IRRIGATION SCHEDULING OF SQUASH UNDER DRIP IRRIGATION AND BLACK PLASTIC MULCH IN THE CENTRAL JORDAN VALLEY.

BY
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TO MY MOTHER,
FATHER,
AND
BROTHER

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IRRIGATION SCHEDULING OF SQUASH UNDER DRIP IRRIGATION AND BLACK PLASTIC MULCH IN THE CENTRAL JORDAN VALLEY

ABSTRACT

The objectives of this research were to study the effect of three irrigation schedules at 30, 50, and 80 kPa soil moisture tensions of squash (Cucurbita pepo l.) under drip and black plastic mulch on water requirements, yields, and root growth and distribution during the winter and spring seasons of 1985-1986. Another objective was to test the crop yield and soil water management simulation model (CRPSM) developed at Utah State University (Hill et al., 1984a and 1984b) and modified later on for squash by Battikhi and Hill (1986a) in order to find out if it can be used to predict yields and to select possible irrigation schedules that will maximize yield and optimize water use efficiency.

Results showed no significant differences between the three treatments for both seasons in respect to yield, total water supplied, irrigation amounts, application water efficiency, water use efficiency, vertical root length, horizontal root length, and oven-dry root weight. The plants under the 30, 50, and 80 kPa treatments consumed average water amounts of 12.79, 12.75, and 12.44 cm, respectively, during the winter season to produce average yields of 19.4, 21.6, and 22.0

t/ha, respectively. On the other hand, during the spring season the plants consumed average water amounts of 15.18, 13.98, and 14.97 cm to produce average yields of 8.6, 7.4, and 7.6 t/ha for the three respective treatments. Average water use efficiencies for the 30, 50, and 80 kPa treatments were 1.58, 1.79, and 1.88 t/ha/cm, respectively, for the winter season, and 0.56, 0.58, and 0.51 t/ha/cm, respectively, for the spring season.

Number of irrigations was significantly lower in the 80 kPa treatment when compared to the 30 kPa treatment during the winter season. During the spring season significant differences in the number of irrigations were revealed between the 30 and 50 kPa and the 30 and 80 kPa treatments.

Recalibration of the yield portion of the CRPSM for squash for both season resulted in new sets of growth stage weighing factors (lambdas) and maximum field attainable yields. Better calibration was obtained during the winter season due to disease and temperature effects during the spring season. The different water management options provided by the model were tested to select the best irrigation schedules that will maximize yields and optimize water use efficiency and cut down field trials to be tested in future studies, therefore lowers costs and time to be spent on such studies.

INTRODUCTION

Drip irrigation systems along with other advanced technologies, such as plastic mulches, were introduced into Jordan to improve agricultural production. Jordan Valley, the center of irrigated agriculture in Jordan has witnessed extensive vegetable production for the last decade. Farmers tend to produce more tomatoes and squash than other vegetable crops due to their high and fast money return.

Water scarcity, in amounts and distribution, is one of the most limiting factors in agricultural production. In Jordan, the total estimated amount of potentially available water by the year 2000 is about 1180 million cubic meters (MCM), of which about 850 MCM will be used for agriculture, and 230 MCM for industrial and municipal purposes (National Water Master Plan of Jordan, 1977).

Due to the low cost of surface water in the Jordan Valley, farmers use it inefficiently. Three factors comprise the problem of water reallocation in the agricultural sector, these are: water scarcity, poor maintenance and operation of the irrigation system, and the low water application efficiency as practiced by farmers. Farmers tend to apply more water than what is really needed. Shatanawi (1986a) reported that water application efficiency for squash, under trickle irrigation in the Jordan Valley, was about 52.5 % only.

The ultimate objectives of irrigation scheduling are to determine the amounts and intervals of water application. Different alternative methods, based on plant observations, soil conditions, and climatic conditions exist when trying to schedule irrigation. Good irrigation schedules require the integration of the above mentioned factors, thus extensive experience on the part of irrigation engineer is required to identify the optimum choices. Such scheduling is important in desicions related to maximizing yields especially in areas where irrigation water supplies are limited. A proper irrigation schedule will provide plants with their water requirements at the time needed and with minimum water losses.

Field research is expensive and time consuming. The use of models have made the use of existing climatic data, soil data, and crop phenological data in research for predicting yields. Existing models can be further developed and modified to meet local conditions and later on to be used by farmers for selecting appropriate irrigation schedules to optimize crop yields.

A study was carried out in the Research Station of the University of Jordan located in the central region of the Jordan Valley during the winter season (December 8, 1985 - April 1, 1986) and the spring season (April 15, 1986 - June 13, 1986) with the objectives of:

1) studying the effect of three different irrigation schedules based on soil moisture tensions of 30, 50, and 80 kPa which are equivalent to 39, 50, and 64 % soil moisture

depletions under black plastic mulch and drip irrigation on the water requirements, root growth and distribution, and yield of squash (Cucurbita pepo l.), and

2) testing the crop yield and soil water management simulation model (CRPSM) modified by Battikhi and Hill (1986a) for squash in the Jordan Valley in predicting yields under the applied field schedules and to select possible irrigation schedules that will optimize yields and optimize water use efficiency.

2-LITERATURE REVIEW

2.1 BACKGROUND ON VEGETABLE PRODUCTION IN THE JORDAN VALLEY

Jordan Valley, the major area of vegetable production in Jordan, has witnessed extensive agricultural development since late 1970's and early 1980's. Drip irrigation systems, plastic houses, plastic mulches, pesticides, hybrid seeds, and fertilizers are used extensively in the valley. Adoptation of advanced technology along with favorable climatic conditions encouraged farmers to plant and produce vegetables, such as squash and tomato, more than other crops. Later on, economic problems had risen due to bad marketing, both in the internal and the external markets. This problem caused a severe drop in the prices of vegetables creating economical crises to many farmers. Therefore, the government role in regulating production by the introduction of a cropping pattern is necessary for the welfare of both farmer and the country.

2.2 USE OF PLASTIC MULCHES

The advantages of using plastic mulches over non-mulch have been studied extensively for different crops in Jordan and other countries. Results showed that equal or lower amounts of water were consumed by plants under mulch, as compared to bare soil, to produce higher yields.

Battikhi and Ghawi (1986a and 1986b) and Ghawi and Battikhi (1986a and 1986b) working on squash, cantaloupe, cucumber, and watermelon in the Jordan Valley, studied the effects of different mulching (transparent, black, and no mulch) under drip irrigation on yields, soil temperature, crop water requirements, and root growth and distribution. The four crops showed no significant differences between transparent, black, and non-mulched treatments with respect to total water supplied, deep percolation losses, and water consumption by plants. Root mass and distribution, horizontally and vertically were also non-significantly different between treatments. Yields were significantly different among the different treatments tested. In the cases of squash, cucumber, and cantaloupe no significant differences in terms of yield were obtained between transparent and black mulches (Squash: 25.9 and 18.0 t/ha, respectively. Cucumber: 7.9 and 11.9 t/ha, respectively. Cantaloupe: 14.2 and 28.7 t/ha, respectively). But yields under both transparent and black mulches were significantly different from those obtained under the non-mulched treatment. Yields of 11.8, 1.7, and 6.0 t/ha were obtained under non-mulched conditions for squash, cucumber, and cantaloupe crops, respectively. On the other hand, watermelon yields were significantly different between the transparent mulch treatment on one hand and the black and non-mulched treatment on the other hand. Yields were 55.3, 13.3, and 10.4 t/ha for the three treatments, respectively. The non-difference in ET between the mulched and non-mulched treatments was probably due to more transpiration in mulched crops and more evaporation in non-mulched crops.

Bhella and Kwolek (1984) evaluated the response of hybrid summer squash (<u>Cucurbita</u> <u>pepo</u> l.) to trickle irrigation and black mulch in field studies. They found out that trickle irrigation and plastic mulch increased plant growth, early bloom, and yield.

Fifty percent reduction in water losses by evaporation in a soybean field using clear plastic mulch was reported by Peters and Johnson (1962). Cotton consumptive use was reduced by 11.6 and 15.3 cm in two consecutive years using black mulches (Bennett et al., 1966).

2.3 DEPLETIONS AND IRRIGATION SCHEDULING

Irrigation specialists are always faced with two questions; when to irrigate? and how much water to apply? These two questions, although seem very easy, yet no simple answers seem logical and available, considering the variations in soils and root and plant growth.

Stanhill (1957) reported that Veihmeyer (1927) in his
sical work on decidious orchards, showed that it was
ble to maintain a constant soil-moisure status around
ts of a transpiring crop. The problem had been
ted in term of degree in depletion of available soil
that could be tolerated by a crop without adverse
on yield. Many workers attempted to determine this for
crops by conducting the so-called "soil-moisture-regime

experiments." A soil-moisture regime is defined as an irrigation treatment in which the soil is allowed to dry until a definite measured point is reached within the available water range before sufficient water is applied to restore the entire root zone to field capacity. Stanhill (1957) found that in 80 per cent of the experiments done in this field of research, growth was affected by differences in the amount of available water depleted before the soil was re-wetted.

A lot of diversity exists in the results obtained in the literature. Some say that it is better to correlate yield with plant water stress, others insist on available water depletion term. Still in all approaches a lot of contradictions seem to appear. For example, Halevy (1972) found that the best way to determine the frequency of watering should not be made by following changes in soil water, but by directly determining the plant water stress in relation to the desired yield.

Smittle and Threadgill (1982) studied the response of squash to irrigation, nitrogen fertilization, and tillage systems. Results of their study showed that the greatest squash yield resulted from moldboard plow tillage, application of 22.5 Kg N/ha through the irrigation system at 2, 3, 4, 5, and 6 weeks from planting, and maintaining the soil water tension below 0.3 bar throughout the growing season. Yields were reduced by 3% to 16% by changing either tillage method, N fertilization, or irrigation.

An approach done by Gregory and Schottman (1982) of using an irrigation scheduling chart developed by Woodruff as modified to use Blaney-Criddle procedure for predicting consumptive use. It had, to that date (1982), given high yields with reduced irrigation water compared to scheduling based on measured plant water stress.

Battikhi et al. (1985) carried out a study in the Jordan Valley with the objective of scheduling irrigation of tomatoes grown inside plastic houses under drip irrigation. Three levels of soil moisture tension 30, 50, and 70 centibars, were used. They concluded that as the soil moisture tension was increased, lower amounts of water were used to obtain almost the same yield as that obtained in the lower tension treatment. No significant difference in the water use efficiency was found between the three treatments.

2.4 ROOT GROWTH AND DISTRIBUTION

Physiological activity of roots and the morphological pattern of root distribution during the growing season are the most important plant characteristics in predicting nutrient and water uptake from the soil. Soil characteristics and cultural practices influence the pattern of root distribution in field soils. One of the soil properties that can affect root development is the moisture content (Proffitt et al., 1985; Osmond and Raper, 1982; Mackay and Barber, 1985; Peacock and Dudeck, 1985).

Proffitt et al. (1985) working on wheat under high- and low-frequency irrigation found that frequency and depth of water front penetration affected root growth and produced different rooting patterns. The high-frequency treatments developed a shallower rooting system than the low-frequency treatments due to the relatively drier soil conditions at greater depths. Considering depletion from field capacity for the whole profile in the last half of the growing season, water content in the soil profile for the high-frequency treatments was kept relatively constant, but marked changes in water content were more evident in the low-frequency treatments. This was attributed to the timing of irrigation scheduling.

Relatively dry soil conditions, such as those occurring in the upper layers of the low-frequency treatments, induce plants to develop a more extensive root system if favorable conditions (i.e., high water content) exist at greater depths (Abdul-Jabbar et al., 1982).

Tayler and Klepper (1971) working with cotton, reported that water extraction became proportionaly less in the upper (dry) layers and greater in the deeper layers as the water content (and hence hydraulic conductivities) of the surface soil layers decreased. Water can, for example, move from one depth to another independent of plant root extraction. However, Molz and Remson (1971) found that water extraction by plant roots was dominant over Darcian flow in the root zone, with this dominance increasing as water content decreased.

Battikhi and Ghawi (1986a) working on squash under trickle irrigation and plastic mulch in the Jordan Valley found that roots extended 23.0, 20.4, and 18.8 cm vertically and 65.6, 52.1, and 56.6 cm horizontally (radius) for transparent, black, and non-mulched treatments, respectively. Dry root weight averaged 4.7, 3.6, and 3.2 gm/plant for the three respective treatments. No significant differences were found in the root weight and distribution between treatments. Irrigation was carried out at 30 cb tensiometer reading for all treatments.

Shatanawi (1986b) working on squash in the Jordan Valley reported that trickle irrigation encouraged the development of shallow root. A greater percentage of the total root mass was located in the upper 100 mm of the soil. Squash roots penetrated on the average to a depth of 320 mm. However, the maximum penetration of roots of some plants was 450 mm.

2.5 MODELING APPROACH

Modern agriculture has become very complex involving management of land, water, climate, and biological factors as well as socio-economic resources. The whole issue behind the modeling approach in agriculture is to take results of past research and fit it into a computer program in order to use it for future forecast. Researchers of vast expertise in their fields were the pioneers of such interdisciplinary approach. Several computer programs had been devised and modified for end users in the United States. Some of these programs are PLANTGRO, IRRIGATE-MATE, DROUGHT-MANAGER, CROP RECORDS, and FERTILIZER (Hanks et al., 1984).

Hanks (1974) developed a model for predicting yield as influenced by water use. Predicted yields were influenced by irrigation frequency and amount, rainfall, and soil water storage.

Hill et al. (1979) developed a model to predict soybean yields. Temperature and day length were used to predict the stages of development. To estimate bean production, they used the effect of soil moisture level on plant transpiration. The influence of environmental parameters on soybean growth was calculated for each stage of development which permitted effects of water management changes to be estimated for different planting dates.

Hill et al. (1984a and 1984b) concluded that the Crop Yield and Soil Water Management Simulation Model (CRPSM) had estimated yields very close to field yields when calibrated for specific site conditions of maximum observed yield and soil water management. The application of CRPSM indicates that irrigation sheduling increases profit by increasing yields. The reduction of non-ET losses (i.e., deep percolation) and the increase in water use efficiency can also be realized from efficient scheduling. The greatest benefit from irrigation scheduling appeared to be realized from improved timing of applications.

Battikhi and Hill (1986a, 1986b, 1986c, 1986d) used the CRPSM developed at Utah State University, for developing squash, cantaloupe, cucumber, and watermelon models for the Jordan Valley. The CRPSM was modified using local weather data and field results from trickle irrigation experiments. Simulated irrigation schedules were developed using the different options provided by the model.

A probabilistic model for predicting the occurrence of soil moisture deficits was presented by Rojiani et al. (1982). Using data on the amount of plant available water on each day of the growing season generated from a soil moisture balance model for a period of 50 years as input, the model predicts upper and lower bounds on the probability of occurrence of soil moisture deficits over a given period starting at any point during the growing season. Since plant water availability is a function of root development and soil water transmission characteristics, the maximum water holding capacity is used as a parameter in order to cover all soil types and plant types.

An irrigation scheduling model was developed by Geiser et al. (1982) using crop canopy-air temperature difference as the dependent variable and net radiation, relative humidity, and available soil water as independent variables. Crop yield and water use were compared with that of corn grown under irrigation scheduled by use of electrical resistance blocks and a water balance (checkbook) method. The yield of the treatment irrigated with the temperature difference scheduling approach was not significantly different from that of other treatments.

3-MATERIALS AND METHODS

3.1 LOCATION & TIME OF EXPERIMENT

The experiment was conducted at the University of Jordan Research Station, located in the central region of the Jordan Valley, for the two seasons: December 8, 1985 till April 1, 1986; and April 15, 1986 till June 13, 1986. The Station lies at 32° N latitude, 35° :30' longitude, and 300 m below sea level altitude.

3.2 IRRIGATION SYSTEM, MULCH TYPE, AND SQUASH VARIETY

A drip irrigation system was used. Emitters of 4 lph discharge (one for each plant) located 50 cm apart were placed on 13 mm (internal diameter) polyethylene laterals (one for each plant). The mulch used was black polyethylene (40 microns) and squash (Cucurbita pepo L.) variety used was "F-1 Hybrid Clairette").

3.3 PHYSICAL & CHEMICAL PROPERTIES

Prior to the beginning of the experiment, three locations representing the experimental area were selected for sampling. Undisturbed soil samples were taken from each location from the 0-30 cm and 31-60 cm layers. The soil sorption curves for the two layers were prepared using the ceramic plate extractor method (Richards, 1965) at 0.1, 0.3, 0.5, 1, 3, 5, 10, and 15 bar, tensions. Textural class and apparent specific gravity (As) were also determined for the two layers using the pipette method (Day, 1965) and core method (Taylor and Aschroft, 1972), respectively. The analyses were conducted on three samples for each layer from each location. In addition, electrical conductivity (EC) was determined using the conductivity bridge in 1:1 soil to water extracts (Bower and Wilcox, 1965). Soil reaction (pH) was measured using the pH-meter in 1:1 soil to water suspensions (Peech, 1965).

Table 1 summerizes the average results for the determined physical and chemical soil properties for the two soil layers.

3.4 TREATMENTS & EXPERIMENTAL DESIGN

Three irrigation treatments were selected. These are: T1 = irrigation when the soil moisture tension reaches 30 KPa, T2 = irrigation when the soil moisture tension reaches 50 KPa, and T3 = irrigation when the soil moisture tension reaches 80 KPa.

From the soil moisture characteristics curve (Fig. 1), T1 reflects 39% soil moisture depletion, T2 reflects 50% soil moisture depletion, and T3 reflects 64% soil moisture depletion.

The experiment layout was selected based on a randomized complete block design (Little and Hills, 1978) having each treatment replicated four times. The total experimental area was 283 square meters, divided into four blocks; each block

Table (1): Some physical and chemical soil properties of the experiment site.

Layer depth (cm)	Field* capacity (%)	Wilting* point (%)	Apparent specific gravity (As)	Sand (%)	Silt (%)	Clay (%)	Textural class	EC (dS/m)	pH
0–30	21.9	12.6	1.51	72.47	4.05	23.48	Sandy clay loam	0.74	8.1
31–60	19.7	10.9	1.53	77.47	4.46	17.81	Sandy loam	0.93	8.1

* % volumetric water content.

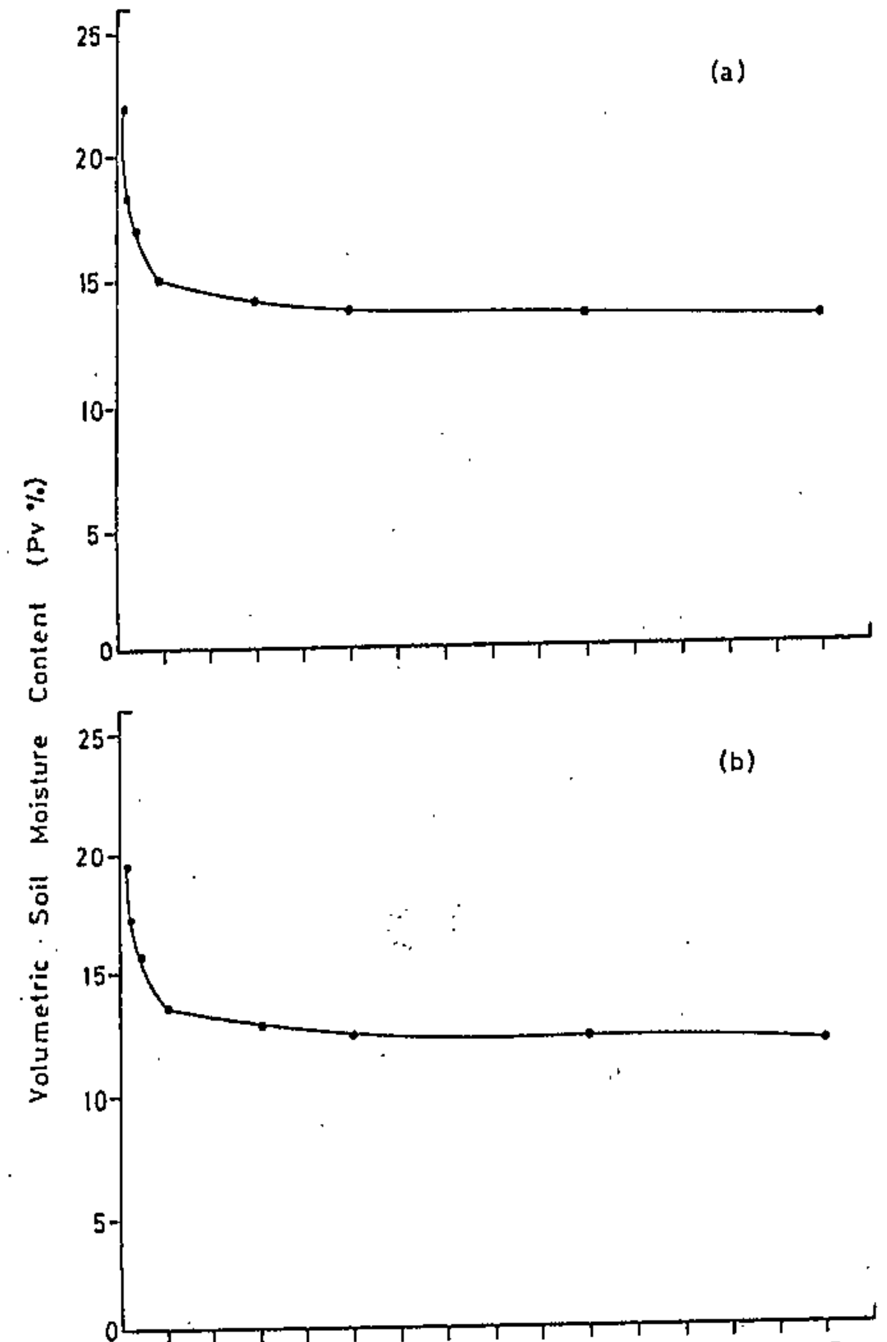

Fig. (1): Soil water characteristics curves for: (a) 0-30 cm; and (b) 31-60 cm, depths for the experiment location at the University of Jordan Research Station in the Jordan Valley.

consisted of three plots, 3 x 6 m each. A border of one meter in width seperated both blocks and plots. Each plot had five rows, 1.2 m apart and 3 meters long (Fig. 2).

3.5 CULTURAL PRACTICES

The experimental area was pre-irrigated, allowed to dry for about 3 days, then plowed with a chisel plow for a depth of approximately 30 cm. Drip irrigation system was installed according to the selected layout. Fertilizer application was practiced by row application of 60 Kg N/ha in the form of ammonium sulfate (21 % N), and 85 Kg P_2O_5/ha in the form of triple superphosphate (46 % P_2O_5). Plastic mulch was spread along each row. Holes of 2.5 cm radius were cut into the mulch, 50 cm apart. Squash seeds (3 seeds/hole) were planted at 3-4 cm depth in the soil. Irrigation water was applied in sufficient amounts so as to ensure adequate environmental conditions for seed emergence. Seedlings were thinned down to one per hole. The same procedure was followed at the beginning of each season.

Weed control and pesticides application were done whenever they were needed. Chemicals were continuously changed and rotated so as to ensure more effectiveness against whiteflies, aphids, powdry mildew, and spider mites. Chemicals used were Phosdrin, Ripcord, Symbush, and Avogan.

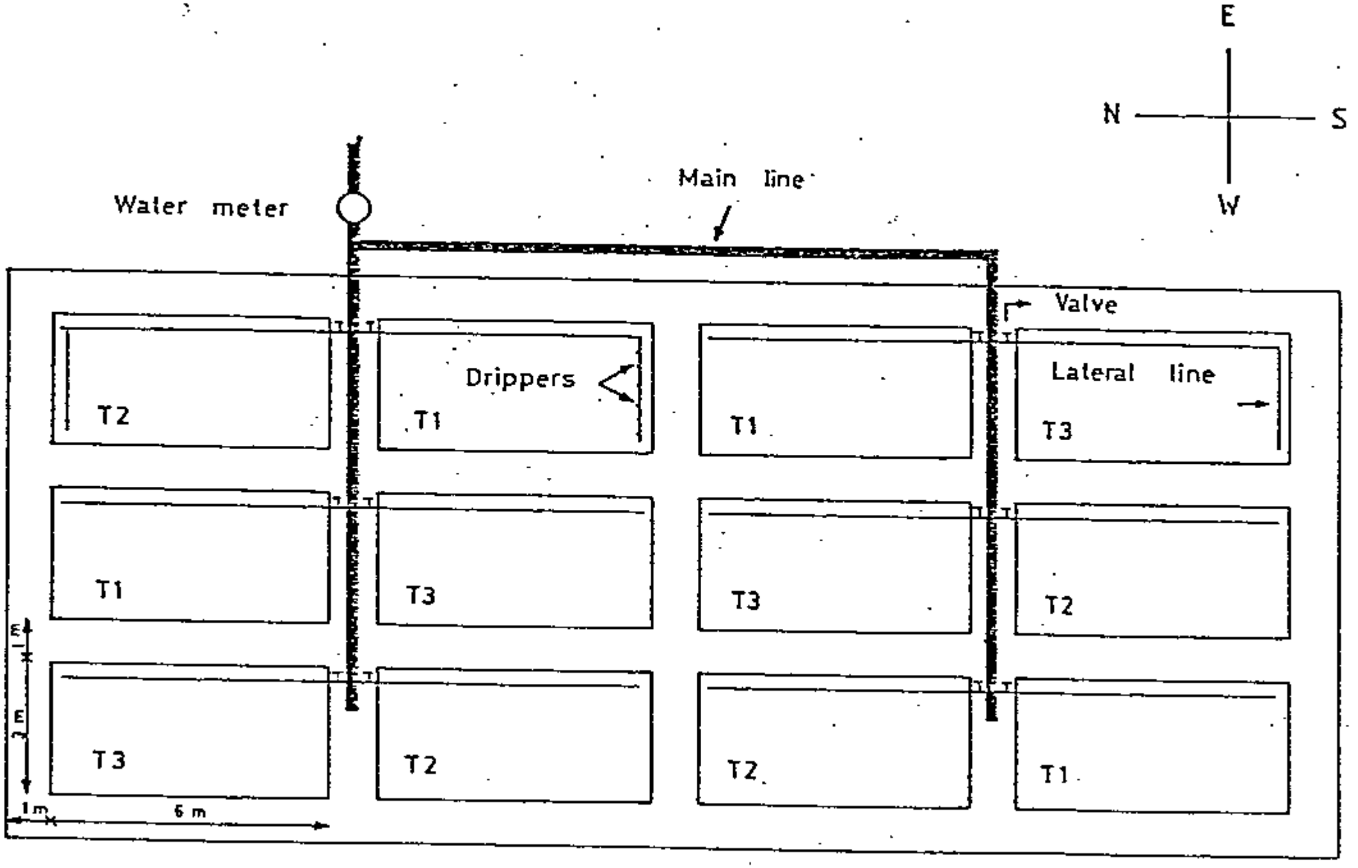

Fig. (2): Experiment and irrigation system layout at the University of Jordan Research Station in the Jordan Valley, 1985-1986.

3.6 IRRIGATION TIMINGS & AMOUNTS

Times of water application were determined using 15-cm (6 inches) tensiometers which were installed in each plot, half way between the central two plants of the middle row. Tensiometer readings of 25-30 kPa, 45-50 kPa, and 75-80 kPa for T1, T2, and T3 treatments respectively were considered. Galvanized steel access tubes, 1.1 meter long and 2 inches in diameter, each, were installed near the center of each plot between two plants. Irrigation amounts were based on Neutron Probe (Campbell Pacific, 503) readings. Neutron Probe readings were taken at 7.5, 22.5, 37.5, 52.5, 67.5, and 82.5 cm, 3 hours after irrigation and before next irrigation (Most of the excess water was assumed to be drained after 3 hours). Neutron Probe calibration was carried out at five depths: 0-15, 16-30, 31-45, 46-60, and 61-90 cm using the method of Van Bavel et al. (1961) (Fig. 3).

The average discharge of emitters was measured in each irrigation. The time of water application was determined for each plot separately. The water applied for each plot was controlled by a separate valve. The net depth of each irrigation application for each plot was calculated as the following:

$$d = \frac{(FC - Pv)}{100} \times D \times P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

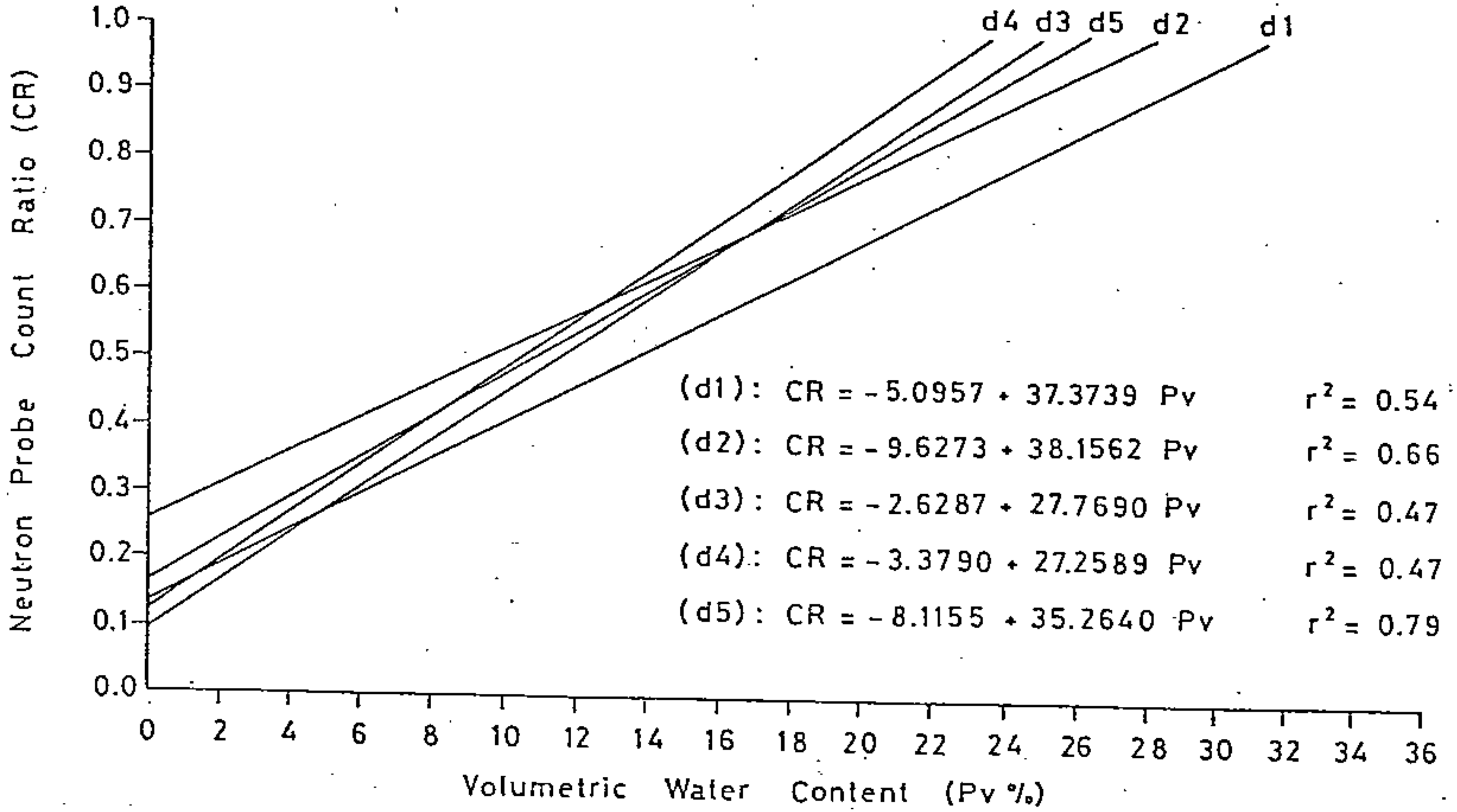

Fig. (3): Neutron probe calibration curves for soil depths of 0–15 cm (d1), 16–30 cm (d2), 31–45 cm (d3), 46–60 cm (d4), and 61–90 cm (d5), for the experiment site at the University of Jordan Research Station in the Jordan Valley.

where: d = net depth of each irrigation application (cm).

FC = volumetric water content at field capacity (%).

Pv = volumetric water content as determined by the neutron probe before irrigation.

D = root depth (cm).

P = fraction of area wetted under drip irrigation in respect to the total plot area (P was assumed to be 1.0).

The duration (hrs) for each irrigation for each plot was calculated as the following:

$$t = \frac{d \times A}{n \times qe} \times 1000 \quad \ldots\ldots (2)$$

where: t = irrigation duration (hrs).

d = net depth of each irrigation application (cm).

A = area under irrigation = 18 square meters.

n = number of emitters = 30.

qe = average emitter discharge in lph.

1000 is convert from liters to cubic meters.

A maximum root depth of 25 cm was considered (Battikhi and Ghawi, 1986a) assuming a linear root growth from emergance till full cover. To check this assumption, root samples were taken throughout the second season. Field capacity was taken at 0.1

bar. The wetting percentage (P) under drip irrigation was assumed to be 100 % (Hawatmeh and Battikhi, 1983). Additional 10 % water was applied so as to overcome any discharge fluctuation.

3.7 YIELD

Squash fruits were picked from the middle twelve plants in each plot. The fruits were weighed and their numbers were also recorded.

3.8 ROOT GROWTH & DISTRIBUTION

After complete wetting of the soil for 24 hrs, two root samples were collected from each plot by carefully digging around the roots in all possible directions. Roots were then washed. Tap root, secondary roots and horizontal roots were measured for each sample. The whole root was then oven-dried at 70 °C and weighed. However, this approach was followed by Battikhi and Ghawi (1986a and 1986b), Ghawi and Battikhi (1986a and 1986b), and Osmond and Raper (1982) for measuring root growth and distribution.

3.9 MODEL DESCRIPTION

The crop yield and soil water management simulation model (CRPSM) was developed at Utah State University (Hill et al., 1984a and 1984b). SQUASH subroutine was developed by Battikhi and Hill (1986a). The model was calibrated using a squash field experiment data for the Jordan Valley. The model consists of a main program and twelve subroutines. The model input data include: site location and elevation, number and thickness of soil layers, available water for each layer, constants for the different evapotranspiration equations used, crop coefficients, daily weather data (maximum and minimum temperatures, wet and dry bulb temperatures, wind run, precipitation, and solar radiation), crop phenology growth stages, and actual dates and amounts of irrigation (if the model was run for actual field experiment). Fig. 4 shows the process flow diagram of the CRPSM as described by Hill et al.(1984a and 1984b).

The model can predict yields for an actual or a simulated field experiment by computing daily available soil moisture in each layer and daily actual and potential evapotranspiration. It can also set up the crop phenology. The model can also simulate different irrigation options. These management options are:

1- Finding the best date to irrigate with a specified water increment.

2- Irrigating at a specified interval with fixed amount.

3- Irrigating on specified dates with specified amounts.

4- Irrigating at a specified depletion with a fixed amount.

To determine seasonal yield as a function of relative transpiration, de Wit equation of the following form was used (Jensen, 1968):

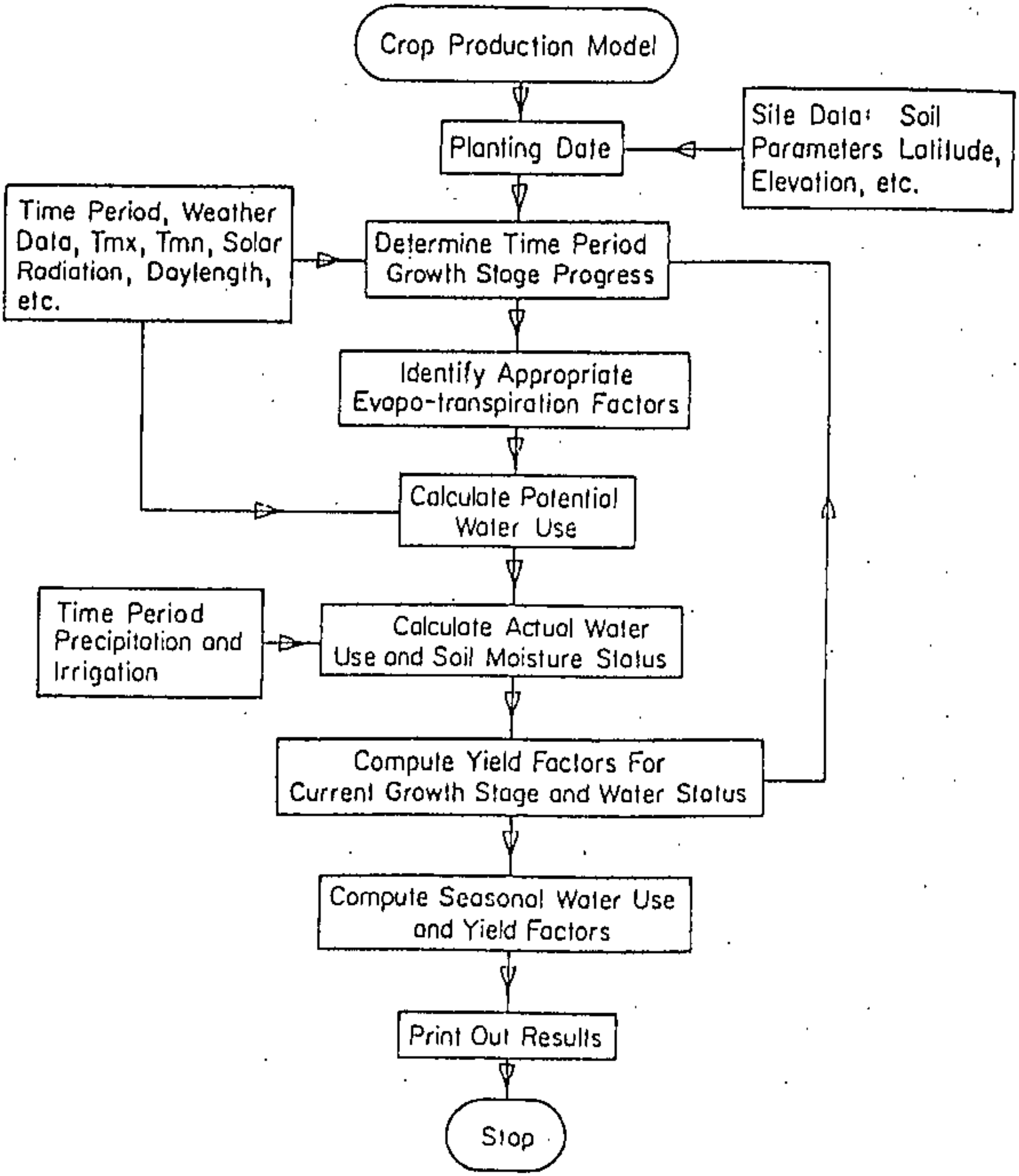

Fig. (4): Process flow diagram of the crop yield and soil water management simulation model (CRPSM) (Hill et al., 1984a and 1984b).

$$Y/Yp = (T/Tp)^{\lambda 1} \times (T/Tp)^{\lambda 2} \times (T/Tp)^{\lambda 3} \times (T/Tp)^{\lambda 4} \quad \ldots\ldots\ldots\ldots \quad (3)$$

In eq. 3, Y and Yp are actual and potential yield, T and Tp are actual and potential transpiration; and $\lambda 1$, $\lambda 2$, $\lambda 3$, and $\lambda 4$ are growth stage weighing factors. The power (lambda) terms reflect the following growth stages: 1- from planting to emergence; 2- from emergence to flowering; 3- from flowering to first pick; and 4- from first pick to last pick. Lambdas developed for squash in the Jordan Valley were 0.0, 1.5, 0.55, and 0.8 for the four growth stages, respectively, with a potential yield of 55 ton/ha (Battikhi and Hill, 1986a).

Potential transpiration (T_P) is calculated as:

$$T_p = K_{ct} \times E_{tr} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where: E_{tr} = reference crop evapotranspiration as determined by modified Penman.

K_{ct} = transpiration crop coefficient for squash developed by Battikhi and Hill (1986a) using FAO data (Doorenbos and Pruitt, 1975) and the method of Hill et al. (1983). The coefficients are:

$$1)\ K_{ct} = 0.115 + 1.229\, r - 0.331\, r^{2} - 0.033\, r^{3} \quad \ldots\ldots\ldots\ldots \quad (5)$$

$(0 < r < 1.0)$

where r is the fraction of time from planting to effective cover (i.e., days from planting to effective cover, percent/100).

2) $K_{ct} = 0.762 + 0.281 \times 10^{-2} d - 0.149 \times 10^{-3} d^2 - 0.330 \times 10^{-3} d^3$ .. (6)

$(0 < d < 40)$

where d is days after effective cover.

Modified Penman equation is used to calculate E_{tr} with the coefficients for the Jordan Valley ($a = 1.1$, $b = -0.1$, $a_1 = 0.39$, $b_1 = -0.05$ and wind term $1.0 + 0.01\ U_2$).

Actual transpiration (T) is estimated from:

$T = T_p$ for $SWS/AVW \geq FAW$ .... (7a)

and

$T = T_p \times (1/FAW) \times SWS/AVW$ for $SWS/AVW < FAW$ .... (7b)

where SWS is existing soil water in the root zone; AVW is the total available water at field capacity; and FAW is the fraction of total available water below which stress will occur, assumed to be 0.5. Potential evaporation from a wet soil surface (E_p) is calculated by:

$E_p = K_s \times E_{tr}$ .... (8)

where K_s is the soil evaporation coefficient dependent on

K_{ct} i.e., $K_s = 1 - K_{ct}$.

Actual soil evaporation (E) as related to the potential evaporation is:

$$E = \frac{E_p}{N^{(t-1)}} \quad \dots\dots (9)$$

where t is the time in days since last soil wetting and the value of N is related to the soil surface drying time. Values of N as used by the model would be approximately 3.0, 1.5, and 2.0 for sandy, loamy, and clay loam soils, respectively. For mulched treatments, E becomes E_m and is defined as:

$$E_m = E \times r \quad \dots\dots (10)$$

where E_m is actual evaporation under mulched conditions and r is the ratio of the non-mulched area to the total area. Thus the actual evapotranspiration (ET_a) under mulch becomes:

$$ET_a = E_m + T \quad \dots\dots (11)$$

The root growth and its downward penetration into the root zone is calculated by:

RT = BR + RDPTH (RTMX - BR) .... (12)

where RT is present root depth, BR, is initial root depth, RTMX is final root zone depth, and RDPTH is the ratio of the number of days since emergence to the date of final root depth.

Deep percolation, DP, is determined from the soil water budget equation whenever soil moisture content exceeds field capacity.

Transpiration water ratio, TWR, as defined by the ratio of the actual transpiration to the total water supply, TSW, indicates the efficiency of the water consumed by plants relative to the total amount of water made available during the season.

The water yield index, WYI, defined as:

WYI = MYP x TWR .... (13)

where MYP (model yield percent) is the percent of the predicted yield to the maximum yield. WYI serves as an indicator of the appropriateness and efficiency of the irrigation schedule under consideration.

4—RESULTS AND DISCUSSION

4.1 YIELD

Tables 2 and 3 show yield (t/ha), fruit number/middle twelve plants, and average fruit weight (gm/fruit) for each plot for the two seasons, respectively.

Yields averaged 19.4, 21.6, and 22.0 t/ha for T1, T2, and T3 treatments, respectively, in the winter season while it averaged 8.6, 7.4, and 7.6 t/ha, respectively in the spring season.

Fruit number for the middle twelve plants averaged 135, 146, and 141 fruits in the winter season compared to 55, 48, and 49 fruits in the spring season for the three respective treatments.

As a result, the average fruit weight was 116, 128, and 123 gm/fruit and 106, 113, and 109 gm/fruit for the three treatments in the two respective seasons.

In addition to the above, yield was analyzed in respect to weekly picks (tables 4 and 5). The yield of the winter season was obtained in a total of six-week picks in comparison to a three-week picks for the spring season. It could be noticed that during the winter season the yield increased during the 2nd week then declined in the 3rd week, increased again in the 4th week, then declined in the 5th and 6th weeks. On the other hand yield of the spring season declined from the 1st till the 3rd week.

Table (2): Yield, fruits number, and average fruit weight of squash planted under drip irrigation and black mulch, in the Jordan Valley (December 8, 1985 - April 1, 1986).

		Parameter+		
Treatment	Block	Yield (t/ha)	Fruit No. / middle 12 plants	Average fruit wt. (gm/fruit)
30 kPa T1	B1	14.7	128	83
	B2	19.4	149	94
	B3	21.6	129	120
	B4	21.8	132	165
	AVG	19.4a*	135a	116a
50 kPa T2	B1	14.3	106	97
	B2	23.4	168	100
	B3	22.5	158	142
	B4	26.2	153	171
	AVG	21.6a	146a	128a
80 kPa T3	B1	27.6	167	119
	B2	21.3	158	97
	B3	17.6	111	158
	B4	21.4	129	119
	AVG	22.0a	141a	123a
F Test		ns	ns	ns

+ All values were based on the average of the middle 12 plants.
* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (3): Yield, fruit number, and average fruit weight of squash planted under drip irrigation and black mulch, in the Jordan Valley (April 15 - June 13, 1986).

		Parameter[+]		
Treatment	Block	Yield (t/ha)	Fruit No. / middle 12 plants	Average fruit wt. (gm/fruit)
30 kPa T1	B1	11.9	62	122
	B2	6.9	49	100
	B3	8.5	59	103
	B4	7.0	51	99
	AVG	8.6a*	55a	106a
50 kPa T2	B1	6.7	41	118
	B2	10.9	70	112
	B3	5.2	40	94
	B4	6.9	39	127
	AVG	7.4a	48a	113a
80 kPa T3	B1	11.4	63	130
	B2	9.3	62	108
	B3	5.2	37	101
	B4	4.4	33	95
	AVG	7.6a	49a	109a
F Test		ns	ns	ns

+ All values were based on the average of the middle 12 plants.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (4): Squash weekly yield (t/ha) obtained during the winter season.

		YIELD+ (t/ha)					
Treatment	Block	1st wk	2nd wk	3rd wk	4th wk	5th wk	6th wk
30 k̄Pa T1	B1	2.7	2.2	2.2	3.4	1.5	2.7
	B2	2.4	4.4	2.7	5.4	1.5	3.0
	B3	0.5	10.3	2.2	4.4	2.8	1.4
	B4	0.8	9.2	2.4	4.4	2.9	2.2
	AVG	1.6a*	6.6a	2.4a	4.4a	2.2a	2.3a
50 k̄Pa T2	B1	2.8	2.0	2.2	3.3	2.4	1.7
	B2	3.0	6.5	3.8	4.7	2.7	2.7
	B3	1.0	6.6	4.8	4.9	2.4	2.8
	B4	0.7	10.3	3.5	6.5	2.6	2.7
	AVG	1.9a	6.4a	3.5a	4.8a	2.5a	2.5a
80 k̄Pa T3	B1	6.0	5.8	3.7	6.9	2.3	2.8
	B2	3.7	5.4	2.7	4.2	2.7	2.7
	B3	0.8	7.6	2.8	3.5	1.6	1.4
	B4	1.3	9.4	2.6	4.3	1.9	1.9
	AVG	2.9a	7.0a	2.9a	4.7a	2.1a	2.2a
F Test		ns	ns	ns	ns	ns	ns

+ 1st week: Feb 18 - Feb 24.
2nd week: Feb 25 - March 3.
3rd week: March 4 - March 10.
4th week: March 11 - March 17.
5th week: March 18 - March 24.
6th Week: March 25 - April 1.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (5): Squash weekly yield (t/ha) obtained during the spring season.

Treatment	Block	YIELD⁺ (t/ha) 1st week	2nd week	3rd week
30 kPa T1	B1	5.3	5.0	1.5
	B2	2.4	2.7	1.7
	B3	3.1	3.5	1.9
	B4	3.8	1.8	1.5
	AVG	3.6a*	3.3a	1.7a
50 kPa T2	B1	2.2	3.2	1.3
	B2	4.5	4.7	1.8
	B3	1.9	1.6	1.7
	B4	3.6	1.7	1.6
	AVG	3.0a	2.8a	1.6a
80 kPa T3	B1	4.6	4.9	1.9
	B2	3.5	3.4	2.4
	B3	2.4	1.8	0.9
	B4	1.8	1.5	1.1
	AVG	3.1a	2.9a	1.6a
F Test		ns	ns	ns

\+ 1st week: May 22 - May 28.
  2nd week: May 29 - June 4.
  3rd week: June 5 - June 13.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Mean separation using the Duncan-Multiple-Range-Test (DMRT) showed no significant differences between the three treatments in each season for all yield parameters measured.

Germination dates for the winter and spring seasons were on December 14 and April 19, respectively; flowering dates were on February 4 and May 15, respectively; first picks were on February 18 and May 25, respectively; and last picks were on April 1 and June 13, for the two respective seasons, for the three treatments.

The severe drop in the quantity of yield and quality in the spring season compared to the winter season maybe attributed to the following two major reasons:
First, predominance of male flowers over female flowers was noticed in the spring season. The winter season wittnessed an opposite situation where female flowers predominated the male flowers. High temperature increases the dominance of male flowers over female flowers. This physiological behavior was reported to be a result of high temperature and long days (Thompson and Kelly, 1985). Also, plastic mulch increased day time temperature, thus contributing in increasing male flowers. Secondly, the high incidence of virus diseases affected the yield of the spring season.

4.2 ROOT GROWTH & DISTRIBUTION

Average mass (oven-dry at 70 °C), vertical (tap and secondary), and horizontal lengths of squash roots planted for the two seasons are shown in tables 6 and 7. Root weight averaged 3.2, 3.4, and 3.6 gm/plant for the treatments T1, T2, and T3 respectively for the first season and 3.9, 3.7, and 3.0 gm/plant for the second season for the three treatments respectively. No significant differences were detected for the two seasons. No significant differences in the vertical (tap and secondary) root penetration were detected between the three treatments for the two seasons. Vertical roots did not exceed 25 cm except in some plots corresponding to the T3 treatment in the first season. This agrees to a certain extent with the assumption made previously for the irrigation scheduling purposes. In the second season, vertical roots exceeded the 25 cm depth in almost all the treatments. This justified the change made in the application of irrigation water especially during the last 10-14 days of the season.

Although the horizontal roots did not show any significant differences for the three treatments for both seasons, yet considerable increase in horizontal roots was noticed for the second season. The lengths averaged 63.5, 59.4, and 59.7 cm for T1, T2, and T3 treatments respectively for the first season, while for the second season they averaged 92.8, 94.8, and 85.0 cm or the three treatments, respectively. While these results seem to agree theoretically with the assumption made that 100% of the area under drip irrigation was wetted because the spacing between rows is 1.2 m and the lateral root length (diameter) exceeds 120 cm, yet it was noticed that the

Table (6): Average root weight, vertical (tap and secondary), and horizontal lengths of squash planted under drip irrigation and black mulch, in the Jordan Valley (December 8, 1985 - April 1, 1986).

		Parameter+			
Treatment	Block	Root Wt. (gm/plant)	Tap Roots (cm)	Secondary Roots (cm)	Horizontal Roots# (cm)
30 kPa T1	B1	3.6	18.0	26.1	74.5
	B2	2.5	25.3	24.5	68.0
	B3	3.7	17.5	25.5	48.3
	B4	2.9	22.5	29.0	63.3
	AVG	3.2a*	20.81a	26.3a	63.5a
50 kPa T2	B1	2.4	18.0	18.8	64.5
	B2	3.7	22.0	24.0	74.3
	B3	4.1	14.0	24.0	49.3
	B4	3.5	16.8	27.5	49.5
	AVG	3.4a	17.7a	23.6a	59.4a
80 kPa T3	B1	3.3	24.0	27.0	56.8
	B2	3.0	22.5	31.0	70.5
	B3	3.5	19.0	27.0	65.8
	B4	4.6	11.8	23.0	45.8
	AVG	3.6a	19.3a	27.0a	59.7a
F Test		ns	ns	ns	ns

+ Every value represents the average of two samples from each plot.

Horizontal length = distance from tap root horizontally to end of roots (average of both sides).

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (7): Average root weight, vertical (tap and secondary), and horizontal lengths of squash planted under drip irrigation and black mulch, in the Jordan Valley (April 15 - June 13, 1986).

		Parameter[+]			
Treatment	Block	Root Wt. (gm/plant)	Tap Roots (cm)	Secondary Roots (cm)	Horizontal Roots (cm)[#]
30 kPa T1	B1	4.3	21.5	27.5	90.8
	B2	3.2	22.3	24.8	93.0
	B3	5.2	21.5	26.0	110.0
	B4	2.8	22.8	26.0	77.3
	AVG	3.9a[*]	22.0a	26.1a	92.8a
50 kPa T2	B1	3.2	24.5	28.5	80.5
	B2	4.9	24.5	28.5	121.3
	B3	4.1	30.0	34.3	108.3
	B4	2.8	17.8	24.7	68.6
	AVG	3.7a	24.2a	29.0a	94.6a
80 kPa T3	B1	3.4	31.5	36.0	94.8
	B2	3.4	25.5	36.0	97.0
	B3	2.4	18.0	29.5	62.8
	B4	2.9	19.8	24.0	85.6
	AVG	3.0a	23.7a	31.4a	85.0a
F Test		ns	ns	ns	ns

+ Every value represents the average of two samples from each plot.

Horizontal length = distance from tap root horizontally to end of roots (average of both sides).

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

horizontal roots did not extend laterally between the rows but it extended laterally along the row and under the mulch. This was noticed during the first season because of high rainfall amount during January and February which prevented the lateral root extension outside the mulch. In the second season lateral roots extended outside the mulch supporting the assumptions of Hawatmeh and Battikhi (1983) and agreeing with the results of Battikhi and Ghawi (1986a).

Root growth is mainly affected by environmental and genetic factors (Kramer, 1969). The main environmental factors are soil moisture, soil temperature, soil aeration, salt concentration, and pH. The major attention was focused on the effect of soil moisture, a rather crucial factor, which is soil temperature was overlooked. Kramer (1969) reported that root growth could often limited or stopped by low temperatures. He also reported that optimum soil temperature varied with species, stage of development, and oxygen supply, but it would probably be about 20 to 25 °C for most species. Black plastic mulch increase soil temperature over the non-mulched portion of the experimental plot, and the rise in temperature provides a more suitable environment for root growth. This could explain why most of the lateral roots were under the mulched area during the winter season. On the other hand, high soil temperatures would increase the rate of root growth. This could probably explain the noticeable differences in lateral and vertical roots between the winter and spring seasons.

4.3 WATER REQUIREMENTS

Water applied by irrigation for the three treatments T1, T2, and T3 for the two seasons is given in Tables 8 and 9 (more details on the dates of irrigation can be found in appendices 1 and 2).

Mean separation using DMRT revealed significant differences at the 5 % level in the number of irrigations between the three treatments, for the two seasons. On the other hand, no significant differences were found in the amounts of applied irrigation water between the three treatments, for the two seasons.

During the winter season an average of 10.5, 9.25, and 7.25 irrigations were needed to supply an average irrigation water of 9.64, 9.63, and 10.91 cm, for T1, T2, and T3, respectively. The number of irrigations in the case of T1 were significantly different from that of T3, while there was no significant difference between the number of irrigations in T1 and T2 on one side, and T2 and T3 on the other side.

On the other hand, during the spring season an average of 13.0, 9.0, and 7.5 irrigations were needed to supply an average of 21.54, 17.14, and 18.02 cm, for the three treatments, respectively. The number of irrigations in the case of T1 was significantly different from that of T2 and T3. No significant differences were detected between T2 and T3.

Table (8): Monthly and seasonal irrigation depths (cm) and number of irrigations for treatments T1, T2, and T3 during the winter season.

	IRRIGATIONS									
	December		January		February		March		Total	
Treatment	No.	Depth	No.	Depth	No.	Depth	No.	Depth	No.	Depth
Block		(cm)		(cm)		(cm)		(cm)		(cm)
30 kPa, T1										
B1	1	1.33	3	2.59	1	1.50	5	5.97	10	11.39
B2	1	1.33	3	2.48	1	1.50	5	5.79	10	11.10
B3	1	1.33	3	2.28	1	1.50	9	4.47	14	9.58
B4	1	1.33	3	1.18	1	1.33	3	2.64	8	6.48
										*
AVG									10.50a	9.64a
50 kPa, T2										
B1	1	1.33	3	1.92	1	1.50	3	2.77	8	7.52
B2	1	1.33	2	1.85	1	1.50	4	5.04	8	9.72
B3	1	1.33	3	2.67	1	1.50	7	2.99	12	8.49
B4	1	1.33	3	1.99			5	9.46	9	12.78
AVG									9.25ab	9.63a
80 kPa, T3										
B1	1	1.33	3	1.99	1	3.04	4	8.38	9	14.71
B2	1	1.33	3	1.81			3	6.33	7	9.47
B3	1	1.33	2	2.25	1	1.50	3	3.50	7	8.58
B4	1	1.33	1	0.58	1	1.50	3	7.45	6	10.86
AVG									7.25b	10.91a
F-test									ns	ns
LSD 0.05										

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

** Significant difference at P= .05.

Table (9): Monthly and seasonal irrigation depths (cm) and number of irrigations for treatments T1, T2, and T3 during the spring season.

Treatment	IRRIGATIONS							
	April		May		June		Total	
	No.	Depth	No.	Depth	No.	Depth	No.	Depth
Block		(cm)		(cm)		(cm)		(cm)
30 kPa, T1								
B1	2	2.66	6	12.56	5	9.85	13	25.07
B2	2	2.66	9	9.24	5	7.89	13	19.79
B3	2	2.66	8	12.37	9	6.92	15	21.95
B4	2	2.66	4	7.56	3	9.09	11	19.31
AVG							13.00a	*21.54a
50 kPa, T2								
B1	2	2.66	4	9.98	3	6.39	9	19.01
B2	2	2.66	5	7.55	3	6.21	10	16.39
B3	2	2.66	3	4.60	3	5.67	8	12.93
B4	2	2.66	4	10.62	4	6.96	9	20.24
AVG							9.00b	17.14a
80 kPa, T3								
B1	2	2.66	4	11.30	2	5.49	8	19.45
B2	2	2.66	4	11.78	2	6.09	8	20.53
B3	2	2.66	3	7.10	2	5.58	7	15.34
B4	2	2.66	3	7.83	2	6.25	7	16.74
AVG							7.50b	18.02a
F-test							**	ns
LSD 0.05							2.0	--

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

** Significant difference at P= .05.

Total actual evapotranspiration, ET, during the growing season was calculated based on soil moisture depletion between irrigations. Depletions were based on the difference in neutron probe readings 3 hours after irrigation and before next irrigation. Depletions along the top 45 cm were considered as crop water consumption.

The soil water budget equation was used as:

$$ET = I + R + DS - DP \quad \ldots\ldots (14)$$

where I is irrigation (cm), R is effective rainfall (cm) calculated in accordance to Doorenbos and Pruitt method (1975), DS is the change in soil moisture content (cm) calculated as the amount of water needed to restore the zone of depletion at the end of the season back to field capacity, and DP is deep percolation (cm) estimated as TSW - ET, where TSW (total supply of water) = I + R + DS.

Water application efficiency, WAE, and irrigation water use efficiency, WUE, were also calculated. These are defined as:

$$AWE = \frac{ET}{TSW} \;; \quad \ldots\ldots (15)$$

$$WUE\ (t/ha/cm) = \frac{Y}{ET} \quad \ldots\ldots (16)$$

The results of the soil moisture budget parameters, WAE, and WUE for the three treatments, for the winter and spring seasons are presented in Tables 10 and 11.

The results of the winter season did not show any significant differences in all soil moisture budget parameters determined for the three treatments. Also, no significant differences were found in water application efficiency (WAE) and water use efficiency (WUE) between the three treatments.

The results of the spring season showed no significant differences between the three treatments in respect to all measured soil moisture budget parameters, except for deep percolation losses which showed significant differences between T1 and T2, and T1 and T3. No significant differences were found in deep percolation losses between T2 and T3. Neither water application efficiency (WAE) nor water use efficiency (WUE) showed any significant differences between the three treatments.

It is worth mentioning that the first block in the first treatment was overestimated ET. Upon root excavations, gravelly layer was noticed at a depth of approximately 20 cm. So, this explains why too much water was supplied to that block. The ET value presented in table 11 for that plot is a recalculated value determined by substracting the overestimated ET throughout the growing season. This value was in turn considered as deep percolation. This would probably explain the significant difference in deep percolation detected in the

Table (10): Soil moisture budget parameters for squash grown in the Jordan Valley under three different irrigation schedules (30 kPa, T1, 50 kPa, T2, and 80 kPa, T3) during the winter season 1985-1986.

		Parameter +						
Treatment	Block	I (cm)	DS (cm)	@ TSW (cm)	DP (cm)	ET (cm)	# WAE (%)	WUE (t/ha /cm)
30 kPa T1	B1	11.39	1.56	19.45	3.41	16.04	82.5	0.92
	B2	11.10	1.68	19.28	9.01	10.27	53.3	1.89
	B3	9.58	0.95	17.03	4.61	12.42	72.9	1.74
	B4	6.48	2.90	15.88	3.47	12.41	78.2	1.76
		*						
	AVG	9.64a	1.77a	17.91a	5.13a	12.79a	71.7a	1.58a
50 kPa T2	B1	7.52	2.67	16.69	1.72	14.97	89.7	0.96
	B2	9.72	1.12	17.34	6.10	11.24	64.8	2.08
	B3	8.49	0.85	15.84	6.53	9.31	58.8	2.41
	B4	12.78	1.60	20.88	5.40	15.48	74.1	1.69
	AVG	9.63a	1.56a	17.69a	4.94a	12.75a	71.9a	1.79a
80 kPa T3	B1	14.71	2.47	23.68	6.45	17.23	72.8	1.60
	B2	9.47	3.22	19.19	8.04	11.15	58.1	1.91
	B3	8.58	1.30	16.38	8.94	7.44	45.4	2.49
	B4	10.86	2.67	20.03	6.08	13.95	69.7	1.53
	AVG	10.91a	2.42a	19.82a	7.38a	12.44a	61.5a	1.88a
F Test		ns	ns	ns	ns	ns	ns	ns

\+ I = irrigation; DS = soil moisture change; TSW = I + R + DS; DP = deep percolation; DP = TSW - ET.

@ Effective rainfall used in TSW = 6.5 cm.

WAE = 100 x ET/TSW and WUE = Yield/ET.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (11): Soil moisture budget parameters for squash grown in the Jordan Valley under three different irrigation schedules (30 kPa, T1, 50 kPa, T2, and 80 kPa, T3) during the spring season 1986.

Treatment	Block	Parameter+						
		I (cm)	DS (cm)	@ TSW (cm)	DP (cm)	ET (cm)	# WAE (%)	WUE (t/ha /cm)
30 kPa T1	B1	25.07	1.62	28.00	12.66	15.34	54.8	0.78
	B2	19.79	1.62	22.72	8.55	14.17	62.4	0.48
	B3	21.95	1.00	24.26	7.86	16.40	67.6	0.50
	B4	19.31	0.40	21.02	6.22	14.80	70.0	0.48
		*						
	AVG	21.53a	1.16a	24.00a	8.82a	15.18a	63.7a	0.56a
50 kPa T2	B1	19.01	1.82	22.14	6.69	15.45	69.8	0.44
	B2	16.39	1.54	19.24	5.74	13.50	70.2	0.95
	B3	12.93	1.22	15.46	5.67	9.79	63.3	0.53
	B4	20.24	1.72	23.27	6.08	17.19	73.9	0.40
	AVG	17.14a	1.58a	20.03a	6.05b	13.98a	69.3a	0.58a
80 kPa T3	B1	19.45	1.43	22.19	6.09	16.10	72.6	0.71
	B2	20.53	1.60	23.44	5.56	17.88	76.3	0.53
	B3	15.34	1.38	18.03	6.72	11.31	62.7	0.48
	B4	16.74	1.62	19.67	5.07	14.60	74.2	0.30
	AVG	18.02a	1.51a	20.83a	5.86b	14.97a	71.5a	0.51a
F Test		ns	ns	ns	**	ns	ns	ns
LSD 0.05		--	--	--	2.56	--	--	--

\+ I = irrigation; DS = soil moisture change; TSW = I + R + DS; DP = deep percolation; ET = TSW - DP.

@ Effective rainfall used in TSW = 1.31 cm.

\# WAE = 100 x ET/TSW and WUE = Yield/ET.

* Along each column, values followed by the same latter are not significantly different at the 5% level, according to DMRT.

** Significant difference at P= .05

spring season.

Figures 5 and 6 show cumulative water consumption by squash during the winter and spring seasons, respectively. No significant differences were found between the treatments for all growth stages for both seasons. The figures show the differences between water consumption during the season. During the winter season low water consumption occured during early months of growth with almost half of the consumption occurring in March. This is a natural result of the low temperatures during January and February which delayed the plant growth and development. The spring season results show the effect of high temperature on a greater water consumption accumulation accompanied by the early and rapid growth.

The climatic data during the two seasons and potential evapotranspiration for a reference crop (E_{tr}) as determined by the modified Penman method are given in Tables 12 and 13 (Appendix 3 show daily climatic data for both seasons). The transpiration crop coefficient curve for squash in the Jordan Valley as developed by Battikhi and Hill (1986a) is given in Figure 7. The maximum value of K_{ct} was estimated as being 5 percent less than the maximum basal crop coefficient. K_{ct} equals zero before emergence and K_s is always greater or equal to 0.08 (Wright, 1982).

Using the transpiration crop coefficient curve, expected squash evapotranspiration under mulch, $ET_q P_m$, was calculated as:

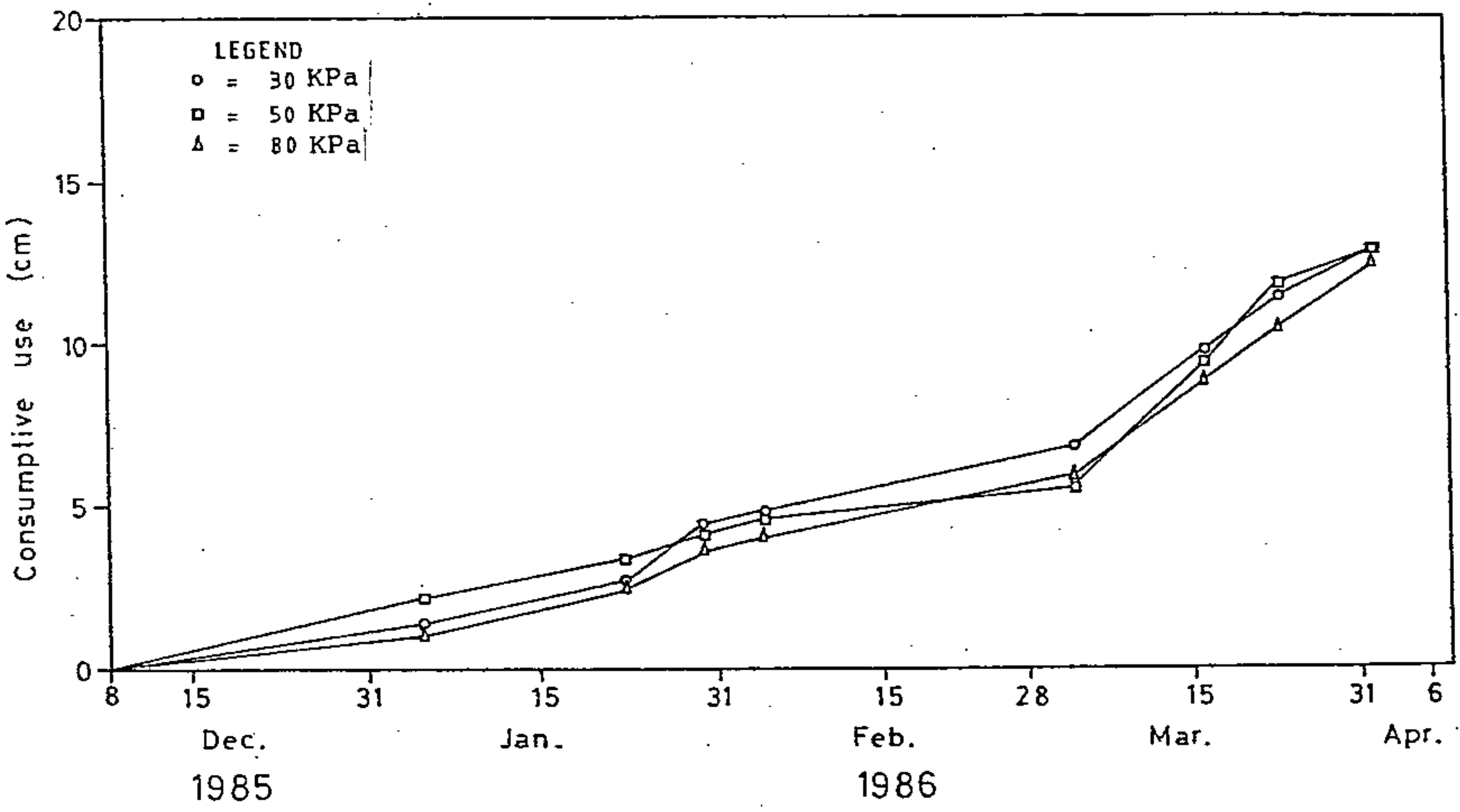

Fig. (5): Cumulative squash water consumption for the three treatments, during the winter season 1985–1986 under black mulch and drip irrigation in the Jordan Valley.

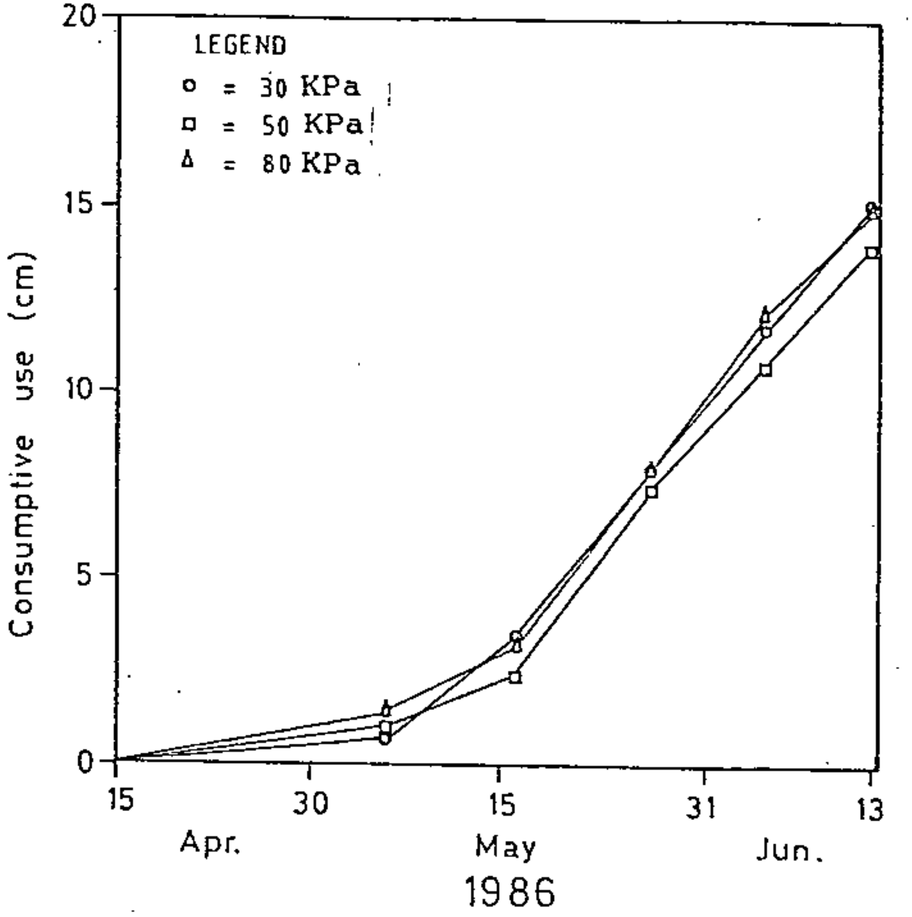

Fig. (6): Cumulative squash water consumption for the three treatments, during the spring season 1986 under black mulch and drip irrigation in the Jordan Valley.

Table (12): Average monthly solar radiation, minimum and maximum temperature, rainfall, wind run, class A pan evaporation and potential evapotranspiration for the University of Jordan Research Station, Jordan Valley (December 8, 1985 - April 1, 1986).

Month	Solar Rad. (l/d)	Temp. (°C). min.	Temp. (°C). max.	Rain fall (cm)	Wind Run (km/day)	E pan (cm)	E_{tr}^{+} (cm)
Dec #	209.9	11.9	21.6	2.2	60.1	6.5	5.31
Jan	215.2	9.6	20.2	3.5	70.2	9.2	6.12
Feb	272.4	10.3	21.3	7.5	78.3	8.9	7.44
March	350.9	13.4	26.2	0.7	81.3	17.7	11.30
April	331.7	15.0	25.2	0.4	81.0	0.4	0.41
Total Seasonal*						42.7	30.58

+ Modified Penman method ($a = 1.1$, $b = -0.1$, $a_1 = 0.39$, $b_1 = -.05$, $w_1 = 1.00$, $w_2 = 0.01$) (Hill et al. 1983).

Dec. 8-31.

* Until April 1.

Table (13): Average monthly solar radiation, minimum and maximum temperature, rainfall, wind run, class A pan evaporation and potential evapotranspiration for the University of Jordan Research Station, Jordan Valley (April 15, 1986 - June 13, 1986).

Month	Solar Rad. (l/d)	Temp. (°C). min.	Temp. (°C). max.	Rain fall (cm)	Wind Run (km/day)	E pan (cm)	E_{tr}+ (cm)
April#	439.3	18.7	33.1	0.0	126.1	14.6	7.82
May	466.0	17.7	31.6	1.9	115.7	25.1	14.38
June	510.7	22.7	38.3	0.0	128.2	15.4	7.04
Total Seasonal*						54.1	29.24

+ Modified Penman method (a = 1.1, b = -0.1, a1 = 0.39, b1 = -.05, w1 = 1.00, w2 = 0.01)(Hill et al. 1983).

April 15-30.

* Until June 13.

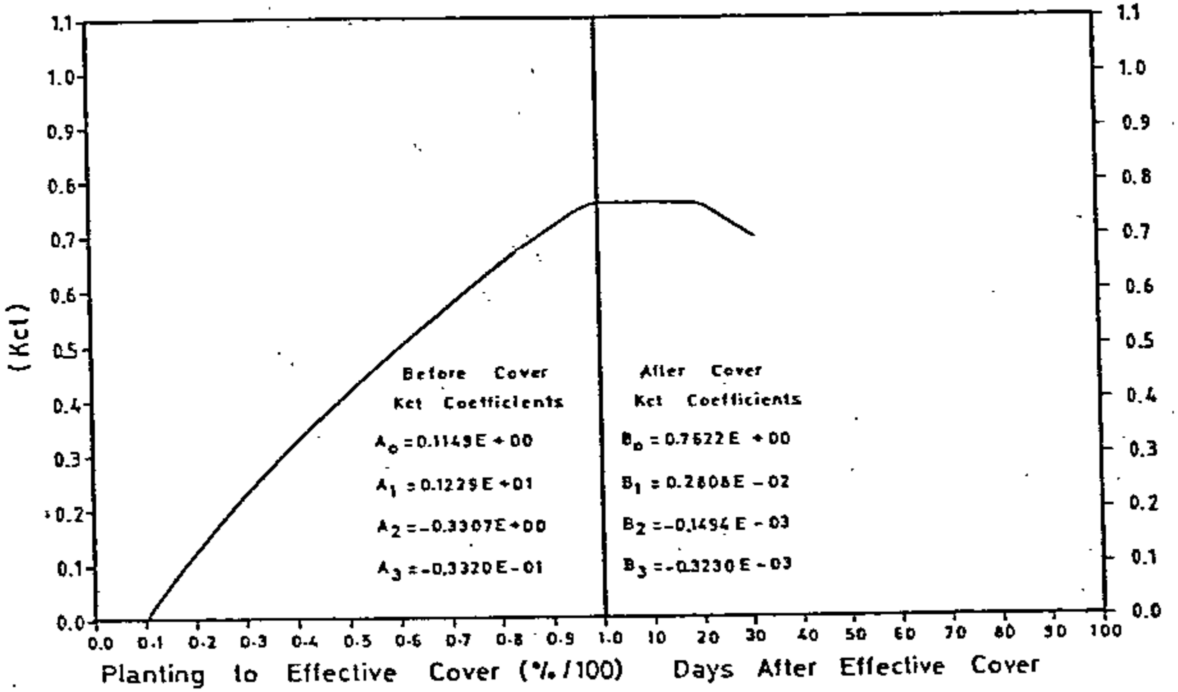

Fig. (7): Squash (Jordan Valley) crop transpiration coefficient curve.

$$ET_q P_m = T_q P + 1/6 \times E_q P \qquad (17)$$

where: $T_q P$ = expected actual transpiration of squash.

$E_q P$ = expected actual evaporation.

1/6 is the field ratio of unmulched to total area (only 17 % of the total surface area is exposed to evaporation).

$T_q P$ and $E_q P$ were calculated as:

$$T_q P = K_{ct} \times E_{tr} \qquad (18)$$

$$E_q P = (1-K_{ct}) \times E_{tr} \qquad (19)$$

where K_{ct} is the crop transpiration coefficient.

Also the K_c values were determined for each treatment as given by:

$$K_c = (ET_q P_m \times 1.15) / E_{tr} \qquad (20)$$

A factor of 1.15 is used to convert E_{tr} (alfalfa) to E_{tr} or ETP (clipped grass); and actual or measured K_c (aK_c) values of the actual field experiment, defined as:

$$aK_c = (ET \times 1.15) / E_{tr} \qquad (21)$$

where ET is the actual evapotranspiration as measured by the neutron probe.

The results for the winter growing season were as follows: 30.58 cm for potential evapotranspiration of alfalfa by modified Penman, 2.39 cm for expected actual evaporation under mulch, 16.49 cm for expected actual transpiration of squash, and 18.88 cm for expected actual evapotranspiration under mulch. On the other hand, the spring growing season results were: 29.24 cm for potential evapotranspiration of alfalfa, 2.67 cm for expected actual evaporation under mulch, 13.52 cm for expected actual transpiration of squash under mulch, and 16.19 cm for expected actual evapotranspiration under mulch. It is worth mentioning that the actual potential ET of grass as determined by a lysimeter study at the University of Jordan Research Station (Shatanawi et al., 1986) during the winter growing season was 27.78 cm. On the other hand, lysimeter actual potential ET of grass was 19.83 cm during the spring growing season (Personal communication, Dept of Soils & Irrigation, University of Jordan).

The Kc values obtained for all treatments were 0.71 and 0.64 for the winter and spring seasons, respectively. Actual or field determined K_c (aK_c) values are presented in table 14.

The results indicate that plants were not provided with their seasonal water requirements during the winter season. Treatments T1, T2, and T3 were provided with an average of 17.91, 17.69, and 19.82 cm (TSW), respectively, from which they

Table (14): Actual field obtained crop coefficents for squash grown under black mulch and drip irrigation in the Jordan Valley for the winter season, 1985-1986, and spring season, 1986, for the treatments T1, 30 kPa, T2, 50 kPa, and T3, 80 kPa.

		aK_c	
		Season	
Treatment	Block	Winter	Spring
30 kPa T1	B1	0.60	0.60
	B2	0.39	0.56
	B3	0.47	0.65
	B4	0.47	0.58
	AVG	0.48a*	0.60a
50 kPa T2	B1	0.56	0.61
	B2	0.42	0.53
	B3	0.35	0.39
	B4	0.58	0.68
	AVG	0.48a	0.55a
80 kPa T3	B1	0.65	0.63
	B2	0.42	0.70
	B3	0.28	0.45
	B4	0.53	0.57
	AVG	0.47a	0.59a
F Test		ns	ns

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

consumed an average of 12.79, 12.75, and 12,44 cm, respectively (Table 10). Their seasonal expected water requirement was 18.8 cm. It seems that the TSW was sufficient to meet the crop requirements, but unfortunately the scheduling was not suitable for providing the plants with their needs at the time needed.

On the other hand, during the spring season the plants were provided with an average of 24.00, 20.03, and 20.83 (TSW) for the three respective treatments, from which they consumed an average of 15.18, 13.98, and 14.97 cm. Their seasonal expected water requirement was 16.19 cm. It seems that the plants were supplied with sufficient water so as to obtain the optimum yield, but other factors, such as disease incidents and the effect of temperature were more decisive in yield determination.

The obtained results show that there were no significant differences in almost all determined soil moisture parameters during both winter and spring seasons. The non-significant results obtained during the winter season could be attributed to the relatively short irrigation season. Rainfall contributed in considerably high amounts, thus maintaining approximately similar soil moisture tension level for the three treatments during late December, January, and most of February.

Although there is no previous published work on the irrigation scheduling of squash in the Jordan Valley, however several studies were carried out on the irrigation scheduling of other crops, mainly tomato. For example, El-Zuraiqi (1986) working on the irrigation scheduling of tomatoes under drip inside plastic houses found out that there were no significant differences in total water applied, ET, deep percolation losses, and water application efficiency between two soil moisture tension treatments (T1 = 30cb and T2 = 70cb). Battikhi et al. (1985), also working on scheduling irrigation for tomatoes under drip irrigation inside plastic houses in the Jordan Valley found significant differences between total water applied under three soil moisture tension treatments (T1 = 30cb, T2 = 50cb, and T3 = 70cb).

4.4 ROOT DEPTH VS. SOIL MOISTURE DEPLETION

In an attempt to correlate root development with soil moisture depletion under the three different treatments, root samples were collected from plants near the border of the different plots. Root samples were collected throughout the spring season only.

Figures 8, 9, and 10 show the general trend for each treatment. Since neutron probe readings were taken at 15 cm increments, the results obtained herein would reflect only the depletion zone incremented by 15 cm. The obtained results indicate that throughout the first 25 days, most of the depletion occured in the top 15 cm. Cumulative squash water consumption (Figure 6) showed that relatively lower ET occured during that period. With vertical root development down the soil profile, depletion started to occur in the top 30 cm. By

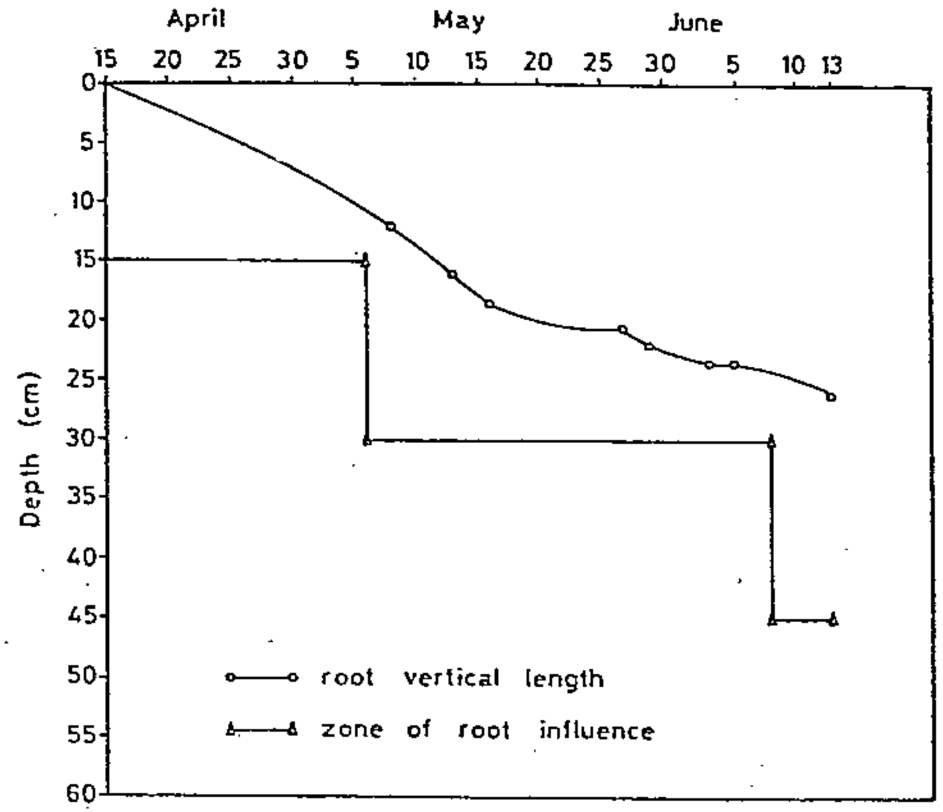

Fig. (8): Actual vertical root length (cm) and depth of zone influenced by vertical roots for squash grown under black mulch and drip irrigation in the Jordan Valley during the spring season 1986 for T1 treatment: irrigation at 30 KPa tensiometer reading.

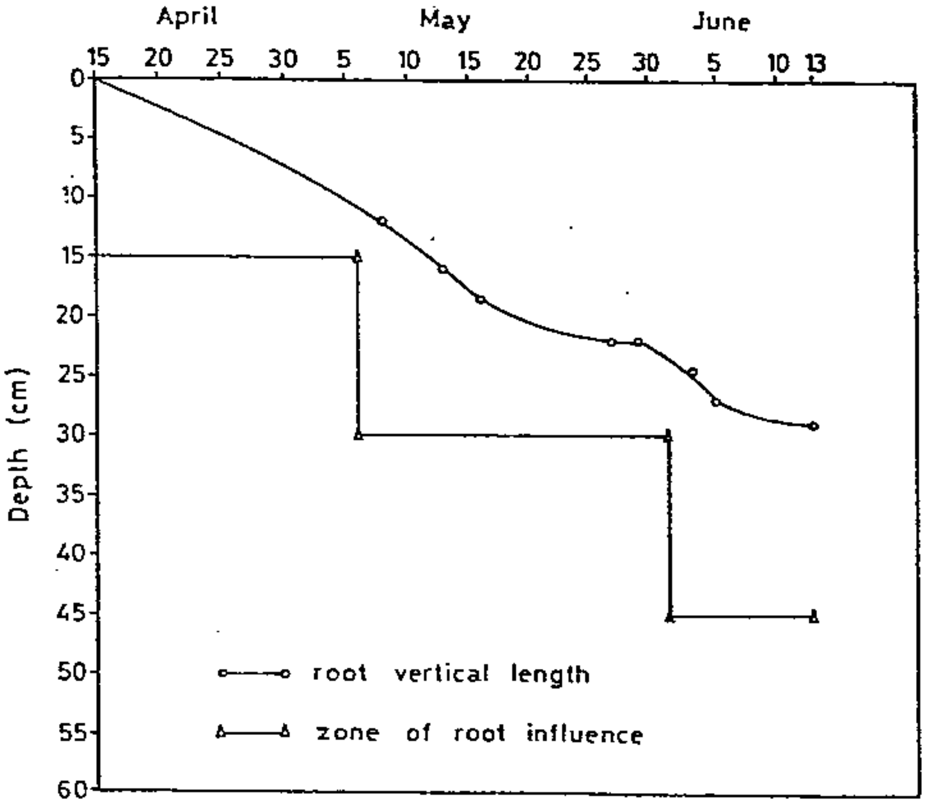

Fig. (9): Actual vertical root length (cm) and depth of zone influenced by vertical roots for squash grown under black mulch and drip irrigation in the Jordan Valley during the spring season 1986 for T2 treatment: irrigation at 50 KPa tensiometer reading.

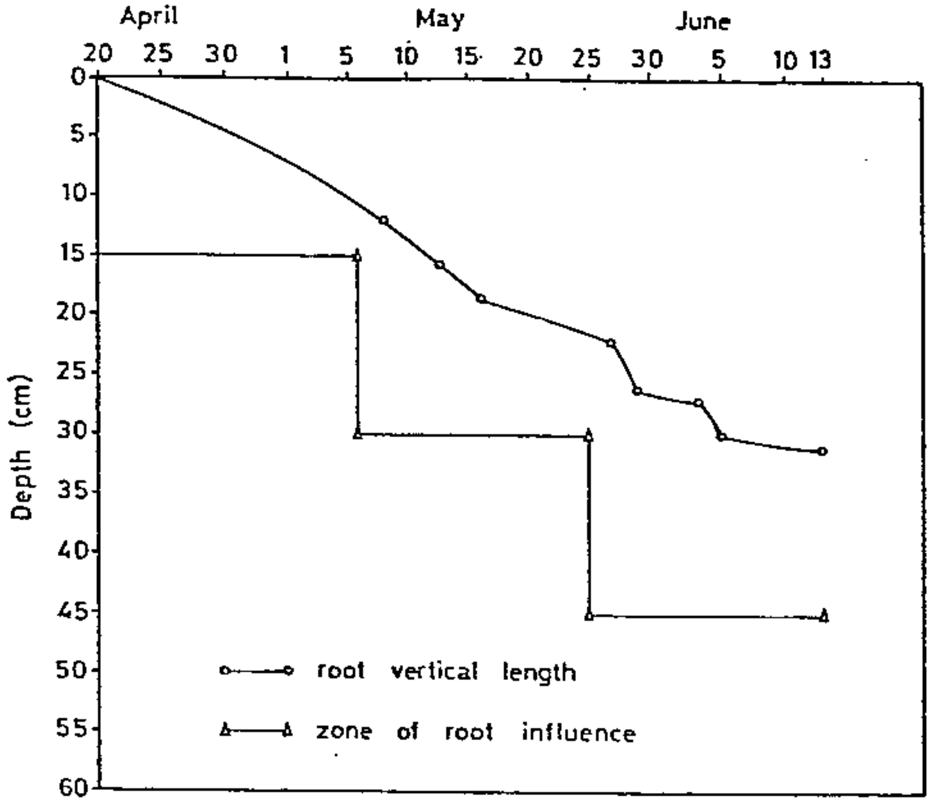

Fig. (10): Actual vertical root length (cm) and depth of zone influenced by vertical roots for squash grown under black mulch and drip irrigation in the Jordan Valley during the spring season 1986 for T3 treatment: irrigation at 80 KPa tensiometer reading.

the end of the season some depletion started in the 30-45 cm layer. Time periods through which soil moisture depletion occured in the 30-45 cm were 5 days for T1, 10 days for T2, and around 15 days for T3. These results indicate that the higher the soil moisture depletion, the more the root extraction from lower soil layers. Amounts of depleted water in the 30-45 cm layer were not high in comparison to the top 30 cm layer. Still, some depletion up to 15 cm depth below the root zone might occur.

4.5 MODEL TEST & CALIBRATION

The crop yield and soil water management simulation model (CRPSM) developed at Utah State University by Hill et al. (1984a and 1984b) and was modified lately by Battikhi and Hill (1986a) for squash was tested using initial soil moisture content, soil water characteristics curves, dates and amounts of irrigation and squash phenological growth stages as determined for the actual two field experiments. Table 15 shows the model predicted yields versus actual obtained yields, for the winter and spring seasons.

The model estimated yields were almost double the actual yields obtained in the winter season, while it did not give good estimate for crop yields of the spring season. As far as the winter season is concerned, disagreement between the model predicted yields and the actual yields is most likely due to the fact that the model potential yield was 55 t/ha which was

Table (15): Predicted yield by the Crop Yield and Soil Water Management Simulation Model developed by Battikhi and Hill (1986a) for squash in the Jordan Valley, versus actual yield obtained from the field experiments for the winter and spring seasons, respectively. (Potential Yield = 55 t/ha)

		Season			
		Winter		Spring	
Treatment	Block	Actual Yield (t/ha)	Predicted Yield (t/ha)	Actual Yield (t/ha)	Predicted Yield (t/ha)
30 kPa T1	B1	14.7	47.1	11.9	54.1
	B2	19.6	45.7	6.9	53.3
	B3	21.6	36.5	8.5	55.0
	B4	21.8	32.0	7.0	52.7
50 kPa T2	B1	14.3	35.1	6.7	52.2
	B2	23.4	40.0	10.9	52.2
	B3	22.5	35.1	5.2	25.9
	B4	26.2	46.3	6.9	52.2
80 kPa T3	B1	27.6	48.9	11.4	47.6
	B2	21.3	39.4	9.3	47.6
	B3	17.6	34.2	5.2	38.7
	B4	21.4	42.9	4.4	42.4

greater than any actual yield obtained. On the other hand, the model did not account for the disease incidents as well as the physiological behaviour of the male flowers predominance in the spring season.

The pattern search technique developed by Hill et al. (1972) was used to recalibrate the yield portion of the program, so as to identify new lambdas, for de Wit equation and potential yields which give the best fit yield for the two seasons. The new sets of lambdas were 0.00, 1.30, 0.55, 0.79 and 0.00, 0.20, 2.00, 0.40 for the following growth stages: planting to emergence, emergence to flowering, flowering to first pick, and first pick to last pick, with a maximum field attainable yields of 30 and 10 t/ha, for the two respective seasons. An important issue worth mentioning is that actual transpiration was equal to potential transpiration in the third growing stage (flowering to first pick) for all plots in the actual field experiment during the winter season, and that is attributed to the high rainfall amounts during that period. This fact means that the lambda given by the calibration process, for that stage could have any value, not necessarily 0.55. Actual and potential transpiration were not crucial factors in yield prediction during that stage. The lambda values obtained for the winter season did not vary from those developed by Battikhi and Hill (1986a), except for the difference in the potential yield (the model was originally calibrated by using results of squash crop grown during

February to May, 1984, while the results obtained here were for a growing season staring in early December and ending in late March), so the variation in expected potential yield is reasonable.

The higher the growth weighing factor (lambda) for a certain growing stage, the lower its contribution towards yield. The results obtained for the winter season show the lower influence of the second growing stage (emergence to flowering) and lays more emphasis on the third (flowering to first pick) and the fourth (first to last pick) growing stages on yield determination. The spring season lambda values emphasize on the second and fourth growing stages in yield prediction.

Figures 11 and 12 show relative field yield (Y/Yp) versus relative model yield using the old and new lambdas for the winter and spring seasons, respectively.

The new lambdas for both winter and spring seasons were placed in the squash subroutine of the CRPSM. Table 16 shows the predicted yield versus the actual yield for the two seasons using the new sets of lambdas.

It is worth mentioning that the first block for the T1 treatment, for the winter season and the third and fourth blocks for the T3 treatment, for the spring season were removed from the calibration, because they were not consistent with what was given by other treatments and blocks and with what was expected. This has an improved effect on lambda values.

WINTER SEASON

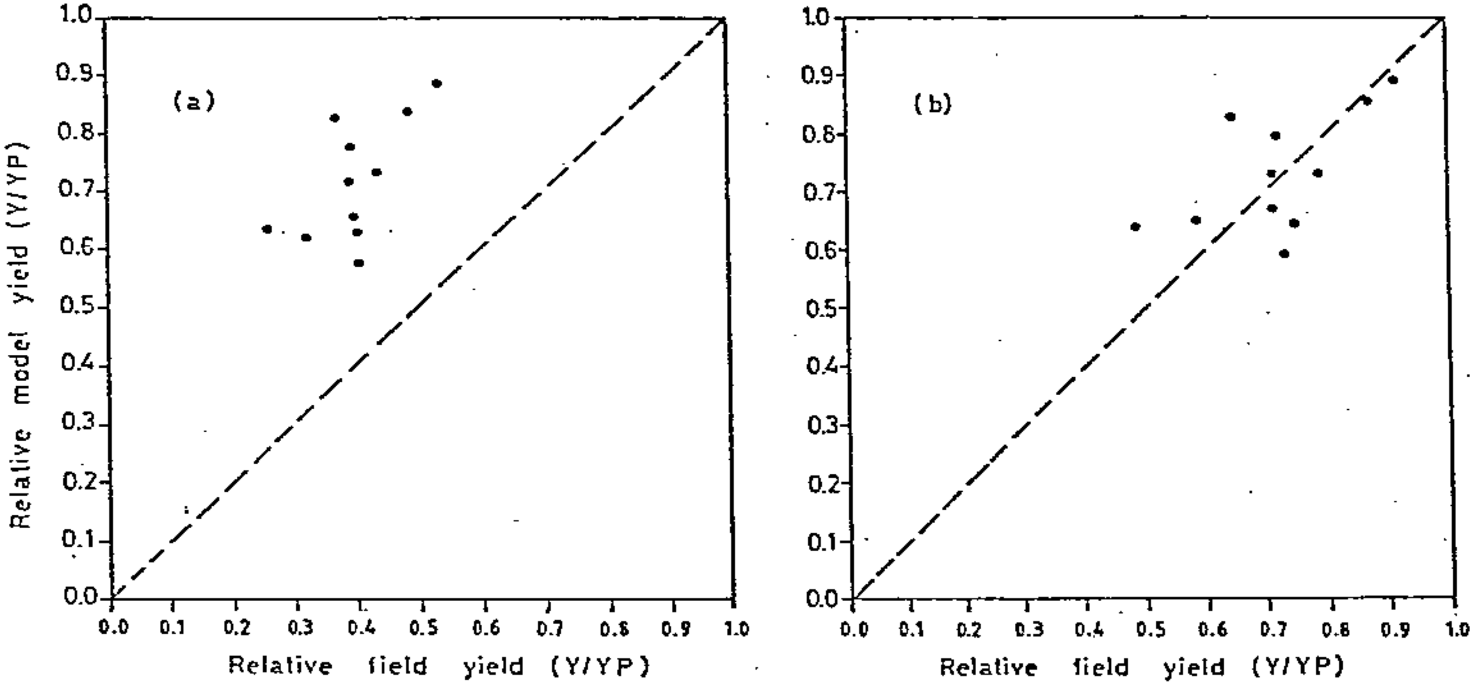

Fig. (11): Relative field yield (Y/Yp) vs. relative model yield using (a) old lambdas (0.00, 1.50, 0.55, and 0.80), and (b) new lambdas (0.00, 1.30, 0.55, and 0.79) for the winter season.

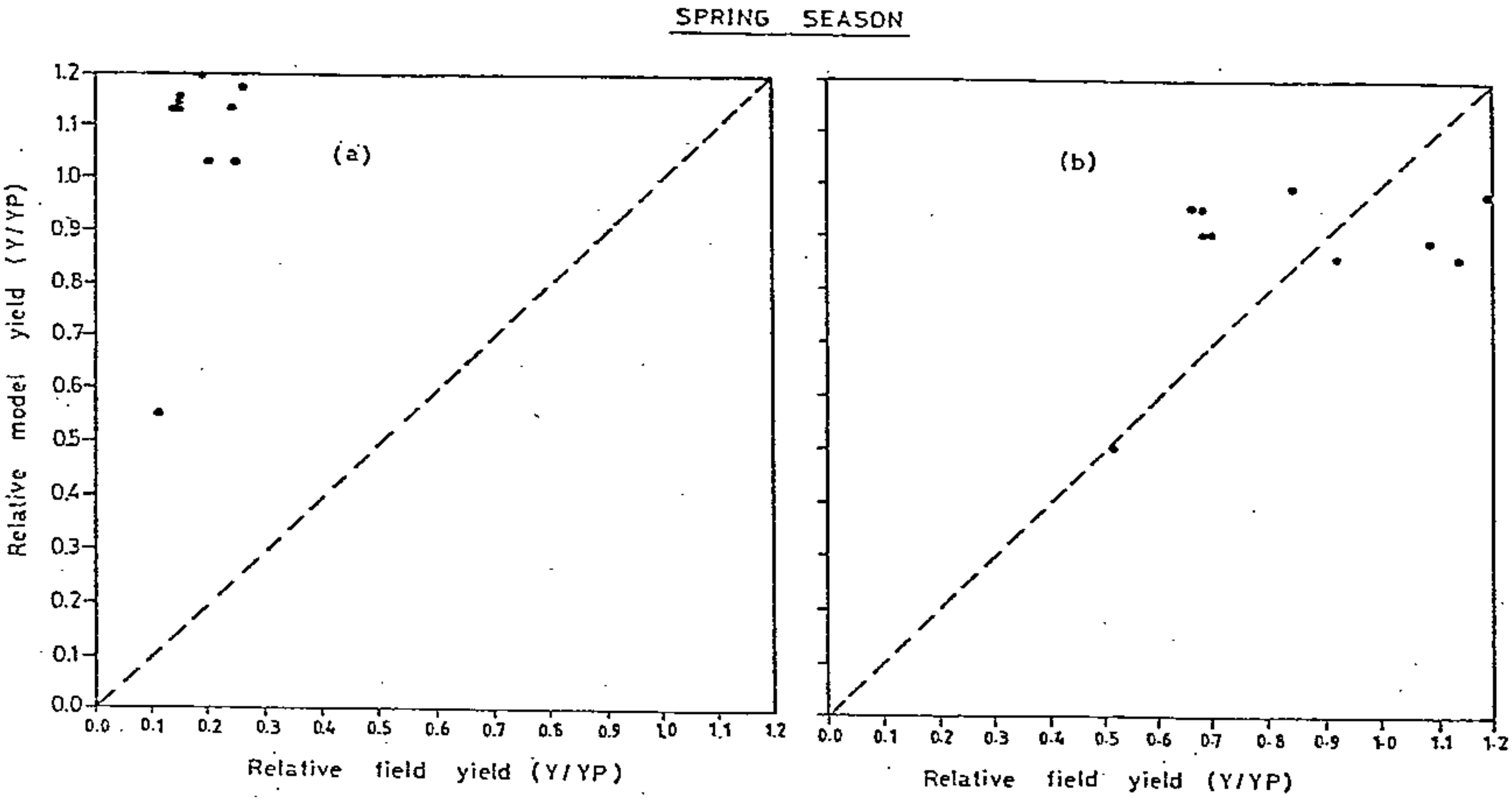

Fig. (12): Relative field yield (Y/Yp) vs. relative model yield using (a) old lambdas (0.00, 1.50, 0.55, and 0.80), and (b) new lambdas (0.00, 0.20, 2.00, and 0.40) for the spring season.

Table (16): Actual yields versus predicted yields obtained by the CRPSM using the new sets of lambdas. Lambdas were 0.0, 1.30, 0.55, 0.79, and 0.0, 0.2, 2.0, 0.4, for the winter and spring seasons, respectively. Maximum attainable field yields were 30 and 10 t/ha for the two respective seasons.

		Season			
		Winter		Spring	
Treatment	Block	Actual Yield (t/ha)	Predicted Yield (t/ha)	Actual Yield (t/ha)	Predicted Yield (t/ha)
30 kPa T1	B1	14.7	*	11.9	9.9
	B2	19.6	25.0	6.9	9.1
	B3	21.6	20.0	8.5	10.0
	B4	21.8	17.8	7.0	9.1
50 kPa T2	B1	14.3	19.3	6.7	9.5
	B2	23.4	22.2	10.9	9.0
	B3	22.5	19.3	5.2	4.0
	B4	26.2	25.6	6.9	9.5
80 kPa T3	B1	27.6	26.9	11.4	8.7
	B2	21.3	21.8	9.3	8.7
	B3	17.6	19.1	5.2	*
	B4	21.4	23.9	4.4	*

* These blocks were eliminated from the calibration because of inconsistency between water use and yields.

4.5.1 APPLICATION OF IRRIGATION SIMULATION MODEL

The calibrated model was used to simulate different irrigation schedules for each season, using the different water management options provided. Several runs were made for each option. Some of the runs were selected. The selected runs were as close as possible to the actual field experiment irrigation schedules. The best run for each option was determined. The best run was the one with the highest percent yield and highest transpiration water ratio (TWR), which eventually resulted in the highest water yield index (WYI), and the lowest deep percolation losses. For practical reasons, the number of irrigations per season was also taken into consideration. Irrigation seasons were from Dec. 8, 1985 to Apr. 1, 1986 and Apr. 15 to June 13, 1986 for the two respective seasons in all simulated runs.

It is worth mentioning that the model does not take effective precipitation into consideration, it considers all rainfall as effective (i.e., no surface runoff). This fact overestimated the TSW and deep percolation losses in all simulated runs. Considering effective rainfall by removing rainfall lower than 5 mm/day affected ET calculations. ET values dropped down by around 1 cm. But in order not to affect the calibration and not to cause underestimation of ET, all runs were based on total rainfall. Would the rainfall values lower than 5 mm/day be removed if rainfall occured in amounts lower than 5 mm/day for 5 or 6 consecutive days ? Wouldn't it be irreasonable to consider them as ineffective ?

4.5.1.1 WATER MANAGEMENT OPTION 1

Tables 17 and 18 show simulated runs using option 1 (finding the best day to irrigate with a specified water increment), for the winter and spring seasons, respectively.

In using this option, the increment of water to be added is specified in addition to the interval between irrigations as well as the maximum expected cycles of irrigation. In all runs, 30 cycles were assumed to be the maximum number of expected irrigations. The model will start adding the specified water increment on a certain day to check its influence on the yield %. Then it will continue adding these increments on different dates in accordance to the specified interval, adding the influence of each increment in accordance to its effect on cumulative yield %. Sometimes the increment is added more than once at a certain date due to the fact that more water is needed so as to increase the yield %.

In general the lower the increment and the shorter the interval, the higher the WYI due to higher TWR (i.e., lower deep percolation losses).

Runs 1 to 5 were selected for the winter season, they were: adding 0.51, 0.76, 1.02, 1.27, and 1.78 cm water increments in intervals of 4, 5, 4, 5, and 5 days, for the five runs, respectively. On the other hand, runs 1 to 4 were selected for the spring season, they were: adding 0.76, 1.02, Table (17): Simulated runs by the calibrated version of the CRPSM using option 1 (Finding the best day to irrigate with a specified increment) for squash planted during the winter season 1985-1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4	5
Increment (cm)	0.51	0.76	1.02	1.27	1.78
Interval (day)	4	5	4	5	5
No. of irrig.	14	9	11	9	9
No. of increments	13	15	12	10	9
Seasonal irrig. water (cm)	11.68	11.43	12.19	12.70	16.00
Actual transp. (cm)	16.49	16.44	16.49	16.49	16.49
Actual evap. (cm)	0.99	0.86	0.90	0.86	0.86
Actual ET^{+} (cm)	17.49	17.30	17.39	17.35	17.35
Deep percolation (cm)	9.92	9.69	9.73	10.35	13.37
DS (cm)	1.40	1.24	0.61	0.67	0.40
TSW* (cm)	27.40	26.99	27.12	27.70	30.72
TWR	0.60	0.61	0.61	0.60	0.54
Yield %	100	99.6	100	100	100
WYI	60	61	61	60	54

+ ETP = 18.88 cm (Tp = 16.49 cm; Ep = 2.39 cm).
* Rainfall used in TSW = 14.31 cm.

Table (18): Simulated runs by the calibrated version of the CRPSM using option 1 (Finding the best day to irrigate with a specified increment) for squash planted during the spring season 1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4
Increment (cm)	0.76	1.02	1.27	1.78
Interval (day)	3	5	4	4
No. of irrig.	11	7	9	9
No. of increments	18	12	14	9
Seasonal irrig. water (cm)	13.72	12.19	17.78	16.00
Actual transp. (cm)	13.52	13.08	13.52	13.52
Actual evap. (cm)	0.80	0.65	0.75	0.75
Actual ET^{+} (cm)	14.32	13.73	14.27	14.27
Deep percolation (cm)	2.52	2.38	7.10	5.33
DS (cm)	1.24	2.04	1.71	1.71
TSW* (cm)	16.84	16.11	21.37	19.60
TWR	0.80	0.81	0.63	0.69
Yield %	100	93.9	100	100
WYI	80	76	63	69

+ ETP = 16.19 cm (Tp = 13.52 cm; Ep = 2.67 cm).

* Rainfall used in TSW = 1.88 cm.

1.27, and 1.78 cm increments in intervals of 3, 5, 4, and 4 days, for the four runs, respectively.

The winter season results did not show any variation with respect to water yield index (WYI) values for the first four runs. A total water supply (TSW) of 27.40, 26.99, 27.12, and 27.7 cm was needed; 11.68, 11.43, 12.19, and 12.70 cm were supplied by irrigation; 9.92, 9.69, 9.73, and 10.35 cm were lost as deep percolation, for the four runs, respectively. Transpiration water ratios (TWR) were 0.60, 0.61, 0.61, and 0.60, accompanied by 100, 99.6, 100, and 100 % yield, which eventually gave water yield indices (WYI) of 60, 61, 61, and 60 for the four respective runs. The fifth run needed a TSW of 30.72 cm which is higher than the previously discussed runs; 16.00 cm was supplied by irrigation; 13.37 cm was lost by deep percolation. TWR was 0.54 to give a 100 % yield, and eventually gave a WYI of 54. The number of irrigations are 14, 9, 11, 9, and 9 for the five runs, respectively. In spite of all the non-difference in all parameters determined for the first four runs, the second run is prefered over the rest due to its lower number of irrigations and lowest irrigation water. The fifth run is not acceptable due to the high irrigation water needed, most of it is lost as deep percolation.

The spring season results gave the following results: a TSW of 16.84, 16.11, 21.37, and 19.60 cm were needed; 13.72, 12.19, 17.78, and 16.00 cm were supplied by irrigation; 2.52, 2.38, 7.10, and 5.33 cm were lost as deep percolation, for the four runs, respectively. All runs produced 100 % yield as a result of having actual transpiration equalling expected crop potential transpiration (13.52 cm) except for run 2 which produced 93.9 % yield as a result of having lower actual transpiration (13.08 cm). TWR were 0.80, 0.81, 0.63, and 0.69. The yield % and TWR eventually resulted in WYI values of 80, 76, 63, and 69 for the four runs, respectively. The results give the following sequence of preference for the four selected runs: runs 1, 2, 4, and 3, arranged from high to low preference as best runs. The number of irrigations of 11 and 7 for runs 1 and 2 is a crucial factor, but in this case, WYI values are also decisive.

The dates and amounts of irrigation for the five runs of the winter season are: January 25 (0.51), 31 (0.51), February 21 (1.02), 24 (0.51), 27 (0.51), and March 2 (0.51), 5 (2.55), 8 (0.51), 11 (0.51), 14 (1.53), 17 (0.51), 20 (1.02), 23 (0.51), and 26 (and 1.02 cm), for run 1, January 27 (0.76), February 21 (0.76), 26 (1.52), and March 3 (2.28), 8 (0.76), 13 (1.52), 18 (1.52), 23 (1.52), and 28 (and 0.76 cm), for run 2, January 29 (1.02), February 22 (1.02), 26 (1.02), and March 2 (2.03), 6 (1.02), 10 (1.02), 14 (1.02), 18 (1.02), 22 (1.02), 26 (1.02), and 30 (1.02), for run 3, and January 27 (1.27), February 21 (1.27), 26 (1.27), and March 3 (1.27), 8 (1.27), 13 (1.27), 18 (1.27), 23 (2.54), and 28 (and 1.27 cm), for run 4, January 27 (1.78), February 21 (1.78), 26 (1.78), and March 3 (1.78), 8 (1.78), 13 (1.78), 18 (1.78), 23 (1.78), and 28 (and

1.78 cm), for run 5. The dates and amounts of irrigation for the four runs of the spring season are: May 9 (0.76), 15 (0.76), 21 (0.76), 24 (1.52), 27 (1.52), 30 (0.76), and June 2 (2.28), 5 (0.76), 8 (1.52), and 11 (and 1.52 cm), for run 1, May 10 (1.02), 15 (1.02), 20 (2.03), 25 (2.03), 30 (2.03), and June 4 (2.03), and 9 (and 2.03 cm), for run 2, May 9 (1.27), 13 (1.27), 17 (1.27), 21 (1.27), 25 (2.54), 29 (2.54), and June 2 (2.54), 6 (2.54), and 10 (and 2.54 cm), for run 3, and May 9 (1.78), 13 (1.78), 17 (1.78), 21 (1.78), 25 (1.78), 29 (1.78), and June 2 (1.78), 6 (1.78), and 10 (and 1.78 cm), for run 4.

4.5.1.2 WATER MANAGEMENT OPTION 2

Tables 19 and 20 show simulated runs using option 2 (irrigating at a specified interval with fixed amount) for the winter and spring seasons, respectively.

The selected runs (1 to 4) are adding 0.76, 1.02, 1.27, and 1.78 cm with an interval of 3, 4, 5, and 7 days and 2, 3, 4, and 5 days for the winter and spring seasons. These were the best runs determined for each fixed amount added.

The winter season results reveal that with almost the same total seasonal irrigation water added in the four runs, there were no differences in WYI as a result of the non-difference in TWR and yield %. The crucial factor in determining the best amount with a specified interval is the number of irrigations. Total supply of water were 44.33, 44.39, 44.55, and 44.84 cm; 29.70, 29.46, 29.21, and 30.23 cm were supplied by irrigation;

Table (19): Simulated runs by the calibrated version of the CRPSM using option 2 (irrigating at a specified interval with a fixed amount) for squash planted during the winter season 1985-1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4
Amount/irrig. (cm)	0.76	1.02	1.27	1.78
Interval (day)	3	4	5	7
No. of irrig.	39	29	23	17
Seasonal irrig. water (cm)	29.70	29.46	29.21	30.23
Actual transp. (cm)	16.49	16.49	16.45	16.14
Actual evap. (cm)	1.55	1.43	1.26	1.03
Actual ET+ (cm)	18.04	17.92	17.71	17.17
Deep percolation (cm)	26.29	26.46	26.84	27.67
DS (cm)	0.30	0.61	1.03	0.30
TSW* (cm)	44.33	44.39	44.55	44.84
TWR	0.37	0.37	0.37	0.36
Yield %	100	100	99.6	97.5
WYI	37	37	37	35

+ ETP = 18.88 cm (Tp = 16.49 cm; Ep = 2.39 cm).
* Rainfall used in TSW = 14.31 cm.

Table (20): Simulated runs by the calibrated version of the CRPSM using option 2 (irrigating at a specified interval with a fixed amount) for squash planted during the spring season 1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4
Amount/irrig. (cm)	0.76	1.02	1.27	1.78
Interval (day)	2	3	4	5
No. of irrig.	30	20	15	12
Seasonal irrig. water (cm)	22.86	20.32	19.05	21.34
Actual transp. (cm)	13.52	13.19	12.66	12.88
Actual evap. (cm)	2.04	1.61	1.40	1.17
Actual ET+ (cm)	15.56	14.80	14.06	14.05
Deep percolation (cm)	10.63	9.55	9.19	11.39
DS (cm)	1.44	2.14	2.31	2.22
TSW* (cm)	26.18	24.35	23.24	25.44
TWR	0.52	0.54	0.54	0.51
Yield %	100	98.2	95.3	92.8
WYI	52	53	52	47

+ ETP = 16.19 cm (Tp = 13.52 cm; Ep = 2.67 cm).
* Rainfall used in TSW = 1.88 cm.

as much as 26.29, 26.46, 26.84, and 27.67 cm were lost as deep percolation, for the four runs, respectively. Water yield indices (WYI) obtained were 37, 37, 37, and 35 as a result of transpiration water ratios (TWR) of 0.37, 0.37, 0.37, and 0.36 and yields of 100, 100, 99.6, and 97.5 percents, for the four runs, respectively. The number of irrigations are 39, 29, 23, and 17 for the four respective runs, thus making the decision of selecting the best run going for run 3 which is the one with the lowest number of irrigations and highest WYI.

The spring season results gave similar trend, where TSW were 26.18, 24.35, 23.24, and 25.44 cm; 22.86, 20.32, 19.05, and 21.34 cm were supplied by irrigation; 10.63, 9.55, 9.19, and 11.39 cm were lost as deep percolation, for the four runs respectively. Water yield indices (WYI) of 52, 53, 52, and 47 were obtained as a result of TWR of 0.52, 0.54, 0.54, and 0.51 accompanied with 100, 98.2, 95.3, and 92.8 yield percents, for the four runs, respectively. The number of irrigations are 30, 20, 15, and 12 for the four respective runs. Run 2 is the best run because it is having the highest WYI and lowest number of irrigations possible. The low value of WYI obtained for run 4 is attributed to low yield % which was due to low actual transpiration. Water was not added at the suitable time to meet crop's actual needs.

This option always provide low WYI values especially in rainy seasons, because rainfall amounts are not taken into consideration in this option, thus irrigation takes place on the basis of fixed interval regardless of rainfall during days of irrigation.

4.5.1.3 WATER MANAGEMENT OPTION 3

Tables 21 and 22 show simulated runs using option 3 (irrigating on specified dates with specified amounts), for the winter and spring seasons, respectively.

The actual dates and amounts of irrigation were those obtained from the field experiment (Appendices 1 and 2).

The obtained results proved that the model estimated actual evapotranspiration is close to that determined by neutron probe measurements. Table 23 shows model estimated ET versus neutron probe (actual) ET for the winter and spring seasons. The actual and model ET values averaged 12.79 vs. 14.36 cm, for T1; 12.75 vs. 13.67 cm, for T2; and 12.44 vs. 14.62 cm, for T3 treatment, respectively, for the winter season. As far as the spring season results are concerned, averages of 15.18 vs. 14.43 cm, for T1; 13.98 vs. 13.67 cm, for T2; and 14.97 vs. 12.93 cm, for T3, for actual and model estimated ET values, respectively.

It can be seen that in the winter season the model estimated ET values were higher than the actual. This could be attributed to the non-consideration of effective precipitation. On the other hand, model and actual ET values were almost the same for the spring season, especially in the cases of T1 and T2. Meanwhile, in the case of T3, the actual values were higher

Table (21): Model calculated soil moisture budget parameters for squash grown in the Jordan Valley under three different irrigation schedules (30 kPa, T1, 50 kPa, T2, and 80 kPa, T3) during the winter season 1985-1986 (based on a maximum root depth of 30 cm).

		Parameter +					
Treatment	Block	I (cm)	DS (cm)	@ TSW (cm)	DP (cm)	ET (cm)	# WAE (%)
30 kPa T1	B1	11.39	2.04	27.81	11.78	16.39	58.9
	B2	11.00	1.75	27.13	11.68	15.56	57.4
	B3	9.58	2.01	25.97	12.85	13.12	50.5
	B4	6.48	2.03	22.89	10.52	12.36	54.0
	AVG	* 9.61a	1.96a	25.95a	11.71a	14.36a	55.2a
50 kPa T2	B1	7.52	2.08	23.98	11.10	12.89	53.8
	B2	9.72	2.11	26.21	13.01	13.20	50.4
	B3	8.49	1.97	24.84	11.86	12.98	52.3
	B4	12.78	0.78	27.95	12.33	15.62	55.9
	AVG	9.63a	1.74a	25.75a	12.08a	13.67a	53.1a
80 kPa T3	B1	14.71	1.42	30.51	14.28	16.26	53.3
	B2	9.47	1.42	25.27	11.03	13.70	54.2
	B3	8.58	1.76	24.72	11.66	13.08	52.9
	B4	10.86	1.58	26.82	10.76	15.44	57.6
	AVG	10.91a	1.55a	26.83a	11.93a	14.62a	54.5a
F Test		ns	ns	ns	ns	ns	ns

\+ I = irrigation; DS = soil moisture change; TSW = I + R + DS; DP = deep percolation; ET = TSW - DP.

@ Rainfall used in TSW = 14.31 cm (all rainfall is considered as effective).

WAE = 100 x ET/TSW.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

Table (22): Model calculated soil moisture budget parameters for squash grown in the Jordan Valley under three different irrigation schedules (30 kPa, T1, 50 kPa, T2, and 80 kPa, T3) during the spring season 1986 (based on a maximum root depth of 30 cm).

		Parameter +					
Treatment	Block	I (cm)	DS (cm)	@ TSW (cm)	DP (cm)	ET (cm)	# WAE (%)
30 kPa T1	B1	25.07	1.71	28.66	14.21	14.46	51.0
	B2	19.79	1.71	23.41	9.04	14.37	61.0
	B3	21.95	1.71	25.54	10.87	14.67	57.0
	B4	19.31	1.71	22.92	8.72	14.20	62.0
	AVG	21.53a *	1.71a	25.13a	10.71a	14.43a	58.0a
50 kPa T2	B1	19.01	1.71	23.10	9.11	14.00	61.0
	B2	16.39	1.71	20.49	6.54	13.95	68.0
	B3	12.93	1.71	17.01	4.30	12.71	75.0
	B4	20.24	1.71	24.32	10.33	14.00	58.0
	AVG	17.14a	1.71a	21.23a	7.57a	13.67b	66.0a
80 kPa T3	B1	19.45	1.71	23.05	9.84	13.21	57.0
	B2	20.53	1.71	24.12	10.91	13.21	55.0
	B3	15.34	1.71	19.45	6.72	12.73	66.0
	B4	16.74	1.71	20.82	8.25	12.57	60.0
	AVG	18.02a	1.71a	21.86a	8.93a	12.93b	60.0a
F Test		ns	ns	ns	ns	**	ns

+ I = irrigation; DS = soil moisture change; TSW = I + R + DS; DP = deep percolation; ET = TSW - DP.

@ Rainfall used in TSW = 1.88 cm (all rainfall is considered as effective).

WAE = 100 x ET/TSW.

* Along each column, values followed by the same letter are not significantly different at the 5% level, according to DMRT.

** Significant difference at P= .05.

Table (23): Model estimated evapotranspiration vs. neutron probe (actual) ET for the winter and spring seasons.

Treatment	Block	Winter		Spring	
		Actual	Model	Actual	Model
30 kPa T1	B1	16.04	16.39	15.34	14.46
	B2	10.27	15.56	14.17	14.37
	B3	12.42	13.12	16.40	14.67
	B4	12.41	12.36	14.80	14.20
	AVG	12.79	14.36	15.18	14.43
50 kPa T2	B1	14.97	12.89	15.45	14.00
	B2	11.24	13.20	13.50	13.95
	B3	9.31	12.98	9.79	12.71
	B4	15.48	15.62	17.19	14.00
	AVG	12.75	13.67	13.98	13.67
80 kPa T3	B1	17.23	16.26	16.10	13.21
	B2	11.15	13.70	17.88	13.21
	B3	7.44	13.08	11.31	12.73
	B4	13.95	15.44	14.60	12.57
	AVG	12.44	14.62	14.97	12.93

than the model values due to the assumption made that the maximum root depth is only 30 cm, in the case of the model. Some depletions occured in the lower layer in the actual field experiment.

Other parameters such as DP and WAE were different between the model and the actual field experiment for the winter season, due to the above mentioned reasoning concerning effective precipitation. Spring season results showed close agreement between model and actual values for $\overline{\mathrm{WAE}}$, averaging 63.7 and 58 %, for T1, and 69.3 and 66 %, for T2 treatments, for actual and model predicted, respectively. T3 treatment gave a value of 71.5 and 60.0 % for the actual and model values, respectively. Also, this might be attributed to the previously discussed depletion from below 30 cm layer in the actual field experiment.

4.5.1.4 WATER MANAGEMENT OPTION 4

Tables 24 and 25 show some of the simulated runs using option 4 (irrigating at a specified depletion with a fixed amount) for the winter and spring seasons, respectively.

In general, this option always provides the best results in comparison to the previously discussed options 1 and 2.

Runs 1 to 4 are adding 0.76, 1.02, 1.27, and 1.78 cm of water upon 0.76, 1.02, 1.27, and 1.78 cm depletion.

As far as the winter season simulated runs are concerned, the first three runs needed a total supply of water (TSW) of

Table (24): Simulated runs by the calibrated version of the CRPSM using option 4 (irrigating at a specified depletion with a fixed amount) for squash planted during the winter season 1985-1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4
Amount/irrig. (cm)	0.76	1.02	1.27	1.78
Depletion (cm)	0.76	1.02	1.27	1.78
No. of irrig.	18	13	10	7
Seasonal irrig. water (cm)	13.72	13.21	12.70	12.45
Actual transp. (cm)	16.49	16.49	16.48	16.01
Actual evap. (cm)	1.03	0.95	0.87	0.74
Actual ET[+] (cm)	17.52	17.44	16.35	16.75
Deep percolation (cm)	10.85	10.42	9.96	10.37
DS (cm)	0.34	0.34	0.30	0.34
TSW[*] (cm)	28.37	27.86	27.31	26.52
TWR	0.58	0.59	0.60	0.59
Yield %	100	100	99.8	88.9
WYI	58	59	60	53

[+] ETP = 18.88 cm (Tp = 16.49 cm; Ep = 2.39 cm).

[*] Rainfall used in TSW = 14.31 cm.

Table (25): Simulated runs by the calibrated version of the CRPSM using option 4 (irrigating at a specified depletion with a fixed amount) for squash planted during the spring season 1986 under black plastic mulch and drip irrigation in the Jordan Valley.

Run	1	2	3	4
Amount/irrig. (cm)	0.76	1.02	1.27	1.78
Depletion (cm)	0.76	1.02	1.27	1.78
No. of irrig.	18	12	10	6
Seasonal irrig. water (cm)	13.72	12.19	12.70	10.67
Actual transp. (cm)	13.52	13.52	13.47	12.60
Actual evap. (cm)	1.05	0.82	0.72	0.54
Actual ET+ (cm)	14.57	14.34	14.19	13.14
Deep percolation (cm)	1.68	0.98	0.89	0.91
DS (cm)	0.65	1.24	0.50	1.49
TSW* (cm)	16.25	15.32	15.09	14.05
TWR	0.83	0.88	0.89	0.90
Yield %	100	100	99.7	77.2
WYI	83	88	89	70

+ ETP = 16.19 cm (Tp = 13.52 cm; Ep = 2.67 cm).

* Rainfall used in TSW = 1.88 cm.

28.37, 27.86, and 27.31 cm; 13.72, 13.21, and 12.70 cm were supplied from irrigation; 10.85, 10.42, and 9.96 cm of the TSW were lost as deep percolation, for the three runs, respectively. Transpiration water ratios (TWR) were 0.58, 0.59, and 0.60, accompanied by 100, 100, and 99.8 % yield, which eventually gave a water yield index (WYI) of 58, 59, and 60 for the three respective runs. On the other hand, the spring season runs needed a TSW of 16.25, 15.32, and 15.09 cm; 13.72, 12.19, and 12.70 cm were supplied by irrigation; only 1.68, 0.98, and 0.89 cm were lost as deep percolation. TWR were 0.83, 0.88, and 0.89, accompanied by 100, 100, and 99.7 % yield which eventually gave a WYI of 83, 88, and 89 for the three runs, respectively.

No tangeable variation is noticed between the three runs during each season except for a crucial managemental factor which is the number of irrigations. The irrigation water was supplied in 18, 13, and 10 irrigations during the winter season and in 18, 12, and 10 irrigations during the spring season, for the three runs, respectively.

The fourth run gave a lower WYI (53 and 70) as a result of lower yield % (77.2 and 88.9) during the winter and spring seasons, respectively. TWR (0.59 and 0.9) were not low when compared to the first three runs, but total water taken into transpiration process was lower than the first three runs, thus causing drop in the yield % obtained.

Its worth mentioning that from other runs made for this option, TWR can be increased by reducing the amount added in comparison to the amount depleted. This condition will improve water utilization as transpiration but with slight decrease in yield %. Some times this leads to a slightly higher WYI and lower deep percolation losses.

Also, it can be noticed that some reduction in evaporation losses could be obtained if we increase the amount of water depleted (i.e., reducing the number of irrigations) and this is attributed to lower wet surface evaporation (Hill et al., 1983). Runs 1 to 4 resulted in 1.03, 0.95, 0.87, and 0.74 cm and 1.05, 0.82, 0.72, and 0.54 cm losses as evaporation for the four respective runs, for the winter and spring seasons, respectively.

The dates of irrigation for the four runs of the winter season were: January 26, February 1, 13, 20, 23, 26, and March 1, 4, 7, 9, 12, 14, 17, 20, 22, 24, 27, and 29, for run 1, January 29, February 4, 21, 25, and March 1, 5, 9, 12, 16, 19, 23, 26, and 29, for run 2, January 31, February 22, 27, March 4, 9, 13, 18, 22, 27, and April 1, for run 3, February 5, 24, and March 3, 10, 17, 23, 1nd 29, for run 4. The dates of irrigation for the runs of the spring season were: April 30, May 9, 13, 17, 19, 22, 24, 26, 28, 30, and June 1, 2, 4, 6, 8, 9, 11, and 13, for run 1, May 10, 15, 19, 22, 26, 29, 31, and June 2, 5, 7, 9, and 11, for run 2, May 12, 18, 22, 26, 29, 31, and June 1, 4, 7, 10, and 13, for run 3, May 17, 23, 28, and June 2, 6, and 11, for run 4.

4.5.2 CRPSM FOR SQUASH: ITS PRESENT & FUTURE APPLICATIONS IN JORDAN

The development of models is a difficult task that requires a lot of experience on the part of the modeler as well as effort and time. In developing countries such as Jordan, and as a step in technology transfer and application, testing, calibration and use of existing models is more reasonable than spending time in developing new ones. The introduction of irrigation scheduling models to Jordan could be usefull in helping farmers and eventually optimizing water allocation and use efficiency.

The results obtained in this research give more confidence in using the CRPSM for squash in the Jordan Valley. The CRPSM once calibrated for a certain season and a certain location can provide a suitable tool for yield prediction as well as estimating crop water consumption.

So far, the model has been used to simulate irrigation schedules and predict yields for past experiments. Some recommended steps should be followed so as to make the model more applicable and suitable for farmer use, they are:

1- To test the model on larger field plots, with different varieties and possibly plant spacings.

2- To test the model under different irrigation systems such as surface and sprinkler irrigation.

3- To try using the model in other locations in the Jordan Valley, other than the University of Jordan Research Station.

4- To apply the model on different regions in Jordan.

5- To test simulated runs by the model in field against the common irrigation scheduling techniques (by the use of tensiometers and neutron probes).

6- To find a more convenient and practical method for estimating effective precipitation to be incorporated in the CRPSM, considering the fact that rainfall in the Valley can occur daily with around 5 mm/day rainfall.

5- SUMMARY, CONCLUSIONS & RECOMMENDATIONS

This study was carried out in the Research Station of the University of Jordan located in the central region of the Jordan Valley during the winter season (December 8, 1985 - April 1, 1986) and the spring season (April 15, 1986 - June 13, 1986) with the objectives of studying the effect of three different irrigation schedules (30, 50, and 80 kPa) of squash (Cucurbita pepo l.) under black plastic mulch and drip irrigation on yield, root growth and distribution, and water requirements.

The crop yield and soil water management simulation model (CRPSM) developed at Utah State University by Hill et al. (1984a and 1984b) and modified later on by Battikhi and Hill (1986a) for squash in the Jordan Valley was tested using the field data obtained in this study.

The results can be summarized as follows:

1- Yield, fruit number, and fruit weight did not vary under the three treatments for both winter and spring seasons. Yields of the winter season were almost double that obtained during the spring season. Average yields were 19.4, 21.6, and 22.0 t/ha during the winter season and 8.6, 7.4, and 7.6 t/ha during the spring season, for the 30, 50, and 80 kPa treatments, respectively.

2- Number of irrigations was significantly lower in the 80 kPa treatment when compared to the 30 kPa treatment during the winter season. During the spring season significant differences in the number of irrigations were revealed between the 30 and 50 kPa and the 30 and 80 kPa treatments.

3- No significant differences were found between treatments with respect to irrigation amounts, total water supply, crop water consumption (ET), water application efficiency, and water use efficiency during the winter and spring seasons. Lower water consumption occured during the winter season when compared to the spring season although the latter was 59 days and the former was 114 days. Crop water consumption, ET, for the 30, 50, and 80 kPa treatments averaged 12.79, 12.75, and 12.44 cm, respectively, during the winter season and 15.18, 13.98, and 14.97 cm, respectively, during the spring season. Higher water use efficiency was obtained during the winter season. Average water use efficiencies for the 30, 50, and 80 kPa treatments were 1.58, 1.79, and 1.88 t/ha/cm and 0.56, 0.58, and 0.51 t/ha/cm for the winter and spring seasons, respectively.

4- No significant differences were detected between treatments with respect to vertical (tap and secondary) and horizontal roots as well as oven-dry root weights during winter and spring seasons. Vertical roots reached maximum averages of 27.0 and 31.4 cm during the winter and spring seasons, respectively.

5- Recalibration of the yield portion of the crop yield and soil water management simulation model (CRPSM) for squash during the winter and spring seasons using new values of maximum attainable field yields resulted in new sets of growth stage weighing factors (lambdas). Better calibration was obtained during the winter season than during the spring season due to the less occurence of disease and due to the relatively high temperature effects during the spring season. The different water management options provided by the model were tested to select the best irrigation schedules that will maximize yields and optimize water use efficiency and cut down field trials to be tested in future studies, therefore lowers costs and time to be spent on such studies.

The obtained results lead to the following recommendations:

1- Under similar field conditions, irrigation at 80 kPa tensiometer reading is recommended.

2- For the purposes of irrigation water application, a 30 cm maximum root depth is recommended.

3- Since a layer of around 15 cm below the root was found to be subjected to water extraction, more attention should be focused on determining root-water extraction power.

4- More squash field experiments, for different growing seasons, are needed in order to achieve better yield prediction by the CRPSM.

LITERATURE CITED

1- Abdul-Jabbar, A.S., T.W. Sammis, and D.G. Lugg. 1982. Effect of moisture level on the root pattern of alfalfa. Irrig. Sci. 3:197-207.

2- Battikhi, A.M., and I. Ghawi. 1986a. Squash (<u>Cucurbita pepo</u> L.) production under mulch and trickle irrigation in the Jordan Valley. Submitted for publication to Dirasat, University of Jordan.

3- Battikhi, A.M., and I. Ghawi. 1986b. Cantaloupe (<u>Cucumis melo</u> L.) production under mulch and trickle irrigation in the Jordan Valley. Accepted for publication in HortScience.

4- Battikhi, A.M., and R.W. Hill. 1986a. Squash yield and irrigation scheduling model for the Jordan Valley. Submitted for publication to TRANSACTIONS of ASAE.

5- Battikhi, A.M., and R.W. Hill. 1986b. Cantaloupe yield and irrigation scheduling model for the Jordan Valley. Submitted for publication to Agricultural Water Management.

6- Battikhi, A.M., and R.W. Hill. 1986c. Cucumber yield and irrigation scheduling model for the Jordan Valley. Submitted for publication to SSSAJ.

7- Battikhi, A.M., and R.W. Hill. 1986d. Watermelon yield and irrigation scheduling model for the Jordan Valley. J. Agronomy & Crop Science, 157:145-155.

8- Battikhi, A., O. Judah, and M.A. Suwwan. 1985. Irrigation scheduling of tomatoes grown under drip-irrigation inside plastic greenhouses in the Jordan Valley. Dirasat vol. 12 pp. 35-46, Univ. of Jordan, Amman, Jordan.

9- Bennett, L.L., D.A. Ashley, and B.D. Doss. 1966. Cotton responses to black plastic mulch and irrigation. Agron. J. 58:57-60.

10- Bhella, H.S., and W. F. Kwolek. 1984. The effects of trickle irrigation and plastic mulch on Zucchini. HortScience 19:410-411.

11- Bower, C.A., and L.V. Wilcox. 1965. Soluble salts. In C.A. Black (ed.). Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agron. Amer. Soc. Madison, Wisconsin. pp. 935-937.

12- Day, P.R. 1965. Particle fractionation and particle size analysis. In C.A. Black (ed.). Methods of Soil Analysis. Part 1. Physical and mineralogical properties. Agron. Amer. Soc. Madison, Wisconsin, pp 545-566.

13- Doorenbos, J., and W.O. Pruitt. 1974. Crop water requirements. FAO Irrig. and Drainage Paper No. 24. Rome.

14- El-Zuraiqi, S.M.S. 1986. The effect of soil moisture tension and frequency of nitrogen application on growth and yield components of tomatoes grown under plastic houses in the Jordan Valley. M.S. Thesis, University of Jordan, Amman, Jordan.

15- Geiser, K.M., D.C. Slack, E.R. Allred and, K.W. Stange. 1982. Irrigation scheduling using crop canopy-air temperature difference. TRANSACTIONS of the ASAE 25(3):689-694.

16- Ghawi, I., and A.M. Battikhi. 1986a. Cucumber (Cucumis sativis) production under mulch and trickle irrigation in the Jordan Valley. Under publication.

17- Ghawi, I., and A.M. Battikhi. 1986b. Watermelon (Citrullus lanatus) production under mulch and trickle irrigation in the Jordan Valley. J. Agronomy & Crop Science 156:225-236.

18- Gregory, J.M., and R.W. Schottman. 1982. Irrigation scheduling procedure for subhumid areas. TRANSACTIONS of the ASAE 25(5):1290-1294.

19- Halevy, A.H. 1972. Water stress and the timing of irrigation. HortScience 7:113-114.

20- Hanks, R.J. 1974. Model for predicting plant yields as influenced by water use. Agron. J. 66:660-664.

21- Hanks, R.J., J.C. Anderson, R.W. Hill, E.A. Richardson, P.V. Rasmussen, and D.L. Snyder. 1984. Optimal agricultural management systems to improve farm/ranch profits: An integrated soil-water-climate-crop modeling approach. Utah Agr. Exp. Sta. Res.

22- Hawatmeh, N., and A.M. Battikhi. 1983. Wetting front under a trickle irrigation source in some soils of the Jordan Valley. Dirasat vol. 10 pp. 17-31, Univ. of Jordan, Amman, Jordan.

23- Hill, R.W., A.L. Huber, E.K. Israelsen, and J. Riley. 1972. A self-verifying hybrid computer model of river basin hydrology. Water Resources Bulletin AWRA. Vol. 8, No. 5. October.

24- Hill, R.W., D.R. Johnson, and K.H. Ryan. 1979. A model for predicting soybean yields from climatic data. Agron. J. 71:251-256.

25- Hill, R.W., E.L. Johns, and K.K. Frevert. 1983. Comparison of equations used for estimating agricultural crop evapotranspiration with field research. Bureau of Reclamation, U.S. Dept. of the Interior.

26- Hill, R.W., R.J. Hanks, and J.L. Wright. 1984a. Crop yield models adapted to irrigation scheduling programs. Final Report USDA-SEA/AR. Cooperative Research No. 58-9AHZ-9-440. Utah Agric. Exp. St. Res. Rept. No. 99. Utah State University, Logan, Utah 84322.

27- Hill, R.W., A.A. Keller, and B. Boman. 1984b. Crop yield models adapted to irrigation scheduling programs. Appendix F. CRPSM User Manual and Sample Input and Output. USDA-SEA /AR Cooperative Research No. 58-9AHZ-9-440. Utah Agric. Exp. St. Proj. No. 796, Utah State University, Logan, Utah 84322.

28- Jensen, J.E. 1968. Water consumption by agricultural plants p. 48 in T.T. Kozlowski (ed.) Water Deficits and Plant Growth, vol. 2. Academic Press, N.Y.

29- Khanjani, M.J., and J.R. Bush. 1982. Optimal irrigation water use from probability and cost-benefit analyses.TRANSACTIONS of the ASAE 25(4):961-965.

30- Kramer, P.J. 1969. Plant & Soil Water Relationships: A Modern Synthesis. pp. 104-149. McGraw-Hill Inc., N.Y.

31- Little, T.M., and F.J. Hills. 1978. Agicultural Experimentation: Design and Analysis. Published by John Wiley and Sons, New York.

32- Mackay, A.D., and S.A. Barber. 1985. Soil moisture effects on root growth and phosphorous uptake by corn. Agron. J. 77:519-523.

33- Molz, F.J., and I. Remson. 1971. Application of an extraction-term model to the study of moisture flow to plant roots. Agron. J. 63:72-77.

34- NWMP (National Water Master Plan of Jordan). 1977. Prepared by GTZ, Hanover, Germany to the Natural Resources Authority, Amman, Jordan, vols 1 to 6.

35- Osmond, D.L., and C.R. Raper. 1982. Root development of field-grown flue-cured tobacco. 1982. Agron. J. 74:541-546.

36- Peacock, C.H., and A.E. Dudeck. 1985. Effect of irrigation interval on St. Augustinegrass rooting. Agron. J. 77:813-815.

37- Peech, M. 1965. Hydrogen ion activity. In C.A. Black (ed.). Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Agron. Amer. Soc. Madison, Wisconsin pp. 914-926.

38- Peters, D.B., and L.C. Johnson. 1962. Soil moisture use by soybeans. Agron. J. 52:687-689.

39- Proffitt, A.P.B., P.R. Berliner, and D.M. Oosterhuis. 1985. A comparative study of root distribution and water extraction by wheat grown under high- and low-frequency irrigation. Agron. J. 77:655-662.

40- Richards, S.J. 1965. Soil suction measurements with tensiometers. In C.A. Black (ed.) Methods of Soil Analysis. Part 1. Physical and mineralogical properties. Agron. Amer. Soc. Madison, Wisconsin. pp. 153-163.

41- Rojiani, K.B., B.B. ross, F.E. Woeste, and V.O. Shanholtz. 1982. A probabilistic model for assessment of plant water availability. TRANSACTIONS of the ASAE 25(6):1576-1581.

42- Shatanawi, M.R. 1986a. Efficiency of the Jordan Valley irrigation system. Dirasat vol. 13 pp. 121-142, Univ. of Jordan, Amman, Jordan.

43- Shatanawi, M.R. 1986b. Trickle irrigation and its effect on squash yield, root development and soil salinity. Accepted for publication in Dirasat, Univ. of Jordan, Amman - Jordan.

44- Shatanawi, M.R., I. Ghawi, R. Sharaiha, and M. Duwayri. 1986. Water consumption of wheat and barley in the Jordan Valley. Accepted for publication in Dirasat, Univ. of Jordan, Amman, Jordan. (In Arabic).

45- Smittle, D.A., and E.D. Threadgill. 1982. Response of squash to irrigation, nitrogen fertilization, and tillage systems. J. Amer. Soc. Hort. Sci. 107:437-440.

46- Stanhill, G. 1957. The effect of difference in soil-moisture status on plant growth: A review and analysis of soil moisture regime experiments. Soil Sci. 84:205-214.

47- Taylor, S.A., and G.L. Aschroft. 1972. Physical edaphology. W.H. Freeman and Company, San Francisco, USA.

48- Taylor, H.M. and B. Klepper. 1971. Water uptake by cotton roots during an irrigation cycle. Aust. J. Biol. Sci. 24:853 -859.

49- Thompson, H.C., and W.C. Kelly. 1985. Vegetable Crops. 5th ed., published by Tata McGraw-Hill Publishing Company.

50- Van Bavel, C., D.R. Nielson, and J.M. Davidson. 1961. Calibration and characteristics of two neutron moisture probes. SSSAP 5:329-334.

51- Wright, J.L. 1982. New evapotranspiration crop coefficients. Journal of the Irrigation and Drainage Division, ASAE, vol. 108, pp. 57-74.

Appendix (1): Dates, Da, depths, Dp (cm), and number, N, of irrigations for the 30 kPa, T1, 50 kPa, T2, 80 kPa, T3, treatments for winter season (December 8, 1985 - April 1, 1986).

Treatment	30 kPa, T1								50 kPa, T2								80 kPa, T3							
Block	1		2		3		4		1		2		3		4		1		2		3		4	
Month	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp
Dec.	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3	12	1.3
Jan.	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6
	5	0.9	5	0.9	5	1.5	5	0.5	5	0.7	5	1.3	5	1.4	5	0.7	5	0.7	5	0.6	5	1.7		
	23	1.2	23	1.0	23	0.2	23	0.1	23	0.7			23	0.7	23	0.7	23	0.7	23	0.7				
Feb.	25	1.3	25	1.5	25	1.3	25	1.3	25	1.5	25	1.3	25	1.5			25	3.0			25	1.5	25	1.5
March	4	0.8	4	0.8	4	0.8	4	0.8	6	0.5	6	1.5	6	0.3	6	2.5	9	1.1	9	1.3	16	2.1	9	2.8
	9	1.3	9	0.8	9	0.3	13	1.1	13	1.4	16	1.4	11	0.4	13	2.3	13	2.9	16	2.7	27	1.4	18	2.7
	13	1.3	13	0.9	11	0.6	25	0.8	20	0.9	20	1.3	16	0.3	18	2.0	18	2.4	25	2.4			27	2.0
	18	1.6	20	1.8	13	0.6					27	0.9	18	0.3	23	1.3	27	2.0						
	23	1.0	23	1.4	16	0.3							20	0.4	27	1.3								
					18	0.3							23	0.7										
					20	0.4							25	0.6										
					23	0.3																		
Total	N=10	11.4	N=10	11.1	N=14	9.6	N=8	6.3	N=8	7.5	N=8	9.7	N=12	8.5	N=9	12.8	N=9	14.7	N=7	9.3	N=7	8.6	N=6	10.9

Appendix (2): Dates, Da, depths, Dp (cm), and number, N, of irrigations for the 30 kPa, T1, 50 kPa, T2, 80 kPa, T3, treatments for spring season (April 15 - June 13, 1985).

Treatment	30 kPa, T1								50 kPa, T2								80 kPa, T3							
Block	1		2		3		4		1		2		3		4		1		2		3		4	
Month	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp	Da	Dp
Apr.	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3	20	1.3
	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3	27	1.3
May	8	2.0	8	1.2	8	0.9	8	0.9	11	2.9	11	1.3	13	1.0	11	3.4	11	2.7	11	2.8	18	2.3	11	2.8
	11	1.4	13	1.3	13	1.4	11	1.2	18	1.8	13	0.8	22	1.5	18	1.8	16	2.4	16	2.4	22	2.0	18	2.3
	16	1.9	16	1.2	19	1.6	16	1.5	22	2.9	16	1.2	27	2.1	22	2.3	22	3.0	22	3.2	27	2.9	27	2.8
	18	1.5	22	2.3	22	1.9	22	2.5	27	2.5	22	1.9			27	2.7	29	3.2	29	3.4				
	22	3.0	25	1.6	25	1.9	27	2.4			27	2.5												
	27	2.8	27	1.7	27	1.6																		
					29	1.7																		
Jun.	1	2.9	1	2.0	1	1.3	1	2.1	1	2.3	1	2.3	1	1.2	1	2.6	5	2.9	5	3.5	3	2.6	3	3.3
	3	1.4	3	1.2	3	1.0	3	1.7	5	1.9	5	2.3	5	2.5	5	2.3	10	2.6	10	2.6	8	3.0	8	2.9
	5	1.4	5	1.2	5	1.2	5	1.7	8	2.2	8	2.0	8	2.0	8	2.1								
	8	2.5	8	2.0	8	2.0	8	2.1																
	10	1.7	10	1.5	10	1.4	10	1.9																
Total	N=13	25.1	N=13	19.8	N=15	22.0	N=11	19.3	N=9	19.0	N=10	16.4	N=8	12.9	N=9	20.2	N=8	19.5	N=8	20.5	N=7	15.3	N=7	16.7

Appendix (3): Daily weather conditions prevailing during the experiment period. All data was obtained from the University of Jordan Research Experimental Station except for solar radiation which was obtained from nearby Deiralla Experimental Station.

			TEMPERATURE					WIND	
			(°C)				RAIN	RUN	SOLAR
					WET	DRY	FALL	(km/	RAD.
YEAR	MONTH	DAY	MAX.	MIN.	BULB	BULB	(mm)	day)	(1/d)
1985	DEC	6	22.2	9.0	9.0	12.0		25	266.3
		7	25.2	9.5	9.8	15.0		50	260.0
		8	27.4	13.0	10.3	16.8		64	288.3
		9	26.3	14.0	10.8	18.8		37	244.9
		10	27.4	15.5	16.0	20.3		29	232.6
		11	26.7	15.5	10.0	17.0		38	288.8
		12	24.2	12.0	12.1	16.3		53	257.0
		13	25.7	13.1	13.8	16.8		25	166.3
		14	25.7	13.0	10.8	16.5		33	206.1
		15	25.5	14.8	14.0	17.8	4.6	46	161.2
		16	21.7	15.0	15.1	15.5	0.2	43	146.9
		17	17.5	14.0	14.0	15.8	4.0	45	150.1
		18	20.7	14.0	13.3	15.5	1.0	136	160.2
		19	17.1	12.5	13.8	16.0	4.2	120	139.5
		20	18.3	14.0	11.0	12.0		23	227.0
		21	19.2	9.1	10.5	13.0		27	224.0
		22	16.8	10.4	12.8	14.0	0.1	75	112.7
		23	19.7	10.0	11.8	13.0		69	118.7
		24	18.6	7.5	8.6	11.8		41	257.6
		25	19.4	6.8	8.0	10.2	0.7	34	278.1
		26	16.5	7.1	10.5	12.0	7.1	112	170.8
		27	17.5	11.5	11.0	11.5	0.2	121	218.7
		28	20.2	11.1	12.1	16.3		146	156.4
		29	22.5	13.1	13.5	16.5		20	253.7
		30	20.3	8.9	11.0	11.8		82	247.4
		31	22.2	9.0	8.8	11.0		23	260.9
1986	JAN	1	22.9	9.5	10.8	14.8		12	188.0
		2	21.0	10.0	10.1	12.7		40	160.4
		3	20.0	14.3	12.9	16.4		78	40.1
		4	20.2	10.1	11.2	12.3	4.2	36	259.1
		5	21.2	11.0	10.5	13.2		19	262.6
		6	21.8	11.0	11.5	14.0		99	232.4
		7	21.6	10.5	13.4	16.5		34	236.3
		8	25.5	11.0	12.8	15.8		34	232.0

		9	22.3	12.0	11.4	13.7	0.2	98	253.8
		10	22.5	10.0	10.4	13.9		113	235.7
		11	20.0	9.8	11.0	16.0	11.2	113	179.9
		12	20.6	11.5	11.8	14.5	1.0	128	139.3
		13	17.3	11.2	12.8	13.8		120	120.2
		14	20.5	8.5	11.5	14.0	6.2	131	240.0
		15	20.0	11.5	13.0	16.0	1.8	100	95.6
		16	17.4	11.0	13.0	14.2		48	205.8
		17	20.0	7.5	9.9	10.4		27	272.7
		18	20.0	7.5	10.2	14.3	9.2	119	280.7
		19	21.2	11.0	10.0	12.0	.8	95	77.3
		20	15.6	11.5	10.0	13.4		55	247.6
		21	18.4	5.4	7.2	10.2		43	285.8
		22	17.9	7.8	10.0	10.5		125	127.3
		23	17.0	7.0	6.4	9.7		127	267.8
		24	17.6	7.0	6.4	9.8		120	288.9
		25	18.6	7.0	8.5	14.6		38	274.6
		26	21.0	8.0	9.0	13.8		47	290.3
		27	19.8	6.7	9.0	11.0		48	136.2
		28	21.3	9.3	10.4	13.2		31	263.1
		29	21.4	10.5	10.4	12.6		26	292.9
		30	22.0	9.5	11.5	13.3		42	246.6
		31	21.5	10.0	11.0	12.5		30	239.5
1986	FEB	1	21.0	8.6	10.2	11.4		35	309.6
		2	22.2	7.8	10.2	11.0		29	299.7
		3	22.2	10.5	10.4	14.0		64	140.3
		4	23.7	12.8	13.2	14.8	0.7	48	292.2
		5	24.2	12.5	13.5	15.2	14.0	168	229.6
		6	19.0	13.4	12.6	13.4	3.6	39	119.8
		7	18.6	9.0	12.4	13.7		137	200.1
		8	16.4	10.7	10.8	11.8	9.0	83	115.8
		9	16.2	12.3	12.3	13.5	12.4	122	106.7
		10	19.8	10.5	14.6	13.6		71	311.8
		11	20.7	8.0	9.8	11.0		22	327.6
		12	21.0	8.1	10.4	12.4		108	346.6
		13	19.0	11.0	10.0	13.0	13.8	116	345.6
		14	14.4	9.0	11.2	13.0	14.7	211	59.2
		15	17.8	10.5	11.0	13.2	7.2	98	144.4
		16	19.2	10.0	11.0	13.0		40	336.1
		17	18.0	9.5	10.5	13.0		24	127.8
		18	21.2	8.5	10.3	12.4		13	353.3
		19	23.0	8.4	10.5	12.5		45	365.3
		20	25.6	10.0	11.8	15.0		13	358.5
		21	24.6	10.1	11.2	14.0		70	371.8
		22	23.7	10.0	13.8	16.5		122	338.4
		23	24.1	10.5	12.0	14.2		84	366.8
		24	23.2	11.4	14.7	17.0		47	254.8
		25	23.0	11.0	13.3	14.7		53	345.5
		26	24.0	10.5	13.0	15.0		76	374.2
		27	25.5	10.8	14.0	16.0		120	382.5

		28	24.0	14.0	14.8	18.3		135	303.9
1986	MAR	1	24.0	13.6	13.8	16.0		47	341.7
		2	22.2	9.5	11.6	14.0		78	320.8
		3	24.5	11.8	11.8	15.8		59	363.4
		4	26.4	14.0	14.7	18.8		71	320.2
		5	25.2	13.7	13.6	18.4		56	315.5
		6	23.7	13.0	14.0	16.0		78	353.8
		7	24.6	10.5	13.0	16.0		54	408.8
		8	25.9	10.6	12.3	15.0		33	351.2
		9	26.5	13.2	14.1	20.1		94	334.5
		10	24.7	14.0	15.0	18.4		79	356.9
		11	24.5	11.5	12.8	16.4		132	407.7
		12	25.1	11.7	12.9	15.7		115	389.8
		13	27.6	9.4	13.4	16.4		180	397.7
		14	27.0	12.3	12.8	20.0		101	326.2
		15	25.2	15.0	16.3	19.0		22	324.2
		16	25.6	14.3	14.7	18.2		109	405.5
		17	26.7	13.4	12.7	17.7		100	431.1
		18	24.9	13.5	13.0	17.0		51	242.1
		19	23.5	13.9	15.7	18.8		64	324.2
		20	23.5	13.5	13.4	15.0		131	347.3
		21	25.0	10.0	13.0	14.0		10	414.8
		22	29.0	14.0	10.3	16.0		79	391.1
		23	29.2	16.0	11.5	17.0		126	408.8
		24	24.9	14.8	19.8	21.0		92	283.8
		25	25.7	14.0	14.0	16.0		85	295.4
		26	27.0	13.8	13.2	13.8		97	406.0
		27	32.8	13.2	12.8	13.7		34	401.5
		28	34.0	15.0	12.4	16.0		90	416.2
		29	36.2	18.8	15.3	19.0	3.5	129	393.3
		30	25.0	17.0	17.4	21.0	3.0	66	241.6
		31	21.8	15.0	15.7	16.0		58	153.1
1986	APR	1	25.2	15.0	15.5	16.0	4.4	81	331.7

1986	APR	13	34.2	18.4	18.6	24.6	64	318.8
		14	29.5	20.8	15.5	25.0	87	156.5
		15	28.7	21.0	20.0	26.4	146	461.5
		16	27.3	14.8	14.0	19.2	155	458.3
		17	32.5	15.5	14.8	20.0	121	450.2
		18	34.8	13.0	15.0	23.8	161	474.4
		19	34.8	18.4	16.8	23.8	112	493.5
		20	35.6	17.5	16.0	25.0	36	418.2
		21	36.8	21.3	16.4	24.8	155	312.5
		22	28.3	17.2	15.4	21.2	113	531.8
		23	31.7	15.3	16.4	21.2	156	503.8
		24	36.0	15.7	19.3	26.3	87	509.6

		25	37.8	21.8	16.0	25.2		138	426.0
		26	29.7	23.5	18.0	25.0		137	267.6
		27	34.8	21.5	16.8	24.8		176	448.3
		28	35.5	20.1	19.0	25.0		84	460.1
		29	34.2	17.4	19.0	24.8		82	349.4
		30	31.7	24.5	19.2	26.8		158	464.3
1986	MAY	1	32.0	17.5	16.0	22.0	0.3	96	430.2
		2	30.6	18.3	17.2	23.0	5.7	146	426.4
		3	20.2	14.7	14.9	18.4	11.3	51	170.5
		4	26.4	15.5	17.0	18.6	0.7	68	369.3
		5	28.7	15.7	17.4	22.4		83	450.6
		6	31.8	16.0	17.5	22.8		94	482.0
		7	36.0	15.9	16.7	25.5		80	456.5
		8	34.0	23.0	20.7	27.0		105	388.3
		9	28.6	18.0	18.3	24.8		103	430.3
		10	28.4	15.5	15.8	21.8		113	500.0
		11	28.3	15.5	14.8	20.0	0.3	123	497.7
		12	25.5	16.5	16.0	20.0	0.5	159	328.1
		13	28.4	16.1	19.3	23.0		100	425.6
		14	28.6	16.0	17.8	22.8		91	492.0
		15	29.0	17.0	17.8	22.8		82	332.2
		16	29.1	17.8	17.0	23.2		97	495.6
		17	30.9	14.8	16.4	23.4		173	544.3
		18	36.0	17.0	16.0	23.0		150	517.5
		19	34.0	19.5	18.5	25.0		128	484.4
		20	33.6	20.5	17.0	25.0		119	504.8
		21	34.0	19.0	18.4	24.0		122	527.5
		22	34.0	18.0	16.3	22.8		142	523.2
		23	33.8	15.0	15.0	25.2		139	498.1
		24	32.7	16.8	19.0	24.4		131	516.4
		25	35.7	18.5	19.0	25.0		127	510.9
		26	36.8	18.6	18.3	26.8		127	540.9
		27	34.8	21.0	20.4	25.7		124	481.4
		28	34.3	21.5	19.4	26.4		102	509.0
		29	34.0	19.5	19.0	26.5		122	519.4
		30	33.8	20.0	20.0	27.2		145	563.2
		31	36.0	18.9	19.0	25.4		146	528.6
1986	JUN	1	37.7	20.0	20.0	25.3		209	557.5
		2	38.3	23.0	19.8	30.4		122	447.3
		3	38.0	25.0	22.0	28.1		130	445.2
		4	38.3	22.5	19.5	28.0		109	532.4
		5	36.0	20.5	20.0	27.0		106	520.8
		6	38.5	21.0	19.0	28.0		99	491.9
		7	42.0	21.0	18.2	30.0		110	532.8
		8	42.5	24.0	18.8	33.8		165	495.9
		9	41.0	23.0	21.0	31.5		90	526.5
		10	42.0	23.5	20.7	30.8		115	526.5
		11	38.6	30.0	22.0	33.0		180	474.5
		12	31.2	22.5	19.7	25.0		95	477.9
		13	34.0	19.0	18.4	24.6		136	439.6

ملخص

برمجة الري لمحصول الكوسا تحت الري بالتنقيط
والاغطية البلاستيكيه السوداء في وادي الاردن

أجريت دراسة باستعمال ثلاث معاملات ري تحت شد رطوبي يعادل ٣٠ ، ٥٠ ، و ٨٠ كيلو باسكال على محصول الكوسا تحت الري بالتنقيط والاغطية البلاستيكيه السوداء لدراسة تأثير معاملات الشد الرطوبي على الاحتياجات المائيه، الانتاج، ونمو وتوزيع الجذور خلال موسمي الشتاء والربيع (١٩٨٥ - ١٩٨٦). وكان من الاهداف الاخرى تجربة نموذج محاكاة انتاج المحصول وادارة ماء التربة (CRPSM) الذى تم تطويره في جامعة ولاية يوتا (هيل ومن معه ، ١٩٨٤ أ و ١٩٨٤ ب) وتم تعديله مؤخرا من قبل بطبخي وهيل (١٩٨٦ أ) على محصول الكوسا لتنبوء الانتاج واختيار برنامج ري يعطي اعلى انتاج وافضل كفاءه استخدام مائي.

لم تظهر النتائج اية فروق ذات دلالة معنوية بين المعاملات الثلاث لكلا الموسمين من ناحية الانتاج ، مجموع الماء المضاف ، كميات الري ، كفاءة اضافة المياه، كفاءة استخدام المياه، طول الجذر العمودى ، طول الجذر الافقي ، ووزن الجذر الجاف . لقد استهلكت النباتات كميات مياه تعادل ١٢ر٧٩ ، ١٢ر٧٥، و ١٢ر٤٤ سم للمعاملات ٣٠، ٥٠، و ٨٠ كيلو باسكال شد رطوبي على التوالي لتعطي انتاج يعادل ١٩ر٤، ٢١ر٦، و ٢٢ر٠ طن/ هكتار ، على التوالي خلال موسم الشتاء. ومن ناحية اخرى ، في موسم الربيع تم استهلاك ١٥ر١٨ ، ١٣ر٩٨، ١٤ر٩٧ سم ماء لانتاج ٨ر٦ ، ٧ر٤، و ٧ر٦ طن / هكتار للمعاملات الثلاث على التوالي . لقد كان معدل كفاءة استخدام المياه يساوى ١ر٥٨ ، ١ر٧٩، و ١ر٨٨ طن / هكتار/ سم ماء لموسم الشتاء و ٠ر٥٦، ٠ر٥٨ ، و ٠ر٥١ طن / هكتار/ سم ماء لموسم الربيع للمعاملات الثلاث على التوالي .

لقد كان عدد الريشات منخفضا بدلالة معنوية في معاملة الشد الرطوبي الذى يعادل ٨٠ كيلو باسكال بالمقارنة مع ٣٠ كيلو باسكال شد رطوبي خلال موسم الشتاء. اما خلال موسم الربيع فقد كان هناك فروقات ذات دلالة معنوية في عدد الريشات بين معاملات ٣٠ و ٥٠ كيلو باسكال شد رطوبي من ناحية و ٣٠ و ٨٠ كيلو باسكال شد رطوبي من ناحية اخرى.

اظهرت اعادة معايرة الجزء الخاص بالانتاج من النموذج مجموعات جديدة من معاملات موازنة مراحل النمو تحت اعلى انتاج حقلي ممكن. لقد تم الحصول على معايرة افضل خلال موسم الشتاء بالمقارنة مع موسم الربيع. وذلك نظرا لوجود الامراض والأثر النسبي للحرارة خلال موسم الربيع. لقد تم فحص خيارات ادارة الري التي يغطيها النموذج وذلك بهدف اختيار افضل خيارات للرى ذات اعلى انتاج واعلى كفاءة استخدام مائي ممكنة مما يؤدي الى تقليل التجارب الحقليه على هذا النوع من الدراسات في المستقبل وبالتالي تقليل التكلفة والتوفير في الوقت.