EFFECT OF TREATED WASTEWATER ON CORN YIELD AND SOME SOIL PHYSICAL PROPERTIES

BY

NABIL IBRAHIM OMAR MOHSEN

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بسم الله الرحمن الرحيم

DEDICATION

I dedicate this study to the late

Dr. Othman Judah,

and may ALLAH be merciful with him.

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ABSTRACT

The effect of treated wastewater on corn yield and some physical properties of Zezia soil (fine, mixed, thermic Xerollic Calciorthids) was investigated by conducting field experiments for two successive seasons (1985 and 1986) at a site near Queen Alia International Airport. The treated wastewater was obtained from the Airport Treatment plant. The field experiments included irrigation by sprinkler and drip systems.

Results indicated that the corn yield components increased slightly due to irrigation with treated wastewater in both sprinkler and drip experiments for two years. Stover yield and ear length were significantly higher in plants treated with wastewater than that irrigated with fresh water. This increase was due to liberation of several nutrients elements to soil solution (N, P, K, Fe, Zn) and then uptake by plants. Treated wastewater had no significant effect on water consumptive use and no change on soil physical properties (apparent specific gravity, available water, and infiltration rate). More reduction in flow rate for emitters under drip irrigation system was obtained by using wastewater rather than fresh water.

INTRODUCTION

Long ago, locations for living were selected to provide adequate water supplies and an adequate quality of water for most needs, most of the time. Today, population throughout the world multiplies at an alarming rate and the technology advances so greatly. This requires ever-increasing water supplies which created a pressure on the use of water sources without the certainty of supply or regardless the desirable quality of water for many uses. For instance, the world population increases 70 million each year. About one-third to one-half of population are either hungry or malnourished. Three out of four donot have adequate water supply (Tayler, 1975).

In 1975, the population of Jordan was 2 million. In 1985, the population increased 740 thousand. By the year 2000 the expected population is 4 million and 445 thousand.

In 1975, the total demand of water in Jordan (for irrigation, municipal, and industrial purposes) was 451 million cubic meter (mcm) while in 1985 it became 920 mcm. By the year 2000 it is expected to be 1100 mcm. (Jordan's national water symposium, 1978).

About 80% of the total area of Jordan(94300 km²) falls under arid climate conditions, with less than 200 mm precipitation per year. Because water resources are very limited, shortage of water has become a serious problem.

Realizing the importance of wastewater re-use for irrigation, this study was initiated aiming at:

1) Comparing the yield and quality of sweet corn irrigated with treated wastewater and fresh water under sprinkler and drip irrigation systems,

2) Studying the effect of treated wastewater on some soil physical properties, and

3) Studying the effect of treated wastewater on emitters clogging of drip irrigation system.

LITERATURE REVIEW

Application of wastewater sludge to agricultural land has become increasingly popular as a method of wastes disposal. Advantages include lower disposal costs for the community and waste contains considerable quantites of plant nutrients, including micronutrients, whose benefit to plant growth has been documented. However, the direct application of these substances on agricultural land is limited by the extent of contamination with heavy metals, toxic organic chemicals, and pathogens. Also, continuous use of wastewater in irrigation may cause an increase in soluble salts and such increase may have a deleterious effect on certain crops (Abdel-Ghaffar, 1983).

A serious problem associated with trickle irrigation is emitter clogging, caused by chemical and biological build up in the minute water passageways. This then causes a discharge reduction. (Oron et al., 1979).

Changes in physical condition and chemical composition of the soil may also be induced by wastes addition and should be considered when designing land application systems.

2.1 Consumptive Use and Crop Coefficient (Kc) of Corn:

Baker and Harza (1955) reported that water requirment of corn is 830-908m^3/donum for the northern and southern zones of Jordan

Vally, respectively. The Jordan Vally Commission (1975) indicated that the net crop water requirement for maize in the northern and southern zones is equal to 501 and 551m^3/du., respectively. At Deir Alla, Hanbali et al. (1977), reported that the consumptive use of sweet corn is about 580m^3/du. during the growing season, while the water requirement is equal to 892 m^3/du.

Evapotranspiration rate varies, depending on the stage of plant growth and development (Fritschen et al., 1961; Doss et al. 1962; Eagleman et al., 1965; and Downey, 1971). Holt and Van Doren (1961) reported that the period of highest water requirement for corn appears to be from tasseling to kernel formation and decreases sharply thereafter. During corn pollination Van Bavel and Harris (1961) observed maximum evapotranspiration values of 9.15 and 7.33 millimeter per day in two successive years. Downey (1971) reported that evapotranspiration rates in maize ranged from 2.6 to 9.2, 2.7 to 6.3, and 2.7 to 6.3 millimeter per day in the no stress, early stress and late stress treatment, respectively. Evapotranspiration rates then decreased to 0.7 millimeter per day for all treatments.

Holt and Van Doren (1961) measured water requirements for corn and found that 40 to 50 percent of the water losses during the growing season could be accounted for by evaporation. Harrold et al. (1959) reported that 56 percent of evapotranspiration in corn would be due to evaporation and 44 percent was due to transpiration. Under field conditions transpiration of corn was estimated to be 0.73 and 0.89 of the evapotranspiration without adjustment and when adjusted for the energy differences, respectively (Fritschen and Shaw, 1961).

Evapotranspiration rates vary with season and climate. Doss et al. (1962) reported that the average evapotranspiration rate in corn was generally low in the spring, increased gradually until a peak-use-rate period was reached during July, then decreased gradually until grain maturity.

Crop coefficient in corn was also studied (Baker and Harza, 1955; Denmead and shaw, 1959; and Doss et al., 1962). Prior to silking, the ratio of evapotranspiration to open pan evaporation increased in a sigmoid manner from planting to silking stage, the ratio declined after the ear growth period (Denmead and Shaw, 1959). Baker and Harza (1955) in their studies in Jordan reported that the Kc values for corn range from 0.75 to 0.85. Doss et al. (1955) found that the ratio of evapotranspiration to evaporation in corn had increased from 0.38 at emergence to 1.12 during early dough stage, then decreased to 0.95 at grain maturity.

2.2 Effect of Wastewater on Crop Yield:

Several researchers (Bielorai et al., 1984; Bole and Bell, 1978; Day et al., 1975; Hinesly et al., 1972) reported that municipal effluent can be used effectively as a source of irrigation water and plant nutrients, they added that high production can be obtained.

Duncomb et al. (1982) studied the effect of wastewater application on crop yield on silty clay loam. The total wastewater applications for the 1976-1979 growing seasons to a 16-ha terraced watershed was 36.7 and 48.6cm to fields of corn and reed canarygrass, respectively. They reported that the corn yields for the years 1976-1979 averaged 18.0 metric tons/ha fodder and 9.8 metric tons/ha grain from the control plots and 18.1 metric tons/ha fodder and 10.4 metric tons/ha grain from the wastewater plots. Mean reed canarygrass dry matter yields for the same 4-years period were 9.4 metric tons/ha and 10.9 metric tons/ha for the control and wastewater plots, respectively. No visual differences in the quality of the corn were detected due to different treatments.

Campbell et al. (1983) irrigated sweet corn and alfalfa with municipal wastewater (4-5cm from the effluent reservior weekly) and fresh water (an equivalent amount of normal irrigation water from the local reservoir) by using furrow irrigation system in the first year and sprinkler irrigation system in the second year on silty clay soil. They reported that the dry weights of sweet corn plants grown on the effluent site were significantly higher than those on the control site in the second year, but not significantly different in the first year. Dry weights of sweet corn ears on effluent site were significantly greater than those on the control site in the first year. There was no significant difference in the number of ears-per-meter between the two sites within each year. However, significant differences in number of seeds-per-year were observed in the first year. No differences were noted in seed weight. While, dry weight of alfaifa was significantly greater and the leaf/stem ratios were lower for those plants growing on the effluent site than for those on the control site.

Day and Tucker (1959) reported that the winter pasture forage yields equivalent to 11.14 tons per acre were obtained from barley irrigated with sewage effluent with no additional fertilizer. Similarly wheat and oats produced 263% and 249% more pasture forage, respectively, than check plots that received only pump water. Barley was more sensitive to the determental effects of sewage effluent than wheat or oats.

Day et al. (1962) produced more barley, oats and wheat on plots irrigated with sewage effluent than was obtained on plots that received well water. Sewage effluent produced very tall, fast growing plants that tended to lodge at maturity.

Day et al. (1981) found on loam soil that irrigating the cotton with 122cm municipal wastewater and pump water in a 50:50 mixture or pump water alone under furrow irrigation system, the yield of seed and lent cotton irrigated with municipal wastewater-pump water mixture was significantly higher and significantly taller with more vegetative than the yield irrigated with pump water alone, and both types of water produced the same quality of lint.

Alfalfa irrigated with 164cm wastewater and pump water in a 50:50 mixture each year produced significantly taller plants and significantly higher yields of hay than did alfalfa grown with 152cm pump water alone each year by using flood irrigation system on loam soil (Day et al., 1982).

Cordonnier and Johnston (1983) studied the effects of wastewater irrigation on soybean yield. Soybean planted on a Miami silt loam soil, received a total of 9.8cm of wastewater or well water as over hand spray irrigation. They found that the yield of nebsoy increased significantly (12%) due to the use of wastewater irrigation compared to no water, while with well water, its yield increased (7%) compared to the no water treatment. With Harcor, well water resulted in a slight increase in yields (5%) compared to no water treatment, while with wastewater the yield increased significantly (17%) compared to no water treatment.

Bielori et al. (1984) studied in a long-term field experiment the effects of treated municipal effluents on cotton yield by using drip irrigation system. Three amounts of irrigation water averaging 350,440, and 515mm were applied during the 1978, 1979, and 1980 irrigation seasons, respectively. They noticed that the cotton plants irrigated with treated municipal effluents grew significantly taller with more vegetative growth and the cotton seed yield was significantly higher than plants irrigated with fresh water.

Day and Cluff (1985) irrigated sorghum with 114cm of pump water and 115cm of wastewater plus pump water in a 50:50 mixture by using furrow irrigation system on loam soil. They found that the sorghum plants irrigated with the wastewater-pump water mixture grew significantly taller, produced significantly more head per unit area, and produced significantly higher grain yield plants than those irrigated with pump water alone.

2.3 Effect of Wastewater on Some Soil Physical Properties:

Hinrichs et al. (1974) applied the effluent from beef foodlot as irrigation to silty clay loam soil over a 2-year period. They reported that the effluent applications (weekly irrigation treatments applied during the growing season were : no effluent or water, 2.5cm water from creek, 5.0cm water from creek, 2.5cm effluent, and 5.0cm effluent) produced no statistically significant differences in soil apparent specific gravity and water-retention characteristies. While, significant decreases were measured in the hydraulic conductivities of disturbed soil samples.

An investigation was carried out by kelling et al. (1977) during the 1971, 1972, and 1973 seasons to evaluate the wastewater sludge on two types of soils (silt loam and sandy loam). Wastewater sludge rates used were 1.25, 2.5, 5, 10, and 20cm. They noticed that the wastewater sludge treatment can apparently increase the water retention and slightly increases infiltration rate, depending upon growing season and soil type.

Abd El-Naim et al. (1982) evaluated the effect of using sewage water on sandy soil during three years. The use of that water for irrigation caused remarkable changes in the water holding capacity and apparent specific gravity of the surface (0-30cm) and subsurface (30-60cm) soil layers. The values of the water holding capacity increased from 20.3 to 30.4 percent for the surface soil layer and from 18.5 to 22.6 percent for the subsurface soil layer. The apparent specific gravity decreased from 1.68 to 1.45 for the surface and from 1.72 to 1.62 for the subsurface.

Zartman and Gichuru (1984) studied the effect of the saline wastewater on soil physical properties on a fine sandy loam. Field plots were furrow irrigated for 4-years with two saline waters of different quality at three quantity levels. Irrigation was with either below-down water from an electrical generating plant (ECw=12 ds/m, SAR=11) or city water (Ec=1.5 ds/m, SAR=4.5). They concluded that the apparent specific gravity and water retention were not significantly affected by irrigation treatments. While, the hydraulic conductivities (K) were significantly reduced in the AP horizon (0-23cm depth) of plots irrigated with high and medium levels of below-down water. K values ranged from 2mm/30min in the AP horizon of high-irrigation, below-down water plots to 37mm/30min in control plots. K values for the B horizons (23-94cm depth) were less significantly affected by irrigation treatments.

2.4 Effect of Treated Wastewater on Clogging of Emitters by Drip Irrigation System:

Clogging of emitters or orifices in trickle irrigation systems is a widespread problem that has caused many early users to abandon their installations. Recently, water treatment methods have been applied to irrigation water for improving the performance and reliability of emitters. In all instances, water quality plays the dominant role in the operation of the system. Defining precisely the involvement of the various constituents in the water to clogging is difficult. In general, water with low amounts of the following constituents appears to create the least problems: (1) suspended inorganic and organic particulate materials; (2) dissolved chemical constituents that cause scaling such as calcium carbonate, iron, and manganese oxide; and (3) microbes that cause slime development and sgglomeration of suspension, or involved in biochemical accumulation of heavy metals and sulfides. Any one of the physical, chemical, or biological factors at sufficient level can be the prime contributor to clogging, but when several of these factors are present simultaneously, the problem can be aggravated almost synergistically (Nakayama et al. 1978).

The use of treated wastewater in trickle irrigation systems is complicated by the problem of emitter clogging and filtration requirements. Physical screening and chemical treatment are sometimes used in conjuction with these systems to minimize emitter clogging (Gilbert et al., 1981; Nekayama et al., 1978;

Oron et al., 1980; and Solomon et al., 1978).

Oron et al., (1979) studied the effect of treated waste-water on emitter clogging of trickle irrigation systems. Eight separate irrigation treatments (tap water (pH=7.9) with 65 or 39 hours/season of total operating time; trickling filter (pH=8.9) with so or 30 hr/season; "fresh" clarified effluent (pH=5.5) with 65 or 39 hr/season; and "ripe" clarified effluent (pH=6.5) with 65 or 39 hr/season). The emitters used were of the labyrinth in line type with an average path length of 25cm and an average path diameter of 1.0mm with a discharge of 8 l/hr. They reported that there was a significant reduction in flow rate in the emitters along the lateral using all irrigants. The reduction in the flow rate was greatest in the emitters at the beginning of the lateral, than decreased linearly in almost every case. The maximum reduction in flow rate was found with the "ripe" clarified effluent where the organic-to-solids content ratio was the highest where only the trickling filter effluent was filtered before application. The minimum values, in terms of emitter discharge reduction, were found in the tap water as was anticipated. The "fresh" clarified effluent and the trickling filter effluent passing through a 50-mesh (0-50mm) filter gave the minimum results in the reduced flow-rate study. There was a marked reduction in flow rate as the operating time was increased in almost every case. As the effluent gained a higher concentration of suspended and organic matter the flow rate decreased significantly. The changes in the flow reduction of the emitters were less significant in the tap water and "fresh" effluent compared to those in the two other types of effluents.

Oron et al. (1980) studied the effects of stormwater run-off which can be collected in reservoirs and reclaimed effluent obtained from sewage treatment plants on emitters clogging of trickle irrigation system. Two types of emitters were examined. One type was the in-line 4-l/hr labyrinth emitter and the other was insert 4-l/hr emitter. The orchard was irrigated once a week with 25mm of mixture. The effluent treatment before entering the trickling laterals consisted one of the following: a 75-mesh net filter (≈0.2mm); a 150-mesh net filter (≈0.1mm); a sand filter followed by a 75-mesh net filter; chemical treatment (activated chloride) with a concentration of 40mg/l; chemical treatment (as a forementioned); followed by a 75-mesh filter; and no filtration control. They reported that for the high organic matter effluent (40% stormwater plus 60% treated wastewater), no significant reduction in emitter flow rate was detected. The relative change in the flow rate remained fairly constant a long the lateral as well as over time. It ranged from 80% to 90% of the nominal discharge. Similar results were found for the nonregulating emitters for the low organic matter effluent (60% stormwater plus 40% treated wastewater). However, the range of relative changes in the discharge of the emitters was in the range of 70%-80% of the nominal discharge. This tendency towards a reduction in flow rate was found with all combinations of emitter types and for all filtration methods.

Oron et al. (1982) studied the effect of treated wastewater on emitter clogging. Labyrinth-type emitters were used in the trickling system (2,4, and 8, liters per hour emitters discharge). Irrigation intervals used were 2, 3, and 12 day. The total annual water amount was approximately 5900m^3/ha. They reported that the flow rate in the emitters along the lateral proved that no clogging of any kind had occurred. At the end of the irrigation season, a few emitters were randomly chosen and the deposits within them were examined in the hydraulic laboratory. The cylinder of the labyrinth emitter and the inlet to the emitter were clean. Only negligable amounts of deposits were detected on the teeth of the labyrinth.

MATERIALS AND METHODS

3.1 Experimental Site:

The experiment site was located at a land part of the sewage treatment plant area at Queen Alia' International Air-port in Jordan. The Air-port is 40km south of Amman at Jiza, 31°43′N latitude, 35°59′longitude, and 715m altitude. Figure 1.

3.2 Treatments:

Two sources of water were used to irrigate sweet corn using drip and sprinkler systems; fresh water and treated waste-water. Fresh water was delivered to the site from Queen Alia′ International Air-port. Water was stored in a tank and pumped to the systems. Treated wastewater was pumped from the irrigation tank of the sewage treatment plant at Queen Alia′International Air-port to a tank which was used to supply treated wastewater to the systems.

3.3 Experimental Design and Technical Data:

Two different experiments were conducted, one by using sprinkler irrigation system, and the other by using drip irrigation system during the 1985 and 1986 growing seasons.

3.3.1 Sprinkler Irrigation Experiment:

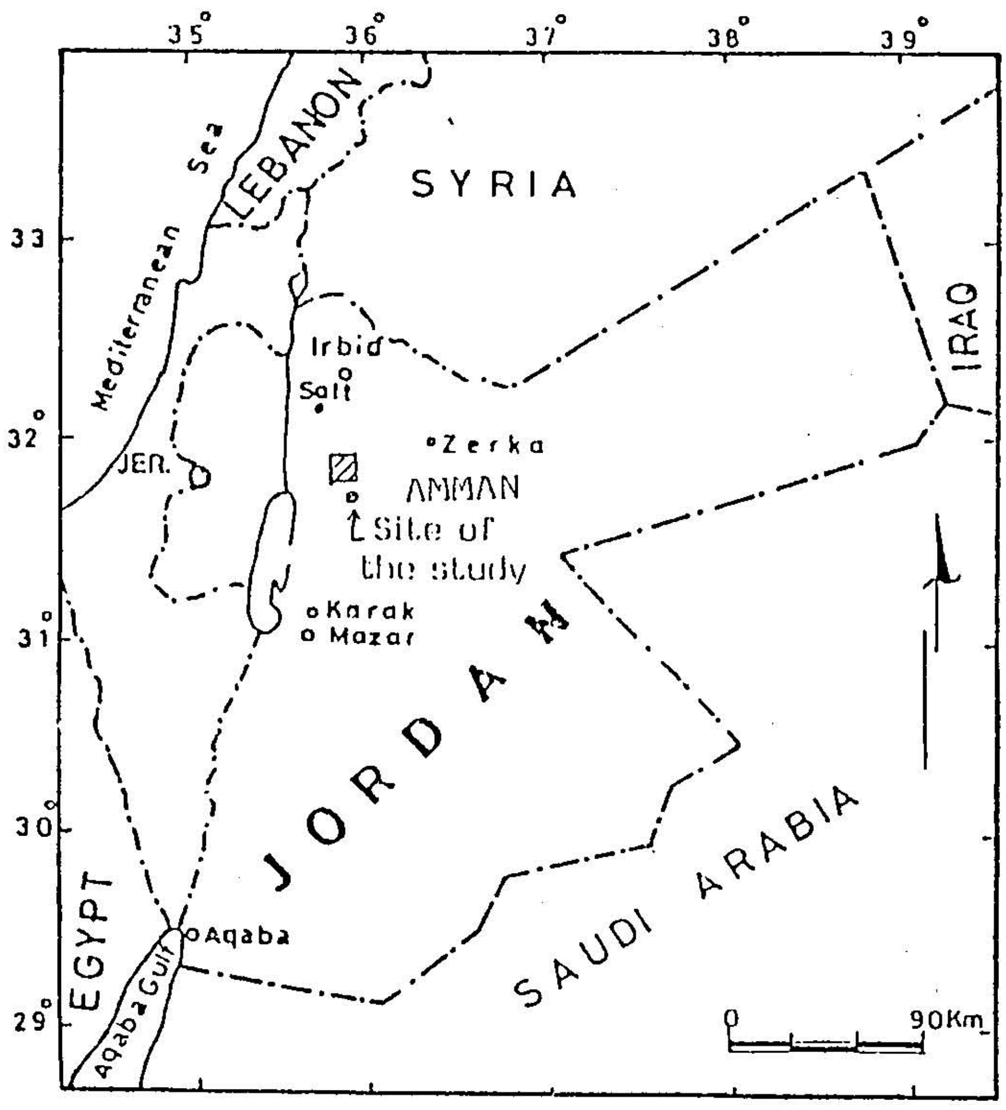


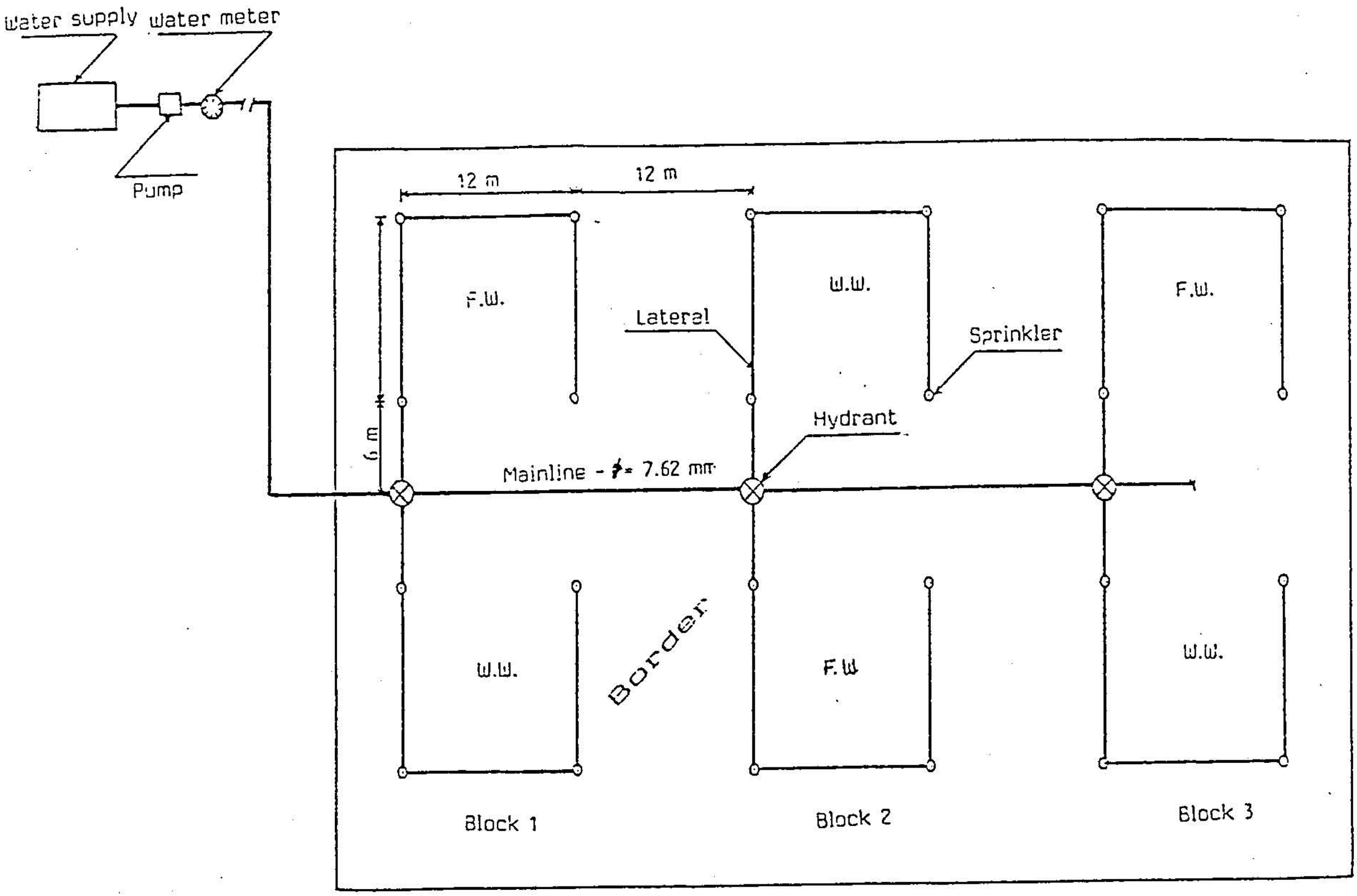
Figure 1: Location of Experiments.

The experiment was in a randomized complete block design with three replications. The system consisted of 76.2mm aluminum pipes as a main line. Hydrants were connected to the 76.2mm aluminum pipes to transport water to 50.8mm aluminum pipes as laterals. Water was then distributed among full circle sprinklers (3.57mm diameter brass nozzles). Water meter was used to measure the quantity of water supplied to the system. This system irrigated six plots of land. Three of them were irrigated with fresh water while the other three were irrigated with treated wastewater. Each plot had 4 sprinklers which were supported by galvanized steel risers 90cm long and 19.0mm diameter. In 1985, 12x12m plots were used. They were seperated by 12x12m border. While in 1986, 6x6m plots were used. They were seperated by 18x6m border. The layouts of the experiments are shown in Figures 2 and 3.

On may 1, 1985 and on march 27, 1986 seeds of (Zea Mays L.) 'Jubilee' sweet corn were planted 5cm deep in rows 75cm apart. Seeds were 30cm apart within a row. They were harvested during the beginning of september 1985 and 1986.

3.3.2 Drip Irrigation Experiment:

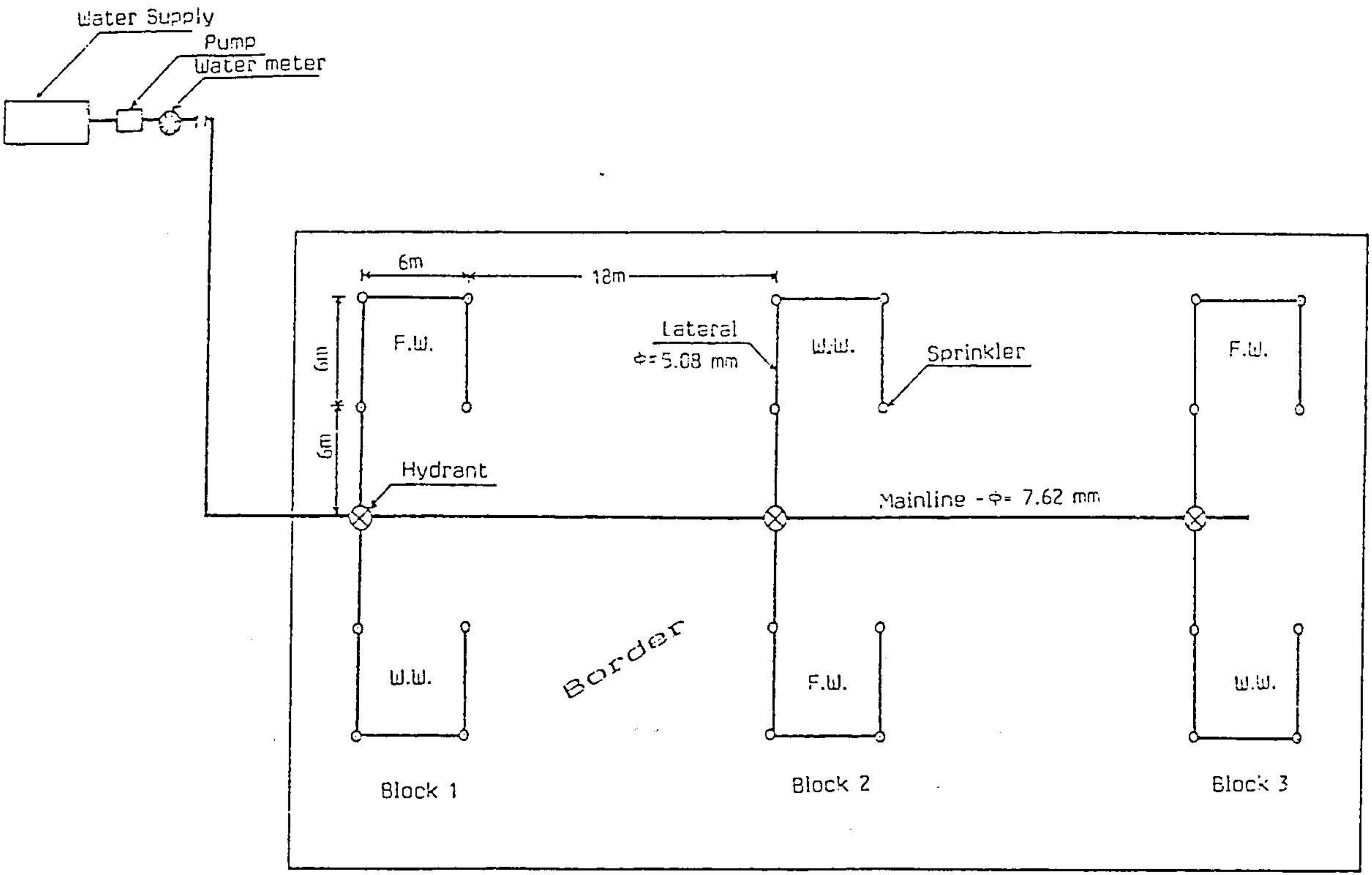
The experiment was in a randomized complete block design with four replications. This experiment consisted of eight plots. Four plots were irrigated with treated wastewater while the other plots were irrigated with fresh water. Each plot consisted of 5, 15m long trickling laterals, with 4 l/hr



F.W. = Plots were irrigated with fresh water.

W.W. = Plots were irrigated with treated wastewater.

Figure 2: Layout of experimental sprinkler irrigation system in 1985.



F.W. = Plots were irrigated with fresh water.
W.W. = Plots were irrigated with treated wastewater.

Figure 3: Layout of experimental sprinkler irrigation system in 1986.

emitters (Tricklon) 0.5m apart. Each lateral served two corn rows and were spaced 1.5m apart. Manual volumetric valves were used to control quantity of water to each plot. The layout of the experiment is shown in Figure 4.

On May 1, 1985 and on March 27, 1986, seeds of (Zea Mays L.) 'Jubilee' sweet corn were planted 5cm deep.

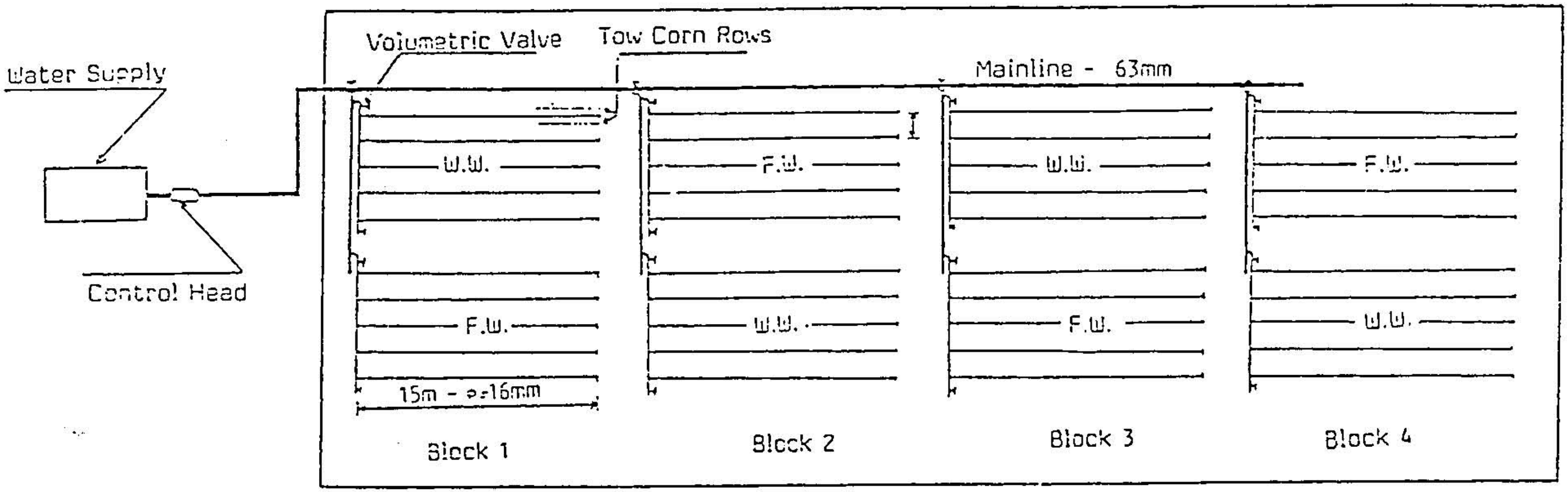
In the two experiments, corn plants were sprayed with Dorospan, one month after planting, to protect the corn from aphids.

In 1985, compound fertilizer (Micafose of 18:18:6-1.5) only were added to soil irrigated by sprinkler irrigation system at the middle of the growing season. The rate of fertilizer addition was 100Kg/du.

3.4 Measurement of Water Applied and Consumptive Use:

In these experiments, tensiometers were installed at the center of each plot at a depth of 15cm. Plants were always irrigated when tensiometer reading is 0.4-0.5 bars. In 1985 growing season, same amounts of water were applied to each plot. While, in 1986 growing season, a neutron probe was used to estimate the amount of water needed to restore the soil water content to its field capacity.

Soil water losses were determined by installing 5.08mm



F.W. = Plots were irrigated with fresh water.
W.W. = Plots were irrigated with treated wastewater.

Figure 4: Layout of experimental drip irrigation system in 1985 and 1986.

aluminum acces tubes to a depth of 90 centimeters at the center of each plot. Tube opennings above the soil surface were covered with a removable cover. Neutron probe readings were taken up to a 90cm depth at 30cm intervals before each irrigation. A calibration curve was prepared for each 30cm layer up to a depth of 90cm, following the procedure described by Victor (1984). Soil moisture content at 30cm depth increments was determined gravimetrically by the use of an auger. Neutron probe counts were taken up to a 90cm depth at 30cm intervals, and the count ratios were recorded. Then the calibration curves were constructed using the linear regression technique as shown in Figure 5.

To determine the average discharge rate for drippers under the drip irrigation system small cans and a stop watch were used. However, under sprinkler irrigation, 16 catch cans were evenly distributed between the 4 sprinklers used for each plot, as shown in Figure 6. The catch cans were raised according to plant height changes.

3.5 Reference Crop Evapotranspiration (ETo):

The ETo was estimated by the following equations (FAO, 1984).

3.5.1 Pan Evaporation Method:

$$ETo = Kp \times Epan$$

where:

Epan : pan evaporation in mm/day and represents the mean

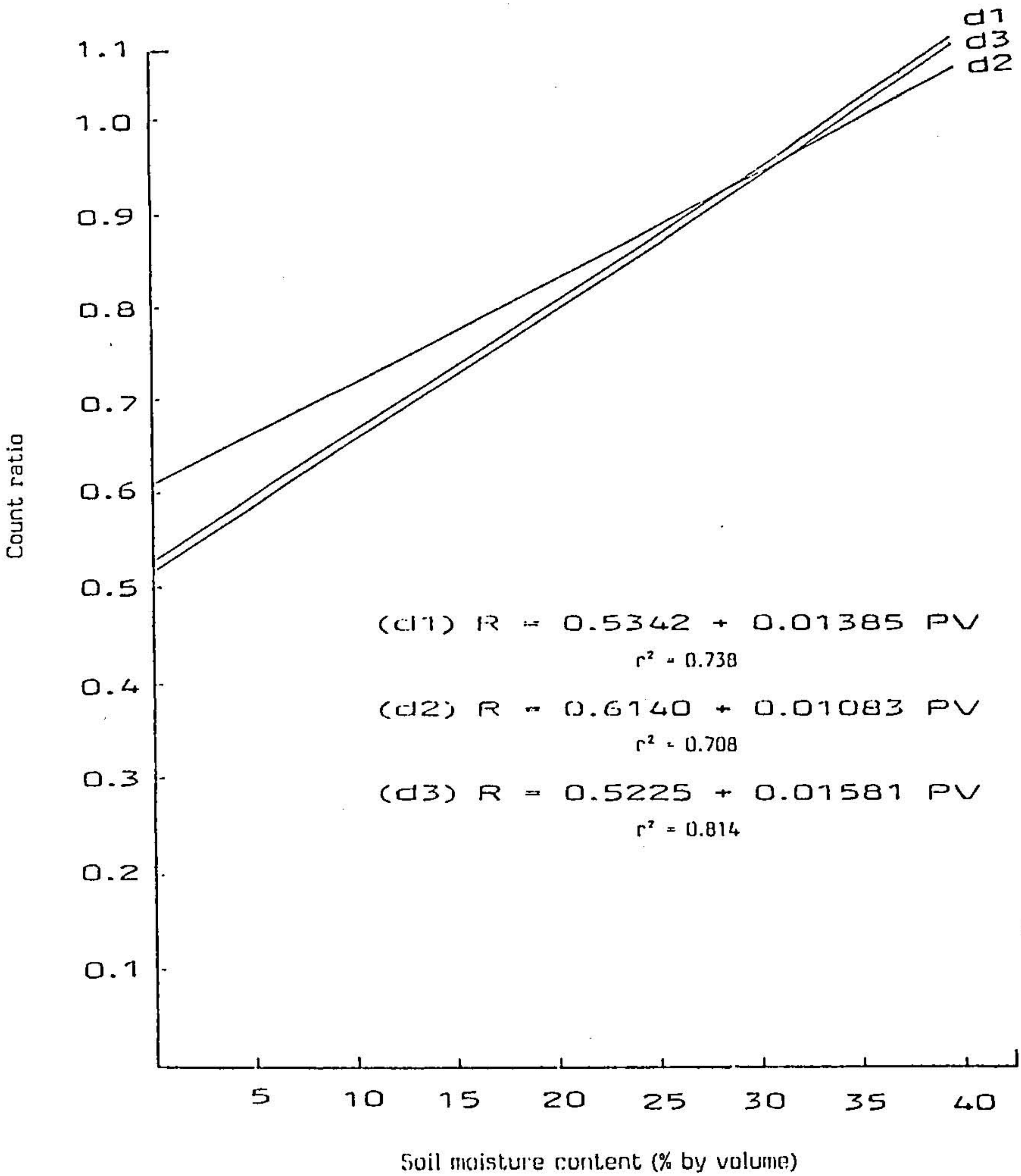


Figure 5: Neutron probe calibration curves for soil depths of (d1) 15cm, (d2) 45cm, and (d3) 75cm at queen Alia' international air-port.

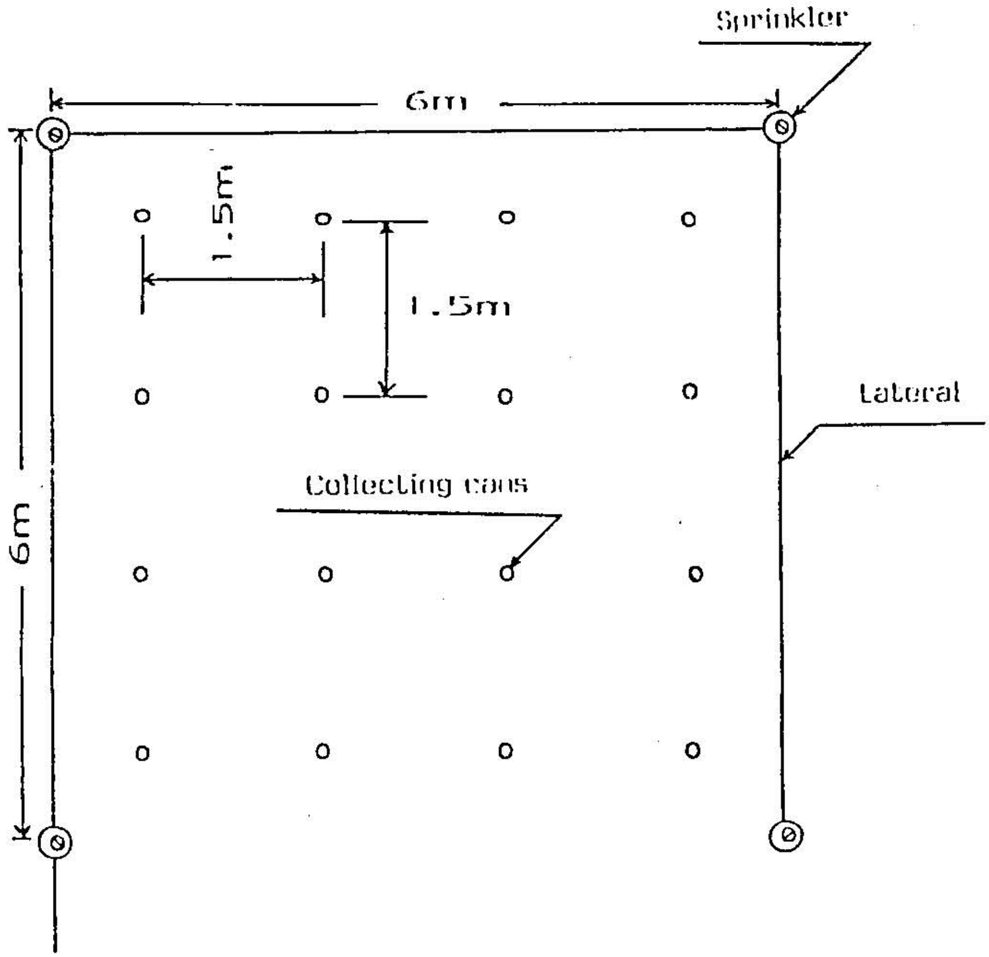


Figure (6): Distribution of catch cans in the sprinkler irrigated plots.

daily value of the period considered.

Kp : pan coefficient.

3.5.2 Blaney-Criddle Method:

$$ETo = c[p(0.46T + 8)] \text{ mm/day}.$$

where:

ETo = reference crop evapotranspiration in mm/day for the month considered.

T = means daily temperature in °c over the month considered.

P = means daily percentage of total annual daytime hours.

c = adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates.

3.5.3 Penman Method:

$$ETo = c[W \cdot Rn + (1-w).f(u).(ea-ed)].$$

where:

ETo = reference crop evapotranspiration in mm/day.

W = temperature-related weighting factor.

Rn = net radiation in equivalent evaporation in mm/day.

f(u) = wind - related function.

(ea-ed) = difference between the saturation vapour pressure at mean temperature and the mean actual vapour pressure of the air, both in mbar.

c = adjustment factor to compensate for the effect of day and night weather conditions.

3.6 Crop Coefficient:

Crop coefficient (Kc) for each period of irrigation was determined for the wastewater treatment using the following equation (FAO, 1984).

$$Kc = \frac{ETc}{ETo}$$

where:

Kc = crop coefficient for the desired period.

ETc= crop evapotranspiration (mm).

ETo= reference crop evapotranspiration (mm), estimated pan evaporation method, Blaney-Criddle method, and Penman method.

3.7 Irrigation Efficiencies:

Distribution efficiency and uniformity coefficient were determined by using the following equations (Merriam and Keller, 1978):

$$Ed = \frac{\text{Average low quarter depth infiltrated}}{\text{Average depth of water infiltrated}} \times 100$$

$$UC = \frac{\text{Average catch - average deviation from average catch}}{\text{Average catch}} \times 100$$

where:

Ed = distribution efficiency.

UC = uniformity coefficient.

The depth of water infiltrated in sprinkler and drip plots was presumed equal to the depth caught on the soil surface.

Water use efficiency (Kg/m^3) was determined using the following equation:

$$WUE = \frac{Y}{ET}$$

where:

WUE = water use efficiency (Kg/m^3).

Y = crop yield (Kg).

ET = evapotranspiration of crop area (m^3).

3.8 Yield Components:

At the optimum harvest time, plant height, weight of total dry matter yield (cobs + grain + stover), and dry matter yield of cobs + grain were recorded. About 40 corn plants were randomly chosen and number of seeds/ear, weight of seeds, diameter of ear, and length of ear were recorded.

3.9 Soil Analysis:

Some physical and chemical properties of a soil profile in the vicinity of the experiments were determined at three different depths (0-30cm, 30-60cm, and 60-90cm). These properties are:-

3.9.1 Soil Reaction (pH):

Was measured in 1:1 soil to water suspension using the glass electrode, as described by USDA, Hand-book No.60 (1954).

3.9.2 Electrical Conductivity (E.C.):

Was measured in soil extracts of 1:2.5 soil to water ratio at 25°c as described by USDA, Hand-book No.60 (1954).

3.9.3 Calcium Carbonate ($CaCO_3$):

Was measured by the calcimeter method as described by Allison and Moodie (1965).

3.9.4 Organic Matter:

Walkley-Black method as described by Allison (1965) was used in determining the organic matter content of tested soils.

3.9.5 Texture:

The particle size distribution of the soil was measured by the pipette method described by Day (1965).

3.9.6 Apparent Specific Gravity and Water Retention Characteristic Curves:

To study the effect of wastewater on apparent specific gravity and water retention, a representative profile was made at the center of the site before planting. A soil profile, of depth 75cm, 50cm long and 50cm wide was made at the center of each plot at the end of the season. Five undisturbed soil samples were collected from each plot at three different depths before planting and after harvesting.

Apparent specific gravity was determined by the core method (Black, 1965).

Water-retention characteristic curves were determined at suctions of 0.1, 0.3, 1.0, 3.0, 7.0, 10, and 15 bars for each plot by using a pressure plate apparatus (Richards, 1965).

3.9.7 Infiltration Rate:

The infiltration rate was measured for each plot of the two experiments before planting and after harvesting of yield by using a double ring infiltrometer (Anson R-Bertrand, 1965).

3.10 Emitter Clogging:

In order to estimate the degree of clogging of the emitters, the flow rate was measured along the lateral before planting, at the middle of the irrigation season, and at the end of the irrigation season. Emitter numbers 2 and 3 were selected as representative of the beginning of each lateral. The discharge of emitters 9, 10, 19, and 20 was taken as being representative of the middle of the laterai while the end was represented by emitters 28 and 29 inclusively.

The reduction in flow rate as a result of emitter clogging was calculated using the nominal discharge qi (in liters per hour) as a function of the operating pressure head, Hi, at the ith emitter. The nominal discharge is given by a calibration curve published by the manufacturer. Accordingly, the reduction in the emitter flow rate along the lateral will be given by Δq (as a percentage)

$$\Delta q = 100 \ (1 - \frac{q_i}{\overline{q_i}})$$

Where qi the measured discharge at pressure head Hi along the lateral and qi - nominal discharge is given by calibration curve puplished by the manufacturer. The pressure was measured at each point along the lateral, which was in a horizontal position, with a handly pressure gauge meter.

3.11 Climatic Data:

Climatic data including maximum and minimum air temperature, rainfall, wind speed, and relative humidity were taken from Queen Alia´International Air-port weather station records. A standardized evaporation pan (120.65cm in diameter, and 25.4cm deep) was used to obtain daily evaporation at the center of the experiments site. Climatic data are shown in Appendix 1.

RESULTS AND DISCUSSION

4.1 Soil properties:

Some physical and chemical properties of the soil were determined before planting. They are presented in Table 1 and Figure 7. The values are the mean value of four samples.

Table 1 shows that the apparent specific gravity value is greater than the average moderate value for this soil (clay loam), especially for 30-60cm soil layer which is mostly between 1.30 and 1.40 (Hansen et al., 1984). This is probably due to the compaction of the site, on which the experiment was conducted, by means of heavy machinery which was on the site. In addition to that the site was planted for the first time. The value of $CaCO_3$ at 60-90cm depth is three times greater than at 0-30cm depth. Organic content in the soil was low. pH value was about the same at three depths.

Figure 7 shows the soil-water characteristic curves at three soil depths namely; 0-30, 30-60, and 60-90cm, respectively.

4.2 Water Analysis:

A list of the chemical composition of the water applied during the irrigation is presented in Table 2. It shows that the wastewater contained more Na, K, and Cl than the fresh water in 1985 and 1986; but other cations were about the same for

Table 1 : Some physical and chemical properties of the soil before planting.

Layer depth (cm)	pH (1:1 ratio)	EC (dsm^{-1})	Organic matter (%)	$CaCO_3$ (%)	Apparent specific gravity	Field* capacity (0.3-bar)	Wilting* point (15-bar)	Mechanical analysis			Textural class
								clay %	silt %	sand %	
0-30	7.92	0.605	0.96	10.30	1.48	26.98	16.99	29.34	34.20	36.46	clay loam
30-60	7.96	0.755	0.87	17.73	1.59	25.14	16.08	32.60	33.43	33.97	clay loam
60-90	8.03	0.85	0.88	31.34	1.49	27.08	17.13	37.51	28.01	34.48	clay loam

* - moisture percent by weight.

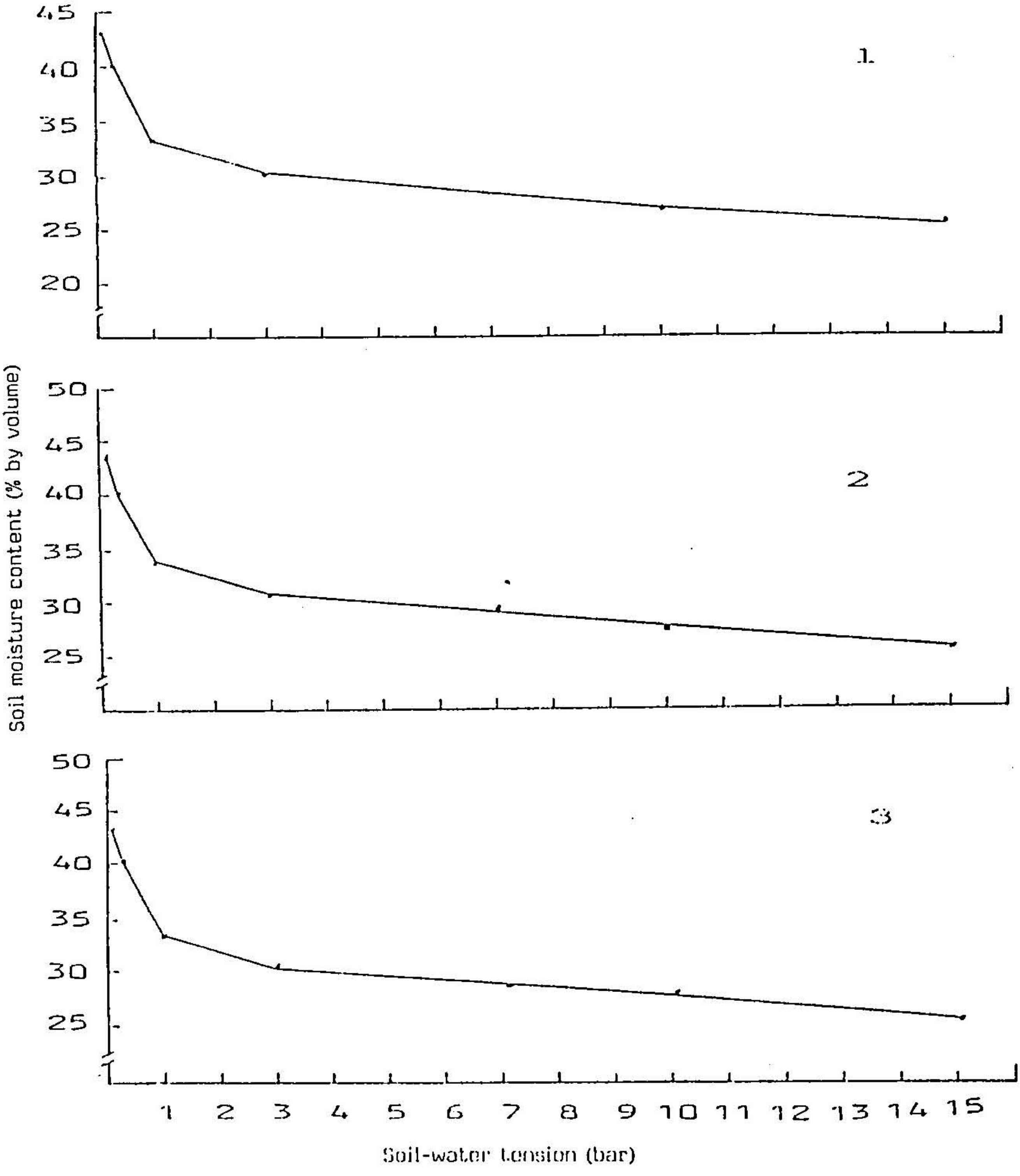


Figure 7: Soil-Water Characteristic Curves For (1) 0-30cm, (2) 30-60cm, and (3) 60-90 cm Depths.

wastewater and fresh water. Trace metals in the wastewater were higher than fresh water. One of the major concerns with the use of wastewater for irrigation is the added salts it contains. The wastewater used in these experiments had an average electrical conductivity of 1.13 ds/m in 1985 and 1.21 ds/m in 1986 which places it in the moderate class of salinity clasification. SAR was low as class 1 for both fresh water and treated wastewater in 1985 and 1986.

4.3 Evaluation of Irrigation Systems Efficiency:

The irrigation systems were tested three times during both seasons to determine both distribution efficiency and uniformity coefficient (Tables 3 and 4).

The difference between test 1, test 2, and test 3 in each case may be due to the variation in the wind speed which effected the sprinkler experiment only.

The value of distribution efficiency in 1986 in sprinkler experiment was higher than 1985 because of different distance between sprinklers which was 12x12m in 1985 and 6x6m in 1986 in addition to the difference in wind speed.

Table 3 : The distribution efficiency (Ed) and uniformity coefficient (Uc) for the drip experiment in 1985 and 1986.

Year	Parameter	Test (1)	Test (2)	Test (3)	Average (%)
1985	Ed	93.00	91.00	89.44	91.15
	Uc	95.47	94.80	90.01	93.43
1986	Ed	89.33	85.70	88.05	87.69
	Uc	89.70	91.12	94.20	91.67

*1 = distribution efficiency as percentage.

*2 = uniformity coefficient as percentage.

Table 4 : The distribution efficiency (Ed) and uniformity coefficient (Uc) for the sprinkler experiment in 1985 and 1986

Year	Parameter	Test (1)	Test (2)	Test (3)	Average (%)
1985	Ed	63.17	69.01	65.04	65.74
	Uc	68.26	81.80	82.26	77.44
1986	Ed	85.67	89.80	82.90	86.12
	Uc	88.47	94.10	88.01	90.19

*1 = distribution efficiency as percentage.

*2 = uniformity coefficient as percentage.

4.4 Effect of Wastewater on Sweet Corn Yield Components:

4.4.1 Biological Yield:

In both seasons for both drip and sprinkler experiments, the total dry matter yield (cobs + grain + stover) under wastewater treatments was greater than that under fresh water treatment and the plant under wastewater treatment was taller than that under fresh water treatment . Those differences are considered to be insignificant (Tables 5 and 6).

In the sprinkler experiment, no significant differences appeared in the vegetative growth (dry leaves and stems) of the year 1985, while in 1986 significant differences appeared. Table 5 shows that the weight of vegetative growth was 715 and 849.7Kg/du. for the fresh water and wastewater treatments, respectively. While in 1986 the weight was 661.6 and 824Kg/du..

In the drip experiment, significant differences between treatments appeared in the vegetative growth of the year 1985, while in the year 1986 no significant differences appeared. Table 6 shows that the weight of vegetative growth was 410 and 586kg/du. under fresh water and wastewater treatments, respectively, while in 1986 the weight was 566.1 and 520.45kg/du., respectively.

Table 5: Total dry matter yield, ears yield, stover yield, and plant height using fresh water and wastewater on sprinkler irrigation site in 1985 and 1986 seasons.

Irrigation treatment	Year	Total dry matter yield (Kg/donum)	Stover yield (Kg/donum)	Ear yield (Kg/donum)	plant height (cm)
Fresh water	1985	1027.0 a*	715.0 a	312.0 a	115.8 a
	1986	1209.6 a	661.6 a	548.0 a	121.0 a
Wastewater	1985	1231.7 a	849.7 a	382.0 a	118.0 a
	1986	1514.8 a	824.0 b	690.8 a	132.0 a

* = Means in the same column, for the same year, followed by the same letter, are not different at the 5% level of significance.

Table 6: Total dry matter yield, ears yield, stover yield, and plant height using fresh water and wastewater on drip irrigation site in 1985 and 1986 seasons.

Irrigation treatment	Year	Total dry matter Yield (Kg/donum)	Stover yield (kg/donum)	Ear yeild (kg/donum)	Plant height (cm)
Fresh water	1985	798.0 a*	410.0 a	388.0 a	143.5 a
	1986	1039.2 a	566.1 a	473.1 a	151.25a
Wastewater	1985	982.70 a	585.95b	396.7 a	146.5 a
	1986	1080.0 a	520.45a	559.5 a	149.25a

*= Means in the same column, for the same year, followed by the same letter, are not different at the 5% level of significance.

4.4.2 Economical Yield:

Tables 5 and 6 include weight of ears yield (dry grain + cobs) for both sprinkler and drip experiments. The data did not show any significant difference between fresh water and wastewater for both 1985 and 1986 growing seasons. The weight of ears under wastewater treatment was slightly greater than that under fresh water treatment.

In 1985, the average weight of ears was 312 and 382Kg/du. for fresh water and wastewater, respectively for the sprinkler experiment, while in 1986 they were 548 and 690.8Kg/du. respectively. On the other hand the average weight of ears for the 1985 was 388 and 396.7Kg/du. for fresh water and wastewater, respectively for the drip experiment, while in 1986 they were 437.1 and 559.5Kg/du., respectively.

4.4.3 Other Economical Quality:

No significant differences have been observed on other economical quality of corn yield (number of columns/ear, number of rows/ear, length and diameter of ear, number of seeds/ear, and weight of 100 seeds) except for the length of ear in drip experiment in 1986 only, between wastewater and fresh water in drip and sprinkler experiments in both years. But there were slight differences as shown in Tables 7 and 8. For instance, in the sprinkler experiment, average number of seeds/ear increased from 331.3 to 393.3 seeds/ear in the first year (1985), and from

477.3 to 500.3 seeds/ear in the second year (1986) for fresh water and wastewater, repectively (Table 7). While in drip experiment the average number of seeds/ear increased from 470 to 522.7 seeds/ear in the first year and from 544.5 to 592.2 seeds/ear in second year for fresh water and wastewater treatments, respectively (Table 8).

All the differences observed are most probably due to the higher addition of plant nutrient elements (N,P,K,Fe,Zn and Mn) from wastewater as compared to fresh water. For example treated wastewater applied by drip irrigation system (1986) added amounts of 14K, 4.5P, 6.92N, 0.14Fe, 0.05Zn, and 0.01Kg/du. Mn as compared to the amounts of 1.8K, 0.0P, 2.3N, 0.03Fe, 0.0Zn, and 0.0Kg/du. Mn added with fresh water. While for sprinkler irrigation system amounts of 17.3K, 5.52P, 8.58N, 0.17Fe, 0.06Zn and 0.01Mn added from wastewater while amounts of 2.2K, 0.05P, 2.85N, 0.03Fe, 0.0Zn and 0.0Kg/du. Mn added from fresh water (Jamjoum, 1987).

The increase in the production in 1986 compared to 1985 might be due to the fact that the growing time of plants was longer in the year 1986 than that in 1985; the change in planting time; the different schedules of irrigation, due to the use of neutron probe in 1986 which provided the accuate amount of water to both sites; and sprinkler experiment the distribution efficiency in 1986 was higher than that in 1985 because of different distances between sprinklers (Figures 2 and 3).

Table 7: Some economical quality of sweet corn by using fresh water and wastewater on sprinkler irrigation site in 1985 and 1986 seasons.

Irrigation treatment	Year	NO. of columns per ear	No. of rows per ear	Av. length per ear (cm)	Av. diameter per ear (cm)	Av. No. of seeds per ear	Av. weight of seeds (gm/100 seeds)
Fresh water	1985	12.9 a*	26.5 a	11.6 a	3.7 a	331.3 a	16.3 a
	1986	13.6 a	34.3 a	16.0 a	3.6 a	477.3 a	16.9 a
Wastewater	1985	13.4 a	30.2 a	15.1 a	3.7 a	392.3 a	16.8 a
	1986	14.3 a	37.0 a	16.8 a	3.9 a	500.3 a	19.2 a

* Means in the same column, for the same year, followed by the same letter, are not different at the 5% level of significance.

4.5 Water Applied and Consumptive Use of Corn:

In both years, in all plots, fresh water was applied at very beginning of planting until the plants average height reached about 10-15cm. After that, the actual treatments took place and continued until the plants matured.

4.5.1 Total Water Applied:

In 1985, in both drip and sprinkler experiments, equal amounts of water were applied to both fresh water and wastewater plots. In 1986, since a neutron probe was used, different amounts of water were applied to both plots.

Table 9 shows that in 1985 the total amount of fresh water that was applied by sprinkler irrigation to the fresh water plots was 832.5mm. On the other hand, 130mm of fresh water and 702.5mm of wastewater were applied to the wastewater plots. In both cases the number of irrigations was 40. While in 1986, 862.5mm of fresh water and 872.0mm of fresh water and wastewater (210mm fresh water plus 662mm wastewater) were applied to fresh water and wastewater plots, respectively. The number of irrigation was 32. In 1985, the total amount of fresh water that was applied by drip irrigation to the fresh water plots was 798mm. On the other hand, 144mm of fresh water and 654mm of wastewater were applied to the wastewater plots. The number of irrigations was 37. In 1986, 705.8mm of fresh water and 698mm of both fresh water and wastewater (150mm fresh

Table 9 : Number of irrigations and actual water applied by sprinkler and drip irrigation systems, for fresh water and wastewater treatments on sweet corn in 1985 and 1986 growing seasons.

Irrigation method	Year	Number of irrigations	Total water applied (mm)		
			fresh water plots	wastewater plots	
				fresh water	wastewater
Sprinkler	1985	40	832.5	130	702.5
	1986	32	862.5	210	662.0
Drip	1985	37	798.0	144	654.0
	1986	29	705.8	150	548.0

water + 548mm wastewater) were applied to the fresh water and wastewater plots, respectively. The number of irrigations was 29. (For of irrigation scheduling see appendices 2, 3, 4, and 5).

4.5.2 Consumptive Use:

The consumptive use was calculated for the year 1986 because neutron probe was used only in this year.

In both experiments (sprinkler and drip), the consumptive use of sweet corn which was irrigated with fresh water and wastewater was measured. Table 10 shows the consumptive use of each period for sprinkler experiment. It also shows that the average total consumptive use values of all periods for all blocks were 648.8 and 662mm for fresh water and wastewater, respectively. In table 11 the average total consumptive use values for drip experiment were 555.85 and 548mm for fresh water and wastewater, respectively. In both cases there were no significant differences in consumptive use between fresh water and wastewater values.

Tables 12 shows the estimated evapotranspiration amounts using pan evaporation, Blaney-Criddle, and Penman methods during the growing season of 1986 during the period of sprinkler irrigation. While Table 13 shows those during the period of drip irrigation.

The curves in Figure 8 (sprinkler experiment) and Figure

Table 10 : Measured evapotranspiration amounts from sweet corn during growing season of the 1986 under sprinkler irrigation system.

Treatment	Fresh water			Wastewater		
Block	B1*	B2	B3	B1	B2	B3
Period	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)
3/7 - 11/5	17.5	15.5	19.5	15.0	15.5	18.5
12/5 - 16/5	15.0	16.5	12.5	12.0	12.7	15.7
17/5 - 20/5	23.0	26.0	22.6	23.0	23.8	24.0
21/5 - 25/5	23.5	26.8	21.7	22.6	23.5	23.0
26/5 - 30/5	26.5	20.9	22.7	24.5	26.3	21.5
31/5 - 3/6	27.2	27.7	21.0	26.0	30.0	21.6
4/6 - 8/6	30.0	33.0	32.0	37.5	27.0	29.5
9/6 - 13/6	26.1	32.1	27.2	32.2	27.2	27.2
14/6 - 17/6	32.6	33.0	28.0	28.7	32.7	32.2
18/6 - 20/6	36.1	32.2	30.6	31.2	36.7	32.2
21/6 - 24/6	39.1	37.2	36.2	37.5	41.7	37.2
25/6 - 27/6	36.0	40.1	37.2	38.5	36.5	40.2
28/6 - 1/7	25.7	42.5	42.1	37.8	39.0	41.4
2/7 - 5/7	45.5	47.6	42.1	49.4	41.2	46.3
6/7 - 9/7	39.0	42.5	38.2	44.0	44.6	43.2
10/7 - 14/7	45.4	48.6	51.6	48.0	46.4	49.1
15/7 - 18/7	52.2	57.3	57.5	54.3	55.1	57.3
19/7 - 22/7	42.3	50.0	44.9	51.0	47.4	50.0
23/7 - 27/7	45.4	52.0	49.2	53.0	52.0	50.4
Total	628.1	681.5	636.7	666.2	659.3	660.5
Average	648.8			662.0		

*= Block

Table 11 : Measured evpotranspiration amounts from sweet corn during growing season of 1986 under drip irrigation system.

Treatment	Fresh water				Wastewater			
Block	B1*	B2	B3	B4	B1	B2	B3	B4
Period	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)
7/5 - 12/5	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
13/5 - 18/5	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
19/5 - 23/5	19.0	19.9	21.7	17.2	18.2	16.90	20.7	17.4
24/5 - 27/5	26.8	27.1	24.0	23.6	22.3	24.90	26.5	18.6
28/5 - 1/6	24.2	28.8	24.4	23.6	25.2	25.10	23.8	21.7
2/6 - 6/6	31.6	28.8	31.5	29.5	32.5	28.5	28.0	26.5
7/6 - 11/6	39.0	36.0	32.5	36.5	37.3	35.2	33.9	41.3
12/6 - 17/6	40.0	42.9	39.2	39.7	40.5	36.9	33.0	39.1
18/6 - 21/6	23.4	24.0	26.2	30.7	23.9	29.5	31.8	54.3
22/6 - 25/6	31.5	27.0	31.9	37.0	27.3	32.0	33.8	29.7
26/6 - 30/6	34.8	31.0	25.3	31.0	32.3	27.0	33.7	28.9
1/7 - 6/7	37.5	44.9	43.2	44.0	39.5	40.7	36.8	36.5
7/7 - 12/7	48.6	47.5	43.0	42.0	41.0	53.0	50.8	45.0
13/7 - 18/7	60.2	59.7	54.2	58.4	54.4	60.2	56.6	58.9
19/7 - 23/7	55.7	56.9	51.0	53.5	55.7	57.3	51.1	60.4
24/7 - 29/7	50.7	56.9	55.2	54.5	50.8	47.1	56.7	56.6
Total	559.4	567.4	539.4	557.2	536.9	550.3	554.0	550.9
Average	555.85				548.0			

*= Block

Table 12 : Estimated evapotranspiration amounts using pan evaporation, Blaney-Criddle, and penman methods during the growing season of 1986 (during the period of sprinkler irrigation).

Period	Duration days	Pan-evaporation method KpxEp (mm)	Blaney-Criddle method (mm)	Penman method
7/5-11/5	5	29.2	32.7	35.3
12/5-16/5	5	23.3	31.8	33.1
17/5-20/5	4	37.0	37.7	37.9
21/5-25/5	5	34.5	33.0	36.2
26/5-30/5	5	25.2	34.5	36.4
31/5- 3/6	4	38.2	33.0	32.7
4/6- 8/6	5	33.0	34.1	35.8
9/6-31/6	5	41.6	41.0	41.5
14/6-17/6	4	31.8	32.0	31.5
18/6-20/6	3	28.7	24.6	24.7
21/6-24/6	4	34.4	32.0	33.7
25/6-27/6	3	28.7	29.7	31.9
28/6- 1/7	4	35.6	31.6	34.1
2/7- 5/7	4	35.7	34.6	36.9
6/7--9/7	4	37.6	31.6	32.9
10/7-14/7	5	45.2	40.0	42.5
15/7-18/7	4	42.5	40.2	39.1
19/7-22/7	4	40.0	37.2	39.5
23/7-27/7	5	47.0	45.3	48.2
Total	82	679.2	656.6	683.90

Table 12 : Estimated evapotranspiration amounts using pan evaporation, Blaney-Criddle, and penman methods during the growing season of 1986 (during the period of sprinkler irrigation).

Period	Duration days	Pan-evaporation method KpxEp (mm)	Blaney-Criddle method (mm)	Penman method
7/5-11/5	5	29.2	32.7	35.3
12/5-16/5	5	23.3	31.8	33.1
17/5-20/5	4	37.0	37.7	37.9
21/5-25/5	5	34.5	33.0	36.2
26/5-30/5	5	25.2	34.5	36.4
31/5- 3/6	4	38.2	33.0	32.7
4/6- 8/6	5	33.0	34.1	35.8
9/6-31/6	5	41.6	41.0	41.5
14/6-17/6	4	31.8	32.0	31.5
18/6-20/6	3	28.7	24.6	24.7
21/6-24/6	4	34.4	32.0	33.7
25/6-27/6	3	28.7	29.7	31.9
28/6- 1/7	4	35.6	31.6	34.1
2/7-! 5/7	4	35.7	34.6	36.9
6/7--9/7	4	37.6	31.6	32.9
10/7-14/7	5	45.2	40.0	42.5
15/7-18/7	4	42.5	40.2	39.1
19/7-22/7	4	40.0	37.2	39.5
23/7-27/7	5	47.0	45.3	48.2
Total	82	679.2	656.6	683.90

Table 13 : Estimated evapotranspiration amounts using pan evaporation, Blaney-Criddle, and Penman methods during the growing season of 1986 (during the period of drip irrigation).

Period	Duration Days	Pan-evaporation method KpxEp (mm)	Blaney-Criddle method (mm)	Penman method (mm)
7/5-12/5	6	35.3	39.0	42.4
13/5-18/5	6	36.5	40.5	41.1
19/5-23/5	5	38.5	38.5	39.2
24/5-27/5	4	33.2	32.6	32.8
28/5- 1/6	5	39.0	34.5	37.5
2/6- 6/6	5	49.0	41.3	44.3
7/6-11/6	5	50.9	42.0	48.0
12/6-17/6	6	50.9	48.0	47.2
18/6-21/6	4	36.9	32.0	32.9
22/6-25/6	4	33.7	32.0	34.0
26/6-30/6	5	47.0	37.0	43.6
1/7- 6/7	6	51.5	47.4	47.9
7/7-12/7	6	54.7	47.7	49.9
13/7-18/7	6	54.9	46.8	49.6
19/7-23/7	5	45.2	41.5	48.1
24/7-29/7	6	51.5	52.5	60.9
Total	84	708.7	653.25	699.4

9 (drip experiment) represent the measured and estimated cumulative consumptive use values for sweet corn which was irrigated with fresh water and wastewater. The estimates were based on class-A pan evaporation, modified Blaney-Criddle equation, and modified Penman equation.

Both figures show that the measured values of cumulative consumptive use of fresh water and wastewater were almost the same. The estimated values by the three above mentioned methods were also almost the same.

It is clear from Figure 8 that at the beginning and at the end of the season of the sprinkler site both measured and estimated values of cumulative consumptive use were almost the same, while in between the season, the values were different. In drip irrigation site, the measured and estimated cumulative consumptive use values were almost the same at the beginning of the season only (Figure 9). The measured and estimated consumptive use values are relativly high because of the weather conditions (Appendix 1). The slight differences between the estimated values by the three methods were due to the climatic changes which affected each method differently.

At the beginning of the season, the rates of consumptive use were 3.25mm/day and 3.0mm/day for wastewater treatment under sprinkler and drip irrigation systems, respectively. Then they increased to maximum values of 11.85mm/day and 9.55mm/day at the end of the season. Those rates dropped down to 10.9mm/day

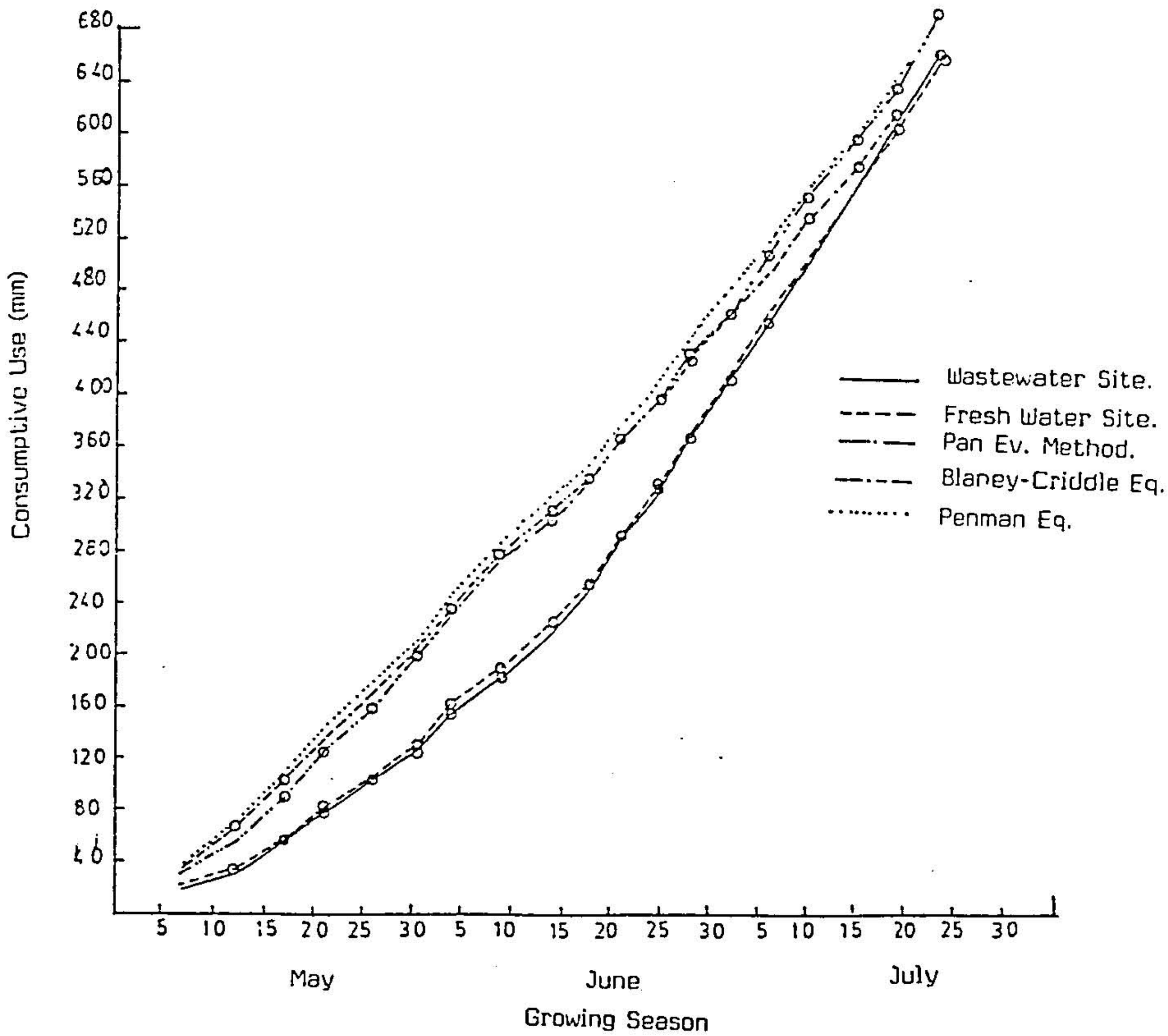


Figure 8 : Measured and Estimated Cumulative Consumptive Use During 1986 Growing season Under Sprinkler Irrigation System.

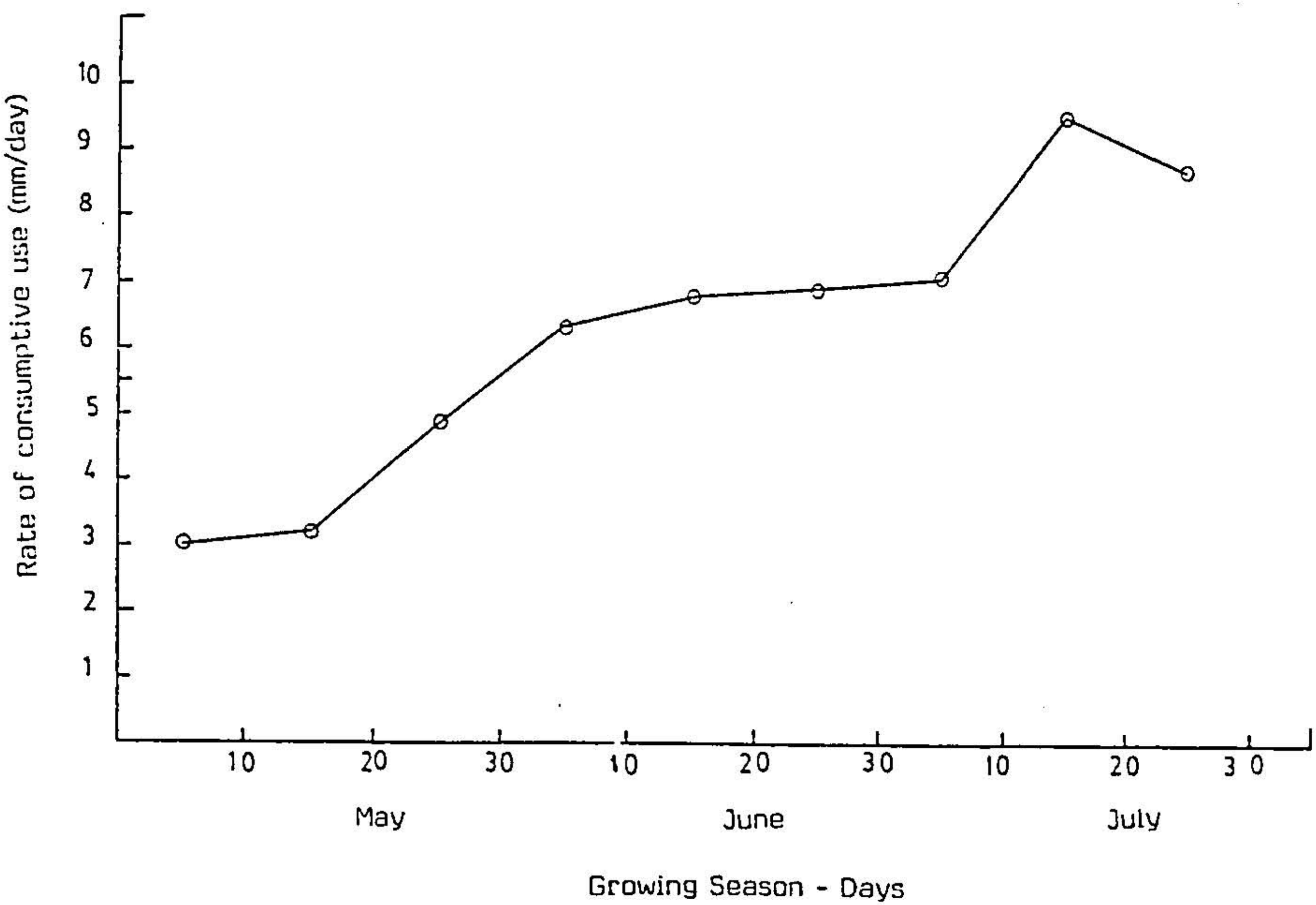


Figure 11 :Rates of consumptive use using treated wastewater under drip irrigation system in 1986 season.

evapotranspiration (ETc) to the estimated refernce crop evapotranspiration (ETo).

Figures 12 and 13 show the variation of Kc values with the growing season on 10-day basis for sprinkler and drip experiments, respectively. Those values were calculated by using class-A pan evaporation, modified Blaney-Criddle equation, and modified Penman equation.

In Figure 12, Kc values for modified Blaney-criddle and modified Penman equation were closer to each other than those for pan evaporation method. At the beginning, Kc values for pan evaporation were higher than those for modified Blaney-Criddle and Penman. Then they began to decrease in there inclination till thay became lower than the later values. Figure 13 is almost the same as Figure 12 except that the middle portion of Kc values for pan evaporation were lower than the others. In both figures, the peak Kc value for Blaney-Criddle was the highest while Kc for pan evaporation was the lowest.

All Kc values were somehow small at the beginning of the growing season, then they increased till 10 days before maturity. After that, they decreased

Table 14 shows monthly Kc values for wastewater under sprinkler experiment, while Table 15 shows them for drip experiment. For both sprinkler and drip experiments, Kc value for the first month given by class-A pan evaporation method was the highest. While for the last month Kc value given by Blaney-Criddle was the highest.

4.5.4 Water Use Efficiency:

No significant differences between treatments were observed fore either experiment.

The water use efficiency values for total dry matter yield under sprinkler experiment were 1.86kg/m^3 and 2.29kg/m^3 for fresh water and wastewater sites, respectively. Those for ears yield were 0.84kg/m^3 and 1.04kg/m^3, while those under drip experiment were 1.87kg/m^3 and 1.97kg/m^3 due to the total dry matter yield, and 0.85kg/m^3 and 1.02kg/m^3 due to the ears yield (Table 16).

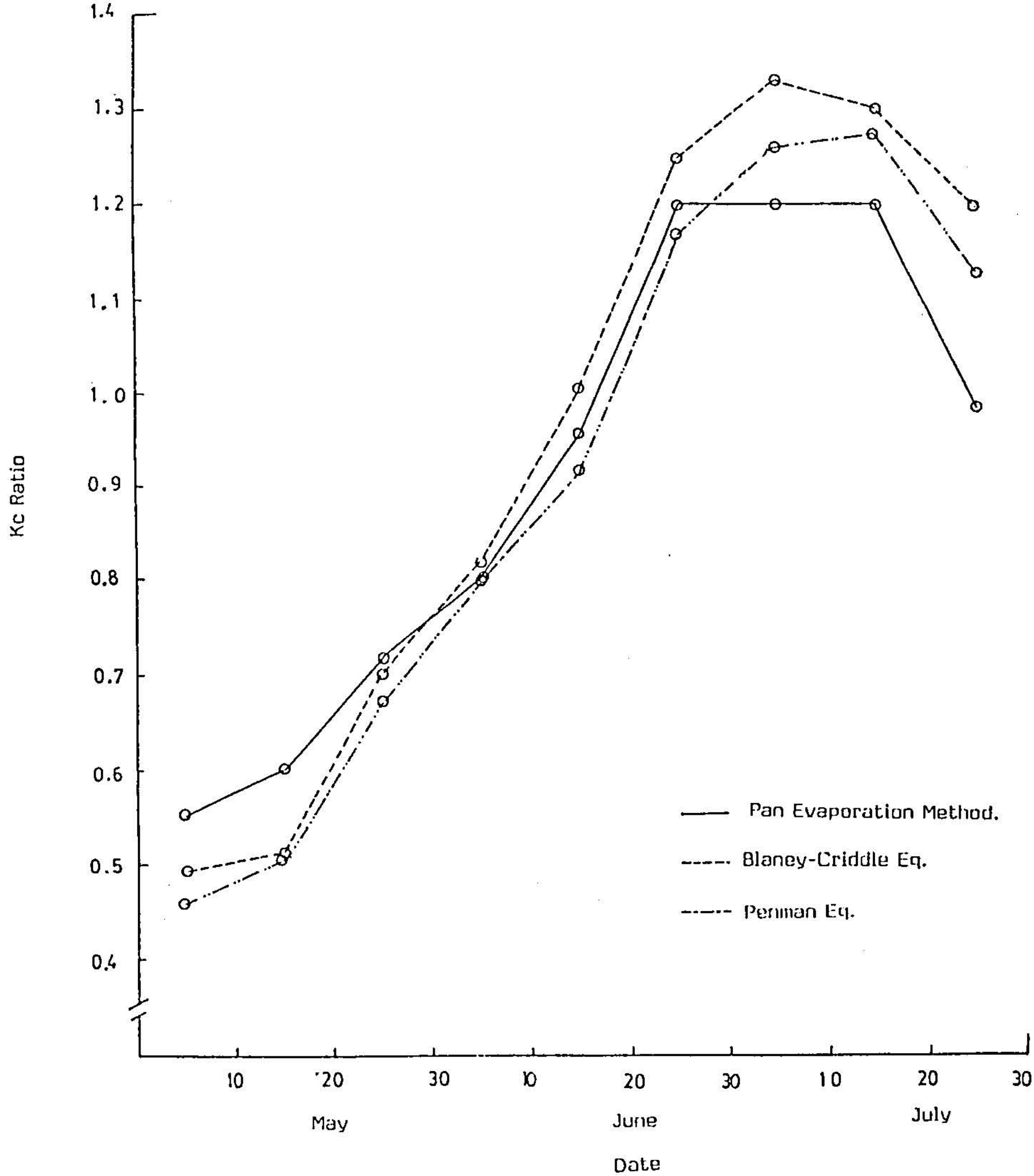


Figure 12 : The Change of Kc Ratio for Three Ways Under Sprinkler Irrigation System in 1986 Season.

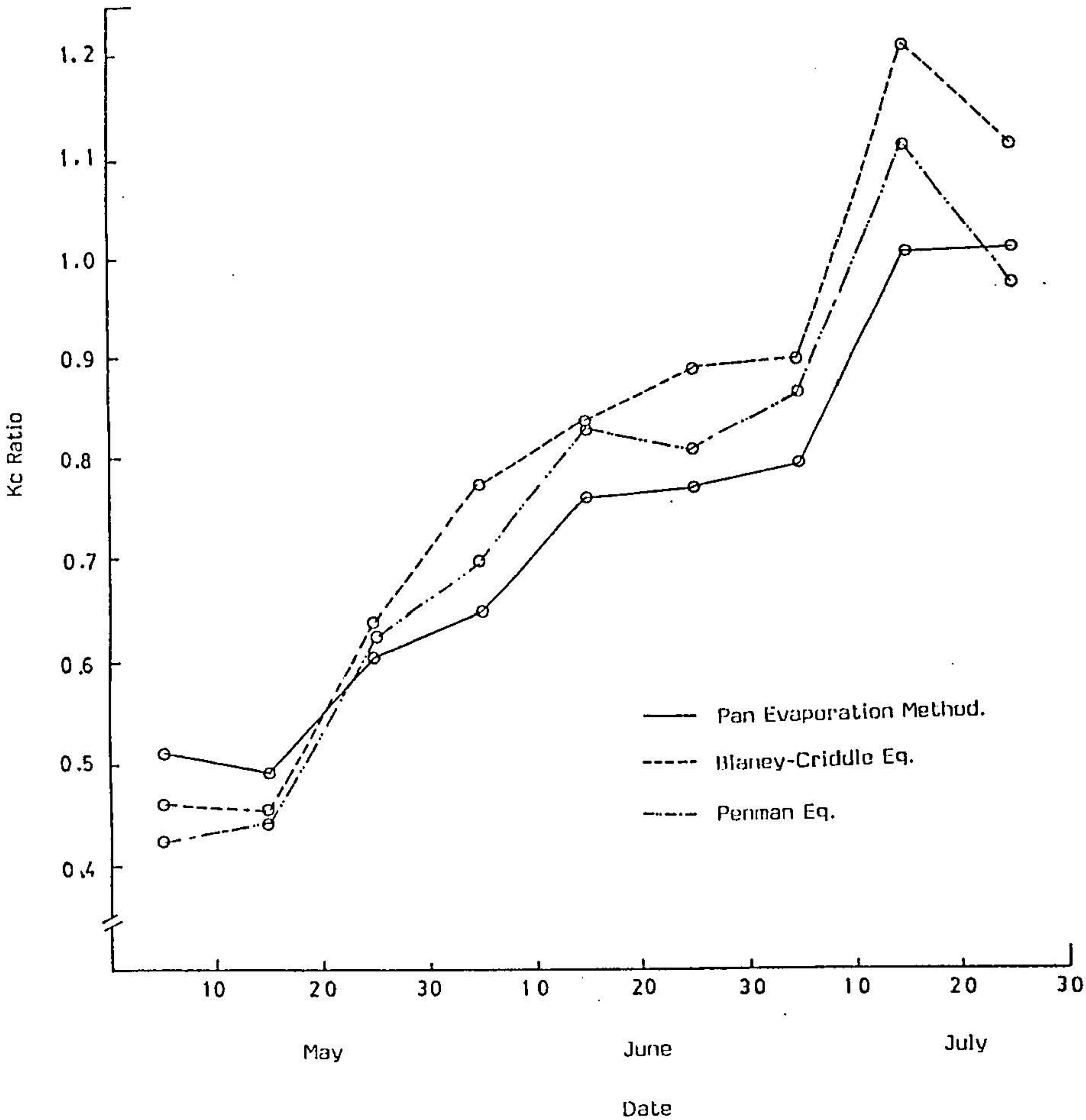


Figure 13 : The Change of Kc Ratio for Three Ways Under Drip Irrigation System in 1986 Season.

Table 14 : Crop coefficient values of class-A pan evaporation, Blaney-Criddle method, and Penman method for wastewater treatment under sprinkler irrigation system in 1986 season on monthly basis.

Period	Days	ETc mm/day	ETo EpxKp mm/day	Kc	ETo Blaney-Criddle method mm/day	Kc	ETo Penman method mm/day	Kc
May	25	4.25	6.75	0.63	7.11	0.59	7.48	0.56
June	30	8.32	8.45	0.98	8.06	1.03	8.30	1.00
July	27	11.26	9.51	1.18	8.76	9.17	9.17	1.22

Table 15 : Crop coefficient values of class-A pan evaporation, Blaney-Criddle method, and Penman method for wastewater treatment under drip irrigation system in 1986 season on monthly basis.

Period	Days	ETc mm/day	ETo EpxKp mm/day	Kc	ETo Blaney-Criddle method mm/day	Kc	ETo Penman method mm/day	Kc
May	25	2.94	6.98	0.42	7.12	0.41	7.41	0.39
June	30	6.64	9.21	0.72	7.97	0.83	8.58	0.77
July	29	8.70	8.99	0.96	8.13	1.07	8.83	0.98

Table 16 : Water use efficiency using treated wastewater and fresh water under sprinkler and drip experiments in 1986.

Irrigation method	Water treatment	Total dry matter Yield (Kg/donum)	Ear yield (Kg/d.)	ETc (mm)	Water use efficiency	
					Kg TDMY*/m³	Kg Ear yield/m³
Sprinkler	Fresh water	1209.6	548.0	648.8	1.86	0.84
	Wastewater	1514.8	690.8	662.0	2.29	1.04
Drip	Fresh water	1039.2	473.1	555.85	1.87	0.85
	Wastewater	1080.0	559.5	548.00	1.97	1.02

* Total dry matter yield.

4.6 Effect of Treated Wastewater on Some Soil Physical Properties:

In both sprinkler and drip experiments, the effects of treated wastewater on soil apparent specific gravity, water retention characteristic curves, and infiltration rate after two-years period were studied.

4.6.1 Effect of Treated Wastewater on Apparent Specific Gravity:

In both years, for both fresh water and wastewater plots, the apparent specific gravity values for the second layer (30-60cm) were smaller than those before planting (Tables 1, 16), while those for the first and third layers [(0-30cm), (30-60cm)] did not change.

The changes in the apparent specific gravity before and after planting are probably due to the tillage of soil and the growth of roots.

The effect of wastewater on apparent specific gravity for the year 1986 was greater than that for the year 1985.

In Tables 17 and 18 the apparent specific gravity values for wastewater plots were little less than those for fresh water plots. This is probably due to the increased of soil organic matter content by the irrigation of treated wastewater.

Table 17: Apparent specific gravity under sprinkler irrigation system on fresh water and wastewater sites after harvesting in 1985 and 1986 seasons.

Irrigation treatment	Year	Layer depth (cm)		
		0-30	30-60	60-90
Fresh water	1985	1.50 a*	1.52 a	1.50 a
	1986	1.43 a	1.42 a	1.51 a
Wastewater	1985	1.51 a	1.51 a	1.49 a
	1986	1.42 a	1.42 a	1.50 a

*= Means in the same column, for the same year, followed by the same letter, are not different at the 5% level of significance.

Table 18: Apparent specific gravity under drip irrigation system on fresh water and wastewater sites after harvesting in 1985 and 1986 seasons.

Irrigation treatment	Year	Layer depth (cm)		
		0-30	30-60	60-90
Fresh water	1985	1.52 a*	1.53 a	1.52 a
	1986	1.45 a	1.44 a	1.51 a
Wastewater	1985	1.51 a	1.52 a	1.53 a
	1986	1.43 a	1.42 a	1.54 a

*= Means in the same column, for the same year, followed by the same letter, are not different at the 5% level of significance.

4.6.2 Effect of Treated Wastewater on Soil Water Retention Characteristic Curves:

In Figures 14 through 17 the curves represent soil water retention data for the three layers (0-30cm, 30-60cm, and 60-90cm) for both the fresh water and wastewater plots under both sprinkler and drip experiments for two years.

Table 20 shows the available water in the soil at the three layers in both fresh water and wastewater plots under sprinkler experiment. While Table 19 shows those under drip experiment.

In both experiment the available water increased after planting. In the first two layers the available water was a little higher in wastewater plots than that in fresh water plots. This is probably due to the fact that since the apparent specific gravity decreased, then the total porosity increased as a result the available water increased

4.6.3 Effect of Treated Wastewater on Infiltration Rate:

In Figures 19 and 20 the curves represent the average infiltration rate values during a 9-hr period for the year 1985 and a 24-hr period for the year 1986 under sprinkler experiment, while in Figures 21 and 22 the curves represent those for drip experiment. In Figure 18 the curve represents the infiltration rate values before planting.

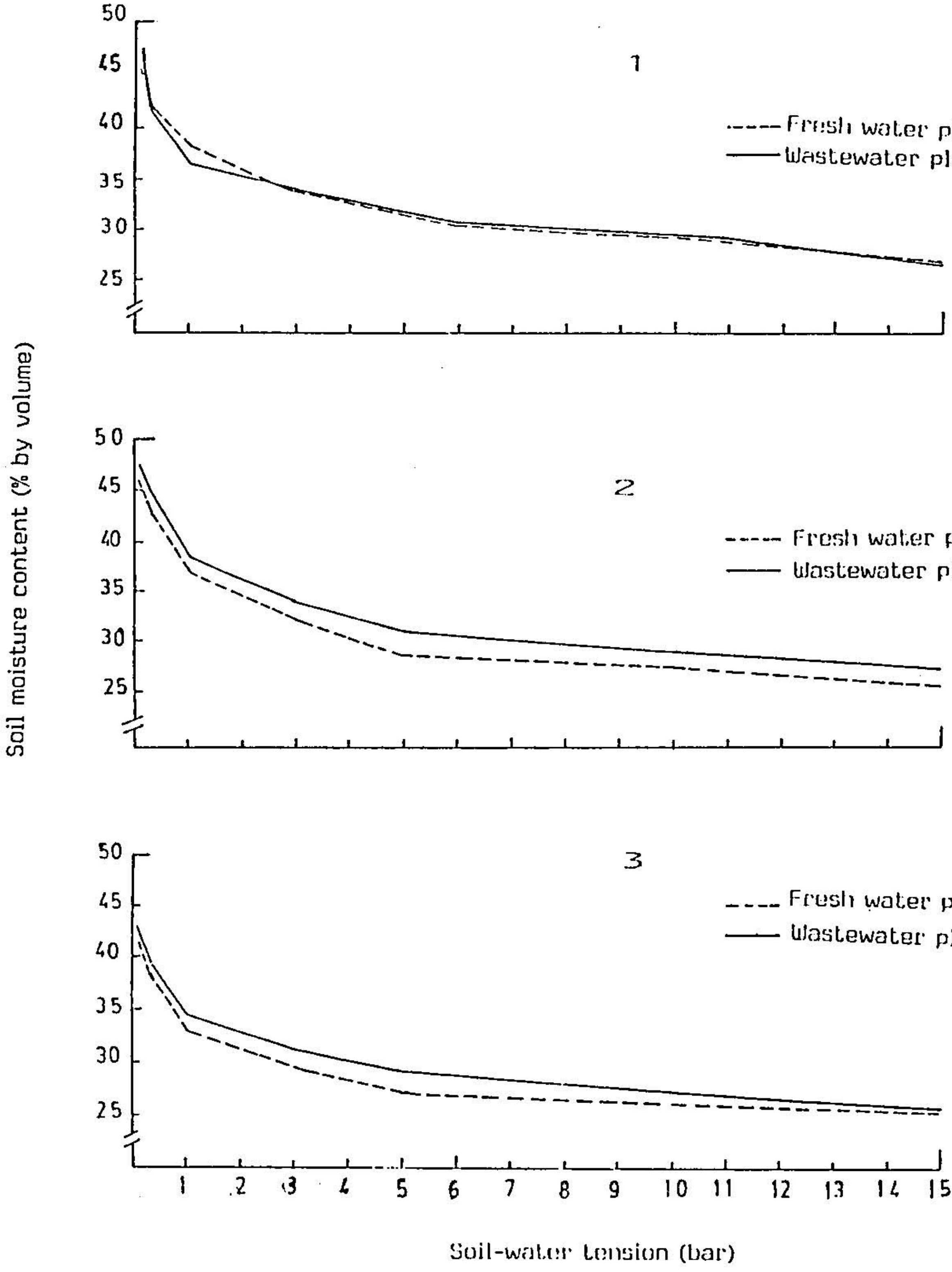


Figure 14 : Soil water characteristic curves for (1) 0-30cm, (2) 30-60cm, and (3) 60-90cm depths under sprinkler irrigation system on fresh water and wastewater plots after harvesting in 1985 season.

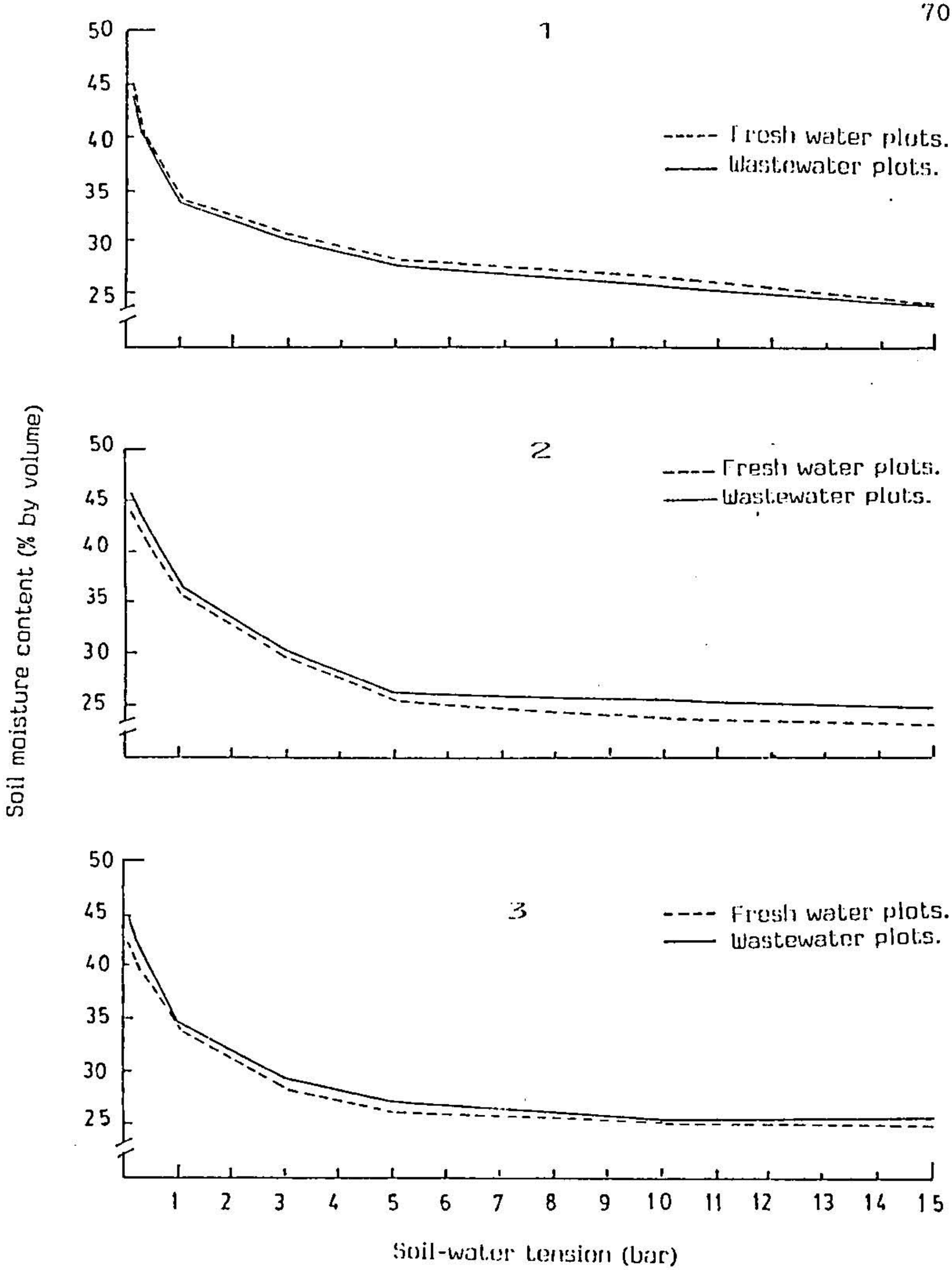


Figure 15 : Soil water characteristic curves for (1) 0-30cm, (2) 30-60cm, and (3) 60-90cm depths under sprinkler irrigation system on fresh water and wastewater plots after harvesting in 1986 season.

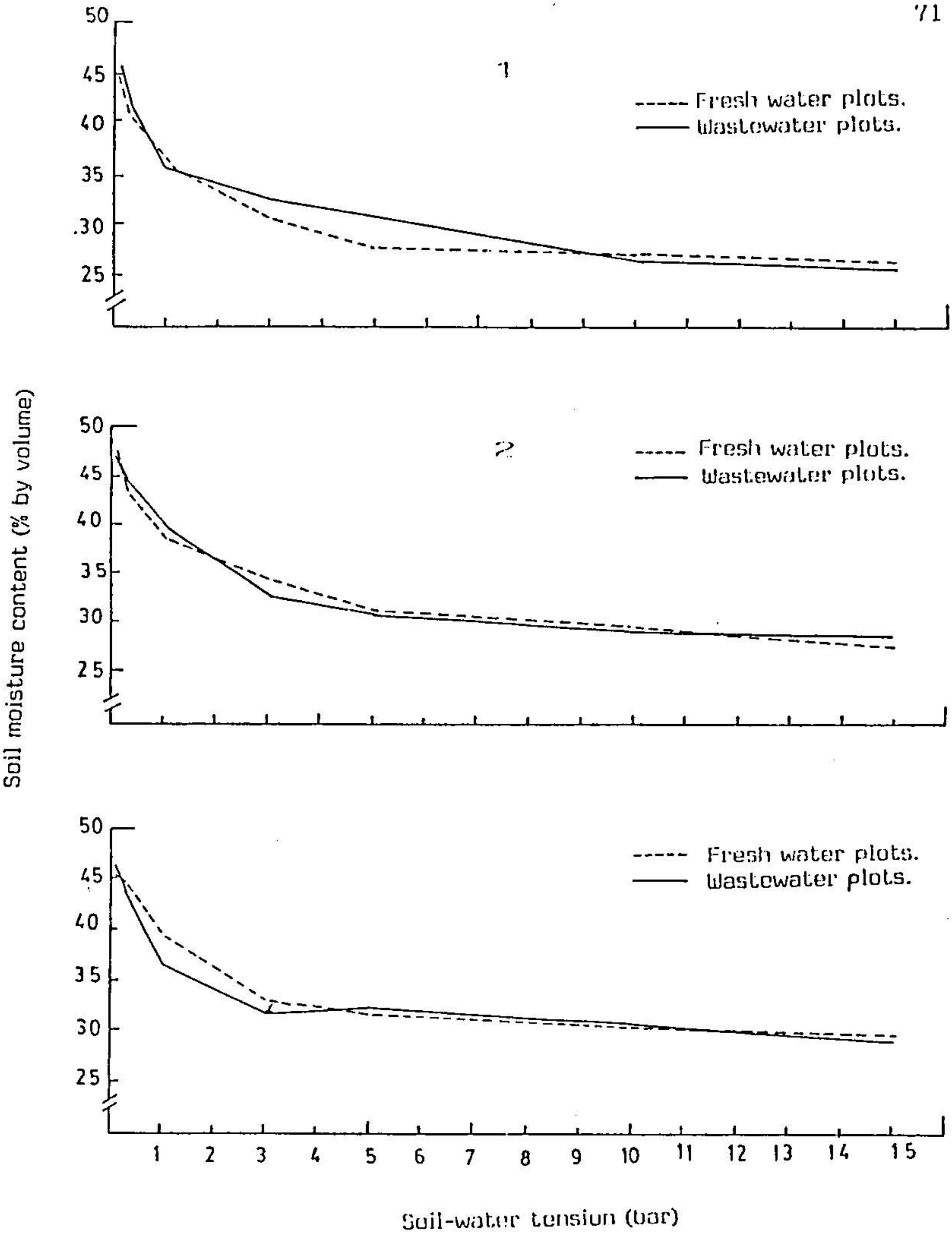


Figure 16 : Soil water characteristic curves for (1) 0-30cm, (2) 30-60cm, and (3) 60-90cm depths under drip irrigation system on fresh water and wastewater plots after harvesting in 1985 season.

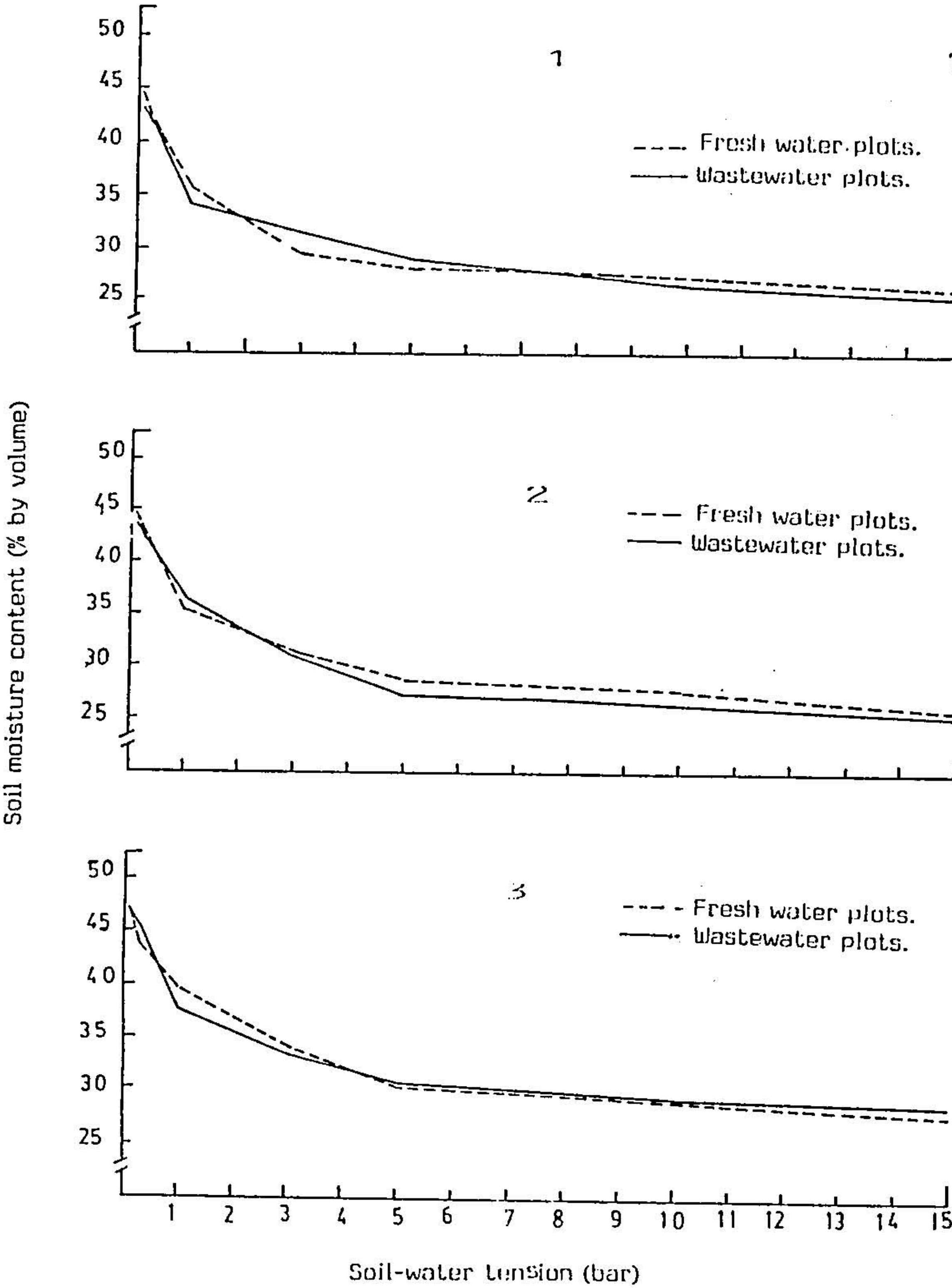


Figure 17 : Soil water characteristic curves for (1)0-30cm, (2) 30-60cm, and (3) 60-90cm depths under drip irrigation system on fresh water and wastewater plots after harvesting in 1986 season.

Table 19 : Available water (% by volume) under drip irrigation system on fresh water and wastewater sites after harvesting in 1985 and 1986 seasons.

Year	Irrigation treatment	Layer depth (cm)	Water content		Available water
			0.3 bar	15 bar	
1985	Fresh water	0-30	41.42	26.94	14.78
		30-60	43.34	27.94	15.40
		60-90	44.84	29.94	14.90
	Wastewater	0-30	42.39	25.98	16.41
		30-60	44.16	28.62	15.54
		60-90	44.00	29.08	14.92
1986	Fresh water	0-30	42.12	26.25	15.87
		30-60	42.27	26.08	16.19
		60-90	43.96	28.26	15.70
	Wastewater	0-30	41.71	25.47	16.24
		30-60	41.89	25.32	16.57
		60-90	45.50	28.84	16.66

Table 20 : Available water (% by volume) under sprinkler irrigation system on fresh water and wastewater sites after harvesting in 1985 and 1986 seasons.

Year	Irrigation treatment	Layer depth (cm)	Water content 0.3 bar	Water content 15 bar	Available water
1985	Fresh water	0-30	41.94	26.98	14.96
		30-60	42.64	25.92	16.72
		60-90	38.89	25.29	13.60
	Wastewater	0-30	41.76	26.89	14.87
		30-60	45.20	27.50	17.70
		60-90	39.28	25.43	13.85
1986	Fresh water	0-30	41.36	24.31	17.05
		30-60	41.76	23.54	18.22
		60-90	39.97	24.97	15.00
	Wastewater	0-30	40.77	24.02	16.75
		30-60	43.41	24.94	18.47
		60-90	41.83	25.71	16.12

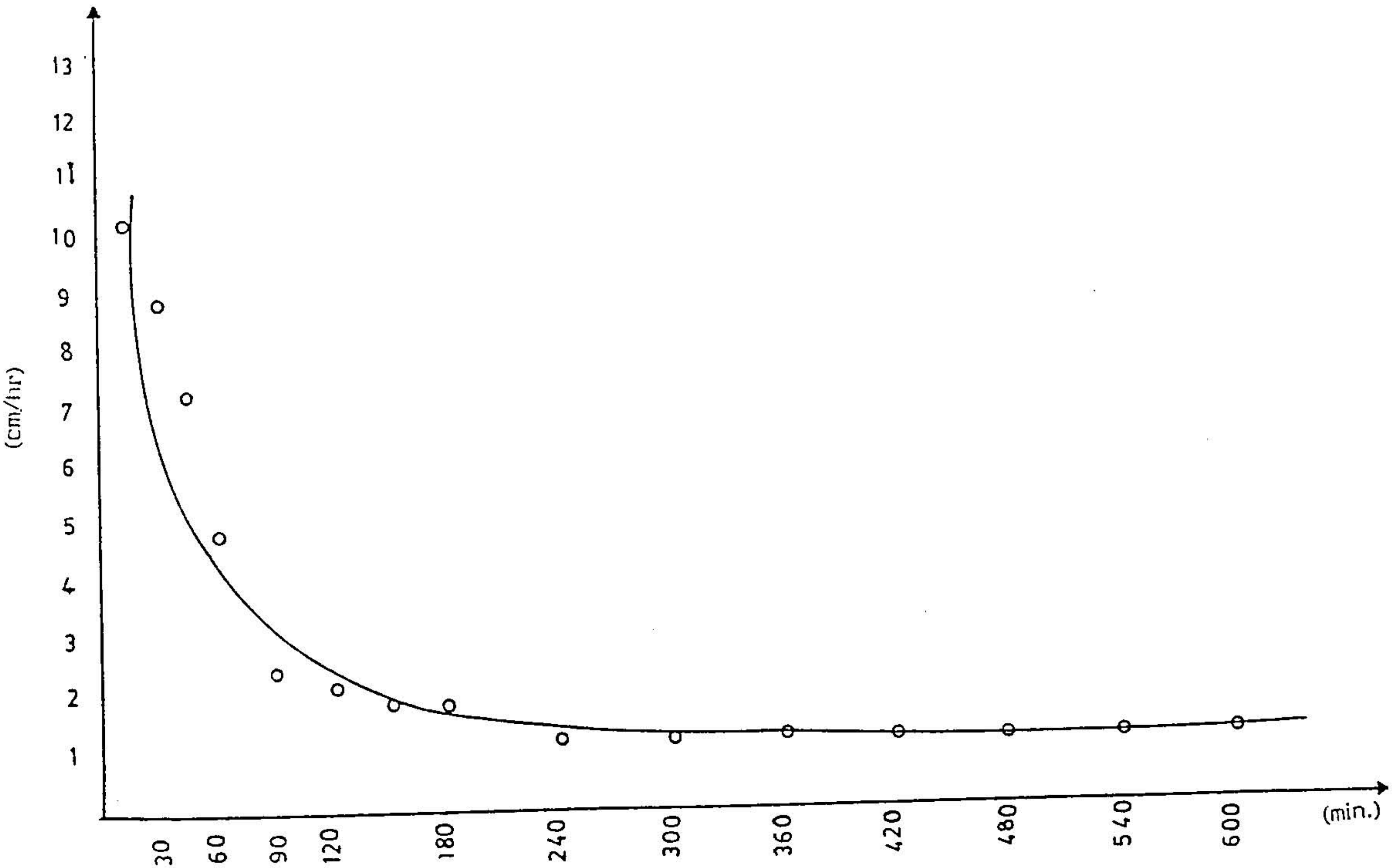


Figure 18: Infiltration rate curve before planting.

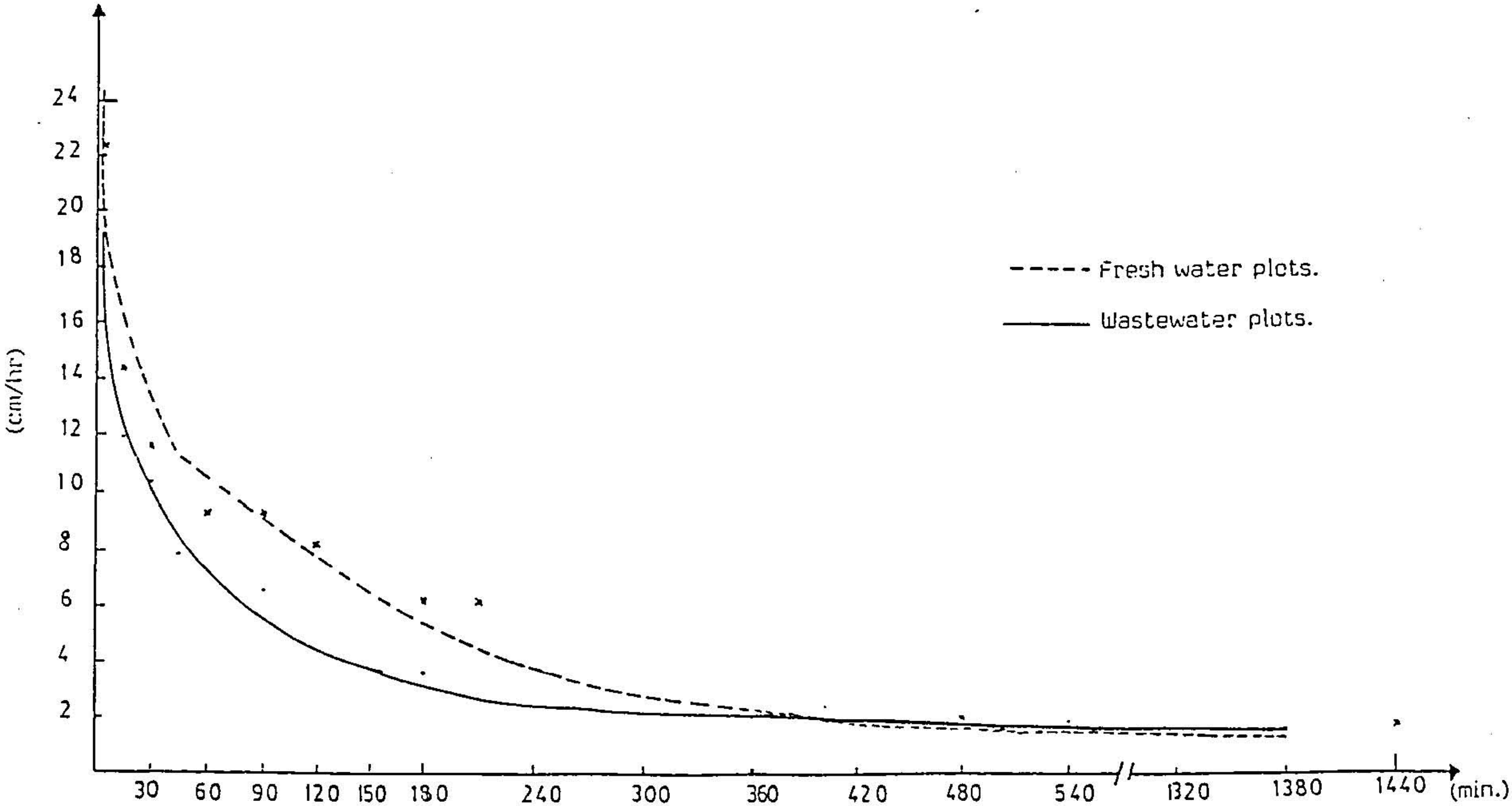


Figure 20: Infiltration rate curves in fresh water and wastewater plots after harvesting in 1986 by using sprinkler irrigation system.

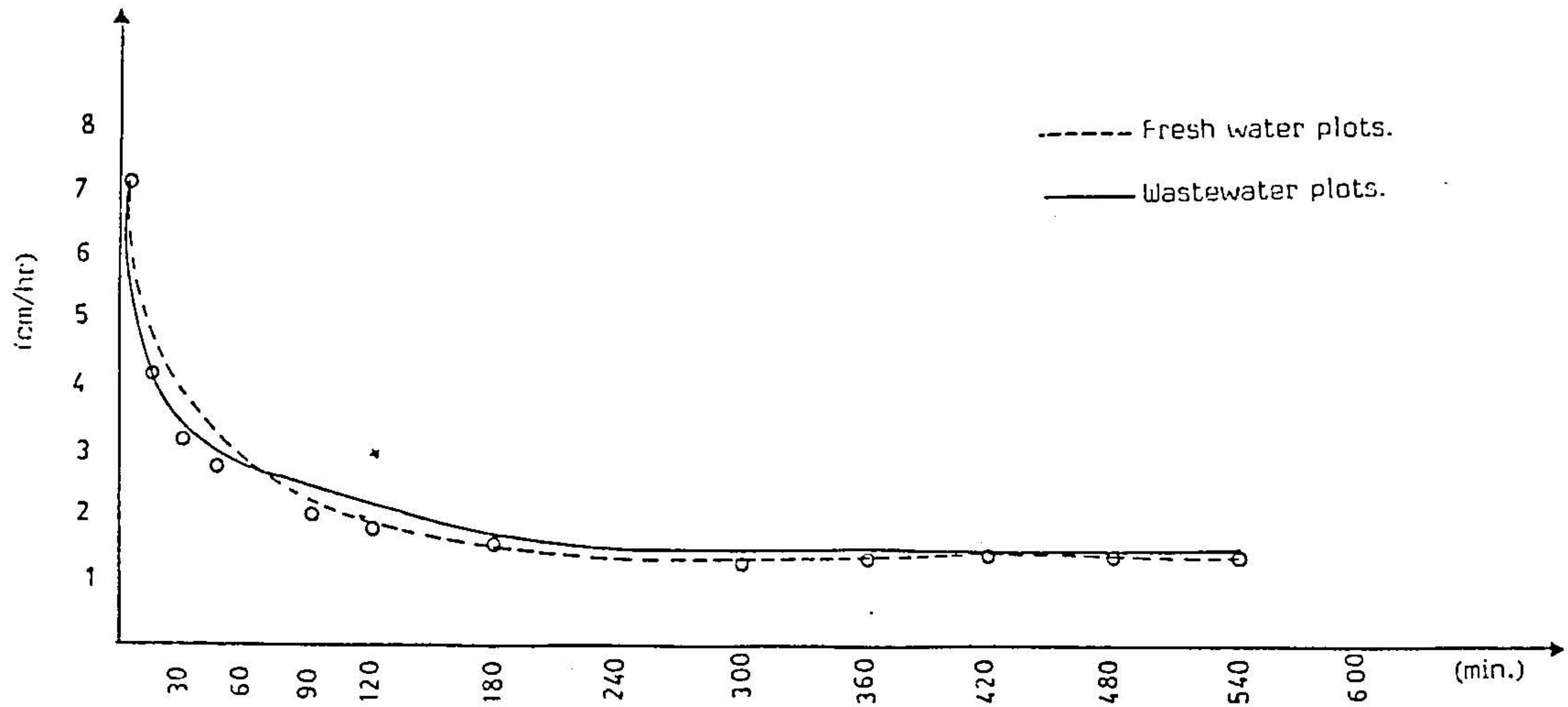


Figure 21: Infiltration rate in fresh water and wastewater plots after harvesting in 1985 by using drip irrigation system.

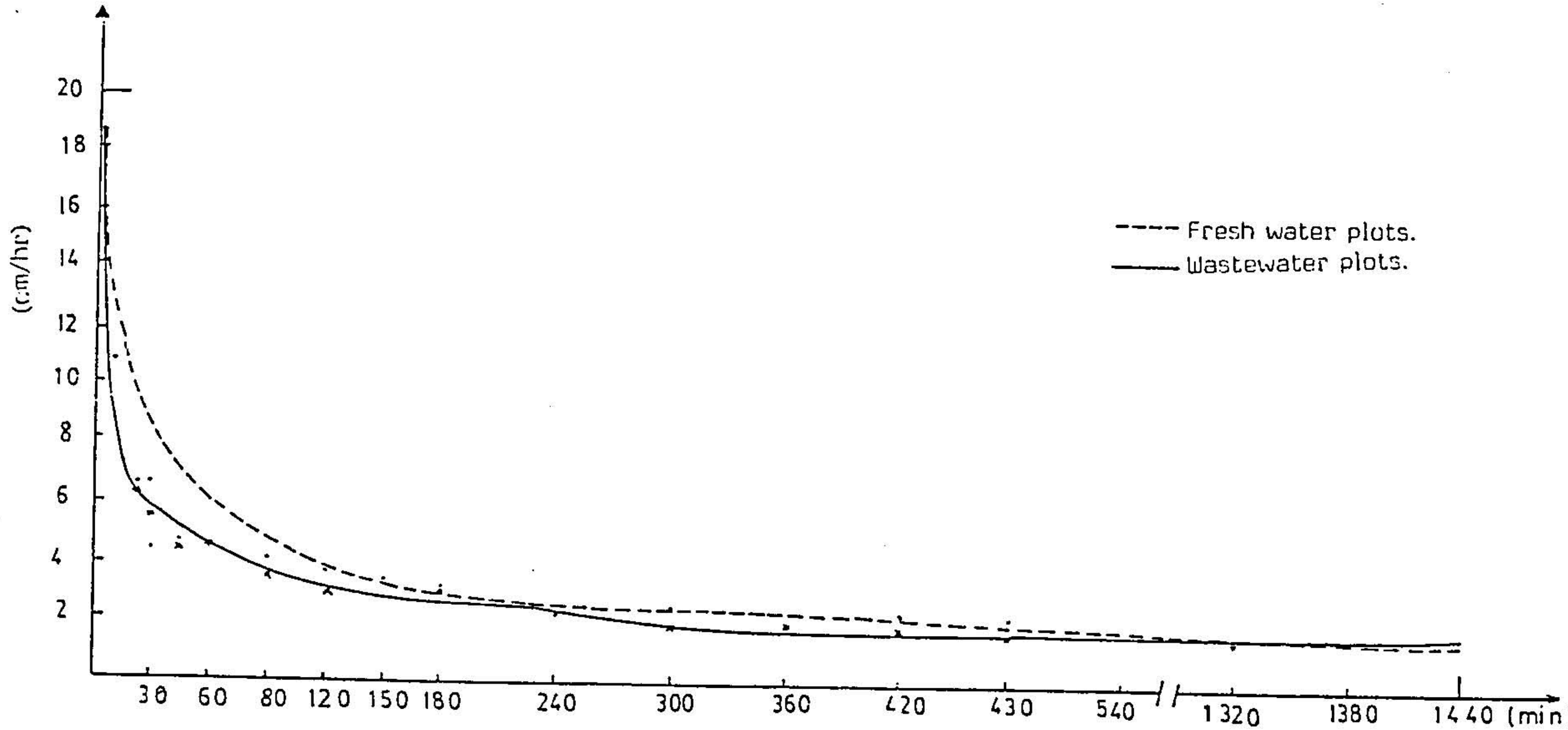


Figure 22: Infiltration rate curves in fresh water and wastewater plots after harvesting in 1986 by using drip irrigation system.

In general, the infiltration rate increased after planting. This is probably due to the tillage of the soil and the growth of the roots. In 1985, the final infiltration rate values were 1.31 and 1.33cm/hr for fresh water and wastewater plots, respectively under sprinkler experiment, while those under drip experiment were 1.44 and 1.5cm/hr. In 1986, on other hand the final infiltration rate values were 1.65 and 1.8cm/hr for fresh water and wastewater plots, respectively under sprinkler, while those under drip experiment were 1.7 and 1.73cm/hr.

4.7 Effect of Treated Wastewater on Emitter Clogging:

The lines in figures 24 and 25 represent the reduction in flow rate through emitters along the laterals of drip system for the middle and the end of the season, respectively.

In both figures the reduction values for the wastewater site was slightly higher than those for the fresh water site but were not significantly different. Those differences might be due to the deposition of some elements which are present in the water.

The linear regression equations resulted from each line of each figure were as follows:

1- For the mid-season case:

   a- Fresh water treatment:-

   $$\Delta q = -\ 0.02154\ N + 4.3681\ ,\quad r^2 = 0.77$$

   b- Wastewater treatment:-

   $$\Delta q = -\ 0.0464\ N + 5.8622\ ,\quad r^2 = 0.73$$

2- For the end season case:-

   a- Fresh water treatment:-

   $$\Delta q = -\ 0.05355\ N + 6.29952\ ,\quad r^2 = 0.86$$

   b- Wastewater treatment:-

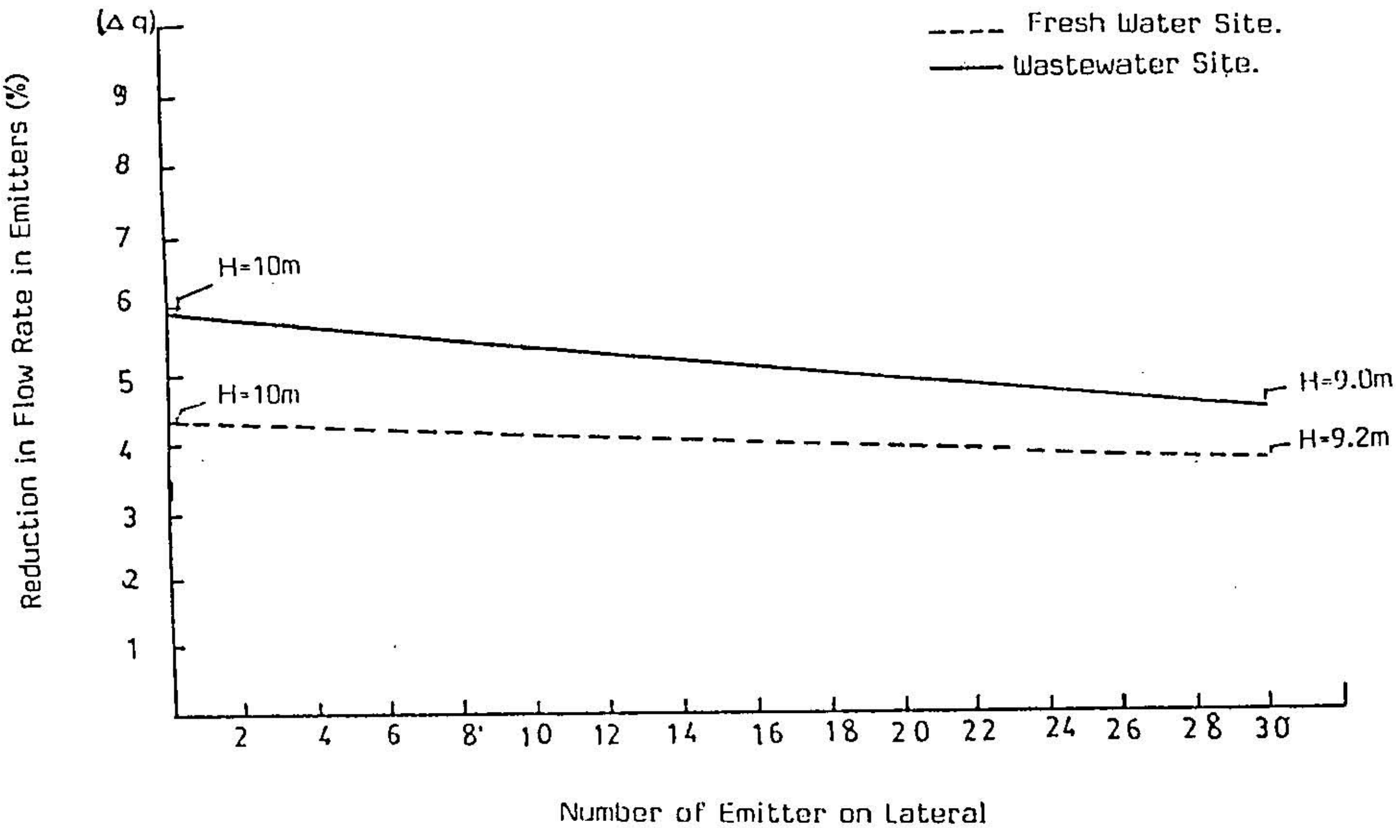
   $$\Delta q = -\ 0.01788\ N + 6.99701\ ,\quad r^2 = 0.71$$

Where:-

Δq = reduction in flow rate through emitters.

N = number of emitters.

r^2 = regression coefficient.



gure 24: Effect of pressure head and location of emitter on reduction of flow rate applying fresh water and wastewater in mid. season of 1986.

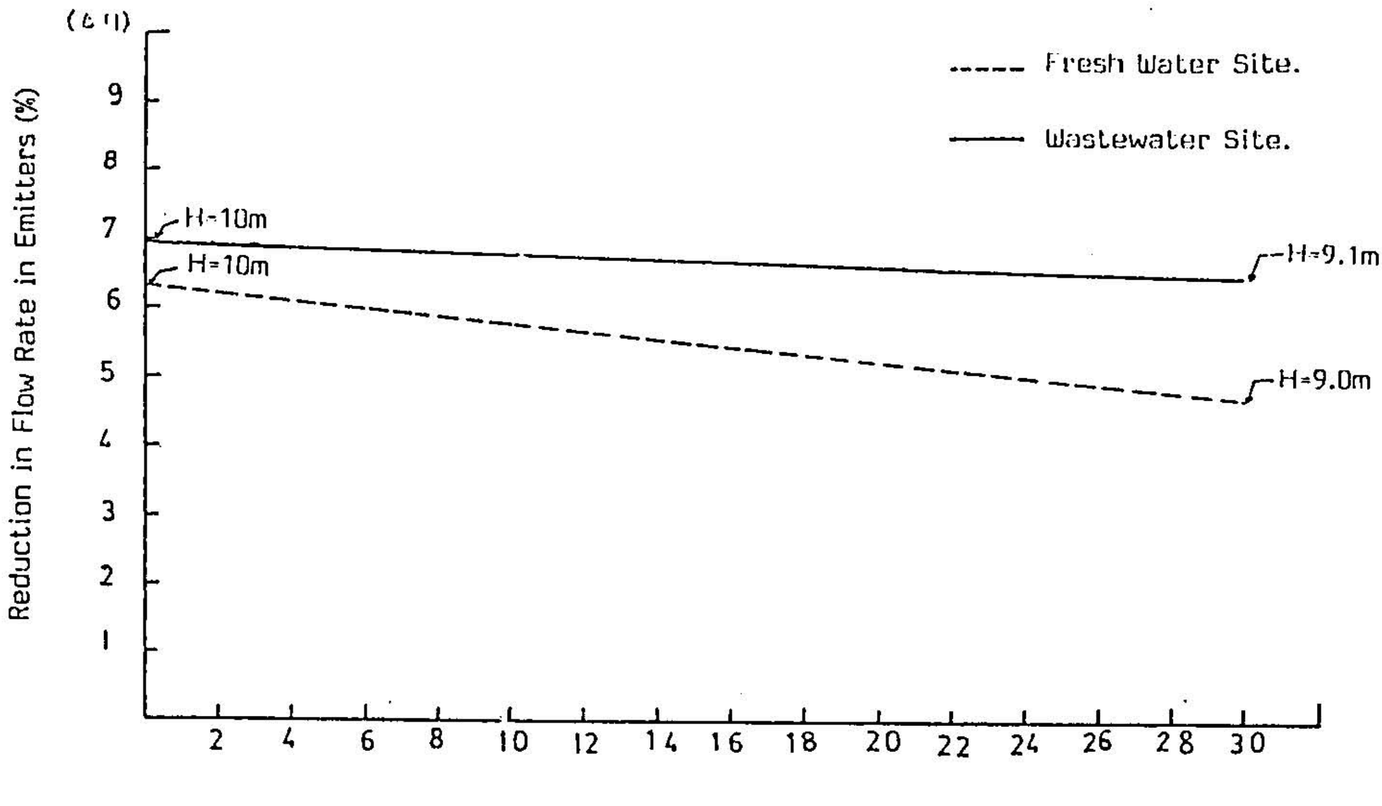


Figure 25: Effect of pressure head and location of emitter on reduction of flow rate applying fresh water and wastewater in end season of 1986.

SUMMARY AND CONCLUSIONS

Experiments were conducted for a two-year period (1985 and 1986) at a land part of sewage treatment plant area at Queen Alia' International Air-port in Jordan to investigate the effect of treated wastewater on :

1- Corn plant yield components.
2- Changes in some soil physical properties.
3- Emitters clogging of drip irrigation system.

Two different experiments were conducted by using :

1- Sprinkler irrigation system. This experiment consisted of three replications for each treatment in a randomized complete block design.
2- Drip irrigation system. This experiment consisted of four replications for each treatment in a randomized complete block design.

Undisturbed soil sample cores (aluminum cylender 4.2cm long and 4.8cm in diameter) were taken from each plot of both experiments at depths of 0-30cm, 30-60cm, and 60-90cm in order to determine bulk density and water-retention characteristic curves.

Disturbed soil samples were taken by augar from each plot of both experiments at the same depths as above in order to determine the chemical and other physical properties.

Two wastewater and fresh water samples were taken weekly during irrigation in order to have them analysed.

Results indicated that the corn yield components increased slightly due to irrigation with treated wastewater in both sprinkler and drip experiments for two years. Stover yield and ear length were significantly higher in plants treated with wastewater than that irrigated with fresh water. This increase was due to liberation of several nutrients elements to soil solution (N, P, K, Fe, Zn) and then uptake by plants. Treated wastewater had no significant effect on water consumptive use and no change on soil physical properties (apparent specific gravity, available water, and infiltration rate). More reduction in flow rate for emitters under drip irrigation system was obtained by using wastewater rather than fresh water.

ملخــص

دراسة تأثير المياه العادمه المكرره على محصول الذره وعلى بعض الخواص الفيزيائيه للتربــه

يعتبر الماء من العوامل المحدده للتطور الزراعي في المناطق الجافه وشبه الجافه كالاردن ، ومع ازدياد الاستهلاك المائي في الاغراض البشريه والصناعيه فان مشكلة نقص المياه سوف تتفاقم مع مرور الزمن ، لذا لا بد من الاهتمام لايجاد مصادر مائيه جديده لتعويض النقص المتوقع حدوثه في المستقبل . ومن المصادر الهامه التي يجب استغلالها المياه العادمه المكرره . ولكن قبل استخدام هذه المياه للاغراض الزراعيه لا بد من دراسة مدى صلاحيتها لذلك.

لقد تم اجراء هذه الدراسه على مساحه من الأرض قرب محطة تنقية مطار الملكه علياء في منطقة زيزياء لمعرفة تأثير المياه العادمة المكرره على محصول الذره وعلى بعض الخواص الفيزيائيه للتربه باستعمال نظامي رى ، بالتنقيط والرشاشات ، خلال موسمي سنة ١٩٨٥ و ١٩٨٦م وقد صممت التجارب تصميما عشوائيا كاملا.

ودلت النتائج ان هناك زياده طفيفه في انتاج محصول الذره الذى روى بالمياه العادمه المكرره مقارنة بالمياه العاديه وذلك في الموسمين وتحت نظامي الرى بالرشاشات والتنقيط . كما وجد أن هناك زياده معنويه بالانتاج الخضرى عند استخدام المياه العادمه بغض النظر عن طريقة الرى . كما ظهرت زيادة معنويه في طول الكوز بعد السنه الثانيه من استخدام المياه العادمه المكرره تحت نظام الرى بالتنقيط. وتعزى هذه الزياده في الاستجابات الى زيادة توفر العناصر الغذائيه التي أضيفت للتربه مع المياه العادمه المكرره مثل النيتروجين ، الفسفور ، البوتاسيوم ، الحديد ، والزنك التي امتصها النبات . أما كمية المياه المستهلكه والخواص الفيزيائيه للتربه (الكثافه الظاهريه ، معدل الرشح ، كمية المياه المتاحه للنبات) فلم يطرأ عليها أى تغيير ملحوظ عند استخدام المياه العادمه المكرره . وقد لوحظ أن معدل تصريف النقاطات في نظام الرى بالتنقيط قد تدنى عند استخدام المياه العادمه المكرره لوجود مواد عالقه .

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Appendix 1 : Climatic data, for the period from April to July, 1986 including maximum and minimum air temperatures, relative humidity, rainfull, wind speed, and evaporation at queen Alia' international air-port.

Date	Air Temperature°c		Relative humidity (%)	Rainfall (mm)	Wind speed (m/s)	Class A pan evaporation (mm)
	maximum	minimum				
1/4	19.3	7.5	80	2.3	2.32	4.0
2/4	14.9	8.0	86		5.41	1.0
3/4	18.3	8.0	85		3.09	2.0
4/4	23.5	7.1	73		1.65	4.0
5/4	26.8	11.4	41		4.64	10.0
6/4	28.8	13.5	37		4.89	14.0
7/4	26.8	9.8	47	Tr.	7.21	9.0
8/4	22.0	12.5	70	1.2	3.09	5.0
9/4	22.3	11.0	76		3.71	4.0
10/4	23.0	7.4	62		2.83	6.0
11/4	26.2	6.0	48		3.61	9.0
12/4	28.8	9.2	37		3.35	9.0
13/4	30.6	11.2	29		6.18	14.0
14/4	26.8	13.6	33		0.52	8.0
15/4	22.5	8.5	64		6.70	3.0
16/4	21.0	5.2	61		4.38	4.0
17/4	29.2	8.8	43		3.61	8.0
18/4	28.8	10.0	30		4.12	7.0
19/4	28.0	12.4	37		5.15	14.0
20/4	29.4	12.6	30		5.15	16.0
21/4	30.8	15.5	34		4.12	11.0
22/4	21.8	8.3	62		3.86	7.0
23/4	25.6	2.8	58		2.83	7.0
24/4	28.1	6.0	41		4.64	18.0
25/4	29.0	15.4	37		6.05	13.0
26/4	20.0	13.5	63	Tr.	4.64	8.0

Date	Air Temperature°c		Relative humidity (%)	Rainfall (mm)	Wind speed (m/s)	Class A pan evaporation (mm)
	maximum	minimum				
27/4	28.0	13.5	46		4.64	10.0
28/4	28.8	9.0	43		3.35	10.0
29/4	29.4	9.7	39		2.06	10.0
30/4	25.5	10.0	57		5.41	6.0
1/5	24.5	7.5	62	1.0	2.83	8.0
2/5	25.5	4.1	54	0.8	4.64	10.0
3/5	17.0	10.0	87	3.2	6.95	2.0
4/5	19.2	9.0	83		6.18	3.0
5/5	22.8	5.1	70		2.32	5.0
6/5	27.5	8.4	47		1.55	10.0
7/5	30.4	11.0	33		1.03	18.0
8/5	24.6	12.5	51		7.21	8.0
9/5	22.0	9.5	66		3.86	7.0
10/5	21.6	8.3	66		5.67	5.0
11/5	21.0	3.6	58		2.58	7.0
12/5	22.4	7.0	62	Tr.	3.86	4.0
13/5	21.8	7.2	65		6.18	8.0
14/5	21.8	6.6	62		6.18	7.0
15/5	21.0	5.6	67		3.35	6.0
16/5	21.8	4.0	66		2.58	6.0
17/5	25.2	5.5	50		2.06	7.0
18/5	30.0	7.4	48		2.32	12.0
19/5	31.4	11.6	54		3.86	8.0
20/5	27.2	10.0	56		3.35	9.0
21/5	24.6	10.0	48		5.15	10.0
22/5	25.4	8.5	49		1.80	10.0
23/5	26.1	8.6	48		4.12	9.0
24/5	24.5	8.4	55		3.85	8.0
25/5	28.4	8.1	43		1.29	9.0
26/5	30.2	10.2	47		3.09	10.0
27/5	28.1	9.5	59		2.32	8.0
28/5	27.0	10.5	61		5.41	10.0
29/5	26.0	9.2	60		4.64	8.0
30/5	26.0	7.2	48		3.09	10.0

Date	Air Temperature°c		Relative humidity (%)	Rainfall (mm)	Wind speed (m/s)	Class A pan evaporation (mm)
	maximum	minimum				
31/5	28.5	6.9	51		2.58	9.0
1/6	32.8	9.3	41		2.70	18.0
2/6	36.6	19.0	38		4.64	15.0
3/6	32.2	13.8	49		2.32	7.0
4/6	30.0	11.2	39		5.02	15.0
5/6	28.2	13.2	51		5.15	10.0
6/6	31.1	12.0	42		2.58	12.0
7/6	33.0	14.0	34		3.61	15.0
8/6	33.6	15.0	37		2.97	15.0
9/6	32.5	15.4	39		4.51	15.0
10/6	33.5	15.4	40		1.29	16.0
11/6	32.0	15.3	50		6.95	12.0
12/6	25.9	14.2	70		4.51	9.0
13/6	26.6	12.2	68		4.38	6.0
14/6	28.5	12.5	60		5.67	6.0
15/6	29.6	11.9	56		4.25	9.0
16/6	29.6	13.5	47		3.86	11.0
17/6	31.9	12.8	48		2.83	13.0
18/6	29.8	12.2	53		3.35	10.0
19/6	30.0	14.9	49		5.15	11.0
20/6	30.3	12.7	55		2.93	12.0
21/6	31.0	11.6	53		3.09	11.0
22/6	31.4	10.4	45		2.83	11.0
23/6	30.6	10.5	46		3.35	11.0
24/6	23.1	14.0	65		8.24	6.0
25/6	31.4	10.6	54		3.09	8.0
26/6	31.0	14.6	52		4.51	10.0
27/6	29.5	16.0	56		5.67	12.0
28/6	28.2	14.0	47		5.41	10.0
29/6	26.7	10.0	61		4.12	9.0
30/6	28.0	11.4	55		5.41	8.0

Date	Air Temperature°c		Relative humidity (%)	Rainfall (mm)	Wind speed (m/s)	Class A pan evaporation (mm)
	maximum	minimum				
1/7	28.6	9.5	59		2.83	7.0
2/7	30.6	9.3	58		2.06	11.0
3/7	31.4	11.8	38		4.89	13.0
4/7	30.5	11.3	43		5.15	11.0
5/7	30.3	10.0	56		4.64	9.0
6/7	30.4	10.0	61		3.09	10.0
7/7	29.6	9.8	59		5.15	10.0
8/7	30.0	12.8	66		5.67	11.0
9/7	31.5	12.0	52		2.58	11.0
10/7	32.7	11.2	48		3.09	13.0
11/7	31.3	12.6	51		3.86	10.0
12/7	32.2	12.5	49		4.89	12.0
13/7	30.6	13.7	62		3.86	9.0
14/7	32.8	11.4	55		2.58	12.0
15/7	37.6	14.4	43		2.32	14.0
16/7	36.1	15.7	42		4.64	15.0
17/7	35.0	17.5	38		4.89	15.0
18/7	37.5	16.5	39		3.35	16.0
19/7	34.0	19.0	37		6.18	15.0
20/7	30.8	16.5	66		5.15	8.0
21/7	34.5	12.4	56		3.09	10.0
22/7	34.4	14.9	53		3.86	10.0
23/7	33.5	15.5	44		6.18	13.0
24/7	30.7	16.0	63		5.67	6.0
25/7	32.1	11.6	60		5.41	11.0
26/7	33.9	17.2	41		5.92	13.0
27/7	35.2	14.0	44		3.09	12.0
28/7	34.2	14.4	35		5.15	14.0
29/7	31.6	11.0	47		5.15	11.0
30/7	31.5	14.66	62		4.64	10.0
31/7	32.6	14.4	53		3.09	11.0

Appendix 2: Depth (mm) and dates of actual water applied by sprinkler irrigation, and number of irrigations, N, for fresh water and wastewater sites on sweet corn in 1985.

Date	Fresh water site Depth (mm)	Wastewater site Depth (mm)
1/5	10	10
2/5	15	15
8/5	20	20
10/5	10	10
14/5	15	15
18/5	15	15
21/5	15	15
25/5	15	15
28/5	15	15
1/6	15	15
5/6	20	20
8/6	20	20
12/6	20	20
15/6	20-	20
19/6	20	20
22/6	20	20
26/6	20	20
29/6	20	20
3/7	22.5	22.5
6/7	22.5	22.5
10/7	22.5	22.5
13/7	22.5	22.5
17/7	22.5	22.5
20/7	22.5	22.5
24/7	22,5	22.5
27/7	22.5	22.5

Date	Fresh water site Depth (mm)	Wastewater site Depth (mm)
31/7	22.5	22.5
3/8	25	25
7/8	25	25
10/8	25	25
14/8	25	25
17/8	25	25
21/8	25	25
24/8	25	25
28/8	25	25
31/8	25	25
4/9	25	25
7/9	25	25
11/9	25	25
14/9	25	25
Total	832.5	832.5
N	40	40

5/7	24	24
8/7	24	24
12/7	24	24
15/7	24	24
19/7	24	24
22/7	24	24
26/7	24	24
29/7	24	24

Date	Fresh water site Depth (mm)	Wastewater site Depth (mm)
2/8	24	24
5/8	24	24
9/8	24	24
12/8	24	24
16/8	24	24
19/8	24	24
23/8	24	24
26/8	24	24
30/8	24	24
2/9	18	18
6/9	18	18
Total	798	798
N	37	37

Appendix 4: Depth (mm) and dates of actual water applied by sprinkler irrigation, and number of irrigations, N, for fresh water and wastewater sites, on sweet corn in 1986 season.

	Fresh water site			Wastewater site		
Block	B1	B2	B3	B1	B2	B3
Date	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)
26/3	25	25	25	25	25	25
27/3	25	25	25	25	25	25
28/3	30	30	30	30	30	30
5/4	10	10	10	10	10	10
9/4	10	10	10	10	10	10
12/4	10	10	10	10	10	10
16/4	10	10	10	10	10	10
19/4	10	10	10	10	10	10
23/4	15	15	15	15	15	15
26/4	15	15	15	15	15	15
30/4	15	15	15	15	15	15
3/5	15	15	15	15	15	15
7/5	17.5	15.5	19.5	15	15.5	18.5
12/5	15.0	16.5	12.5	12	12.70	15.7
17/5	23.0	26.0	22.6	23.0	23.30	24.0
21/5	23/5	26.8	21.7	22.6	23.5	23.0
26/5	26.5	20.9	22.7	24.5	26.3	21.5
31/5	27.2	27.7	21.0	26.0	30.0	21.6
4/66	30.0	33.0	32.0	37.5	27	29.5
9/6	26.1	32.1	27.2	32.2	27.2	27.2
14/6	32.6	33.0	28.0	28.7	32.7	32.2
18/6	36.1	32.2	30.6	31.2	36.7	32.2
21/6	39.1	37.2	36.2	37.5	41.7	37.2
25/6	36.0	40.1	37.2	38.5	36.5	40.2
28/6	35.7	42.5	42.1	37.8	39.0	41.4

Appendix 5: Depth (mm) and dates of actual water applied by drip irrigation, and number of irrigations, N, for fresh- and wastewater site during 1986 season.

	Fresh water site				Wastewater site			
Block	B1	B2	B3	B4	B1	B2	B3	B4
Date	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)	Depth (mm)
26/3	24	24	24	24	24	24	24	24
27/3	24	24	24	24	24	24	24	24
28/3	24	24	24	24	24	24	24	24
5/4	6	6	6	6	6	6	6	6
9/4	6	6	6	6	6	6	6	6
12/4	6	6	6	6	6	6	6	6
16/4	9	9	9	9	9	9	9	9
23/4	9	9	9	9	9	9	9	9
26/4	9	9	9	9	9	9	9	9
28/4	6	6	6	6	6	6	6	6
29/4	6	6	6	6	6	6	6	6
30/4	6	6	6	6	6	6	6	6
3/5	15	15	15	15	15	15	15	15
7/5	18	18	18	18	18	18	18	18
13/5	18	18	18	18	18	18	18	18
19/5	19.0	19.9	21.7	17.2	18.2	16.9	20.7	17.4
24/5	26.8	27.1	24.0	23.6	22.3	24.9	26.5	18.6
28/5	24.2	28.8	24.4	23.6	25.2	25.1	23.8	21.7
2/6	31.6	28.8	31.5	29.5	32.5	28.5	28.0	26.5
7/6	39.0	36.0	32.5	36.5	37.3	35.2	33.9	41.3
12/6	40.4	42.9	39.2	39.7	40.5	36.9	33.8	39.1
18/6	23.4	24.0	26.2	30.7	23.9	29.5	31.8	34.3
22/6	31.5	27.0	31.9	37.0	27.3	32.0	33.8	29.7
26/6	34.8	31.0	25.3	31.0	32.3	27.0	33.7	28.9

1/7	37.5	44.9	43.2	44.0	39.5	40.7	36.2	36.5
7/7	48.6	47.5	43.0	42.0	41.0	53.0	50.8	45.0
13/7	60.2	59.7	54.2	58.4	54.4	60.2	56.6	58.9
19/7	55.7	56.9	51.0	53.5	55.7	57.3	51.1	60.4
23/7	50.7	56.9	55.2	54.5	50.8	47.1	56.7	56.6
Total	709.4	717.4	689.3	707.2	686.9	700.3	704.0	700.9
N	29	29	29	29	29	29	29	29