net Irrigation		
Date	Rain-fall	Every Row Drip	Every Other Row Drip	Sprinkler
1				
2				
3				
4				
5				
6	0.51			
7				
8				
9	0.94			
10	2.11			
11				
12				
13				
14				
15				
16				
17				
18				1.27
19				
20				
21		1.35	1.35	
22	0.33			
23				
24		0.69	0.69	1.27
25				
26				
27		1.75	1.75	
28				
29				
30				1.27
Totals	3.89	3.79	3.79	3.81

July 1974				
		Net Irrigation		
Date	Rain-fall	Every Row Drip	Every Other Row Drip	Sprinkler
1		1.27	1.27	
2				1.27
3	0.89			
4				
5		1.27	1.27	
6				
7				1.27
8				
9	1.02			
10		1.27	1.27	1.27
11				
12		1.27	1.27	1.27
13				
14	0.79			
15				
16				
17				
18	0.38	1.27	1.27	1.27
19	0.91			
20	0.89			
21				
22				
23		1.27	1.27	1.27
24				
25				
26				
27				
28				
29				
30		1.27	1.27	1.27
31				
Totals	4.88	8.89	8.89	8.89

August 1974				
		Net Irrigation		
Date	Rain-fall	Every Row Drip	Every Other Row Drip	Sprinkler
1				
2	0.23			
3	0.33			
4				
5		1.27	1.27	1.27
6				
7				
8				
9	5.28			
10	2.54			
11	0.25			
12				
13				
14				
15				
16		1.27	1.27	1.27
17				
18	0.84			
19				
20				
21				
22		1.27	1.27	1.27
23				
24				
25				
26				
27		1.27	1.27	1.27
28				
29				
30				
31				
Totals	9.47	5.08	5.08	5.08

May 1975				
		Gross Irrigation Amount		
Date	Rainfall	Every Row Drip Treatment	Every Other Row Drip Treatments	Sprinkler Treatment
1				
2				
3	0.15			
4				
5				
6				
7	1.04			
8				
9				
10				
11	1.12			
12				
13				
14	0.13			
15				
16				
17		0.76	0.86	0.69
18		0.76	0.86	0.69
19		0.76	0.86	0.69
20		0.76	0.86	0.69
21				
22	0.76			
23	0.91			
24				
25				
26				
27				
28		0.76	0.86	0.69
29				
30		0.76	0.86	0.69
31				
Totals	4.11	4.56	5.16	4.14

June 1975				
		Gross Irrigation Amount		
Date	Rainfall	Every Row Drip Treatment	Every Other Row Drip Treatments	Sprinkler Treatment
1		0.76	0.86	0.69
2				
3	0.18			
4	0.48			
5				
6		0.76	0.86	0.69
7				
8				
9	3.53			
10				
11	0.13			
12	0.61			
13				
14	0.13			
15	1.35			
16	0.94			
17	0.13			
18				
19	0.97			
20	1.60			
21	0.35			
22	0.28			
23				
24				
25		0.76	0.86	0.69
26				
27				
28				
29		0.76	0.86	0.69
30		0.76	0.86	0.69
Totals	10.68	3.80	4.30	3.45

July 1975				
		Gross Irrigation Amount		
Date	Rainfall	Every Row Drip Treatment	Every Other Row Drip Treatments	Sprinkler Treatment
[illegible]				
[illegible]				
[illegible]		1.14	1.30	1.37
[illegible]				
5				
6	0.25			
7		1.52	1.73	1.27
8				
9				
10		1.52	1.73	1.49
11				
12		1.52	1.73	1.71
13				
14		1.52	1.73	1.71
15		1.52	1.73	1.58
16				
17		1.14	1.30	1.27
18				
19				
20		1.14	1.30	1.37
21		1.14	1.30	1.19
22	0.15			
23	1.68			
24	0.18			
25				
26				
27				
28		1.14	1.30	1.27
29				
30		1.14	1.30	1.27
31		1.14	1.30	1.27
Totals	2.26	15.58	17.75	16.77

August 1975

Date	Rainfall	Gross Irrigation Amount: Every Row Drip Treatment	Every Other Row Drip Treatments	Sprinkler Treatment
1	5.21			
2	0.20			
3				
4		1.14	1.29	1.37
5				
6				
7		1.52	1.73	1.59
8				
9				
10				
11	0.35			
12	1.14			
13		1.71	1.94	2.40
14				
15		1.14	1.29	1.39
16				
17				
18	0.30			
19	3.71			
20				
21	0.33			
22	0.64			
23				
24				
25				
26		1.14	1.29	1.39
27				
28	1.47			
29				
30	0.18			
31				
Totals	13.50	6.65	7.54	8.14

September 1975

Date	Rainfall	Gross Irrigation Amount: Every Row Drip Treatment	Every Other Row Drip Treatments	Sprinkler Treatment
[illegible]				
[illegible]				
[illegible]				
[illegible]				
5	0.96			
6				
7				
8				
9				
10				
11	5.36			
12				
13				
14				
15				
16				
17				
18	1.90			
19				
20	0.20			
21				
22				
23				
24				
25				
26				
27				
28	1.37			
29	0.25			
30				
Totals	10.00	0.00	0.00	0.00

APPENDIX B

REPLICATION AVERAGES OF VOLUMETRIC MOISTURE CONTENT AND NEGATIVE PRESSURE HEAD FROM THE 1975 TENSIOMETER DATA

CARROT PLOTS
1975

EVERY ROW DRIP TREATMENT — EMITTER LINE ON ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.282	0.260	0.243	0.147	-488.2	-501.1	-172.1	-541.8
JULY 24	0.328	0.298	0.243	0.161	-122.3	-137.3	-168.7	-332.1
JULY 28	0.268	0.249	0.205	0.144	-766.2	-766.1	-557.3	-637.3
JULY 29	0.273	0.251	0.200	0.149	-647.3	-713.4	-711.8	-502.0
JULY 31	0.272	0.254	0.198	0.142	-657.7	-529.2	-760.3	-671.2
AUG 2	0.332	0.308	0.259	0.195	-108.0	-107.6	-116.4	-113.1
AUG 3	0.302	0.278	0.235	0.183	-257.5	-222.3	-202.7	-139.5
AUG [illegible]	0.294	0.273	0.231	0.180	-334.1	-270.0	-222.8	-149.1
AUG [illegible]	0.320	0.293	0.240	0.178	-160.8	-152.4	-178.0	-160.0
AUG [illegible]	0.279	0.264	0.217	0.171	-549.7	-405.7	-335.8	-196.0
AUG 8	0.324	0.284	0.234	0.168	-141.5	-178.3	-208.1	-211.5
AUG 11	0.280	0.260	0.214	0.161	-518.8	-502.0	-361.3	-286.8
AUG 12	0.329	0.255	0.206	0.155	-128.6	-633.0	-545.5	-368.9
AUG 13	0.311	0.258	0.204	0.153	-198.1	-550.5	-579.9	-411.2
AUG 14	0.325	0.274	0.226	0.154	-135.3	-159.1	-260.5	-357.4
AUG 15	0.320	0.286	0.227	0.155	-155.8	-180.8	-258.3	-383.6
AUG 18	0.311	0.275	0.224	0.157	-201.8	-250.8	-273.8	-363.5
AUG 19	0.341	0.321	0.274	0.204	-77.5	-78.7	-85.9	-92.8
AUG 20	0.327	0.300	0.252	0.186	-123.9	-128.1	-136.5	-134.1
AUG 21	0.344	0.303	0.245	0.180	-69.1	-119.3	-158.7	-157.1
AUG 22	0.341	0.314	0.255	0.182	-76.2	-94.2	-131.1	-145.7
AUG 25	0.285	0.271	0.227	0.176	-442.6	-297.7	-250.6	-166.7
AUG 26	0.277	0.265	0.223	0.174	-584.5	-385.6	-278.0	-181.8
AUG 27	0.342	0.318	0.263	0.170	-74.1	-83.3	-108.0	-204.4
AUG 29	0.330	0.301	0.249	0.172	-113.5	-123.9	-144.9	-195.6
SEPT 2	0.281	0.265	0.219	0.168	-508.7	-402.7	-316.1	-215.7
SEPT 3	0.272	0.259	0.213	0.165	-677.4	-526.7	-394.0	-239.9
SEPT 6	0.296	0.257	0.203	0.156	-290.2	-565.2	-609.6	-347.5
SEPT 12	0.319	0.305	0.198	0.144	-162.0	-113.9	-750.7	-620.1
SEPT 15	0.283	0.268	0.200	0.147	-461.4	-335.3	-712.6	-551.4
SEPT 29	0.310	0.300	0.211	0.165	-115.5	-128.5	-400.7	-245.4

EVERY ROW DRIP TREATMENT — EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.288	0.266	0.208	0.157	-398.2	-376.4	-470.6	-378.1
JULY 24	0.329	0.297	0.241	0.160	-117.7	-138.6	-176.7	-323.7
JULY 28	0.267	0.251	0.202	0.167	-826.5	-729.3	-649.0	-224.0
JULY 29	0.268	0.250	0.198	0.150	-770.0	-759.9	-762.8	-512.5
JULY 31	0.276	0.259	0.204	0.144	-588.7	-532.5	-587.0	-622.2
AUG [illegible]	0.331	0.308	0.264	0.199	-111.8	-107.2	-103.9	-104.3
AUG [illegible]	0.302	0.282	0.241	0.195	-243.7	-194.2	-175.9	-113.9
AUG [illegible]	0.293	0.276	0.237	0.190	-311.9	-239.5	-193.0	-126.1
AUG [illegible]	0.312	0.296	0.245	0.185	-194.3	-139.8	-158.7	-138.2
AUG 7	0.277	0.267	0.223	0.181	-574.9	-352.5	-278.4	-159.1
AUG 8	0.326	0.300	0.246	0.176	-130.6	-130.2	-155.4	-170.0
AUG 11	0.267	0.260	0.212	0.167	-807.6	-494.0	-390.2	-234.1
AUG 12	0.325	0.253	0.208	0.162	-134.4	-664.8	-474.4	-299.0
AUG 13	0.249	0.255	0.206	0.158	-264.6	-638.9	-528.4	-339.2
AUG 14	0.324	0.297	0.242	0.160	-134.8	-138.1	-169.2	-314.5
AUG 15	0.317	0.286	0.234	0.160	-168.3	-181.3	-710.6	-312.0
AUG 18	0.307	0.273	0.224	0.160	-216.1	-268.8	-269.6	-319.9
AUG 19	0.339	0.320	0.278	0.188	-84.6	-80.8	-78.3	-128.6
AUG 20	0.325	0.300	0.256	0.195	-131.5	-127.7	-124.0	-124.4
AUG 21	0.341	0.305	0.249	0.186	-76.6	-114.7	-145.3	-143.2
AUG 22	0.338	0.313	0.255	0.191	-86.7	-94.6	-127.3	-131.5
AUG 25	0.285	0.271	0.232	0.183	-418.3	-288.9	-217.3	-151.2
AUG 26	0.275	0.266	0.228	0.179	-611.7	-368.4	-239.9	-165.8
AUG 27	0.340	0.323	0.265	0.178	-79.6	-74.1	-102.6	-175.5
AUG 29	0.328	0.301	0.252	0.178	-121.0	-125.6	-134.4	-172.5
SEPT 2	0.284	0.265	0.224	0.175	-440.9	-399.4	-270.1	-185.9
SEPT 3	0.282	0.259	0.217	0.172	-504.1	-534.6	-332.9	-204.4
SEPT 6	0.311	0.254	0.208	0.158	-205.2	-639.7	-479.4	-310.7
SEPT 12	0.331	0.279	0.227	0.146	-110.6	-213.1	-249.6	-565.7
SEPT 15	0.317	0.265	0.216	0.150	-165.8	-341.9	-346.3	-475.2
SEPT 29	0.342	0.296	0.236	0.167	-75.8	-155.3	-193.0	-228.2

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.303	0.268	0.218	0.161	-312.8	-430.8	-449.7	-413.7
JULY 24	0.328	0.299	0.242	0.167	-123.9	-132.3	-171.7	-219.9
JULY 28	0.273	0.251	0.200	0.148	-671.6	-733.5	-715.1	-536.8
JULY 29	0.292	0.270	0.208	0.149	-336.6	-327.0	-539.7	-497.0
JULY 31	0.277	0.251	0.202	0.147	-631.8	-715.9	-653.1	-559.4
AUG 2	0.339	0.315	0.265	0.201	-82.9	-90.0	-101.3	-98.4
AUG [illegible]	0.306	0.288	0.243	0.197	-219.8	-173.7	-172.1	-108.1
AUG [illegible]	0.296	0.279	0.239	0.192	-284.3	-226.5	-188.4	-117.7
AUG 5	0.330	0.308	0.253	0.191	-114.7	-106.7	-137.3	-121.5
AUG 7	0.288	0.268	0.227	0.182	-384.8	-337.4	-265.9	-142.4
AUG 8	0.436	0.313	0.256	0.181	-94.6	-94.2	-128.1	-146.6
AUG 11	0.284	0.256	0.215	0.167	-486.5	-592.4	-355.1	-242.5
AUG 12	0.342	0.273	0.212	0.168	-73.3	-345.0	-455.5	-213.2
AUG 13	0.313	0.280	0.213	0.165	-184.7	-217.3	-461.8	-239.1
AUG 14	0.330	0.306	0.251	0.171	-113.5	-111.3	-142.0	-203.9
AUG 15	0.322	0.293	0.239	0.171	-143.2	-148.2	-188.4	-201.4
AUG 18	0.316	0.276	0.228	0.177	-175.4	-240.3	-266.3	-162.1
AUG 19	0.343	0.328	0.284	0.214	-70.8	-63.6	-69.5	-79.2
AUG 20	0.332	0.307	0.260	0.204	-107.6	-109.7	-115.2	-93.8
AUG 21	0.346	0.323	0.254	0.189	-60.7	-74.9	-132.3	-139.9
AUG 22	0.344	0.326	0.268	0.203	-66.6	-68.6	-97.6	-95.5
AUG 25	0.284	0.269	0.235	0.195	-431.7	-317.3	-209.4	-112.3
AUG 26	0.282	0.263	0.231	0.191	-496.6	-430.8	-232.0	-121.5
AUG 27	0.346	0.330	0.280	0.183	-61.6	-59.8	-75.0	-137.4
AUG 29	0.337	0.310	0.257	0.187	-99.2	-102.1	-123.1	-128.2
SEPT 2	0.287	0.264	0.225	0.181	-410.7	-406.5	-275.1	-143.2
SEPT 3	0.268	0.254	0.217	0.178	-788.4	-643.1	-361.3	-157.9
SEPT 6	0.291	0.258	0.208	0.169	-347.5	-554.7	-492.8	-206.0
SEPT 12	0.331	0.302	0.255	0.166	-113.1	-125.6	-128.1	-261.3
SEPT 15	0.293	0.270	0.219	0.170	-310.3	-301.8	-386.0	-203.1
SEPT 29	0.334	0.305	0.249	0.174	-99.7	-114.7	-148.2	-178.4

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.268	0.259	0.212	0.156	-775.0	-542.6	-473.5	-419.1
JULY 24	0.332	0.298	0.241	0.167	-106.8	-136.5	-178.0	-225.3
JULY 28	0.268	0.252	0.201	0.148	-758.2	-692.5	-669.5	-544.7
JULY 29	0.278	0.254	0.198	0.147	-556.0	-644.7	-767.9	-556.0
JULY 31	0.267	0.249	0.196	0.143	-806.8	-773.3	-806.0	-651.9
AUG 2	0.336	0.312	0.268	0.200	-92.5	-96.7	-95.9	-100.1
AUG 3	0.302	0.284	0.242	0.195	-252.9	-184.6	-172.1	-111.8
AUG [illegible]	0.293	0.277	0.241	0.193	-338.3	-226.1	-175.4	-115.2
AUG [illegible]	0.321	0.298	0.247	0.192	-149.1	-134.0	-152.0	-118.5
AUG [illegible]	0.279	0.267	0.225	0.182	-539.7	-351.2	-270.9	-139.5
AUG 8	0.330	0.303	0.247	0.186	-117.7	-119.7	-153.3	-131.9
AUG 11	0.272	0.261	0.217	0.165	-677.4	-468.0	-346.3	-245.0
AUG 12	0.335	0.260	0.213	0.164	-102.2	-512.4	-388.1	-275.5
AUG 13	0.315	0.267	0.212	0.162	-177.1	-337.8	-414.5	-297.7
AUG 14	0.328	0.299	0.240	0.175	-123.1	-130.2	-178.4	-172.1
AUG 15	0.319	0.287	0.232	0.176	-159.1	-173.7	-219.8	-166.7
AUG 18	0.303	0.273	0.224	0.177	-238.2	-267.5	-281.4	-162.9
AUG 19	0.342	0.326	0.283	0.216	-72.9	-68.6	-69.9	-77.1
AUG 20	0.329	0.306	0.260	0.205	-118.1	-112.2	-114.7	-90.9
AUG 21	0.346	0.325	0.246	0.178	-60.7	-69.1	-167.9	-174.2
AUG 22	0.343	0.324	0.264	0.192	-70.4	-72.0	-111.0	-126.5
AUG 25	0.287	0.273	0.238	0.192	-399.0	-272.5	-185.9	-117.7
AUG 26	0.290	0.269	0.232	0.188	-401.1	-319.4	-216.9	-126.9
AUG 27	0.344	0.328	0.256	0.182	-67.0	-64.0	-124.0	-139.9
AUG 29	0.335	0.309	0.251	0.187	-97.2	-105.1	-138.2	-129.8
SEPT 2	0.284	0.267	0.226	0.180	-431.7	-355.4	-255.4	-150.4
SEPT 3	0.271	0.260	0.221	0.177	-685.4	-507.0	-302.3	-161.7
SEPT 6	0.299	0.258	0.211	0.165	-277.6	-538.8	-424.1	-251.3
SEPT 12	0.333	0.308	0.231	0.168	-105.5	-106.7	-244.9	-219.0
SEPT 15	0.291	0.270	0.216	0.161	-337.9	-297.2	-378.1	-330.8
SEPT 29	0.337	0.299	0.231	0.169	-90.5	-134.0	-236.2	-224.5

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.299	0.266	0.216	0.157	-374.7	-444.2	-395.2	-382.3
JULY 24	0.331	0.298	0.236	0.168	-113.1	-132.7	-200.1	-212.3
JULY 28	0.267	0.251	0.202	0.147	-817.7	-723.9	-648.1	-566.9
JULY 29	0.269	0.250	0.198	0.144	-744.0	-755.3	-762.0	-622.6
JULY 31	0.267	0.248	0.197	0.142	-816.4	-791.3	-792.6	-672.0
AUG 2	0.339	0.311	0.261	0.202	-82.1	-102.1	-111.8	-96.8
AUG 3	0.316	0.290	0.244	0.195	-173.8	-157.8	-162.9	-112.7
AUG 4	0.309	0.285	0.240	0.192	-204.3	-181.3	-185.9	-117.3
AUG 5	0.296	0.283	0.243	0.185	-288.5	-187.5	-175.4	-148.7
AUG 7	0.282	0.273	0.231	0.176	-476.0	-270.0	-230.3	-173.8
AUG 8	0.283	0.272	0.237	0.186	-482.7	-275.0	-206.0	-130.3
AUG 11	0.268	0.265	0.233	0.176	-757.0	-417.4	-211.5	-168.8
AUG 12	0.314	0.269	0.218	0.164	-261.3	-355.8	-343.8	-261.3
AUG 13	0.312	0.266	0.217	0.162	-195.5	-355.0	-362.2	-283.1
AUG 14	0.302	0.275	0.235	0.169	-259.2	-251.2	-208.5	-231.6
AUG 15	0.306	0.276	0.231	0.169	-241.2	-243.2	-229.9	-226.1
AUG 18	0.314	0.274	0.234	0.176	-183.0	-270.4	-204.3	-165.4
AUG 19	0.340	0.321	0.276	0.213	-80.0	-78.3	-80.8	-80.9
AUG 20	0.331	0.306	0.256	0.204	-111.4	-113.0	-129.0	-93.4
AUG 21	0.342	0.315	0.245	0.178	-73.7	-92.1	-170.8	-171.3
AUG 22	0.341	0.317	0.261	0.192	-76.2	-85.8	-119.8	-125.2
AUG 25	0.299	0.279	0.238	0.191	-265.0	-211.8	-189.7	-119.4
AUG 26	0.289	0.275	0.236	0.188	-357.1	-244.5	-201.0	-127.3
AUG 27	0.340	0.318	0.257	0.181	-44.8	-85.4	-125.2	-142.4
AUG 29	0.333	0.308	0.253	0.187	-102.6	-108.4	-134.8	-129.8
SEPT 2	0.291	0.272	0.231	0.180	-340.4	-278.8	-231.1	-149.9
SEPT 3	0.279	0.266	0.227	0.177	-529.2	-361.7	-253.3	-161.2
SEPT 6	0.315	0.265	0.216	0.164	-176.3	-376.4	-359.7	-259.6
SEPT 12	0.332	0.306	0.233	0.160	-107.2	-111.3	-239.9	-327.9
SEPT 15	0.299	0.273	0.219	0.161	-264.6	-262.1	-353.0	-293.5
SEPT 29	0.335	0.304	0.236	0.169	-98.0	-118.5	-213.1	-219.9

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.307	0.274	0.223	0.172	-218.6	-258.7	-322.4	-203.5
JULY 24	0.323	0.294	0.249	0.206	-144.0	-145.7	-163.3	-112.7
JULY 28	0.290	0.256	0.205	0.139	-345.4	-594.1	-569.0	-759.1
JULY 29	0.292	0.264	0.206	0.154	-322.8	-400.6	-546.4	-381.0
JULY 31	0.278	0.256	0.208	0.150	-552.7	-605.0	-528.4	-465.2
AUG 2	0.350	0.321	0.274	0.205	-53.6	-79.1	-96.3	-90.9
AUG 3	0.312	0.289	0.260	0.186	-194.3	-167.9	-117.3	-134.9
AUG 4	0.299	0.277	0.246	0.189	-275.1	-231.5	-158.3	-129.0
AUG 5	0.320	0.302	0.256	0.192	-154.1	-123.9	-126.5	-122.7
AUG 7	0.298	0.269	0.238	0.180	-303.6	-314.8	-194.7	-158.3
AUG 8	0.324	0.303	0.253	0.179	-141.1	-119.7	-132.7	-159.6
AUG 11	0.280	0.264	0.224	0.165	-516.2	-418.2	-270.5	-262.1
AUG 12	0.340	0.277	0.219	0.164	-81.7	-231.1	-312.4	-254.6
AUG 13	0.319	0.277	0.224	0.170	-162.0	-228.2	-285.6	-244.1
AUG 14	0.331	0.301	0.239	0.174	-113.1	-125.2	-184.7	-178.8
AUG 15	0.331	0.292	0.238	0.175	-113.5	-149.9	-187.2	-171.3
AUG 18	0.317	0.279	0.238	0.171	-171.3	-208.5	-196.8	-202.3
AUG 19	0.340	0.324	0.267	0.201	-80.0	-71.6	-96.3	-99.3
AUG 20	0.333	0.306	0.250	0.195	-103.4	-111.3	-142.0	-112.7
AUG 21	0.340	0.313	0.244	0.183	-80.8	-94.6	-163.3	-147.8
AUG 22	0.341	0.319	0.256	0.197	-77.5	-82.9	-124.0	-107.2
AUG 25	0.289	0.274	0.237	0.183	-373.9	-254.1	-190.5	-139.9
AUG 26	0.282	0.270	0.236	0.181	-469.3	-305.6	-195.5	-146.2
AUG 27	0.342	0.326	0.258	0.181	-73.3	-67.8	-119.8	-147.4
AUG 29	0.333	0.308	0.248	0.183	-104.3	-106.7	-149.1	-140.7
SEPT 2	0.286	0.271	0.231	0.175	-416.6	-292.2	-223.2	-172.5
SEPT 3	0.273	0.264	0.226	0.171	-656.1	-410.3	-256.7	-192.6
SEPT 6	0.296	0.264	0.216	0.159	-296.4	-399.0	-345.4	-306.5
SEPT 12	0.338	0.307	0.231	0.158	-85.9	-110.9	-247.5	-322.4
SEPT 15	0.290	0.272	0.214	0.157	-369.3	-291.8	-372.6	-328.7
SEPT 29	0.336	0.307	0.239	0.166	-93.0	-111.3	-181.3	-234.5

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.303	0.284	0.219	0.162	-245.4	-193.0	-358.4	-372.2
JULY 24	0.320	0.290	0.251	0.204	-164.1	-164.9	-147.0	-145.3
JULY 28	0.291	0.254	0.202	0.142	-330.8	-650.6	-649.8	-669.9
JULY 29	0.282	0.260	0.204	0.151	-515.4	-517.5	-591.2	-464.8
JULY 31	0.270	0.252	0.201	0.148	-724.7	-711.3	-672.8	-542.2
AUG 2	0.340	0.315	0.296	0.195	-79.6	-90.4	-57.8	-114.8
AUG 3	0.315	0.288	0.254	0.195	-178.4	-167.4	-132.7	-111.8
AUG 4	0.309	0.280	0.251	0.191	-209.8	-206.8	-140.3	-120.2
AUG 5	0.326	0.305	0.265	0.192	-130.2	-114.7	-103.0	-118.1
AUG 7	0.291	0.272	0.237	0.183	-331.6	-276.7	-193.0	-139.9
AUG 8	0.329	0.307	0.271	0.184	-122.3	-110.1	-91.3	-142.4
AUG 11	0.279	0.265	0.223	0.175	-522.5	-387.2	-275.5	-180.9
AUG 12	0.338	0.282	0.219	0.170	-86.3	-202.6	-314.9	-210.6
AUG 13	0.320	0.276	0.226	0.166	-154.1	-234.4	-279.3	-239.9
AUG 14	0.328	0.303	0.252	0.174	-123.1	-120.6	-138.2	-183.4
AUG 15	0.326	0.292	0.243	0.189	-129.4	-152.8	-168.7	-127.7
AUG 18	0.320	0.279	0.234	0.175	-153.3	-213.9	-208.9	-175.5
AUG 19	0.340	0.323	0.282	0.209	-81.7	-74.9	-75.4	-88.4
AUG 20	0.332	0.305	0.261	0.204	-106.4	-114.3	-115.2	-95.1
AUG 21	0.341	0.314	0.258	0.195	-77.1	-94.2	-118.9	-111.8
AUG 22	0.340	0.319	0.265	0.204	-79.6	-82.9	-102.2	-95.9
AUG 25	0.295	0.281	0.241	0.192	-306.5	-195.5	-174.2	-119.8
AUG 26	0.287	0.272	0.239	0.185	-391.5	-282.6	-185.9	-137.0
AUG 27	0.342	0.327	0.272	0.184	-74.5	-66.5	-90.0	-139.5
AUG 29	0.332	0.307	0.254	0.184	-109.7	-108.8	-131.5	-140.7
SEPT 2	0.292	0.271	0.232	0.178	-339.6	-302.7	-219.0	-160.4
SEPT 3	0.277	0.264	0.226	0.175	-561.5	-418.2	-259.6	-175.9
SEPT 6	0.312	0.261	0.216	0.167	-219.4	-495.3	-344.6	-227.0
SEPT 12	0.331	0.298	0.230	0.161	-111.8	-137.7	-233.2	-295.2
SEPT 15	0.297	0.271	0.216	0.160	-298.5	-299.3	-345.8	-303.2
SEPT 29	0.336	0.297	0.231	0.176	-93.8	-139.8	-222.8	-175.1

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.294	0.273	0.232	0.175	-314.9	-269.2	-224.9	-246.6
JULY 24	0.316	0.292	0.259	0.206	-175.9	-151.5	-116.4	-143.7
JULY 28	0.282	0.255	0.203	0.144	-502.4	-622.1	-620.5	-622.6
JULY 29	0.286	0.259	0.206	0.149	-457.2	-523.3	-527.1	-496.2
JULY 31	0.273	0.252	0.203	0.148	-665.7	-693.7	-629.3	-525.5
AUG 2	0.339	0.315	0.265	0.198	-83.3	-90.0	-101.3	-110.6
AUG 3	0.308	0.281	0.239	0.189	-210.2	-200.1	-188.4	-131.1
AUG 4	0.311	0.281	0.244	0.181	-198.9	-216.4	-176.7	-151.2
AUG 5	0.334	0.297	0.262	0.181	-100.1	-134.4	-123.5	-151.2
AUG 7	0.292	0.272	0.233	0.174	-336.6	-298.5	-234.5	-179.2
AUG 8	0.343	0.305	0.263	0.177	-75.4	-114.7	-115.6	-167.1
AUG 11	0.286	0.263	0.219	0.168	-417.4	-443.8	-334.1	-223.6
AUG 12	0.340	0.275	0.220	0.164	-79.6	-277.6	-302.3	-252.1
AUG 13	0.314	0.275	0.231	0.162	-184.7	-245.3	-228.2	-274.7
AUG 14	0.330	0.299	0.251	0.170	-116.4	-134.4	-148.2	-207.7
AUG 15	0.326	0.289	0.250	0.184	-131.5	-167.0	-141.5	-137.8
AUG 18	0.313	0.276	0.230	0.171	-186.3	-238.2	-240.8	-202.7
AUG 19	0.342	0.315	0.268	0.193	-73.3	-94.2	-101.8	-121.5
AUG 20	0.332	0.299	0.252	0.188	-108.9	-133.1	-142.0	-132.8
AUG 21	0.345	0.307	0.243	0.185	-64.1	-114.7	-170.4	-139.9
AUG 22	0.343	0.311	0.257	0.186	-69.1	-103.8	-126.0	-138.6
AUG 25	0.296	0.271	0.231	0.180	-304.8	-296.4	-232.8	-156.6
AUG 26	0.287	0.267	0.230	0.182	-403.2	-357.1	-234.9	-149.9
AUG 27	0.345	0.315	0.263	0.185	-62.8	-92.9	-111.0	-143.7
AUG 29	0.336	0.298	0.248	0.181	-93.8	-136.5	-152.8	-156.2
SEPT 2	0.295	0.267	0.225	0.187	-329.5	-354.2	-273.0	-150.8
SEPT 3	0.283	0.261	0.218	0.191	-482.7	-483.5	-337.5	-156.6
SEPT 6	0.296	0.259	0.212	0.163	-305.2	-528.8	-421.6	-260.5
SEPT 15	0.324	0.300	0.233	0.154	-158.3	-143.2	-217.7	-376.0
SEPT 15	0.306	0.271	0.214	0.156	-242.4	-299.7	-373.1	-356.3
SEPT 29	0.336	0.293	0.227	0.175	-92.1	-161.2	-267.6	-175.1

CARROT PLOTS
1975

SPRINKLER TREATMENT
TENSIOMETER LOCATION IN CARROT ROW
REPLICATION AVERAGES

	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS				PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS			
DATE	5CM	13CM	23CM	46CM	5CM	13CM	23CM	46CM
JULY 21	0.326	0.279	0.227	0.150	-129.4	-291.4	-327.4	-519.6
JULY 24	0.332	0.301	0.255	0.147	-109.3	-127.7	-134.4	-556.5
JULY 28	0.269	0.255	0.229	0.145	-736.5	-627.1	-311.9	-588.7
JULY 29	0.278	0.256	0.214	0.142	-558.9	-590.7	-440.5	-674.1
JULY 31	0.274	0.257	0.214	0.143	-633.5	-583.6	-434.2	-654.8
AUG 2	0.339	0.317	0.292	0.219	-82.1	-85.4	-59.9	-73.7
AUG 3	0.298	0.283	0.257	0.206	-290.6	-194.7	-121.4	-92.2
AUG 4	0.286	0.276	0.251	0.206	-428.7	-240.7	-136.9	-93.0
AUG 5	0.310	0.276	0.246	0.194	-205.2	-276.3	-162.9	-113.9
AUG 7	0.284	0.266	0.237	0.181	-436.7	-377.6	-198.5	-146.2
AUG 8	0.325	0.287	0.247	0.173	-134.4	-172.1	-155.4	-181.3
AUG 11	0.312	0.262	0.237	0.168	-200.6	-446.7	-190.5	-214.0
AUG 12	0.343	0.286	0.236	0.178	-70.4	-301.4	-199.3	-163.8
AUG 13	0.322	0.282	0.227	0.165	-146.1	-200.5	-249.6	-239.5
AUG 14	0.338	0.317	0.283	0.164	-87.9	-87.9	-71.2	-252.9
AUG 15	0.332	0.309	0.271	0.166	-108.5	-104.2	-88.8	-234.1
AUG 18	0.337	0.289	0.255	0.169	-91.3	-164.1	-127.7	-207.7
AUG 19	0.344	0.329	0.305	0.220	-67.0	-62.4	-45.2	-71.6
AUG 20	0.331	0.309	0.288	0.206	-112.2	-104.2	-62.4	-90.1
AUG 21	0.345	0.315	0.282	0.191	-64.1	-92.1	-72.5	-123.1
AUG 22	0.343	0.320	0.300	0.196	-69.5	-79.9	-49.8	-109.7
AUG 25	0.281	0.270	0.250	0.185	-5C9.1	-300.6	-144.5	-136.1
AUG 26	0.276	0.265	0.244	0.183	-593.3	-385.2	-168.7	-144.5
AUG 27	0.338	0.301	0.238	0.181	-87.1	-126.0	-191.8	-153.3
AUG 29	0.336	0.313	0.270	0.187	-95.1	-96.3	-92.6	-129.8
SEPT 2	0.282	0.267	0.238	0.178	-481.9	-355.8	-189.7	-163.8
SEPT 3	0.273	0.263	0.227	0.176	-654.8	-444.2	-249.6	-166.3
SEPT 6	0.296	0.262	0.217	0.163	-288.9	-464.3	-342.5	-261.3
SEPT 12	0.338	0.314	0.240	0.155	-88.4	-94.2	-185.5	-384.0
SEPT 15	0.288	0.271	0.228	0.153	-378.5	-287.2	-239.5	-421.7
SEPT 29	0.340	0.301	0.254	0.164	-79.2	-125.2	-131.5	-254.2

SPRINKLER TREATMENT
TENSIOMETER LOCATION ONE-HALF ROW FROM CARROT ROW
REPLICATION AVERAGES

	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS				PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS			
DATE	5CM	13CM	23CM	46CM	5CM	13CM	23CM	46CM
JULY 21	0.312	0.286	0.211	0.147	-276.8	-278.C	-539.3	-554.8
JULY 24	0.331	0.305	0.250	0.152	-110.6	-118.5	-150.3	-484.9
JULY 28	0.269	0.257	0.206	0.148	-74C.6	-580.7	-547.6	-517.9
JULY 29	0.290	0.251	0.209	0.147	-350.4	-726.4	-564.4	-557.3
JULY 31	0.286	0.252	0.199	0.149	-396.1	-691.2	-716.8	-494.5
AUG 2	0.345	0.319	0.276	0.213	-71.6	-82.5	-80.4	-80.4
AUG 3	0.316	0.295	0.257	0.197	-173.8	-141.9	-121.4	-107.2
AUG 4	0.306	0.288	0.254	0.193	-221.1	-168.3	-130.7	-115.6
AUG 5	0.296	0.284	0.246	0.184	-301.0	-211.4	-157.9	-137.8
AUG 7	0.285	0.275	0.239	0.181	-428.3	-272.9	-188.C	-148.3
AUG 8	0.298	0.296	0.242	0.175	-339.1	-140.7	-171.7	-173.4
AUG 11	0.309	0.280	0.245	0.177	-210.6	-211.0	-167.5	-161.2
AUG 12	0.334	0.284	0.243	0.164	-100.9	-223.5	-180.1	-250.4
AUG 13	0.317	0.281	0.226	0.170	-167.1	-204.7	-253.3	-198.1
AUG 14	0.333	0.316	0.260	0.169	-103.4	-89.2	-113.9	-209.0
AUG 15	0.327	0.308	0.260	0.170	-126.9	-107.6	-115.2	-200.6
AUG 18	0.321	0.292	0.245	0.179	-148.2	-152.8	-157.9	-155.4
AUG 19	0.346	0.340	0.303	0.228	-64.5	-42.7	-46.9	-62.4
AUG 20	0.333	0.316	0.269	0.210	-103.9	-89.2	-93.8	-84.2
AUG 21	0.341	0.316	0.258	0.194	-75.8	-89.2	-121.0	-117.3
AUG 22	0.345	0.326	0.269	0.199	-67.4	-68.2	-93.0	-103.0
AUG 25	0.293	0.280	0.241	0.188	-320.3	-203.9	-173.4	-132.8
AUG 26	0.284	0.273	0.237	0.185	-449.7	-259.1	-193.9	-144.1
AUG 27	0.334	0.290	0.235	0.183	-99.2	-176.7	-205.2	-151.6
AUG 29	0.334	0.314	0.256	0.192	-100.9	-92.5	-124.0	-117.7
SEPT 2	0.293	0.273	0.232	0.178	-319.5	-260.4	-220.2	-167.1
SEPT 3	0.279	0.264	0.228	0.180	-538.8	-409.9	-241.2	-149.5
SEPT 6	0.300	0.259	0.213	0.166	-260.0	-527.9	-387.7	-245.8
SEPT 12	0.331	0.314	0.207	0.154	-110.6	-93.8	-510.0	-409.5
SEPT 15	0.300	0.279	0.220	0.153	-255.0	-216.8	-316.1	-441.3
SEPT 29	0.332	0.300	0.227	0.166	-108.0	-127.3	-253.3	-237.9

ONION PLOTS
1975

EVERY ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.360	0.322	0.284	0.200	-35.2	-88.3	-79.6	-101.0
JULY 24	0.329	0.311	0.267	0.211	-118.5	-100.9	-96.7	-84.6
JULY 28	0.270	0.262	0.226	0.183	-721.0	-443.3	-255.4	-137.8
JULY 29	0.269	0.256	0.212	0.176	-748.6	-609.1	-391.5	-165.0
JULY 31	0.279	0.265	0.228	0.180	-531.3	-377.2	-242.4	-150.8
AUG 2	0.337	0.320	0.283	0.224	-89.2	-79.9	-72.5	-67.9
AUG 3	0.296	0.274	0.251	0.209	-329.1	-257.9	-141.1	-87.1
AUG 4	0.285	0.270	0.244	0.201	-437.1	-312.3	-163.7	-98.0
AUG 5	0.300	0.277	0.247	0.196	-266.3	-227.7	-152.0	-108.9
AUG 7	0.272	0.259	0.219	0.185	-654.8	-532.9	-316.1	-133.6
AUG 8	0.311	0.296	0.246	0.181	-206.0	-138.1	-166.2	-147.8
AUG 11	0.271	0.252	0.210	0.170	-683.7	-708.4	-443.8	-200.6
AUG 12	0.283	0.255	0.205	0.165	-508.7	-639.7	-578.2	-237.0
AUG 13	0.283	0.247	0.205	0.162	-495.3	-819.7	-572.8	-265.1
AUG 14	0.309	0.280	0.243	0.164	-250.4	-412.8	-168.3	-252.9
AUG 15	0.309	0.275	0.225	0.164	-208.5	-271.7	-272.6	-246.6
AUG 18	0.272	0.268	0.218	0.165	-323.2	-319.8	-342.9	-237.0
AUG 19	0.335	0.326	0.273	0.182	-98.0	-68.6	-85.0	-142.0
AUG 20	0.318	0.309	0.253	0.191	-160.8	-106.7	-134.0	-121.0
AUG 21	0.335	0.306	0.245	0.187	-96.7	-111.8	-157.9	-131.1
AUG 22	0.334	0.324	0.259	0.200	-99.7	-72.8	-117.7	-106.8
AUG 25	0.281	0.269	0.230	0.189	-502.4	-345.0	-237.8	-129.4
AUG 26	0.274	0.262	0.226	0.184	-620.9	-452.6	-264.2	-146.6
AUG 27	0.334	0.316	0.247	0.180	-100.5	-89.6	-156.2	-154.5
AUG 29	0.334	0.291	0.238	0.177	-101.8	-165.8	-185.9	-167.1
SEPT 2	0.286	0.263	0.231	0.182	-435.0	-323.6	-234.9	-152.9
SEPT 3	0.276	0.263	0.218	0.175	-589.5	-437.1	-328.3	-180.1
SEPT 6	0.275	0.257	0.207	0.164	-297.7	-564.3	-517.9	-262.6
SEPT 12	0.329	0.266	0.234	0.162	-119.3	-360.0	-225.7	-322.8
SEPT 15	0.293	0.267	0.214	0.159	-313.2	-345.8	-367.6	-319.5

EVERY ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.340	0.322	0.288	0.209	-97.6	-86.2	-69.9	-91.3
JULY 24	0.329	0.305	0.265	0.213	-116.8	-115.9	-102.2	-80.4
JULY 28	0.275	0.263	0.227	0.184	-631.4	-436.6	-251.2	-136.1
JULY 29	0.271	0.257	0.220	0.175	-730.6	-584.9	-308.6	-174.6
JULY 31	0.281	0.264	0.229	0.180	-497.0	-408.2	-236.6	-150.4
AUG 2	0.336	0.319	0.271	0.219	-92.5	-82.0	-90.9	-73.3
AUG 3	0.297	0.283	0.251	0.204	-335.8	-199.7	-141.5	-93.8
AUG 4	0.288	0.275	0.245	0.201	-437.1	-255.8	-162.1	-98.9
AUG 5	0.303	0.283	0.246	0.196	-259.6	-186.7	-156.2	-109.7
AUG 7	0.275	0.260	0.223	0.185	-620.1	-503.2	-282.2	-133.2
AUG 8	0.325	0.283	0.244	0.184	-135.3	-188.4	-165.8	-137.8
AUG 11	0.269	0.257	0.214	0.170	-754.0	-569.8	-361.8	-199.8
AUG 12	0.268	0.251	0.210	0.166	-778.3	-730.6	-433.8	-228.2
AUG 13	0.275	0.256	0.214	0.163	-635.6	-590.3	-412.0	-264.7
AUG 14	0.316	0.284	0.235	0.164	-212.7	-199.3	-203.9	-247.1
AUG 15	0.300	0.272	0.227	0.166	-370.1	-304.8	-250.4	-232.0
AUG 18	0.283	0.263	0.218	0.164	-494.1	-449.2	-326.2	-245.8
AUG 19	0.335	0.332	0.274	0.175	-96.7	-56.9	-86.7	-179.2
AUG 20	0.337	0.298	0.252	0.193	-97.6	-131.9	-140.7	-116.9
AUG 21	0.335	0.294	0.247	0.187	-95.5	-143.2	-154.1	-132.8
AUG 22	0.331	0.315	0.257	0.194	-110.6	-91.2	-124.8	-114.8
AUG 25	0.284	0.264	0.227	0.183	-466.0	-406.5	-257.9	-143.2
AUG 26	0.277	0.263	0.225	0.177	-564.4	-440.8	-267.6	-161.2
AUG 27	0.327	0.317	0.248	0.172	-128.1	-86.2	-156.6	-193.1
AUG 29	0.338	0.296	0.244	0.178	-90.9	-142.3	-166.2	-165.4
SEPT 2	0.285	0.265	0.229	0.177	-420.4	-378.5	-241.6	-167.9
SEPT 3	0.278	0.258	0.219	0.171	-550.2	-538.8	-321.1	-197.7
SEPT 6	0.282	0.254	0.208	0.161	-485.7	-648.9	-477.7	-286.4
SEPT 12	0.328	0.266	0.274	0.155	-123.5	-386.8	-83.8	-377.3
SEPT 15	0.290	0.263	0.243	0.156	-347.9	-435.4	-166.7	-349.6

ONION PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS				PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS			
DATE	5CM	13CM	23CM	46CM	5CM	13CM	23CM	46CM
JULY 21	0.286	0.276	0.245	0.196	-439.2	-254.9	-159.1	-109.3
JULY 24	0.326	0.301	0.261	0.204	-131.1	-125.2	-113.1	-91.7
JULY 28	0.268	0.263	0.228	0.178	-708.4	-437.5	-273.4	-184.7
JULY 29	0.271	0.259	0.218	0.178	-694.6	-530.4	-329.1	-160.0
JULY 31	0.267	0.254	0.213	0.169	-812.7	-652.7	-399.0	-220.7
AUG 2	0.339	0.318	0.270	0.215	-82.5	-84.5	-90.0	-77.5
AUG 3	0.295	0.279	0.251	0.204	-297.7	-223.1	-137.8	-93.8
AUG [illegible]	0.287	0.272	0.246	0.202	-391.5	-298.1	-156.6	-96.8
AUG 5	0.297	0.280	0.252	0.199	-340.4	-216.8	-134.0	-103.5
AUG 7	0.271	0.258	0.228	0.191	-680.4	-545.5	-253.3	-120.6
AUG 8	0.288	0.281	0.248	0.189	-556.4	-249.1	-147.8	-124.4
AUG 11	0.267	0.255	0.218	0.175	-826.1	-636.4	-347.5	-176.7
AUG 12	0.310	0.251	0.212	0.169	-301.0	-718.0	-468.5	-212.3
AUG 13	0.287	0.252	0.210	0.166	-382.3	-630.4	-503.7	-233.7
AUG 14	0.297	0.272	0.234	0.169	-358.0	-352.5	-212.3	-209.8
AUG 15	0.295	0.270	0.229	0.179	-353.8	-332.0	-235.3	-161.7
AUG 18	0.289	0.264	0.216	0.167	-410.3	-423.7	-362.6	-231.2
AUG 19	0.347	0.324	0.285	0.186	-63.2	-72.4	-71.6	-139.5
AUG 20	0.329	0.299	0.258	0.190	-118.9	-134.0	-120.2	-123.1
AUG 21	0.343	0.303	0.252	0.187	-71.2	-119.3	-140.7	-131.1
AUG 22	0.342	0.313	0.266	0.192	-74.1	-94.6	-105.5	-117.3
AUG 25	0.278	0.264	0.224	0.189	-551.8	-420.3	-293.9	-124.4
AUG 26	0.271	0.262	0.222	0.184	-700.5	-467.6	-310.3	-136.1
AUG 27	0.341	0.307	0.248	0.179	-78.3	-110.9	-154.1	-154.5
AUG 29	0.328	0.290	0.240	0.185	-124.8	-157.8	-178.0	-135.7
SEPT 2	0.275	0.262	0.218	0.178	-615.0	-459.7	-372.6	-158.3
SEPT 3	0.269	0.257	0.213	0.175	-748.6	-565.2	-458.0	-173.8
SEPT 6	0.280	0.255	0.208	0.166	-506.2	-615.4	-547.2	-229.1
SEPT 12	0.324	0.288	0.212	0.162	-137.3	-169.5	-459.3	-270.9
SEPT 15	0.285	0.263	0.214	0.156	-425.4	-436.2	-391.9	-388.2

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS				PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS			
DATE	5CM	13CM	23CM	46CM	5CM	13CM	23CM	46CM
JULY 21	0.288	0.277	0.243	0.194	-373.1	-247.0	-165.4	-114.8
JULY 24	0.326	0.301	0.261	0.203	-129.0	-126.0	-112.2	-95.1
JULY 28	0.271	0.263	0.221	0.175	-711.8	-449.6	-309.4	-191.8
JULY 29	0.268	0.260	0.215	0.177	-763.3	-519.5	-358.4	-162.9
JULY 31	0.267	0.253	0.211	0.168	-822.7	-666.9	-430.4	-227.4
AUG 2	0.339	0.315	0.272	0.217	-82.9	-91.2	-86.7	-75.8
AUG 3	0.289	0.277	0.248	0.202	-367.6	-226.1	-149.1	-96.8
AUG 4	0.282	0.271	0.244	0.200	-471.9	-285.9	-162.5	-101.4
AUG 5	0.300	0.284	0.249	0.198	-259.6	-181.7	-143.2	-104.7
AUG 7	0.270	0.260	0.226	0.189	-709.7	-496.1	-256.7	-124.4
AUG 8	0.295	0.290	0.245	0.189	-386.9	-157.8	-157.4	-124.0
AUG 11	0.267	0.257	0.218	0.174	-816.4	-584.0	-324.5	-180.5
AUG 12	0.267	0.254	0.213	0.168	-817.7	-652.7	-389.8	-216.1
AUG 13	0.267	0.252	0.212	0.166	-798.8	-703.3	-417.9	-237.4
AUG 14	0.288	0.287	0.232	0.171	-502.4	-171.2	-228.2	-202.3
AUG 15	0.284	0.275	0.229	0.179	-497.8	-249.9	-240.3	-160.4
AUG 18	0.280	0.265	0.220	0.167	-507.9	-385.2	-311.5	-230.7
AUG 19	0.343	0.326	0.289	0.191	-71.2	-67.8	-62.8	-133.2
AUG 20	0.326	0.310	0.258	0.190	-128.1	-104.2	-120.6	-122.7
AUG 21	0.341	0.301	0.252	0.188	-76.2	-125.2	-137.3	-129.4
AUG 22	0.341	0.311	0.267	0.198	-77.5	-100.0	-99.7	-105.1
AUG 25	0.279	0.268	0.229	0.188	-524.6	-346.2	-241.6	-127.7
AUG 26	0.271	0.266	0.227	0.177	-685.0	-379.7	-256.3	-169.2
AUG 27	0.342	0.302	0.261	0.181	-75.8	-127.7	-115.2	-147.4
AUG 29	0.326	0.293	0.245	0.184	-128.6	-147.3	-165.0	-137.8
SEPT 2	0.274	0.265	0.232	0.177	-622.6	-402.7	-215.6	-162.5
SEPT 3	0.269	0.260	0.222	0.172	-744.4	-516.2	-297.3	-183.8
SEPT 6	0.272	0.255	0.208	0.165	-686.2	-614.2	-547.2	-244.1
SEPT 12	0.329	0.286	0.241	0.163	-116.8	-174.1	-174.2	-263.0
SEPT 15	0.288	0.264	0.216	0.162	-374.3	-406.9	-385.2	-265.1

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
REPLICATION AVERAGES

	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS				PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS			
DATE	5CM	13CM	23CM	46CM	5CM	13CM	23CM	46CM
JULY 21	0.296	0.279	0.240	0.191	-351.3	-229.0	-180.1	-119.4
JULY 24	0.327	0.304	0.256	0.205	-126.5	-118.5	-125.2	-91.3
JULY 28	0.272	0.265	0.219	0.170	-696.3	-399.8	-314.0	-214.8
JULY 29	0.274	0.259	0.218	0.177	-636.0	-545.5	-333.7	-161.7
JULY 31	0.268	0.253	0.212	0.169	-793.4	-665.7	-413.7	-224.9
AUG 2	0.338	0.315	0.271	0.216	-85.9	-91.7	-89.2	-76.7
AUG 3	0.291	0.281	0.249	0.204	-353.4	-205.1	-145.7	-93.4
AUG 4	0.281	0.274	0.243	0.200	-488.2	-266.3	-168.7	-101.0
AUG 5	0.304	0.283	0.248	0.198	-246.2	-198.8	-146.6	-104.7
AUG 7	0.271	0.261	0.226	0.190	-692.5	-491.9	-259.2	-123.1
AUG 8	0.307	0.280	0.246	0.190	-272.6	-237.8	-157.4	-123.6
AUG 11	0.267	0.258	0.217	0.174	-818.9	-557.6	-334.5	-177.1
AUG 12	0.267	0.253	0.215	0.169	-829.4	-663.6	-364.3	-209.4
AUG 13	0.276	0.254	0.214	0.167	-613.8	-662.3	-391.1	-226.6
AUG 14	0.316	0.274	0.232	0.171	-173.8	-304.3	-235.3	-202.7
AUG 15	0.300	0.271	0.227	0.179	-272.6	-303.5	-251.6	-156.6
AUG 18	0.283	0.265	0.219	0.168	-465.2	-390.2	-314.0	-224.5
AUG 19	0.341	0.328	0.281	0.188	-75.8	-64.9	-74.1	-151.6
AUG 20	0.324	0.302	0.254	0.189	-135.7	-122.2	-131.5	-124.8
AUG 21	0.342	0.297	0.251	0.188	-73.7	-134.8	-139.9	-128.6
AUG 22	0.339	0.310	0.262	0.193	-83.3	-102.1	-109.7	-116.0
AUG 25	0.277	0.268	0.227	0.188	-566.1	-327.4	-249.1	-127.7
AUG 26	0.271	0.267	0.226	0.184	-682.5	-358.4	-261.7	-137.0
AUG 27	0.341	0.319	0.265	0.183	-75.4	-82.9	-106.4	-143.7
AUG 29	0.324	0.290	0.242	0.184	-136.5	-163.3	-175.9	-138.2
SEPT 2	0.273	0.265	0.231	0.178	-651.9	-395.6	-226.1	-157.5
SEPT 3	0.268	0.258	0.219	0.173	-765.3	-540.9	-318.6	-182.6
SEPT 6	0.274	0.256	0.206	0.164	-652.3	-640.5	-551.8	-246.6
SEPT 12	0.322	0.282	0.227	0.164	-147.4	-213.5	-256.7	-250.0
SEPT 15	0.284	0.264	0.215	0.164	-442.1	-410.7	-381.4	-253.3

ONION PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION AT EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.308	0.283	0.232	0.159	-247.0	-193.8	-237.0	-312.0
JULY 24	0.325	0.300	0.261	0.209	-133.2	-127.7	-113.1	-84.6
JULY 28	0.268	0.264	0.230	0.185	-784.2	-395.2	-228.6	-134.9
JULY 29	0.271	0.259	0.217	0.178	-678.3	-532.1	-327.8	-160.4
JULY 31	0.268	0.257	0.213	0.183	-762.4	-587.4	-378.9	-144.9
AUG 2	0.338	0.311	0.275	0.226	-88.8	-100.9	-82.5	-64.5
AUG 3	0.287	0.272	0.250	0.206	-401.9	-278.8	-146.1	-89.6
AUG 4	0.282	0.268	0.245	0.203	-474.8	-333.7	-159.5	-95.5
AUG 5	0.300	0.280	0.253	0.203	-290.6	-208.1	-134.0	-95.1
AUG 7	0.273	0.260	0.228	0.180	-648.5	-493.6	-242.0	-152.0
AUG 8	0.289	0.277	0.250	0.182	-452.2	-258.7	-148.2	-139.9
AUG 11	0.268	0.261	0.222	0.175	-791.3	-480.2	-289.7	-176.3
AUG 12	0.269	0.255	0.219	0.169	-758.6	-626.3	-319.9	-210.2
AUG 13	0.276	0.258	0.216	0.165	-622.2	-549.7	-340.4	-239.5
AUG 14	0.322	0.286	0.251	0.190	-149.5	-173.3	-137.3	-123.6
AUG 15	0.314	0.282	0.235	0.193	-180.5	-200.9	-200.6	-118.0
AUG 18	0.298	0.275	0.250	0.198	-281.8	-259.6	-141.5	-104.7
AUG 19	0.336	0.320	0.283	0.220	-95.9	-82.0	-71.2	-76.7
AUG 20	0.316	0.294	0.255	0.203	-179.2	-150.3	-131.9	-100.1
AUG 21	0.332	0.303	0.255	0.201	-111.0	-126.0	-129.0	-102.6
AUG 22	0.335	0.313	0.264	0.206	-100.1	-97.5	-106.4	-92.2
AUG 25	0.279	0.269	0.237	0.191	-527.1	-323.6	-196.0	-120.2
AUG 26	0.272	0.270	0.241	0.188	-667.8	-297.2	-176.3	-128.6
AUG 27	0.340	0.320	0.250	0.187	-81.7	-80.4	-154.1	-133.6
AUG 29	0.320	0.298	0.250	0.193	-160.0	-136.5	-147.8	-120.2
SEPT 2	0.278	0.270	0.235	0.183	-551.0	-306.0	-206.8	-146.6
SEPT 3	0.272	0.265	0.225	0.176	-675.3	-378.5	-270.9	-171.7
SEPT 6	0.281	0.261	0.213	0.159	-508.3	-463.0	-405.3	-318.2
SEPT 12	0.295	0.287	0.227	0.158	-342.9	-171.6	-254.2	-306.1
SEPT 15	0.285	0.266	0.217	0.162	-419.5	-370.5	-335.8	-265.5

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.310	0.290	0.232	0.167	-221.9	-177.9	-221.1	-270.5
JULY 24	0.328	0.303	0.259	0.207	-121.9	-119.7	-116.4	-91.3
JULY 28	0.275	0.265	0.229	0.183	-603.7	-376.8	-236.2	-139.5
JULY 29	0.271	0.258	0.212	0.179	-687.9	-558.5	-448.0	-154.5
JULY 31	0.269	0.256	0.213	0.174	-748.6	-591.6	-376.4	-175.1
AUG 2	0.339	0.317	0.274	0.217	-82.5	-85.4	-85.0	-75.8
AUG 3	0.297	0.277	0.247	0.204	-278.4	-232.8	-149.9	-94.3
AUG 4	0.290	0.272	0.245	0.200	-351.7	-286.8	-160.8	-101.4
AUG 5	0.297	0.275	0.247	0.200	-315.7	-261.6	-152.8	-103.0
AUG 7	0.274	0.257	0.226	0.188	-625.9	-571.9	-258.3	-126.1
AUG 8	0.271	0.270	0.239	0.189	-673.7	-332.8	-185.1	-124.8
AUG 11	0.274	0.261	0.221	0.175	-661.5	-491.9	-304.4	-175.9
AUG 12	0.267	0.256	0.220	0.166	-809.3	-588.2	-300.2	-235.3
AUG 13	0.268	0.258	0.216	0.166	-774.6	-545.5	-345.4	-233.3
AUG 14	0.313	0.275	0.236	0.176	-235.7	-246.2	-199.3	-167.1
AUG 15	0.308	0.279	0.238	0.180	-261.7	-214.3	-185.9	-154.5
AUG 18	0.303	0.278	0.238	0.185	-236.2	-216.0	-188.0	-138.6
AUG 19	0.342	0.325	0.284	0.211	-73.7	-69.1	-69.5	-85.9
AUG 20	0.329	0.303	0.256	0.201	-118.1	-120.6	-128.6	-104.7
AUG 21	0.344	0.307	0.258	0.200	-68.7	-114.3	-123.5	-104.7
AUG 22	0.342	0.317	0.268	0.204	-73.3	-86.2	-99.3	-98.0
AUG 25	0.283	0.274	0.238	0.192	-467.7	-256.2	-191.8	-119.0
AUG 26	0.277	0.273	0.237	0.187	-569.4	-265.0	-191.8	-130.7
AUG 27	0.342	0.320	0.276	0.184	-75.0	-80.4	-83.8	-142.8
AUG 29	0.330	0.304	0.250	0.189	-116.4	-117.6	-147.8	-128.6
SEPT 2	0.281	0.272	0.234	0.182	-494.1	-285.5	-209.4	-150.4
SEPT 3	0.274	0.267	0.225	0.175	-629.3	-347.5	-264.6	-173.8
SEPT 6	0.284	0.265	0.211	0.158	-446.7	-395.2	-423.3	-334.1
SEPT 12	0.329	0.294	0.235	0.162	-116.8	-146.1	-208.1	-268.4
SEPT 15	0.270	0.269	0.221	0.163	-342.9	-319.0	-299.4	-258.0

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE ON ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	45CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.314	0.284	0.234	0.170	-185.5	-198.4	-206.0	-312.8
JULY 24	0.328	0.305	0.261	0.210	-121.4	-114.7	-111.4	-84.6
JULY 28	0.277	0.265	0.229	0.182	-567.7	-387.2	-233.2	-140.3
JULY 29	0.275	0.258	0.225	0.180	-616.7	-552.6	-268.0	-151.2
JULY 31	0.270	0.256	0.219	0.174	-723.9	-610.8	-312.8	-177.6
AUG 2	0.335	0.319	0.274	0.219	-97.2	-82.9	-85.4	-73.7
AUG 3	0.296	0.276	0.248	0.203	-304.4	-241.5	-147.8	-93.8
AUG 4	0.291	0.271	0.242	0.198	-357.6	-292.2	-170.4	-105.1
AUG 5	0.313	0.275	0.248	0.201	-185.9	-260.4	-149.5	-99.7
AUG 7	0.276	0.260	0.226	0.191	-578.6	-491.5	-260.0	-119.8
AUG 8	0.289	0.272	0.247	0.191	-482.3	-351.7	-150.7	-121.5
AUG 11	0.268	0.258	0.221	0.176	-792.6	-554.7	-297.7	-165.4
AUG 12	0.303	0.263	0.222	0.170	-339.6	-442.5	-293.1	-198.1
AUG 13	0.284	0.258	0.218	0.166	-515.8	-567.7	-323.7	-232.4
AUG 14	0.323	0.278	0.238	0.177	-140.3	-219.4	-187.2	-162.5
AUG 15	0.314	0.278	0.237	0.181	-183.0	-220.2	-188.4	-146.2
AUG 18	0.293	0.275	0.236	0.183	-316.5	-245.7	-194.7	-144.9
AUG 19	0.343	0.327	0.280	0.214	-71.2	-65.3	-75.0	-80.9
AUG 20	0.328	0.299	0.258	0.202	-124.4	-133.1	-119.3	-102.6
AUG 21	0.343	0.311	0.259	0.200	-69.5	-100.9	-118.9	-104.3
AUG 22	0.345	0.321	0.269	0.205	-64.1	-78.3	-95.9	-95.9
AUG 25	0.284	0.272	0.241	0.194	-462.2	-280.9	-175.0	-113.9
AUG 26	0.276	0.270	0.239	0.186	-591.6	-302.3	-181.3	-130.7
AUG 27	0.341	0.327	0.277	0.186	-79.6	-67.0	-80.4	-136.5
AUG 29	0.328	0.304	0.250	0.190	-124.4	-117.6	-147.4	-126.5
SEPT 2	0.279	0.271	0.236	0.182	-533.4	-303.1	-198.5	-149.5
SEPT 3	0.273	0.267	0.229	0.175	-643.5	-361.7	-235.3	-173.8
SEPT 6	0.281	0.263	0.209	0.159	-508.7	-430.8	-448.8	-330.0
SEPT 12	0.332	0.297	0.248	0.166	-108.9	-134.0	-151.6	-234.9
SEPT 15	0.287	0.270	0.223	0.166	-396.5	-310.6	-284.7	-235.3

ONION PLOTS
1975

SPRINKLER TREATMENT
TENSIOMETER LOCATION IN ONION ROW
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	45CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.303	0.276	0.235	0.191	-286.4	-247.4	-210.2	-121.9
JULY 24	0.328	0.305	0.259	0.195	-122.7	-114.7	-118.5	-111.4
JULY 28	0.269	0.255	0.217	0.180	-753.6	-628.8	-334.1	-147.8
JULY 29	0.270	0.249	0.218	0.176	-716.4	-778.3	-334.1	-167.5
JULY 31	0.269	0.249	0.211	0.175	-739.8	-764.5	-431.7	-173.0
AUG 2	0.340	0.321	0.274	0.212	-79.6	-77.4	-85.4	-81.3
AUG 3	0.291	0.280	0.250	0.201	-358.4	-213.9	-140.7	-98.9
AUG 4	0.281	0.266	0.236	0.200	-504.9	-369.2	-211.5	-101.4
AUG 5	0.298	0.265	0.230	0.193	-275.9	-416.6	-231.5	-116.0
AUG 7	0.271	0.255	0.218	0.190	-704.6	-613.7	-323.2	-122.3
AUG 8	0.287	0.251	0.215	0.184	-393.2	-715.1	-354.2	-135.7
AUG 11	0.268	0.247	0.213	0.177	-771.6	-812.6	-378.9	-160.8
AUG 12	0.268	0.247	0.211	0.175	-773.7	-832.3	-409.9	-172.5
AUG 13	0.279	0.247	0.212	0.174	-581.1	-832.3	-399.0	-178.0
AUG 14	0.296	0.247	0.218	0.172	-474.8	-833.5	-347.1	-186.4
AUG 15	0.290	0.272	0.223	0.173	-493.2	-466.0	-295.2	-184.7
AUG 18	0.280	0.267	0.223	0.177	-536.3	-481.9	-300.2	-168.8
AUG 19	0.343	0.334	0.284	0.181	-75.0	-51.9	-69.9	-160.0
AUG 20	0.324	0.295	0.256	0.189	-141.1	-144.0	-124.8	-131.1
AUG 21	0.337	0.309	0.252	0.187	-90.9	-110.5	-139.4	-133.2
AUG 22	0.338	0.318	0.266	0.191	-87.1	-86.6	-100.5	-122.3
AUG 25	0.281	0.272	0.231	0.187	-489.4	-293.0	-225.7	-130.7
AUG 26	0.276	0.267	0.231	0.183	-585.7	-361.7	-224.4	-139.5
AUG 27	0.332	0.268	0.233	0.182	-108.0	-334.5	-214.4	-142.8
AUG 29	0.328	0.293	0.249	0.181	-121.9	-155.3	-146.1	-144.9
SEPT 2	0.281	0.269	0.231	0.180	-502.8	-319.4	-224.9	-148.7
SEPT 3	0.276	0.265	0.223	0.178	-584.1	-390.2	-286.0	-160.4
SEPT 6	0.287	0.261	0.215	0.173	-417.0	-467.2	-369.3	-184.3
SEPT 12	0.331	0.278	0.229	0.168	-114.3	-242.0	-260.4	-216.5
SEPT 15	0.290	0.271	0.220	0.168	-345.4	-288.4	-320.7	-218.2

SPRINKLER TREATMENT
TENSIOMETER LOCATION ONE-HALF ROW FROM ONION ROW
REPLICATION AVERAGES

DATE	VOLUMETRIC MOISTURE CONTENT (VMC) AT GIVEN DEPTHS 5CM	13CM	23CM	46CM	PRESSURE HEAD (PH) IN CM OF WATER AT GIVEN DEPTHS 5CM	13CM	23CM	46CM
JULY 21	0.306	0.269	0.237	0.182	-227.8	-333.2	-196.0	-146.6
JULY 24	0.330	0.303	0.251	0.193	-113.9	-118.9	-140.3	-116.9
JULY 28	0.268	0.251	0.208	0.181	-774.1	-722.2	-487.4	-142.8
JULY 29	0.270	0.249	0.217	0.173	-738.6	-763.2	-330.4	-180.1
JULY 31	0.269	0.249	0.213	0.174	-754.0	-770.7	-389.8	-180.1
AUG 2	0.340	0.320	0.264	0.218	-80.4	-79.9	-105.5	-75.0
AUG 3	0.305	0.280	0.241	0.206	-255.4	-214.3	-176.7	-90.1
AUG 4	0.285	0.269	0.235	0.206	-453.9	-329.9	-204.3	-91.7
AUG 5	0.295	0.260	0.222	0.199	-301.0	-512.0	-284.7	-105.6
AUG 7	0.272	0.254	0.213	0.197	-679.5	-639.7	-376.4	-107.7
AUG 8	0.279	0.252	0.211	0.186	-537.6	-689.9	-409.5	-131.5
AUG 11	0.267	0.250	0.211	0.184	-794.7	-756.1	-410.3	-138.2
AUG 12	0.267	0.249	0.208	0.177	-793.8	-770.3	-479.8	-162.5
AUG 13	0.268	0.248	0.208	0.175	-782.5	-798.0	-469.8	-170.5
AUG 14	0.335	0.275	0.209	0.175	-97.2	-382.6	-443.4	-172.5
AUG 15	0.326	0.274	0.214	0.176	-128.6	-387.2	-370.5	-165.0
AUG 18	0.304	0.267	0.218	0.184	-229.4	-416.6	-328.3	-138.6
AUG 19	0.342	0.324	0.277	0.189	-73.7	-73.2	-80.8	-126.5
AUG 20	0.327	0.321	0.251	0.197	-127.7	-78.3	-143.2	-106.8
AUG 21	0.338	0.311	0.246	0.196	-87.5	-99.6	-157.4	-110.2
AUG 22	0.337	0.328	0.258	0.204	-91.3	-64.9	-119.8	-96.3
AUG 25	0.279	0.266	0.230	0.191	-526.7	-372.6	-233.6	-120.2
AUG 26	0.273	0.261	0.231	0.186	-654.8	-471.4	-228.6	-131.1
AUG 27	0.323	0.263	0.231	0.191	-144.9	-432.5	-228.2	-121.0
AUG 29	0.326	0.300	0.244	0.181	-129.8	-130.6	-165.4	-144.9
SEPT 2	0.279	0.263	0.230	0.181	-530.9	-434.1	-234.1	-146.6
SEPT 3	0.275	0.261	0.231	0.191	-614.6	-478.1	-222.8	-122.3
SEPT 6	0.282	0.254	0.217	0.176	-500.3	-648.1	-353.0	-169.2
SEPT 12	0.328	0.306	0.232	0.170	-123.5	-113.0	-230.7	-210.2
SEPT 15	0.290	0.268	0.223	0.162	-363.0	-394.4	-310.7	-271.8

APPENDIX C

VOLUMETRIC MOISTURE CONTENT VALUES FROM THE 1974 FIELD INVESTIGATION

Table C1. Volumetric Moisture Content at Various Depths in the Carrot Plots, 1974.

Date	Soil Depth Increment (cm)	Treatment		
		Every Row Drip	Every Other Row Drip	Sprinkler
June 18	0-15	23.2	22.7	18.4
	15-30	27.8	27.3	23.7
	30-46	27.3	24.0	16.8
June 27	0-15	22.1	19.5	16.4
	15-30	29.4	26.7	19.7
	30-46	25.1	23.1	15.5
July 5	0-15	25.6	22.8	20.9
	15-30	28.5	26.6	20.4
	30-46	25.1	22.6	13.8
July 11	0-15	29.4	23.8	20.4
	15-30	30.2	26.1	18.0
	30-46	23.4	22.0	11.6
July 18	0-15	27.9	23.4	19.0
	15-30	29.2	24.9	18.2
	30-46	30.2	20.0	26.0
July 26	0-15	26.0	22.8	17.9
	15-30	26.6	24.9	18.6
	30-46	21.8	20.5	12.1
August 2	0-15	27.9	22.1	19.3
	15-30	27.3	24.4	17.2
	30-46	23.4	21.5	12.1
August 8	0-15	21.3	18.8	15.7
	15-30	22.0	20.7	14.6
	30-46	17.4	17.2	9.8
August 16	0-15	22.8	22.5	17.9
	15-30	26.4	26.4	20.2
	30-46	22.2	23.4	16.6
August 22	0-15	23.8	24.9	18.2
	15-30	27.0	26.0	19.8
	30-46	23.9	21.1	16.1
September 3	0-15	20.9	19.6	14.0
	15-30	18.9	20.7	14.5
	30-46	19.4	18.4	9.1

Table C2. Volumetric Moisture Content at Various Depths in the Onion Plots, 1974.

Date	Soil Depth Increment (cm)	Treatment: Every Row Drip	Treatment: Every Other Row Drip	Treatment: Sprinkler
June 18	0-15	23.2	22.7	18.4
	15-30	27.8	27.3	23.7
	30-46	27.3	24.0	16.8
June 27	0-15	22.1	19.6	16.2
	15-30	27.2	26.8	20.8
	30-46	24.0	24.5	18.0
July 5	0-15	22.7	21.0	17.9
	15-30	28.4	21.9	21.2
	30-46	23.7	22.8	20.1
July 11	0-15	28.4	20.0	21.1
	15-30	29.7	27.0	17.0
	30-46	23.7	23.2	26.6
July 18	0-15	26.7	22.2	17.9
	15-30	29.6	27.6	22.0
	30-46	24.5	23.6	20.8
July 26	0-15	24.2	20.3	17.6
	15-30	25.7	26.2	19.1
	30-46	22.3	23.6	15.2
August 2	0-15	23.5	18.2	17.2
	15-30	29.4	25.1	21.8
	30-46	24.2	21.4	19.1
August 8	0-15	21.4	17.1	14.9
	15-30	25.4	21.8	16.8
	30-46	20.2	20.5	16.4
August 16	0-15	21.6	20.3	15.5
	15-30	25.5	26.1	20.7
	30-46	21.4	23.1	19.7
August 22	0-15	22.4	21.1	16.0
	15-30	27.0	26.2	19.7
	30-46	21.5	22.0	18.0
September 3	0-15	21.0	20.0	16.0
	15-30	26.0	26.1	17.9
	30-46	22.8	22.6	17.8

APPENDIX D

INDIVIDUAL PLOT YIELDS

Table D1. Individual Plot Yields for Carrots, 1974.

Treatment	Plot Number	Yield metric ton/hectare	Yield bu*/acre
Every Row Drip	2	55.2	985
	4	61.1	1091
	8	53.9	962
	9	54.6	975
Every Other Row Drip Emitter Line Between Rows	3	47.2	843
	5	42.6	760
	6	45.8	817
	7	48.5	865
	10	42.9	765
Sprinkler	11	56.6	1010
	12	50.2	896
	13	52.3	946
	14	46.9	837

* One bushel is considered to weigh 50 lb.

Table D2. Individual Plot Yields for Onions, 1974.

Treatment	Number	Yield metric ton/hectare	Yield bags*/acre
Every Row Drip	1	24.8	442
	2	25.2	450
	6	25.2	450
	8	24.9	444
	9	25.3	452
Every Other Row Drip Emitter Line Between Rows	3	15.3	274
	4	21.4	382
	5	17.0	304
	7	18.8	336
	10	18.6	332
Sprinkler	15	19.9	356
	16	21.5	384
	17	26.9	480
	18	24.6	440

* One bag is considered to weigh 50 lb.

Table D1. Individual Plot Yields for Carrots, 1975.*

Treatment	Plot Number	Yield metric ton/hectare	Yield bu[+]/acre
1	4	111.8	1995
	5	118.5	2114
	8	103.2	1842
	11	102.7	1833
2	1	103.4	1845
	3	106.4	1899
	9	104.2	1859
	12	85.2	1521
3	2	109.6	1956
	6	117.1	2089
	7	94.6	1688
	10	106.2	1894
4	29	86.6	1545
	30	86.8	1548
	31	82.5	1472
	32	83.8	1495

[+] One bushel is considered to weigh 50 lb.

* To account for excess soil and foliage on the carrots, the yields in this table are reported as 5% less than the gross yield measurements.

Table D4. Individual Plot Yields for Onions, 1975.

Treatment	Plot Number	Yield	
		metric ton/hectare	bags*/acre
1	17	61.0	1088
	19	75.2	1342
	23	70.0	1249
	24	70.9	1265
2	13	63.9	1136
	15	54.0	963
	18	61.6	1099
	20	57.9	1033
3	14	62.0	1106
	16	51.2	914
	21	65.0	1160
	22	64.2	1145
4	25	55.8	996
	26	58.1	1037
	27	56.5	1008
	28	48.5	866

* One bag is considered to weigh 50 lb.

Table D-5. Individual Row Yields for Carrots for Treatment Number 3, 1975.*

Plot Number	Yield† (kg/m of row length)	
	row with emitter line	row without emitter line
7	3.71	2.82 2.90
10	4.29	3.36 3.16
Average	4.00	3.06

* Only two of the four plots for this treatment were harvested and weighed by rows because of mixing problems encountered with the carrot digger.

† The middle row of each plot (row with the emitter line) and the two rows adjacent to the middle row (rows without the emitter line) were harvested for yield.

Table D-6. Individual Row Yields for Onions for Treatment Number 3, 1975.

Plot Number	Yield* (kg/m of row length)	
	row with emitter line	row without emitter line
14	2.70	1.08 1.63
16	2.26	1.39 1.19
21	2.85	1.59 1.76
22	2.72	1.59 1.98
Average	2.63	1.53

* The middle row of each plot (row with the emitter line) and the two rows adjacent to the middle row (rows without the emitter line) were harvested for yield.

APPENDIX E

SAMPLE OF THE ORIGINAL TENSIOMETER DATA FOR TREATMENT 2 IN 1975

Abbreviations Used in the Appendix

CM	Centimeters
CTM	Cumulative total moisture
DG	Downward gradient
IN	Inches
PH	Pressure head
TH	Total head
TM	Total moisture
VMC	Volumetric moisture content

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION AT EMITTER LINE
AUG 4 1500 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
1	5	-262.5	-267.5	0.30	1.06	1.06	29.73
	13	-165.4	-178.4	0.29	1.02	2.08	-9.91
	23	-146.6	-169.6	0.25	1.61	3.69	-0.53
	46	-124.8	-170.8	0.19	1.71	5.40	0.05
[illegible]	5	-286.4	-291.4	0.30	1.05	1.05	32.38
	13	-277.1	-290.1	0.27	0.96	2.01	-0.14
	23	-253.3	-276.3	0.23	1.47	3.48	-0.84
	46	-112.3	-158.3	0.19	1.76	5.24	-5.13
12	5	-304.0	-309.0	0.29	1.04	1.04	34.33
	13	-236.9	-249.9	0.28	0.98	2.01	-6.56
	23	-165.4	-188.4	0.24	1.58	3.60	-3.73
	46	-116.0	-162.0	0.19	1.75	5.34	-1.15

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.296   13 CM = 0.279
23 CM = 0.239   46 CM = 0.192

PH AT 5 CM = -284.3   13 CM = -226.5
23 CM = -188.4   46 CM = -117.7

DOWNWARD GRADIENT 5-13 CM = -6.23   13-23 CM = -2.81
23-46 CM = -2.08

TOTAL MOISTURE IN 5 CM PROFILE = 0.58 INCHES
13 CM PROFILE = 1.54 INCHES
23 CM PROFILE = 2.03 INCHES
46 CM PROFILE = 4.46 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
AUG 4 1500 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
1	5	-477.3	-482.3	0.28	1.00	1.00	53.59
	13	-220.6	-233.6	0.28	0.98	1.98	-27.63
	23	-175.4	-198.4	0.24	1.57	3.55	-2.13
	46	-114.8	-160.8	0.19	1.75	5.30	-1.64
9	5	-272.6	-277.6	0.30	1.05	1.05	30.84
	13	-254.5	-267.5	0.27	0.97	2.02	-1.12
	23	-190.5	-213.5	0.24	1.54	3.56	-3.27
	46	-114.8	-160.8	0.19	1.75	5.32	-2.29
12	5	-265.0	-270.0	0.30	1.06	1.06	30.00
	13	-203.0	-216.0	0.28	0.99	2.05	-6.00
	23	-160.4	-183.4	0.24	1.59	3.64	-1.98
	46	-116.0	-162.0	0.19	1.75	5.39	-0.93

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.293   13 CM = 0.277
23 CM = 0.241   46 CM = 0.193

PH AT 5 CM = -338.3   13 CM = -226.1
23 CM = -175.4   46 CM = -115.2

DOWNWARD GRADIENT 5-13 CM = -13.03   13-23 CM = -4.06
23-46 CM = -1.62

TOTAL MOISTURE IN 5 CM PROFILE = 0.58 INCHES
13 CM PROFILE = 1.53 INCHES
23 CM PROFILE = 2.02 INCHES
46 CM PROFILE = 4.46 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
AUG 4 1500 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
1	5	-211.0	-216.0	0.31	1.09	1.09	24.00
	13	-172.9	-185.9	0.29	1.01	2.10	-3.35
	23	-160.4	-183.4	0.24	1.59	3.69	-0.15
	46	-117.3	-163.3	0.19	1.74	5.44	-0.87
9	5	-197.2	-202.2	0.31	1.10	1.10	22.47
	13	-199.3	-212.3	0.28	0.99	2.09	1.12
	23	-248.3	-271.3	0.23	1.48	3.57	3.58
	46	-117.3	-163.3	0.19	1.74	5.31	-4.70
12	5	-204.8	-209.8	0.31	1.09	1.09	23.31
	13	-171.6	-184.6	0.29	1.02	2.11	-2.79
	23	-149.1	-172.1	0.25	1.61	3.72	-0.76
	46	-117.3	-163.3	0.19	1.74	5.46	-0.38

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.309   13 CM = 0.285
23 CM = 0.240   46 CM = 0.192

PH AT 5 CM = -204.3   13 CM = -181.3
23 CM = -185.9   46 CM = -117.3

DOWNWARD GRADIENT 5-13 CM = -1.88   13-23 CM = 1.47
23-46 CM = -1.98

TOTAL MOISTURE IN 5 CM PROFILE = 0.61 INCHES
13 CM PROFILE = 1.60 INCHES
23 CM PROFILE = 2.10 INCHES
46 CM PROFILE = 4.53 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION AT EMITTER LINE
AUG 5 1400 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
[illegible]	5	-110.6	-115.6	0.33	1.17	1.17	12.84
	13	-96.3	-109.3	0.31	1.11	2.28	-0.70
	23	-116.4	-139.4	0.26	1.69	3.97	1.83
	46	-127.3	-173.3	0.19	1.70	5.66	1.47
[illegible]	5	-108.0	-113.0	0.33	1.18	1.18	12.56
	13	-111.3	-124.3	0.31	1.08	2.26	1.26
	23	-174.2	-197.2	0.24	1.57	3.83	4.42
	46	-119.8	-165.8	0.19	1.73	5.56	-1.37
12	5	-125.6	-130.6	0.33	1.16	1.16	14.51
	13	-112.6	-125.6	0.31	1.08	2.24	-0.56
	23	-121.4	-144.4	0.26	1.67	3.91	1.14
	46	-117.3	-163.3	0.19	1.74	5.66	0.82

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.330   13 CM = 0.308
23 CM = 0.253   46 CM = 0.191

PH AT 5 CM = -114.7   13 CM = -106.7
23 CM = -137.3   46 CM = -121.5

DOWNWARD GRADIENT 5-13 CM = 0.0   13-23 CM = 4.06
23-46 CM = 0.31

TOTAL MOISTURE IN 5 CM PROFILE = 0.65 INCHES
13 CM PROFILE = 1.71 INCHES
23 CM PROFILE = 2.26 INCHES
46 CM PROFILE = 4.76 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
AUG 5 1400 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
1	5	-158.3	-163.3	0.32	1.13	1.13	18.14
	13	-113.9	-126.9	0.31	1.08	2.21	-4.05
	23	-151.6	-174.6	0.25	1.61	3.82	2.89
	46	-114.8	-160.8	0.19	1.75	5.57	-0.60
9	5	-157.0	-162.0	0.32	1.13	1.13	18.00
	13	-154.0	-167.0	0.29	1.03	2.16	0.56
	23	-174.2	-197.2	0.24	1.57	3.73	1.83
	46	-123.6	-169.6	0.19	1.72	5.44	-1.20
12	5	-131.9	-136.9	0.33	1.15	1.15	15.21
	13	-134.0	-147.0	0.30	1.05	2.20	1.12
	23	-130.2	-153.2	0.25	1.65	3.85	0.38
	46	-117.3	-163.3	0.19	1.74	5.60	0.44

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.321   13 CM = 0.298
23 CM = 0.247   46 CM = 0.192

PH AT 5 CM = -149.1   13 CM = -134.0
23 CM = -152.0   46 CM = -118.5

DOWNWARD GRADIENT 5-13 CM = -0.89   13-23 CM = 2.81
23-46 CM = -0.46

TOTAL MOISTURE IN 5 CM PROFILE = 0.63 INCHES
13 CM PROFILE = 1.66 INCHES
23 CM PROFILE = 2.19 INCHES
46 CM PROFILE = 4.67 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT   EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
AUG 5 1400 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
1	5	-320.3	-325.3	0.29	1.03	1.03	36.14
	13	-189.2	-202.2	0.28	1.00	2.03	-13.68
	23	-152.8	-175.8	0.25	1.60	3.64	-1.60
	46	-116.0	-162.0	0.19	1.75	5.38	-0.60
9	5	-286.4	-291.4	0.30	1.05	1.05	32.38
	13	-194.2	-207.2	0.28	1.00	2.04	-9.35
	23	-243.3	-266.3	0.23	1.48	3.52	3.58
	46	-212.7	-258.7	0.17	1.52	5.05	-0.33
12	5	-258.8	-263.8	0.30	1.06	1.06	29.31
	13	-179.2	-192.2	0.28	1.01	2.07	-7.95
	23	-130.2	-153.2	0.25	1.65	3.72	-2.36
	46	-117.3	-163.3	0.19	1.74	5.46	0.44

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.296   13 CM = 0.283
23 CM = 0.243   46 CM = 0.185

PH AT 5 CM = -288.5   13 CM = -187.5
23 CM = -175.4   46 CM = -148.7

DOWNWARD GRADIENT 5-13 CM = -11.62   13-23 CM = -0.21
23-46 CM = -0.16

TOTAL MOISTURE IN 5 CM PROFILE = 0.58 INCHES
13 CM PROFILE = 1.55 INCHES
23 CM PROFILE = 2.05 INCHES
46 CM PROFILE = 4.46 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION AT EMITTER LINE
AUG 7 1100 HOURS

PLCT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
[illegible]	5	-290.2	-295.2	0.30	1.05	1.05	32.80
	13	-288.4	-301.4	0.27	0.96	2.01	0.70
	23	-193.0	-216.0	0.24	1.54	3.54	-5.18
	46	-148.7	-194.7	0.18	1.63	5.17	-0.93
[illegible]	5	-409.5	-414.5	0.29	1.01	1.01	46.05
	13	-372.6	-385.6	0.27	0.94	1.95	-3.21
	23	-382.7	-405.7	0.21	1.38	3.33	1.22
	46	-136.1	-182.1	0.18	1.66	5.00	-9.72
12	5	-454.7	-459.7	0.28	1.00	1.00	51.08
	13	-351.2	-364.2	0.27	0.94	1.95	-10.61
	23	-221.9	-244.9	0.23	1.50	3.45	-7.23
	46	-142.4	-188.4	0.18	1.64	5.09	-2.46

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.288 13 CM = 0.268
23 CM = 0.227 46 CM = 0.182

PH AT 5 CM = -384.8 13 CM = -337.4
23 CM = -265.9 46 CM = -142.4

DOWNWARC GRADIENT 5-13 CM = -4.92 13-23 CM = -6.15
23-46 CM = -4.37

TOTAL MOISTURE IN 5 CM PROFILE = 0.57 INCHES
13 CM PROFILE = 1.49 INCHES
23 CM PROFILE = 1.97 INCHES
46 CM PROFILE = 4.26 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE-HALF ROW FROM EMITTER LINE
AUG 7 1100 HOURS

PLCT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
[illegible]	5	-731.0	-736.0	0.27	0.95	0.95	81.78
	13	-363.8	-376.8	0.27	0.94	1.89	-39.91
	23	-270.9	-293.9	0.22	1.46	3.35	-5.02
	46	-137.4	-183.4	0.18	1.66	5.01	-4.81
[illegible]	5	-415.8	-420.8	0.29	1.01	1.01	46.75
	13	-390.2	-403.2	0.26	0.94	1.95	-1.95
	23	-327.4	-350.4	0.22	1.41	3.36	-3.20
	46	-139.9	-185.9	0.18	1.65	5.01	-7.15
12	5	-472.3	-477.3	0.28	1.00	1.00	53.03
	13	-299.7	-312.7	0.27	0.96	1.95	-18.28
	23	-214.4	-237.4	0.23	1.51	3.47	-4.57
	46	-141.1	-187.1	0.18	1.64	5.11	-2.18

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.279 13 CM = 0.267
23 CM = 0.225 46 CM = 0.182

PH AT 5 CM = -539.7 13 CM = -351.2
23 CM = -270.9 46 CM = -139.5

DOWNWARC GRADIENT 5-13 CM = -22.56 13-23 CM = -7.03
23-46 CM = -4.71

TOTAL MOISTURE IN 5 CM PROFILE = 0.55 INCHES
13 CM PROFILE = 1.46 INCHES
23 CM PROFILE = 1.93 INCHES
46 CM PROFILE = 4.22 INCHES

CARROT PLOTS
1975

EVERY OTHER ROW DRIP TREATMENT EMITTER LINE IN BETWEEN ROW
TENSIOMETER LOCATION ONE ROW FROM EMITTER LINE
AUG 7 1100 HOURS

PLOT	DEPTH CM	PH CM	TH CM	VMC	TM IN	CTM IN	DG
[illegible]	5	-537.6	-542.6	0.28	0.99	0.99	60.29
	13	-267.1	-280.1	0.27	0.97	1.95	-29.17
	23	-201.8	-224.8	0.23	1.53	3.48	-3.35
	46	-137.4	-183.4	0.18	1.66	5.14	-1.80
[illegible]	5	-443.4	-448.4	0.28	1.00	1.00	49.82
	13	-311.0	-324.0	0.27	0.95	1.96	-13.82
	23	-293.5	-316.5	0.22	1.44	3.39	-0.46
	46	-239.1	-285.1	0.17	1.49	4.89	-1.37
12	5	-447.2	-452.2	0.28	1.00	1.00	50.24
	13	-231.9	-244.9	0.28	0.98	1.98	-23.03
	23	-195.5	-218.5	0.24	1.53	3.52	-1.60
	46	-144.9	-190.9	0.18	1.64	5.15	-1.20

AVERAGE VALUES OF THE THREE PLOTS

VMC AT 5 CM = 0.282 13 CM = 0.273
23 CM = 0.231 46 CM = 0.176

PH AT 5 CM = -476.0 13 CM = -270.0
23 CM = -230.3 46 CM = -173.8

DOWNWARC GRADIENT 5-13 CM = -24.75 13-23 CM = -2.97
23-46 CM = -1.46

TOTAL MOISTURE IN 5 CM PROFILE = 0.56 INCHES
13 CM PROFILE = 1.48 INCHES
23 CM PROFILE = 1.96 INCHES
46 CM PROFILE = 4.26 INCHES

APPENDIX F

COST INFORMATION

Table F1. Pump, Panel and Motor Costs*.

Drip System				Sprinkler System			
Pump	Base	Motor	Panel	Pump	Base	Motor	Panel
$772	$575	$571	$247	$1023	$768	$289	$575

Table F2. Well and Casing Costs for Both Systems*.

Item+	Unit Cost	Total Cost
Installation	$300/well	$ 300
Development	$500/well	$ 500
Casing	$39.40/m ($12/ft)	$ 480
Screen	$262.50/m ($80/ft)	$ 800
Drilling	$82/m ($25/ft)	$1250
Suction Tube	$60/well	$ 60
Column	$656/10m ($200/10ft)	$ 800

* Cost information was obtained from Getting Industries, Sioux Falls, South Dakota.

+ Drilling depths for both irrigation systems were assumed to be 15.2m (50ft). Development costs include well testing and gravel packing. The screen lengths for both wells were assumed to be 3m (10ft).