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EFFECT OF SUPPLEMENTARY IRRIGATION ON WHEAT PRODUCTION AS RELATED TO CROP WATER REQUIREMENTS AND PLANTING DATES.

B Y

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**DEDICATED TO MY
FATHER, MOTHER,
BROTHERS, AND SISTERS**

TABLE OF CONTENTS

COMMITTEE DECISION ii

DEDICATION iii

ACKNOWLEDGMENT iv

TABLE OF CONTENTS v

LIST OF TABLES viii

LIST OF FIGURES x

LIST OF APPENDICES xiii

ABSTRACT xiv

CHAPTER PAGE

1. INTRODUCTION 1

2. LITERATURE REVIEW 3

2-1 Background on wheat production and wheat research in Jordan 3

2-2 Wheat yield, evapotranspiration, drought sensitivity at various growth stages, and planting dates 5

2-3 Supplementary irrigation, yields, and weather variability 9

3. MATERIALS AND METHODS 13

3-1 Study location 13

3-2 Soil 13

3-3-1 Experimental design 13

3-3-2 Planting dates (main treatments) 13

3-3-3 Supplementary irrigation treatments (sub treatments) 16

3-3-4 Cultural Practices 21

3-4 Soil Properties 21

3-5 Soil moisture measurements 22

3-6 Neutron probe calibration curves 22

3-7 Effective rainfall 23

3-8 Actual evapotranspiration measurements 25

3-9 Potential evapotranspiration measurements 26

3-10 Crop coefficient 26

3-11 Wheat yield and yield components 27

3-12 Climatic data 27

4. RESULTS AND DISCUSSION 28

4-1 Soil properties 28

4-2 Calibration curves 28

4-3 Soil characteristic curves 28

4-4 Climatic data 28

4-5 Water application 28

4-6 Wheat yield and yield components 40

4-6-1 Wheat grain yield 44

4-6-2 Wheat straw yield 47

4-6-3 Biological wheat yield 49

4-6-4 One thousand kernel weight 49

4-6-5 Number of heads/m^2 50

4-6-6 Wheat plant height 50

4-6-7 Grain yield/ straw yield and grain yield/biological yield (Harvest index) 53

4-6-8 Water use efficiency (W.U.E) 53

4-6-9 Water use efficiency for irrigation 53

4-6-10 Actual evapotranspiration of wheat by depletion method (ETa) 54

4-7 Potential evapotranspiration (ETP) and crop coefficients (Kc) 58

4-8 Wheat crop water use at different growth stages 68

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 72

6. REFERENCES 75

7. APPENDICES 82

8. ABSTRACT IN ARABIC 93

LIST OF TABLES

TABLE PAGE

1. Pan coefficient (Kp) for class-A pan for different ground cover and levels of mean relative humidity and 24 hour wind velocity 18
2. Average monthly effective rainfall as related to average monthly ET crop and mean monthly rainfall 24
3. Some physical soil properties of the experiment site 29
4. Some chemical soil properties and fertility status of the experiment site 30
5. Amounts of water applied and rainfall for different treatments during 1991/1992 growing season 39
6. Results of analysis of variance for 13 parameters at (5%) probability level of the F- test 41
7. Average wheat grain yield, yield components, actual evapotranspiration and W.U.E under different irrigation treatments in Mushaqqar, during 1991/1992 growing season 42
8. Average wheat grain yield, yield components, actual evapotranspiration and W.U.E under early planting, and late planting treatments at Mushaqqer, during 1991/1992 growing season 43
9. Average actual daily evapotranspiration (mm/day) measured by depletion method for early planted wheat (D1)

under different irrigation treatments during
1991/1992 growing season 59

10. Average actual daily evapotranspiration (mm/day) measured by depletion method for late planted wheat (D2) underdifferent irrigation treatments during 1991/1992 growing season 60

11. Average actual daily evapotranspiration (mm/day) for early planted wheat (D1) on monthly basis under different irrigation treatments 61

12. Average actual daily evapotranspiration (mm/day) for late planted wheat (D2) on monthly basis under different irrigation treatments 62

13. Average actual daily evapotranspiration (ETa) measured by depletion method for early planted wheat (D1) with 100% of estimated ETa, average daily potential evapotranspiration (ETpan), and the corresponding Kc values during the growing season 65

14. Average actual daily evapotranspiration (ETa) measured by depletion method for late planted wheat (D2) with 100% of estimated ETa, average daily ETpan, and the corresponding Kc values during the growing season 66

15. Wheat crop water use (mm) during the different growth stages for all treatments, during 1991/1992 growing season 71

LIST OF FIGURES

FIGURE **PAGE**

1. Wheat planted area and mean annual rainfall in Jordan 14
2. Experiment layout at Mushaqqar Agricultural Experiment Station, 1991/1992 15
3. Average Kc value for initial crop development stage as related to level of ET_o and frequency of irrigation and/or significant rain 19
4. Crop coefficient curve for wheat planted at Mushaqqar Agricultural Station 20

5a. Neutron probe calibration curves for 0-15 (D1), 15-30 (D2), and 30-60cm (D3) soil depths for the experiment site at Mushaqqar Agricultural Station 31

5b. Neutron probe calibration curves for 60-90 (D4), and 90-120 cm (D5), soil depths for the experiment site at Mushaqqar Agricultural Station 32

6a. Soil- water characteristic curve for 0-15 cm soil depth for the experiment site at Mushaqqer Agricultural Station 33

6b. Soil- water characteristic curve for 15-30 cm soil depth for the experiment site at Mushaqqer Agricultural Station 34

6c. Soil- water characteristic curve for 30-60 cm soil depth for the experiment site at Mushaqqer

Agricultural station 35

6d. Soil- water characteristic curve for 60-90 cm soil depth for the experiment site at Mushaqqer Agricultural Station 36

6e. Soil- water characteristic curve for 90-120 cm soil depth for the experiment site at Mushaqqer Agricultural Station 37

7. Rainfall amounts and mean monthly temperature during the growing season (1991/1992) at Mushaqqer Agricultural Station 38

8. Relationships between wheat grain yield and water applied under early planting (D1), and late planting (D2) 46

9. Relationships between wheat straw yield and water applied under early planting (D1), and late planting (D2) 48

10a Average plant height under different irrigation treatments for early planted wheat, during the growing season 1991/1992 51

10b Average plant height under different irrigation treatments for late planted wheat, during the growing season 1991/1992 52

11. Relationships between wheat grain yield and actual evapotranspiration under early planting (D1), and late planting (D2) 55

12. Relationships between wheat straw yield and actual evapotranspiration under early planting (D1), and late planting (D2) 57

13a Average daily actual evapotranspiration (mm/day) for early planted wheat on monthly basis under the four irrigation treatments 63

13b Average daily actual evapotranspiration (mm/day) for late planted wheat on monthly basis under the four irrigation treatments 64

14. Crop coefficient values variation with the growing season on monthly basis interval for early planted (D1) and late planted (D2) wheat 67

15. Cumulative actual evapotranspiration (ETa), potential evapotranspiration (ETpan), and estimated actual evapotranspiration (est.ETa) for early planted wheat during the growing season 69

16. Cumulative actual evapotranspiration (ETa), potential evapotranspiration (ETpan), and estimated actual evapotranspiration (est.ETa) for late planted wheat during the growing season 70

LIST OF APPENDICES

APPENDIX PAGE

1. Maximum temperature (Tmax), minimum temperature (Tmin), wet bulb (Wb), dry bulb (Db), wind velocity (U), class-A pan evaporation (Ep), relative humidity (RH %), and rainfall (Rn) taken from Mushaqqar Meteorological Station 82

2. Average wheat grain yield, yield components, actual evapotranspiration and W.U.E under different planting dates and different irrigation treatments at Mushaqqar, during 1991/1992 growing season 90

3. Average actual daily evapotranspiration (mm/day) for early planted wheat (D1) under different irrigation treatments during (1991 / 1 992) growing season 91

4. Average actual daily evapotranspiration (mm/day) for late planted wheat (D2) under different irrigation treatments during (1991/ 1992) growing season 92

ABSTRACT

EFFECT OF SUPPLEMENTARY IRRIGATION ON WHEAT PRODUCTION AS RELATED TO CROP WATER REQUIREMENTS AND PLANTING DATES.

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SUPERVISED BY : Dr. Muhammad R. Shatanawi

A study was carried out during 1991/1992 growing season at Mushaqqar Agricultural Experiment Station located approximately 28 km southwest of Amman. The objectives of the study were; (1) to investigate the effect of supplementary irrigation on wheat yield in rainfed areas, (2) to study the effect of different planting dates on wheat yield, and (3) to determine the actual water consumption of wheat and establish a crop coefficient curve for the area.

A split plot design, with four replications was used. The main treatments were early planting and late planting. The subtreatments were four levels of irrigation (T1= 100% of estimated ETa, T2= 50% of estimated ETa, T3= 100% of estimated ETa at critical stages, and T4 = rainfed treatment).

Actual evapotranspiration (ETa) was measured by depletion method using neutron scattering techniques. Potential evapotranspiration was measured by class-A pan evaporation method.

Results indicated that ETa of wheat increased significantly with the increase in water applied. Total ETa for T1, T2, T3, and T4 were 474.8, 427.8, 445.54, and 375.54 mm, respectively. An increase of 99.26 mm in

1. INTRODUCTION

In arid and semi-arid regions, like Jordan , water supply is considered as the major constraint facing agricultural development. Accordingly , more efficient utilization of the limited and costly water resources should be achieved through maximizing the production per unit volume of water which can be accompalished through good water management.

Approximately, 93% of the total cultivable area in Jordan is dependent on rainfall (1). In spite of the fact that the most up-to-date rainfed production techniques are used in these areas , their contribution to the total agricultural production is very low and unstable. This could be attributed mainly to the weather variability which in turn affects water availability to the crops. (2) .

Wheat is the principal cereal crop grown in Jordan and the major stable food for the population. Wheat in Jordan is grown in areas where mean annual rainfall ranges from 250 to 500 mm. It occupies about 76% of the total area grown with cereal crops. National wheat production contributes 28% of the local needs (3). The most important factor contributing to production instability and low wheat yields in Jordan is the great fluctuation of rainfall and its uneven seasonal distribution. In fact, the average total rainfall during the season might be adequate to sustain optimal wheat yield; but both the total amount and its distribution vary from one season to another which causes a wide variation in production. As a result , periods of soil moisture deficits may develop and adversely affect crop production especially if they occur during crucial stages of plant growth and development (4) .

As a protective measure , supplementary irrigation had proven to have tremendous potential for increasing and stabilizing agricultural production in many rainfed areas (5). Supplementary irrigation is the process of providing additional water to stabilize and increase yields under site conditions where a crop can normaly be grown under direct rainfall , the additional water alone being insufficient to produce a crop (6). In addition, supplementary irrigation can provide conditions suitable for high inputs such as high yielding varieties, fertilizer , as well as more intensive cropping.

This study was carried out at Al-Mushaqqer Agricultural Experiment Station with the following objectives :

1. to investigate the effect of supplemental irrigation on wheat yield in rainfed areas,
2. to study the effect of different planting dates on wheat yield to determine the most appropriate one for the most efficient utilization of rainfall, and
3. to determine the actual water consumption of wheat and establish a crop coefficient curve for the area .

2. LITERATURE REVIEW

2.1 Background on wheat production and wheat research in Jordan.

Since 1970, Jordan's direct imports of wheat have risen to about 70% of total annual needs (7). Consequently, a greater burden has been placed on the government budget and more foreign currency must be allocated to purchase an increasing amount of wheat. Although the government has incentive plans to wheat producers, the cultivated area with wheat and the production is still dramatically variable in the rainfed areas from year to year due to the variation in the total annual rainfall. During 1980-1986, the production of wheat declined from 133.6 thousand tons produced on 133.7 thousand hectares in 1980 to 30.8 thousand tons on 59.4 thousand hectares in 1986 (8). Being a basic staple in Jordan, the average yearly consumption per capita is around 130-150 kg (9). The total domestic wheat consumption in 1988 reached 575 thousand tons and the total imports reached 430 thousand tons or 72% of the local needs (3).

The areas planted with wheat are classified into five sub-regions, a) desert region, b) eastern region, c) plains region, d) upland region, and e) Jordan Vally region. The average yield for the five sub-regions are 30, 64, 71, 90 and 137 kg/du, respectively (10). However, the contributions of these sub-regions to the national wheat production are 8, 33, 40, 14, and 5 %, respectively (9).

Over the last three decades, various national and international agencies have been involved in research on wheat in Jordan. At the beginning, the emphasis was on improved wheat varieties and cultural practices such as fertilizer application, weed control and dates of planting. A series of seeding date experiments at different locations and several growing seasons indicated that early planting resulted in higher yields than late planting (7). The second stage of research was oriented towards studying the introduction of a package of appropriate technology and the availability of goods and services for improved wheat production. More recently, research on water relations of wheat has been introduced as a new research stage. In this regard, Shatanawi et al (11) studied the irrigation production functions of wheat during 1984/1985 and 1985/ 1986 growing seasons in the Jordan Valley. The results showed that the relationship between yield and applied water could be described by a second degree equation. On the other hand, linear relationship was obtained between yield and evapotranspiration (ET).

Duwayri (12) evaluated four wheat cultivars planted at Jubeiha under three levels of moisture : rainfed conditions, supplementary irrigation, and stress conditions. The results proved that the availability of rainfall during the late part of the growing season, i.e., from March to mid-May improved yield significantly even in the presence of early high rainfall. Also, a supplement of 66.5 mm of water above the rainfall during April and May improved grain yield by 359 kg/ha or by 13% of the rainfed plot. Jaradat and Duwayri (13) studied the effect of different moisture deficits on durum wheat seed germination and seedling growth. They showed that higher germination percentages were obtained under low moisture tension (0 and 6 atmosphere) than under high moisture tension (12 atm). All varieties did not germinate under the 24 atm treatment. No differences were observed in the percentage of germination produced by 0 and 6 atm treatments.

Zeidan (4) developed a simulation model for the spring wheat water requirements and moisture consumption throughout the growing season at Irbid region. The results showed that heading- flowering and grain formation to milk ripe stages were the most sensitive to water stress; also the occurrence of these stages is accompanied with high moisture depletion rates and severe moisture stress resulting in a very low crop yields. The model showed that early December is the optimal sowing date. In addition, the model proved that the potential yield (350 kg/du) at Irbid region could be attained by supplement of 125mm of water during critical stages of growth.

2.2 Wheat yield, evapotranspiration, drought sensitivity at various growth stages, and planting dates.

knowledge of evapotranspiration and yield (ET-Y) relationships is fundamental to evaluating strategies for managing limited resources of water for irrigation. Such knowledge is lacking in Jordan, so there is a need to carry out field experiments to develop ET-Y functions during each stage of growth (14). Shatanawi et al. (15) measured water consumption of wheat in the Jordan Valley during 1985/1986 growing season using drainage type lysimeters. Seasonal ET for wheat was 325 mm.

Wheat crop yield as related to evapotranspiration and irrigation was studied by Hanks et al. (16). Yield and water use data were obtained for several winter wheat cultivars subjected to varying levels of irrigation under field conditions in Utah. The results indicated that both grain yield and straw yield showed a linear relationship to evapotranspiration and applied water at different levels. Omar and Aziz (17), in Egypt, found that the relationship between grain and straw yield and seasonal evapotranspiration were highly significant and could be described by a third-degree equation. Imtiyaz et al (18), in Denmark, evaluated the effect of supplementary irrigation on wheat yield, evapotranspiration, and water use efficiency. The calculated ET during the growing season for irrigated and non-irrigated wheat were 347 and 264 mm, respectively. Limited available water for plants reduced wheat grain yield by 38%. The water use efficiency of each mm of irrigation water transpired was 20.1 kg grain dry matter per hectare.

Insufficient available water in the root zone during crucial periods of growth is common occurrence in non-irrigated areas receiving less than 500 mm rainfall. Occasional water shortage is not limited to arid and semi-arid regions but also in sub-humid regions. These conditions result in lower rainfed crop yields than potential maximum yield. Sing and Bhushan (19), in India, conducted a three year field experiment and found that supplementary irrigation of 50 mm at crown root initiation stage or as pre-sowing increased wheat yield by 25 and 110 % in wet and dry season, respectively. Also , the data showed that supplemental irrigation helped the crop to utilize soil and rain water more efficiently.

Food production can be increased substantially in the semi-arid regions under rainfed conditions with improved technologies. Runoff water from rainfed agricultural systems can be feasibly harvested, stored in ponds, and then used for supplemental irrigation. The efficient use of limited amounts of supplementary irrigation water requires a good understanding of the relationships of transpiration and evapotranspiration to dry-matter and grain yields, and to water application rates. (20).

Singh and Wolkewitz (21), in Germany, studied the relationships between wheat evapotranspiration during different growth stages, class-A pan evaporation and soil water parameters. The actual evapotranspiration during different crop growth stages was greatly influenced by amount and time of irrigation.

According to Large (1954), wheat growing season can be divided into the following standard phenological stages: a)establishment (planting to emergence); b)vegetative growth (tillering to jointing to shooting to booting to heading); c)flowering; d)yield formation; e)milk ripening and maturity. Heading-flowering are the most sensitive stages to water stress (22).

The influence of water stress at various growth stages on yield and yield structure of wheat has received considerable attention. Mogensen et al. (23) evaluated the response of spring wheat to irrigation water applied at different growth stages. They concluded that the response of grain yield to applied irrigation water during heading stage is very significant. Robins and Domingo (24), in Washington, reported that severe soil moisture stress should be avoided from booting stage to maturity for maximum wheat yield. Day and Intalap (25), in Arizona, investigated the effect of water stress on irrigated spring wheat. They found that water stress at the jointing stage caused early flowering and reduced grain yield due to fewer heads and seeds per head. Also, stressing the crop for water at flowering and dough stages had resulted in early maturity and reduced grain yield due to lighter seeds. They showed that this could be attributed to high consumptive use of water by wheat during these stages. Musick and Dusek (26), in Texas, evaluated the response of irrigated wheat crop to water deficit at different growth stages with different planting dates. They found that early planting increased dry matter and grain yields. Also plant water deficits reduced yields by reducing the harvested heads and grain numbers. Wayne et al. (27), in South Africa, defined the time at which evapotranspiration begins to decline as a result of water stress. They found that 70 to 80% of the available water could be used at or near potential evapotranspiration. Monitoring of leaf growth showed that between 52 and 57% of the total plant available water could be used before a reduction in growth became evident. Proper sowing date ensures a proper stand establishment and a better utilization of rainfall, which result in higher yields especially under dry land conditions. Ur-Rehman et al. (28), in Pakistan, concluded that the number of days to heading and grain yield of wheat was decreased with delayed sowing. This was supported by a strong positive correlation between days to heading and grain yield. Mc Donald et al. (29), in Wales, stated that a delay in sowing date reduced average wheat yields by 20%. Also delayed sowing reduced the time to anthesis, irrespective of the irrigation treatment. El-Shaer et al. (30), in Egypt, found that early planted wheat produced higher number of spikes/plant and spikes/m^2, higher kernel weight, and higher grain and straw yield due to longer growth period.

2.3 Supplementary irrigation, yields, and weather variability.

Supplementary irrigation is one of the most rapidly proliferating agricultural practice which can alleviate climatic risk factors in arid and semi-arid regions by protecting crops during periods of drought, which in turn can stabilize yields.

Shatanawi (5) reported that supplementary irrigation has a tremendous impact on the improvement and stabilization of crop production. Monthly rainfall distribution with seasonal evapotranspiration variation were used in predicting the time and the amounts of supplementary irrigation needed. He also reported that additional water at critical growth stages of wheat, which are accompanied with decreasing rainfall and peak evapotranspiration, is essential to maximize crop production.

Perrier and Salkini (31), in Syria, investigated the effect of supplementary irrigation on yield of spring wheat. They showed that well-timed light applications of supplementary irrigation at critical stages (heading, flowering, milk stage) ensured a significant increase in the yield. The yield of variety Sham I increased at least by a factor of three with lowest amount of supplementary irrigation. Data also emphasized that water applied at sowing time for early germination is an important factor in increasing yield and plant height.

Supplementary irrigation on wheat would guarantee an increase in the yield more than 100% (from 1.5 to 3.5 t/ha) in the wheat - growing areas of four mid eastern countries including Jordan (350 mm rainfall and above) with an amount of irrigation water varying from 50 to 200 mm depending on the zone and the amount and distribution of the seasonal rainfall. Also supplementary irrigation would increase considerably the efficiency of the utilization of water resources for food production. It was shown that a linear relationship existed between cereal yields and seasonal rainfall. The relation showed that for every mm above the first 100 to 150 mm of water (whether from rain or supplementary irrigation) about 14 to 16 kg of grain/ha could be produced (14).

El-Dehni et al. (32), in Syria, studied the effect of supplementary irrigation on spring wheat yield. They concluded that the weather had a clear effect on plant growth and production. Also, grain yield increased by 190% and straw yield increased by 73% with a gross benefit for grain and straw of 136% and a net benefit of 124%. Data emphasized that scheduling of supplemental irrigation was as important as quantity of water applied. They also reported that the margin of return from supplemental irrigation was higher than the cost of capital investment and operation. The small volume of water, 60 mm, applied as supplementary irrigation with 20 mm at germination, 20 mm during anthesis, and 20 mm during milk stage had a significant effect on yield when compared with yields of rainfed wheat.

The potential for increasing food production from rainfed agriculture in semi-arid regions may be high, but the risk involved with the amount, frequency, and duration of rainfall requires efficient implementation of supplemental irrigation to stabilize production. This requires optimal scheduling based on consumptive use with minimal irrigation during critical growth stages and drought periods (33).

Al-Janabi (34), in Iraq, showed that when rainfall was considered as a source of water, there was an average reduction of 65% in yield of wheat over two growing seasons. The production of the rainfed areas could be stabilized by applying supplemental irrigation.

Al-Rifai (35) reported that with supplementary irrigation, wheat production was increased from about 900 kg/ha to about 3000 kg/ha in Hassakeh region. He also reported that supplementary irrigation under rainfed conditions in the Near east region would not only triple the average present yield, but also stabilize production, thus ensuring regular income to farmers.

Supplementary irrigation has the potential to stabilize and increase the low crop yields in the rainfed agricultural sector in Jordan. Preliminary results of a computerized simulation study indicated that the net income from wheat could be increased 7-10 times with supplementary irrigation (1).

Abdel Ilah (36) concluded that wheat yields in semi-arid conditions of Morocco, were more than doubled with 150 mm of supplementary irrigation.

Gangopadhyaya and Sarker (37), in India, used long-term records of rainfall and yield at Rothmasted (India) to study the effect of rainfall distribution on wheat yield. They obtained response curves indicating that about 75% of the total variations in wheat yield maybe accounted for by the rainfall distribution.

Estimates of the number of dry days in any month of a rainfall season are essential in planning of supplemental irrigation schemes in arid and semi-arid regions. Aldabagh et al. (38) suggested a procedure to estimate the recurrence interval for the months of total drought. Data on dry days have been proceeded for 10 stations in Iraq making use of 38 year records. Several data transformations and distribution functions showed that estimates of dry days with a probability level of 20 percent would be useful in developing five-year plans of supplemental irrigation schemes.

Steichen and Zovne (39), in Kansas, evaluated the risk of having insufficient water for supplemental irrigation. They simulated the daily operations of a system consisting of a watershed, pond, and irrigated plot. At least 25 years of data was used to determine the frequency of failure of the storage pond to deliver water when there was an irrigation demand. Generalized system reliability curves are useful for designing an individual system or for establishing design guidelines for a region.

3. MATERIALS AND METHODS

3-1 Study location :

The experiment was carried out during 1991/ 1992 growing season at Mushaqqar Agricultural Experiment Station, located approximately 28 km southwest of Amman. It's mean annual rainfall is about 360 mm. The station lies at 31.5° North latitude and 790 m above sea level altitude. Wheat is the major field crop grown in the area .

3-2 Soil :

Taimeh and Khreisat (40) classified the soil at Mushaqqar Agricultural Experiment Station as very fine ,smectitic, thermic , Typic, Chromoxerert.

3-3-1 Experimental design .

The experiment was laid out in a split plot design in a completely randomized block design with four replications (Fig. 2).The design consisted of two planting dates as main treatments, and four supplementary irrigation levels as subtreatments, replicated four times.

3-3-2 Planting dates(main treatments).

The two main treatments were as follows:

(1) D_1= early planting commenced on November ,11, 1991.

This main treatment received a planting irrigation of 15 mm depth of water to all subtreatments except rainfed treatment.

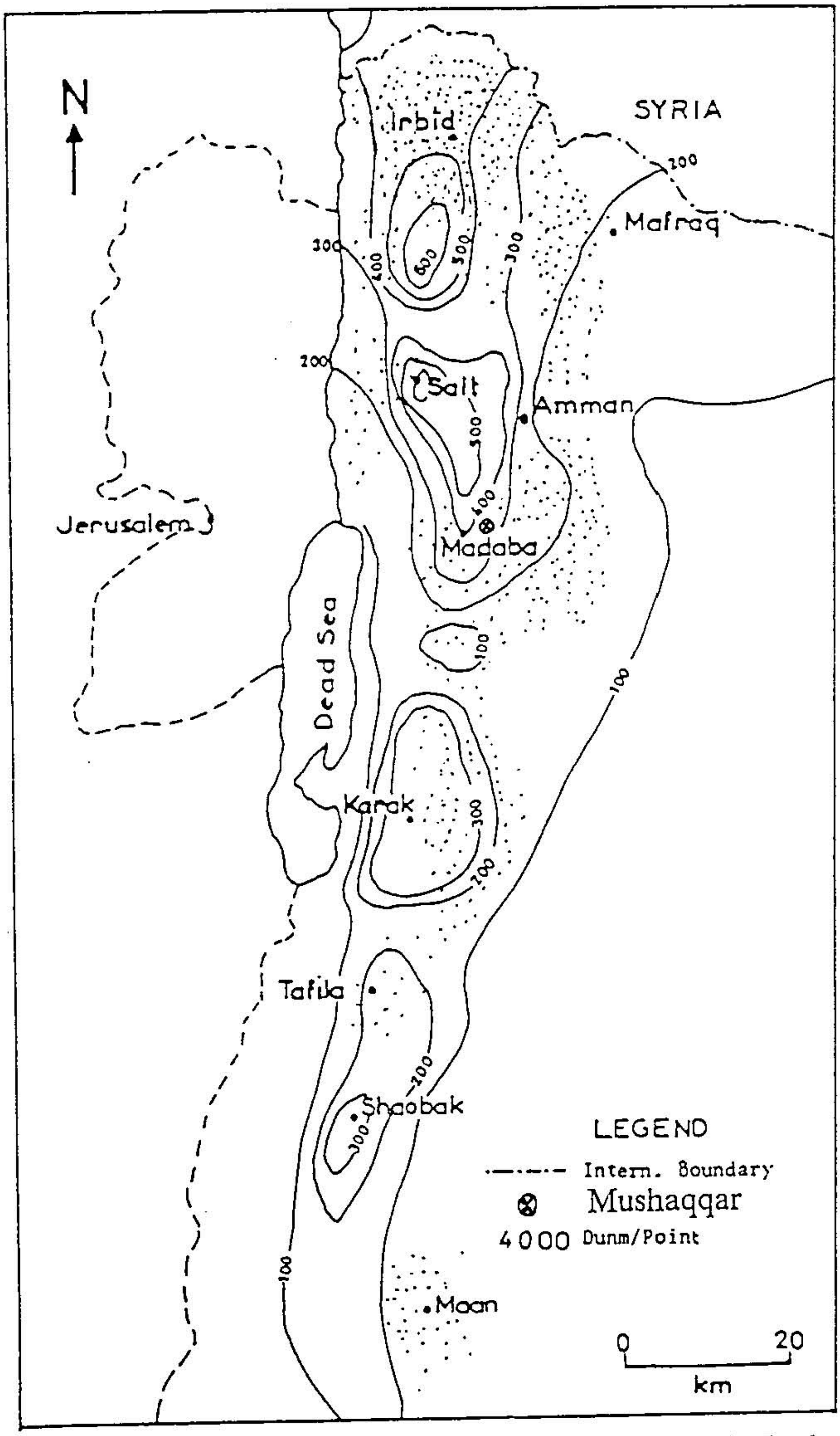

Figure 1 : Wheat planted area and mean annual rainfall in Jordan.
Source : National Atlas of Jordan, Climate and Agroclimatology

Figure 2 : Experiment layout at Mushaqqar Agricultural Experiment Station, 1991/1992.

الصفحة غير موجودة من أصل المصدر

Table 1 : Pan coefficient (Kp) for class-A pan for different ground cover and levels of mean relative humidity and 24 hour wind velocity.

Class A pan Case A: Pan placed in short green Cropped area Case B : Pan placed in dry fallow area

RH mean%		Low <40	Medium 40-70	High >70		Low <40	Medium 40-70	High >70
Wind km/day	Windward Side distance of green crop m				Windward Side distance of dry fallow m			
Light <175	1	.55	.65	.75	1	.70	.80	.85
	10	.65	.75	.85	10	.60	.70	.80
	100	.70	.80	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.50	.60	.70
Moderate 175-425	1	.50	.60	.65	1	.65	.75	.80
	10	.60	.70	.75	10	.55	.65	.70
	100	.65	.75	.80	100	.50	.60	.65
	100	.70	.80	.80	100	.45	.55	.60
Strong 425-700	1	.45	.50	.60	1	.60	.65	.70
	10	.55	.60	.65	10	.50	.55	.65
	100	.60	.65	.70	100	.45	.50	.60
	1000	.65	.70	.75	1000	.40	.45	.55
Very strong >700	1	.40	.45	.50	1	.50	.60	.65
	10	.45	.55	.60	10	.45	.50	.55
	100	.50	.60	.65	100	.40	.45	.50
	1000	.55	.60	.65	1000	.35	.40	.45

Doorenbos and Pruitt (41)

الصفحة غير موجودة من أصل المصدر

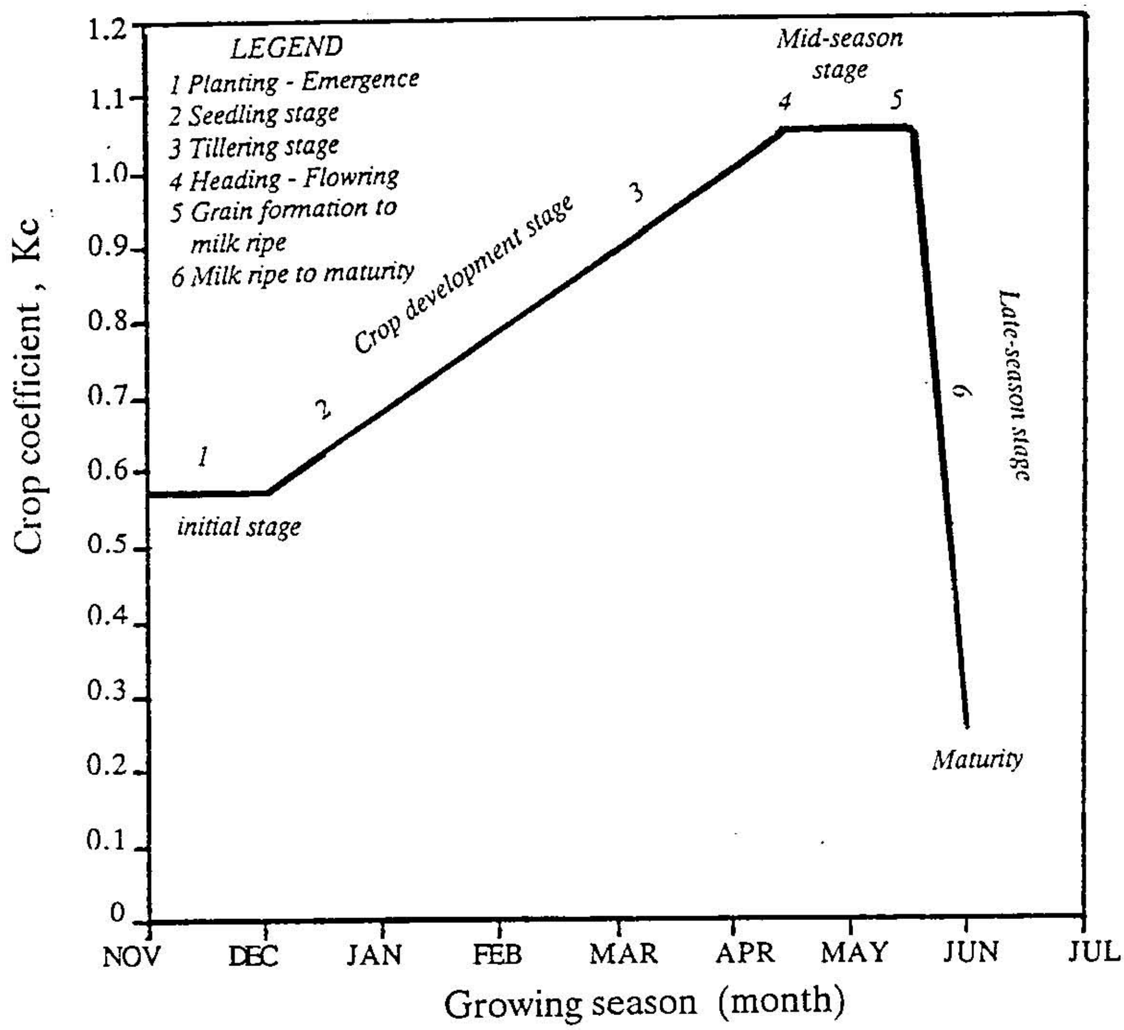

Figure 4 : Crop coefficient curve for wheat planted at Mushaqqar Agricultural Station .

humidity conditions (Table 21, Doorenbos and Pruitt, 41). The Kc values for the crop development stage were assumed to be linear between Kc value at the end of initial stage and the beginning of mid-season stage. Similarly, Kc values for the late season stage were assumed to be linear between Kc value at end of mid-season stage and at harvest.

3-3-4 Cultural practices.

The experiment started on November 11, 1991. Prior to the beginning of the experiment , the whole area (2000 m^2) was plowed with chisel plow in September 1991 followed by sweeping for seed bed preparation just before planting. All plots were fertilized with triple superphosphate at a rate of 100 kg/ha (46 kg $P_2 O_2$/ha), and urea at a rate of 130 kg/ha (60 kg N/ha). Nitrogen was hand broadcasted just before grain sowing. Phosphorus was banded at time of sowing .

Spring wheat (F8 G5) was planted at each planting date by grain drill at a rate of 100 kg/ha. Seed depth was about 8 cm with 17.5 cm spacing between rows. Weed control was done by spraying the whole experimental area with 2,4-D (24% 2,4-D acid esters with 36-37% content in 2,4-D acid) at a rate of 800 cm^3 of solution per hectare, and continued manually when needed.

3-4 Soil properties

One representative profile at the experimental site was selected for sampling. Undisturbed soil samples were taken from the 0-15, 15-30, 30-60, 60-90, and 90-120 cm soil depths. The soil sorption curves for the five layers were prepared using the ceramic plate extractor method (42) at 0.1, 0.3, 0.5, 1.0, 3.0, 5.0,10, and 15 bars. Textural classes and apparent specific gravity were determined for the five layers using pipette method (43) and core method (44), respectively. Electrical conductivity (EC) was determined using the conductivity bridge 1:2.5 soil to water extract (45). Soil reaction (pH) was measured using the pH-meter in 1:1 soil water suspensions (46). Soil samples for the upper 30 cm depth were taken from three locations representing the experimental area to determine soil fertility status. Total nitrogen, available phosphorus, and available potassium were determined by Kjeldhal method (47), $NaHCO_3$ extraction method (48), Ammonium acetate (CH_3, $COONH_4$) extraction method (49), respectively.

3-5 Soil moisture measurements.

The neutron probe (Hydroprobe Model 503) was used to measure the moisture content in the soil at 7.5, 22.5, 45, 75, and 105 cm soil depth to represent the whole 120 cm soil layers.

Thirty two access tubes were installed in the plots (one tube in each plot). Holes for tubes were dug using a two inch diameter auger then galvanized steel pipes (120 cm long and 5 cm I. D.) were driven into the holes leaving 6 cm of the tube above the soil surface.

3-6 Neutron probe calibration curves .

The calibration curves for the five soil layers were obtained by taking soil moisture count ratios and soil moisture samples for gravimetric moisture measurements using the one inch diameter auger for depths 7.5, 22.5, 45, 75, and 105 cm depths around the access tube. The measured gravimetric moisture contents were multiplied by apparent specific gravity to obtain the volumetric moisture contents which were plotted versus the count ratio readings for each depth. Soil samples and neutron probe readings were collected during winter, spring, and summer seasons to cover the whole wetting and drying cycle of the soil.

The regression analysis technique was used to draw the calibration curves for each soil layer.

3-7 Effective rainfall.

Effective rainfall is the fraction of total rainfall that can infiltrate and stored in the root zone for crop water use. The method presented here for determining effective rainfall follows the evapotranspiration -rainfall ratio method developed by the USDA soil conservation service as outlined in Dastane (50). Regression analysis has been used to force a function to fit through the data of Table 2 (51). This function is given as

$$P_{ef} = f(D)[1.25\ (P_t)^{0.824} - 2.93] \times 10^{(0.000955ETc)}$$

Where ,

Pef = effective precipitation, (mm/month)

$f(D)$ = function to account for depth of soil moisture depletion other than 75 mm

P_t = total precipitation, (mm/month)

ETc = crop evapotranspiration , (mm/month)

The function f(D) is given by:

Table 2 : Average monthly effective rainfall as related to average monthly ET crop and mean monthly rainfall. (Dastane, 5O).

Monthly Mean Rainfall		12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	137.5	150	162.5	175	187.5	200
Average monthly ET crop (mm)	25	8	15	23	25	25	25	25	25	25	25	25	25	25	25	25	25
	50	8	16	24	32	40	46	50	50	50	50	50	50	50	50	50	50
	75	9	18	24	35	43	50	57	64	71	75	75	75	75	75	75	75
	100	9	18	28	36	45	53	60	68	75	82	89	95	100	100	100	100
	125	9	19	28	37	46	55	64	72	80	88	95	102	109	115	121	125
	150	10	20	29	39	49	58	66	74	83	91	99	106	113	120	126	133
	175	11	21	31	41	51	60	70	79	87	96	104	112	120	127	134	141
	200	11	22	33	44	54	64	74	83	93	102	111	120	128	135	142	148
	225	12	25	37	47	58	68	78	88	98	108	118	127	135	143	151	158
	250	12	25	37	50	62	74	85	95	105	115	126	136	145	154	161	168
	275	12	25	37	50	62	75	87	100	111	121	132	143	153	164	170	179
	300	12	25	37	50	62	75	87	100	112	125	137	150	160	170	179	188

Where net depth of water that can be stored in soil at time of irrigation is greater or smaller than 75 mm, the correction factor to be used is:

Allowable storage	20	25	36.5	50	62.5	75	100	125	150	175	200
Storage factor	.73	.77	.86	93	0.97	1.00	1.02	1.04	1.06	1.07	1.08

$$f(D)=0.53+0.0116D-8.94\times10^{-5}(D)^2+2.32\times10^{-7}(D)^3$$

Where ,

D = normal depth of soil moisture depletion prior to irrigation, (mm).

The above formulas were used to estimate the effective rainfall during the season. Effective rainfall was considered in calculating actual evapotranspiration.

3-8 Actual evapotranspiration measurements

Actual evapotranspiration for wheat (ETa) was measured using the depletion method. Soil moisture measurements at the five depths were taken before and after 48 hours of each rainfall event. Also, soil moisture measurements were taken directly before and after 48 hours of each irrigation at the five depths. Evapotranspiration rate was calculated using the following formula:

$$ET=\left[\sum_{i=1}^{n}(PV1_i-PV2_i)\,S_i\right]/\Delta t$$

Where ,

ET = evapotranspiration ($mm.day^{-1}$)

n = number of soil layers sampled in the effective root zone.

$PV1_i$ and $PV2_i$ = volumetric moisture content at the first and second measurements of irrigation or rainfall in the i-th layer, respectively.

S_i = the thickness of i-th layer (mm).

Δt = the time interval between irrigations or rainfall events (days).

Evapotranspiration during the 48 hours after irrigation or rainfall was considered as potential evapotranspiration and was measured using class-A pan evaporation multiplied by the appropriate pan coefficient (Kp).

3-9 Potential evapotranspiration measurements.

Class A-pan evaporation method was used to estimate the potential evapotranspiration (ETP) using the following relationship:

$$ETP = Ep \times Kp$$

Where ,

ETP = potential evapotranspiration (mm),

Ep = calss-A pan evaporation (mm), and

Kp = pan coefficient .

3-10 Crop coefficient.

Crop coefficients were determined using the following equation:

$$Kc = ETa / ETP$$

Where ,

ETa = actual evapotranspiration (mm) measured by depletion method,

ETP = potential evapotranspiration (mm)estimated using class A-pan

3-11 Wheat yield and yield components .

One random sample of half square meter was collected from each plot (32 plots) then weighed and threshed to determine the biological yield, and straw yield. The whole plot was harvested to determine the grain yield for each plot. In addition , number of heads per meter square, plant height, number of tillers per plant, and a one thousand kernel weight were measured.

Continuous record of the plant phenology and development of growth stages was taken during the growing season.

3-12 Climatic data .

Rainfall (mm), class-A pan evaporation (mm), maximum and minimum temperature (°c), wet bulb and dry bulb (°c), relative humidity (%), and wind velocity (km/h) were collected from Mushaqqer Meteorological station located about 100 m from the experiment site. The total rainfall amounts during 1991/1992 season was 684.4 mm.

4 . RESULTS AND DISCUSSION

4-1 **Soil properties**

Selected soil physical and chemical properties are presented in Tables 3 & 4 .

4-2 **Calibration curves**

Linear regression equations and correlation coefficients (R^2) for the neutron probe calibration curves for 0-15, 15-30, 30-60 cm depths, and for 60-90, 90-120 cm depths are shown in Figures 5a and 5b, respectively .

4-3 **Soil characteristic curves.**

Soil water characteristic curves for 0-15, 15-30, 30-60, 60-90, and 90-120 cm depths are shown in Figures 6a, 6b, 6c, 6d, and 6e, respectively.

4-4 **Climatic data .**

Rainfall (mm), class-A pan evaporation (mm), maximum and minimum temperature ($^{\circ}$c), wet bulb and dry bulb ($^{\circ}$c), relative humidity (%), and wind velocity (km/h) were taken from Mushaqqer Meteorological Station and presented in Appendix I Table 1. Rainfall in millimeters and mean monthly temperature in $^{\circ}$c are shown in Figure 7.

4-5 **Water application .**

Quantity of water applied for each supplementary irrigation treatment, and the total water applied (irrigation and rainfall) for all treatments are presented in Table 5. Irrigation water applied for T1, T2,

Table 3 : Some physical soil properties of the experiment site

Layer depth (cm)	Field capacity % *	Wilting point (%) *	Apparent specific gravity	Sand (%)	Silt (%)	Clay (%)	Textural class
0 -15	39.9	27.1	1.14	26.1	33.7	40.2	clay
15-30	42.4	30.6	1.21	23.7	29.9	46.4	clay
30-60	41.3	31.0	1.25	21.1	31.0	47.9	clay
60-90	41.4	32.1	1.23	22.2	30.3	47.5	clay
90-120	43.1	31.8	1.32	19.3	26.6	54.1	clay

* % Volumetric water content .

Table 4 : Some chemical soil properties and fertility status of the experiment site.

layer depth (cm)	EC (ds/m)	pH	Total Nitrogen (%)	Available phoshours (ppm)	Available Potassium (ppm)
0 -15	0.16	7.57	0.10	4.4	410
15-30	0.19	7.64			
30-60	0.24	7.79			
60-90	0.23	7.74			
90-120	0.31	7.72			

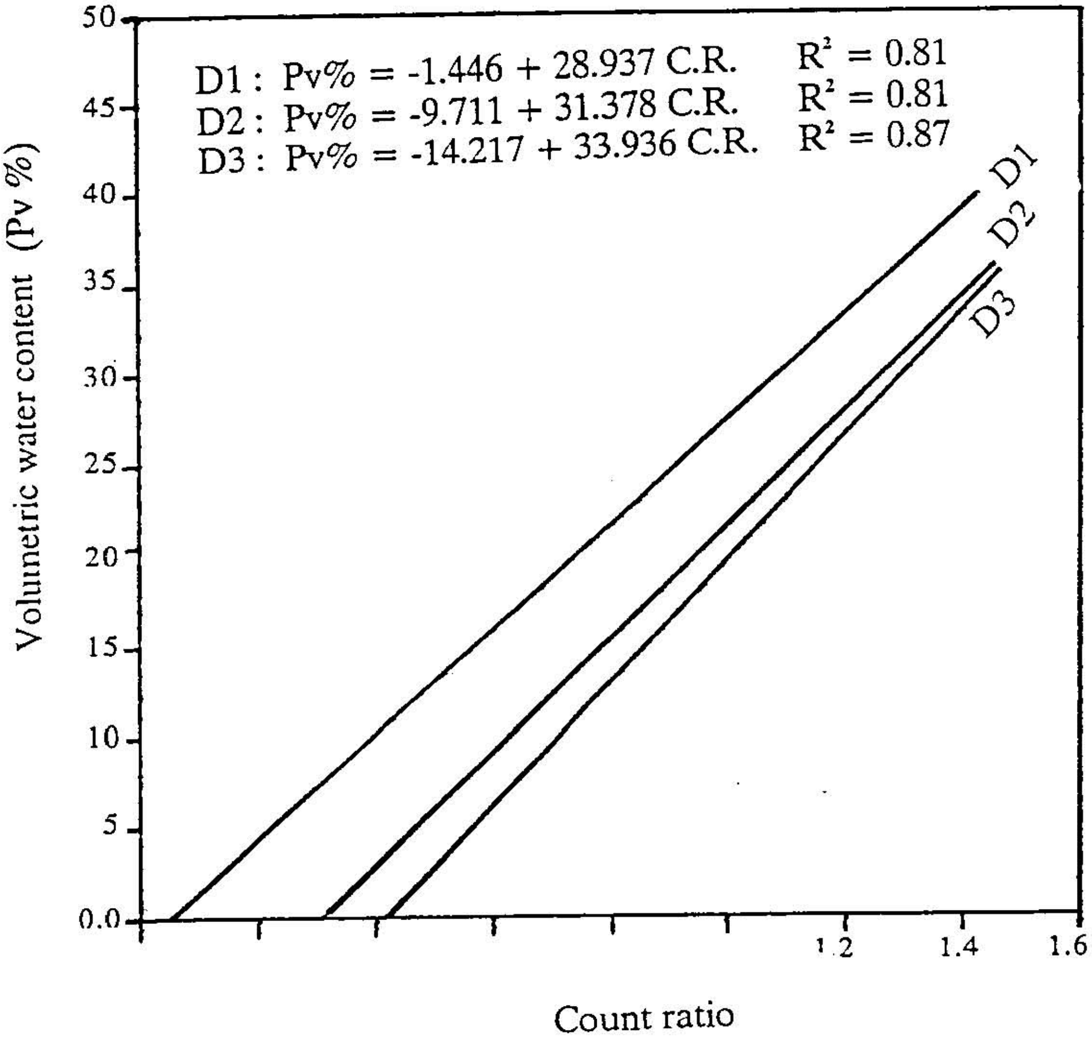

Figure 5a : Neutron probe calibration curves for 0-15 (D1), 15-30 (D2), and 30-60 cm (D3) soil depths for the experiment site at Mushaqqar Agricultural Sation.

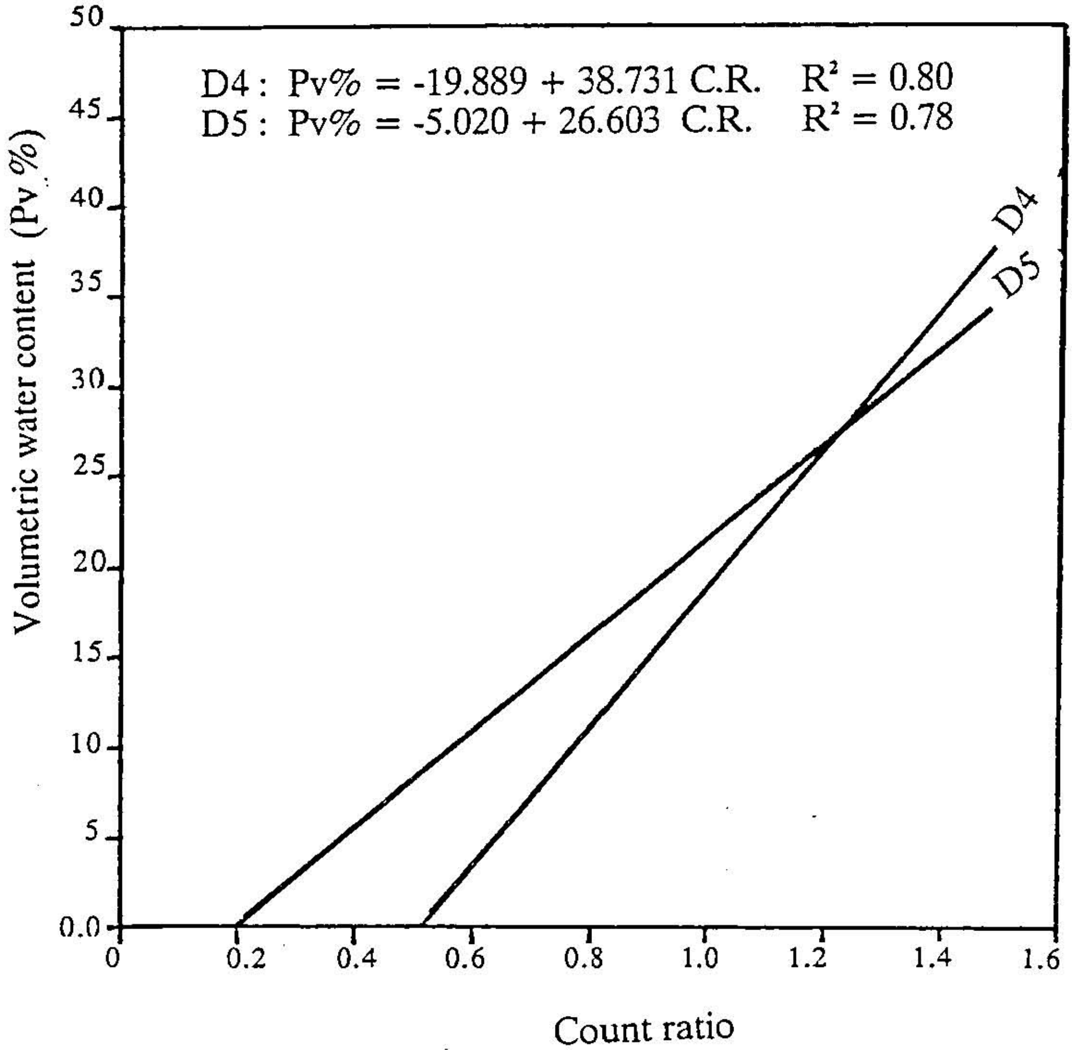

Figure 5b : Neutron probe calibration curves for 60-90 (D4), and 90-120 cm (D5) soil depths for the experiment site at Mushaqqar Agricultural Sation.

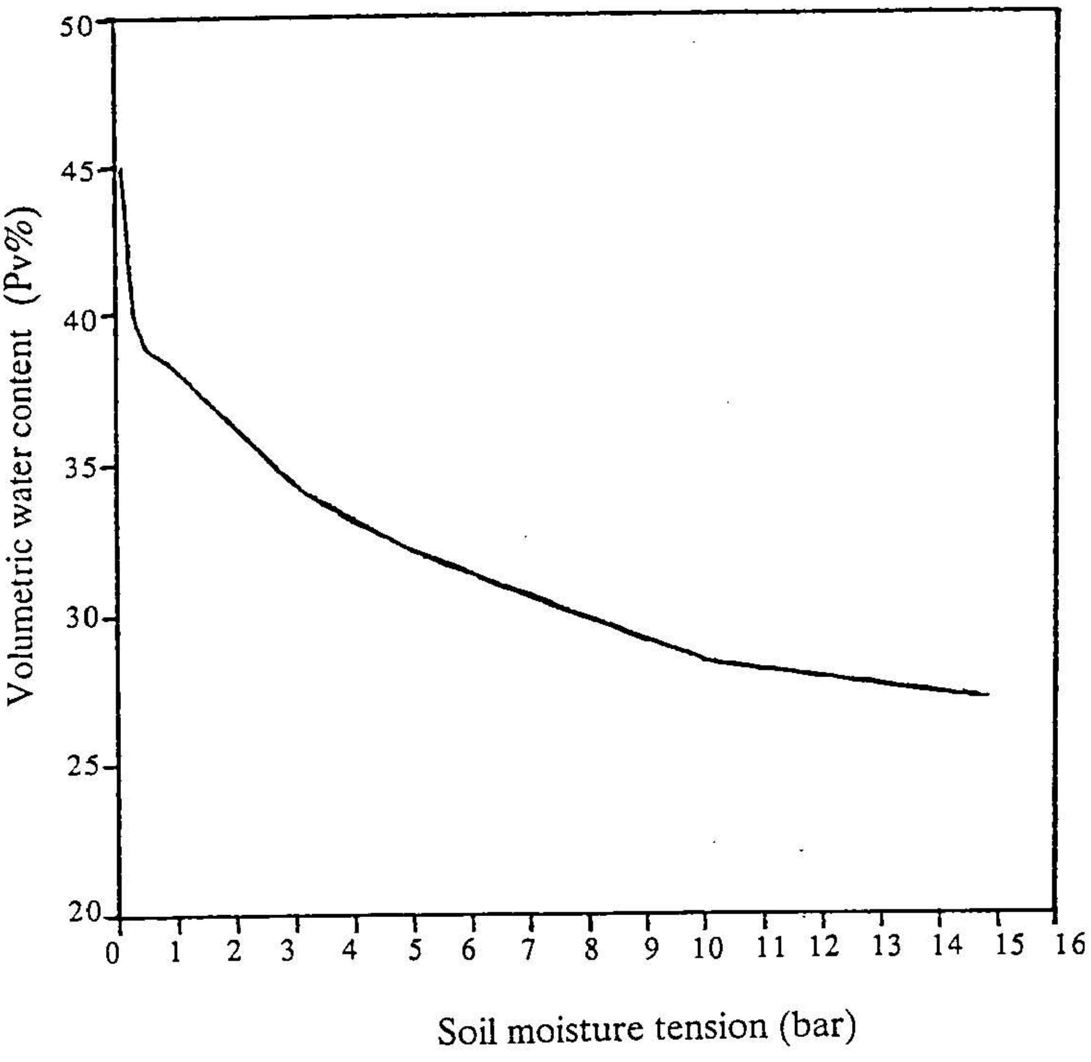

Figure 6a : Soil-water characteristic curve for 0-15 cm soil depth for the experiment site at Mushaqqar Agricultural Station.

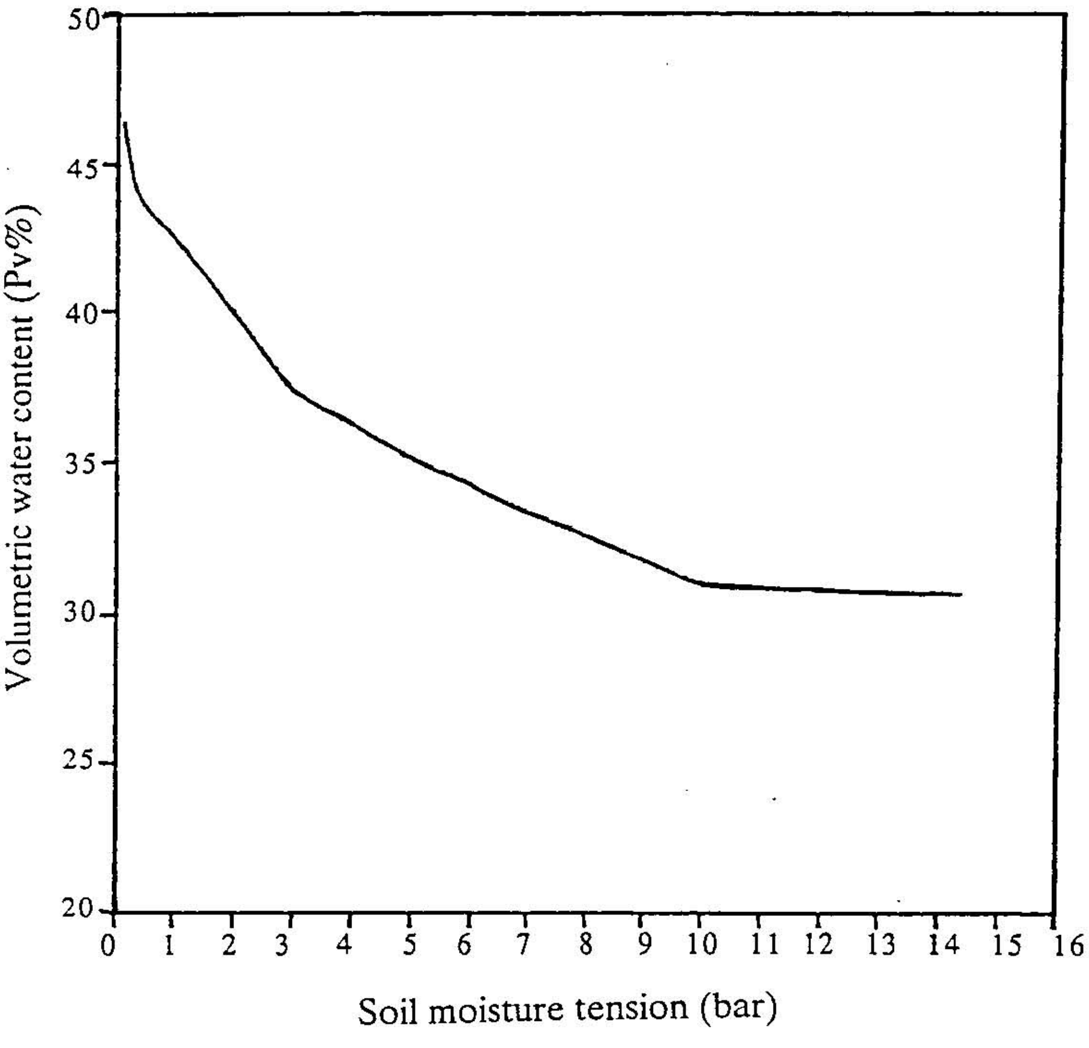

Figure 6b : Soil-water characteristic curve for 15-30 cm soil depth for the experiment site at Mushaqqar Agricultural Station.

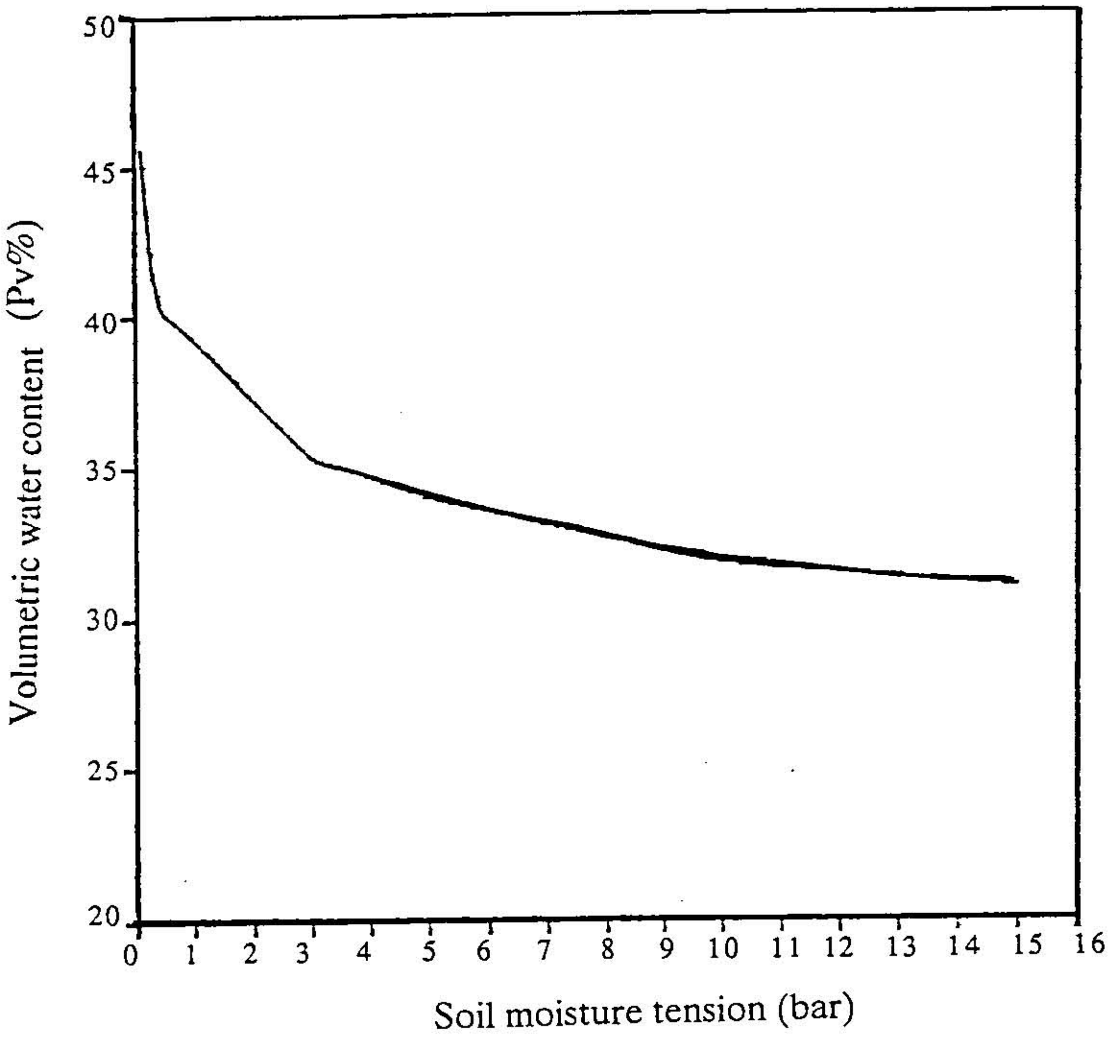

Figure 6c : Soil-water characteristic curve for 30-60 cm soil depth for the experiment site at Mushaqqar Agricultural Station.

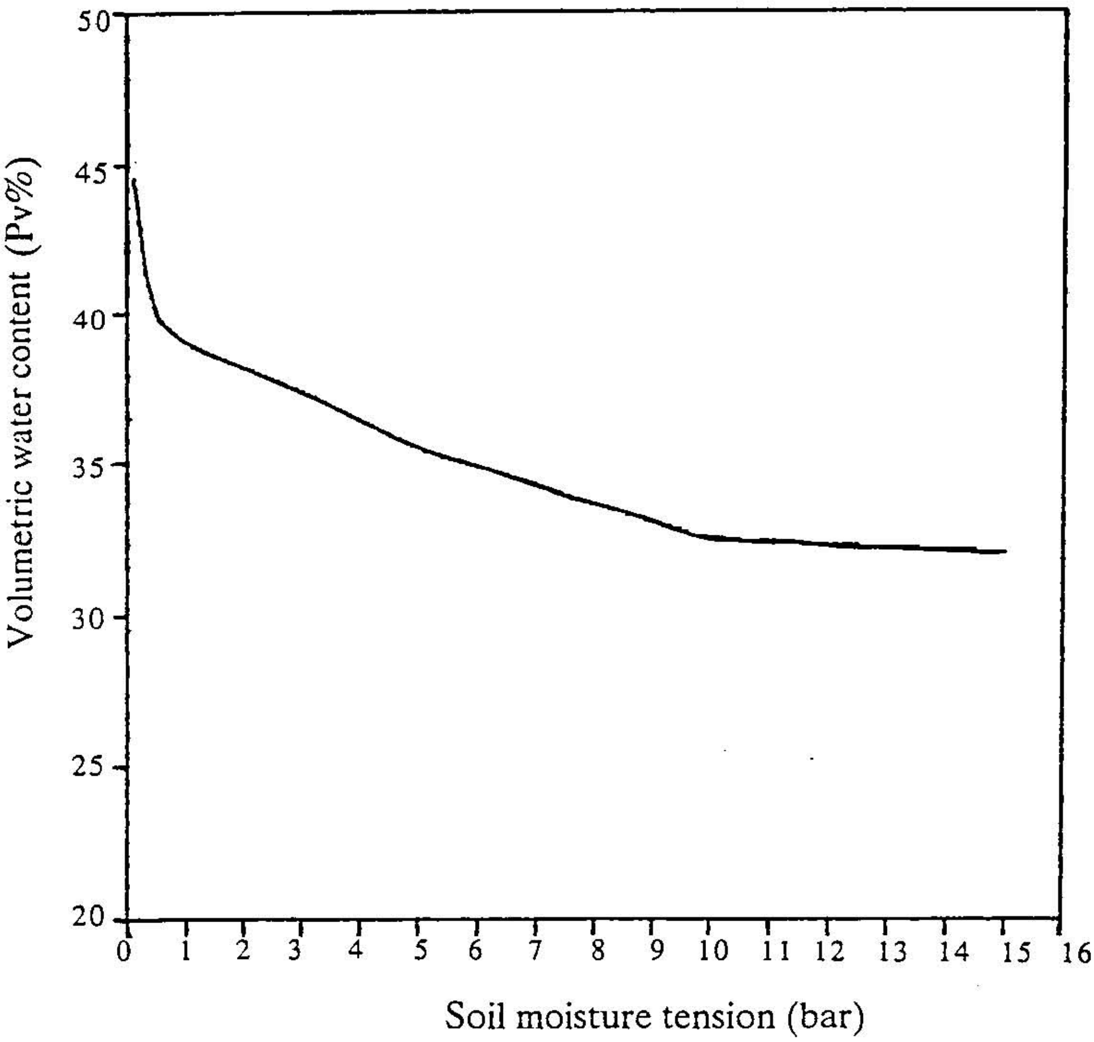

Figure 6d : Soil-water characteristic curve for 60-90 cm soil depth for the experiment site at Mushaqqar Agricultural Station.

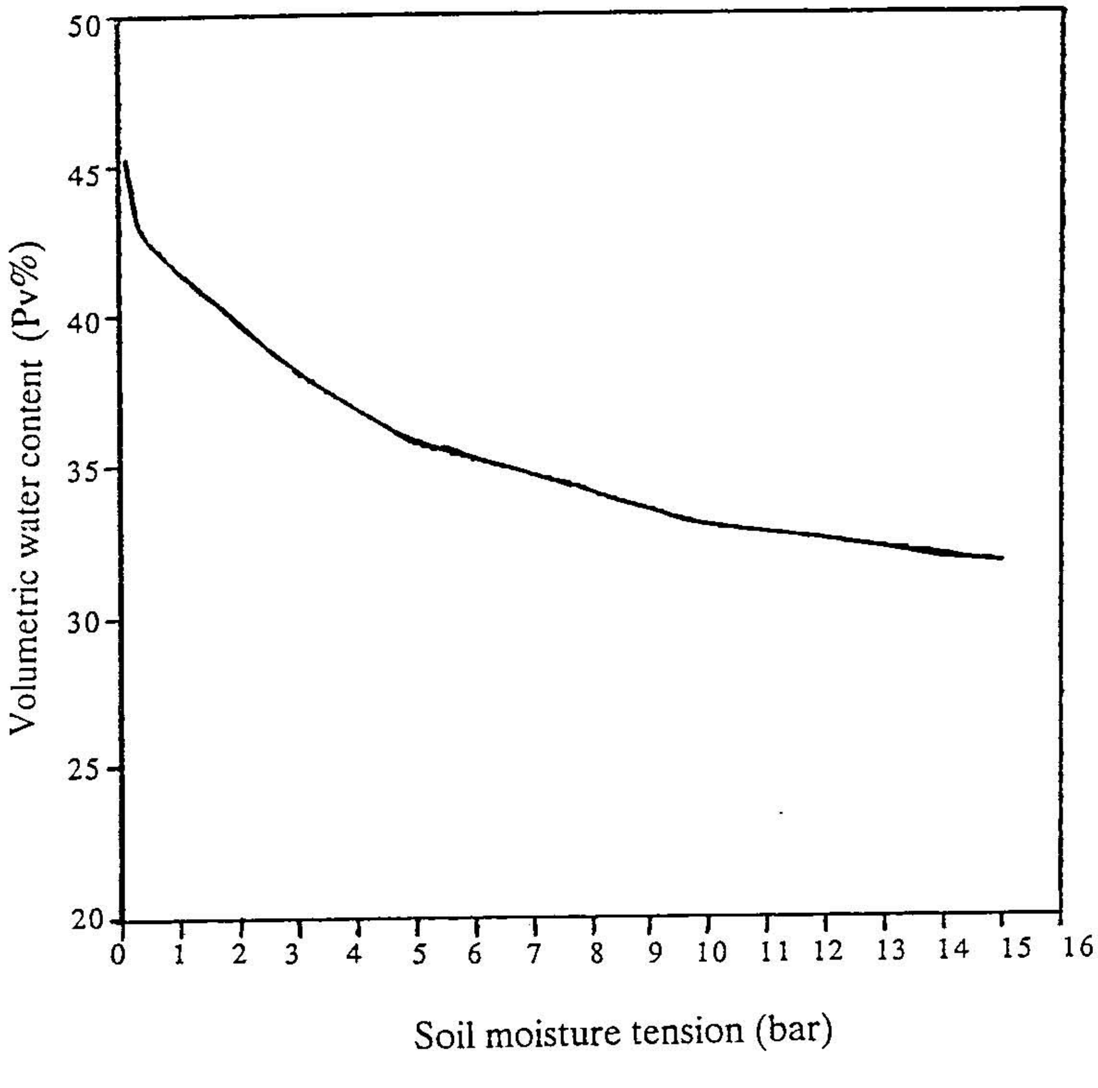

Figure 6e : Soil-water characteristic curve for 90-120 cm soil depth for the experiment site at Mushaqqar Agricultural Station.

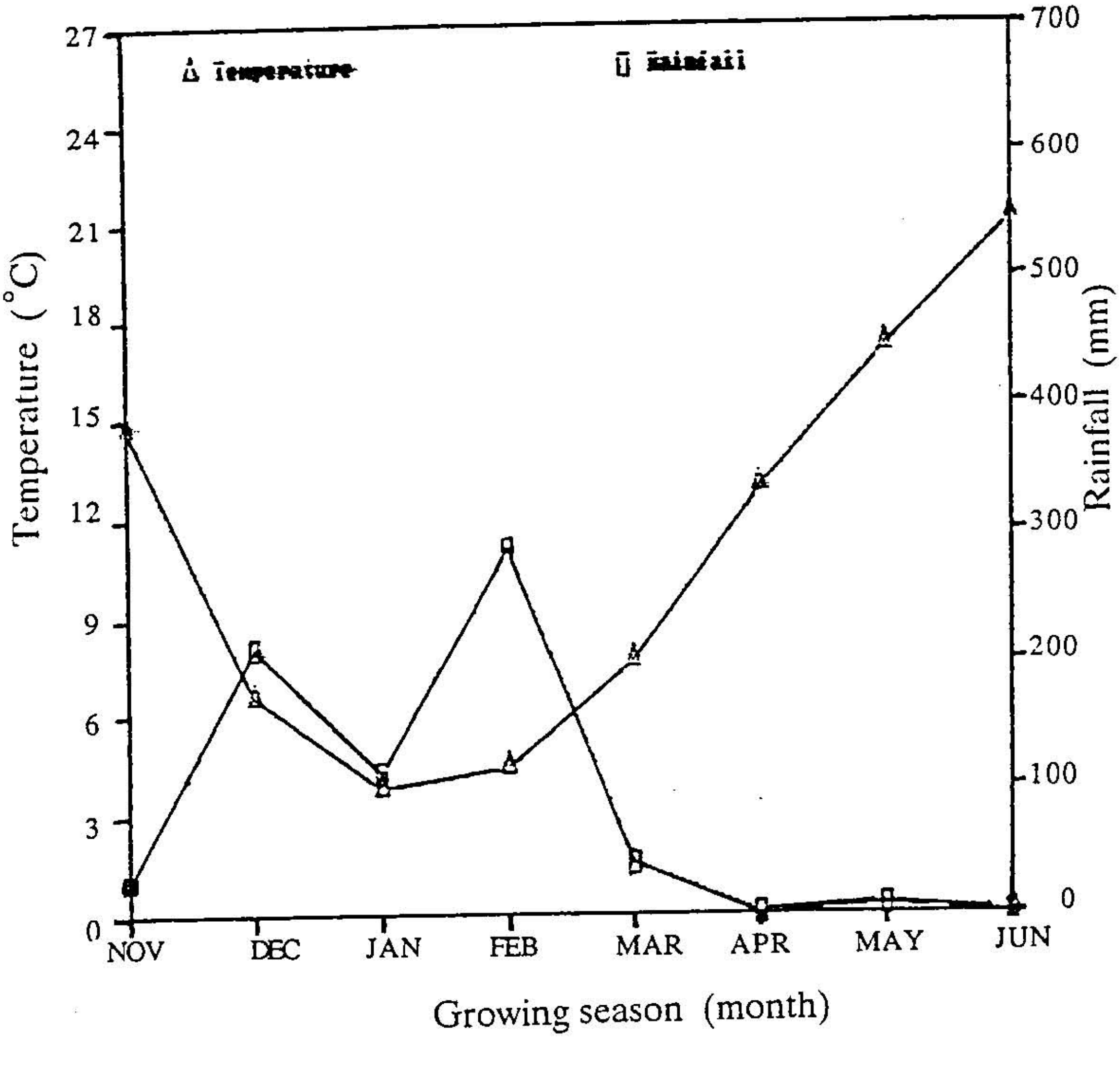

Figure 7 : Rainfall amounts and mean monthly temperature during the growing season (1991/1992) at Mushaqqar Agricultural Station.

Table 5 : Amounts of water applied and rainfall for different treatments during 1991/1992 growing season .

Planting dates	Irrigation treatments	Rainfall (mm)	Supplementary Irrigation (mm)	Total added
Early Planting	100% of est. ETa	684.4	127.30	811.70
	50 % of est. ETa	684.4	71.12	755.52
	100% of est. ETa at critical stages	684.4	92.05	776.45
	Rainfed	684.4	0.00	684.40
Late Planting	100% of est. ETa	684.4	138.04	822.44
	50 % of est. ETa	684.4	69.02	753.42
	100% of est. ETa at critical stages	684.4	76.38	760.78
	Rainfed	684.4	0.00	684.40

T3, and T4 were 127.3, 71.12, 92.05, zero mm under early planting, and, 138.04, 69.02, 76.38, zero mm under late planting, respectively.

4-6 Wheat yield and yield components.

Results of analysis of variance for 13 parameters at 5% probability level of the F-test for the main treatments, subtreatments and the interaction between them are shown in Table 6.

The interaction between planting date and supplementary irrigation treatments (A X B) showed insignificant differences concerning all the parameters measured. The average wheat grain yield, yield components, actual evapotranspiration, and water use efficiency (W.U.E) for the interaction are shown in Appendix I Table 2.

As for irrigation treatments (subplot treatments), there were significant differences among them with respect to all the parameters measured except in the number of fertile tillers per plant, W.U.E based on biological yield, and W.U.E for irrigation. Table 7 shows the average wheat grain yield, yield components, actual evapotranspiration, and W.U.E under different irrigation treatments .

The planting date treatments (main treatments) showed significant differences between them with respect to grain yield, straw yield, biological yield , actual evapotranspiration, 1,000 kernel weight, number of heads/m^2, plant height, and W.U.E based on biological yield. Number of fertile tillers/plant, grain yield/straw yield, grain yield/biological yield, W.U.E based on grain yield, and W.U.E for irrigation showed insignificant differences. Table 8 shows the average

Table 6 : Results of analysis of variance for 13 parameters at (5%) probability level of the F-test.

Parameters	Treatments		
	A	B	A x B
01. Grain yield	*	*	ns
02. Straw yield	*	*	ns
03. Biological yield	*	*	ns
04. Actual evapotranspiration	*	*	ns
05. 1.000 kernel weight	*	*	ns
06. Number of fertile tillers / plant	ns	ns	ns
07. Number of heads /m^2	*	*	ns
08. wheat plant height	*	*	ns
09. Grain yield / straw yield	ns	*	ns
10. Grain yield / biological yield (Harvest index)	ns	*	ns
11. W.U.E based on grain yield	ns	*	ns
12. W.U.E based on biological yield	*	ns	ns
13. W.U.E for irrigation	ns	ns	ns

A Planting date treatments

B Supplementary irrigation treatments

* Significant difference at 0.05 level

ns insignificant

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4-6-2 Wheat straw yield.

Average straw yield of T1, T2, and T3 were significantly higher than T4. Insignificant differences between the straw yields of T1 and T3, or between T2 and T3 were observed. Straw yield of T1 was significantly higher than T2 (Table 7).

Average straw yields were 8.52, 7.92, 8.19, and 6.73 t/ha for T1, T2, T3, and T4, respectively. These results indicated that addition of water would increase straw yield to a certain limit. Further addition of water would not increase it significantly. The percent increments in straw yields of T1, T2, and T3 compared to T4 were 126.6, 117.7, and 121.7 % , respectively.

Table 8 shows that the average straw yield under early planting (8.52 t/ha) was significantly higher than late planting (7.16 t/ha). The percent increase in straw yield of D1 compared to D2 was 119% . These results agree with the findings of Perrier and Salkini (31), El-Dehni (32), and El-Shaer et al. (30).

The relationships between straw yield and water applied (Figure 9) were as follows :

For D1, $Y = -51.79 + 0.15W - 8.79 \times 10^{-5} W^2$ $R^2=0.99$

ForD2, $Y = -30.00 + 0.087W - 4.94 \times 10^{-5} W^2$ $R^2=0.97$

where, Y = straw yield , (ton/ha)

W = water applied , (mm)

The relative straw yield-water applied functions were:

For D1, $Y/Ym = -5.65 + 12.97\ W/Wm - 6.32\ (W/Wm)^2$ $R^2=0.99$

For D2, $Y/Ym = -3.82 + 9.07\ W/Wm - 4.25\ (W/Wm)^2$ $R^2=0.97$

الصفحة غير موجودة من أصل المصدر

4-6-5 Number of heads/m^2

Irrigation and planting date treatments had significant effect on the average number of heads/m^2 similar to their effect on average grain yield. The average number of heads/m^2 for T1, T2, T3, and T4 were 412.38, 398.63, 402.38, and 360, respectively (Table 7). Number of heads/m^2 of T1, T2, and T3 was significantly higher than T4. insignificant differences between T1, T2, and T3 were observed.

Table 8 shows that the average number of heads/m^2 of D1(406.88) was significantly higher than D2 (379.81). These results are similar to those found by El-shaer et al. (30) and Perrier and Salkini (31).

4-6-6 Wheat plant height.

Similar results were obtained with plant height as those observed with grain yield and number of heads/m^2. The average plant height of T1, T2, and T3 were significantly higher than T4. Insignificant differences between T1, T2, and T3 were observed. The average plant heights of T1, T2, T3 and T4 were 115.88, 112.38, 113.63, and 99.13 cm, respectively (Table 7). The percent increase of T1, T2, and T3 compared to T4 was 116.9, 113.4, and 114.6% respectively.

Average plant height under early planting (118.06 cm) was significantly higher than late planting (102.44 cm) as shown in Table 8. The percent increase in plant height of D1 compared to D2 was 115.2%.

Average plant height during the growing season under different irrigation treatments for early planting and late planting is shown in Figures 10a and 10b, respectively.

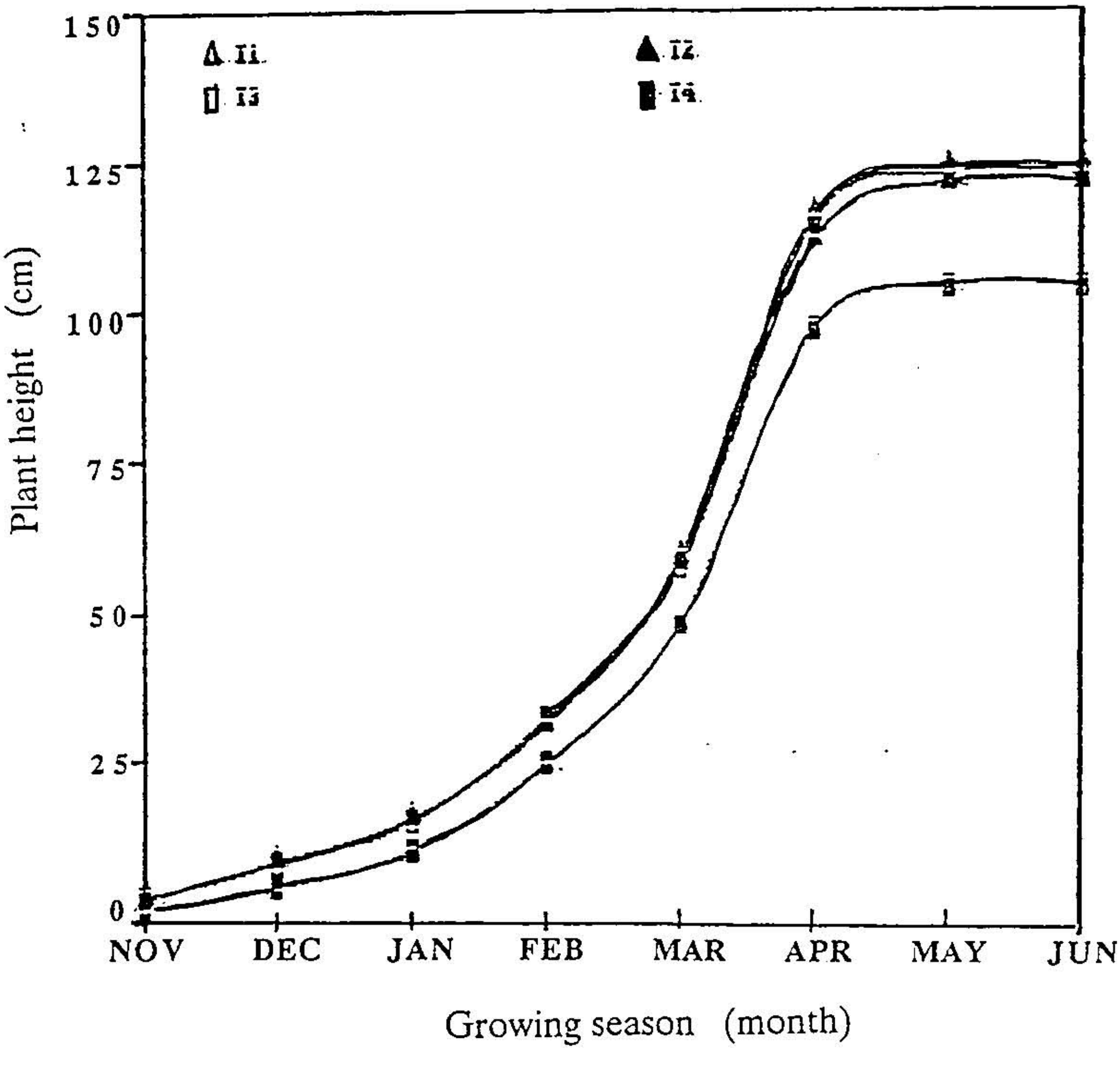

Figure 10a : Average plant height under different irrigation treatments for early planted wheat, during the growing season 1991/1992.

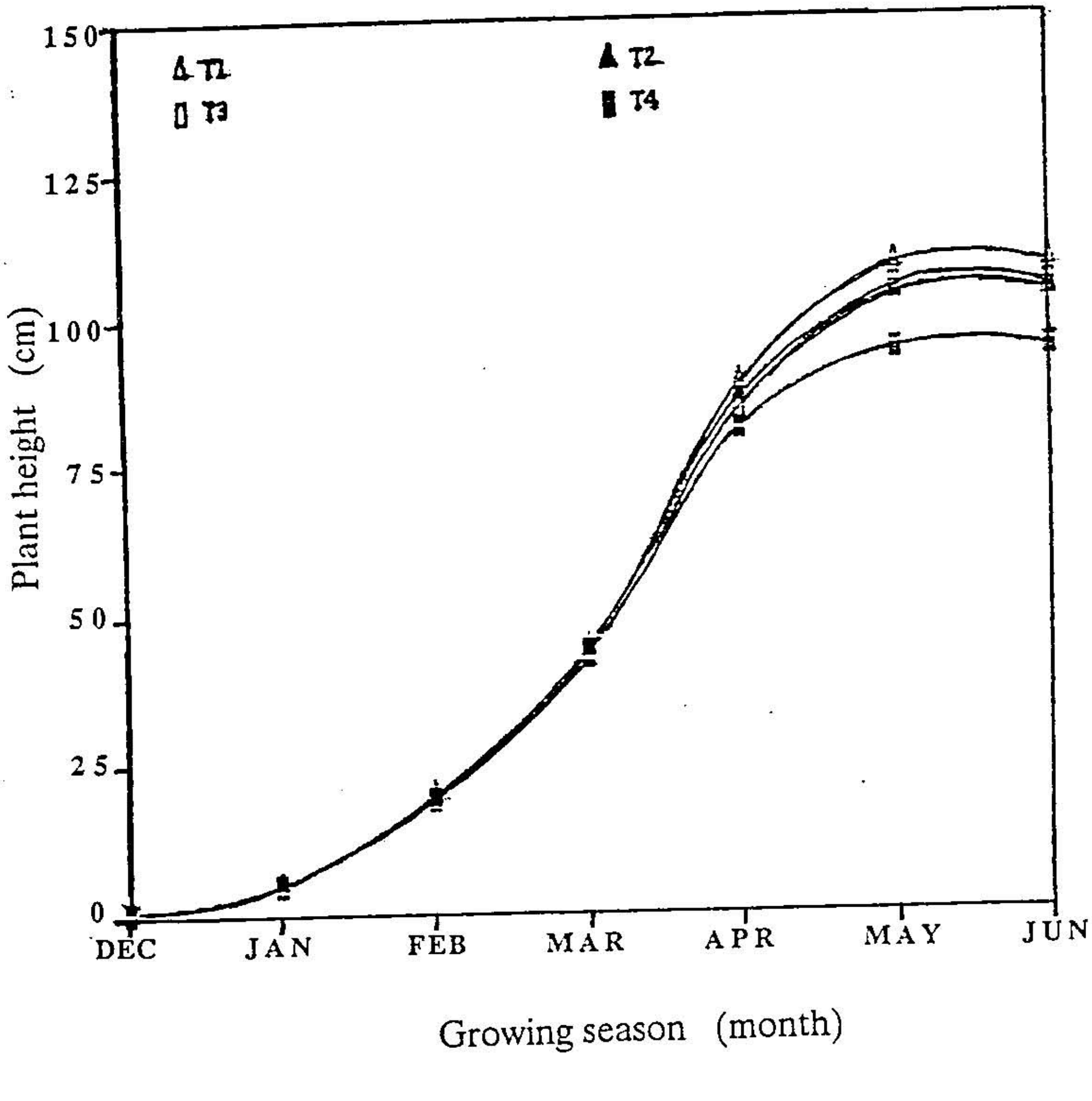

Figure 10b : Average plant height under different irrigation treatments for late planted wheat, during the growing season 1991/1992.

4-6-7 Grain yield/straw yield and grain yield/biological yield (Harvest index)

Table 7 shows that grain yield/straw yield of T1(0.56), T2 (0.55), and T3 (0.55) were significantly higher than T4 (0.5). Insignificant differences between T1, T2, and T3 were observed. Grain yield/biological yield of T1(0.36), T2(0.35), and T3 (0.35) were significantly higher than T4 (0.33). Planting date had insignificant effect on both grain yield/ straw yield and grain yield/ biological yield (Table 8).

4-6-8 Water use efficiency (W.U.E).

Water use efficiency is the yield of marketable crop production per unit of water used in evapotranspiration. W.U.E based on grain yield was significantly affected by irrigation treatments. Water use efficiency (grain) of T1 (1.00), T2 (1.02), and T3 (1.00 kg/mm) were significantly higher than T4 (0.90 kg/mm). Insignificant difference between W.U.E (grain) of T1, T2, and T3 was observed (Table 7). Insignificant difference in water use efficiency (grain) was observed between D1 and D2 (Table8). Water use efficiency based on biological yield was insignificantly affected by irrigation treatments . Water use efficiency (biological) under early planting (2.88 kg/mm) was significantly higher than late planting (2.7 kg/mm) as shown in Table 8.

4-6-9 Water use efficiency for irrigation.

Water use efficiency for irrigation reflects the response to supplementary irrigation, and is calculated as:

$$\text{W.U.E (irrigation)} = \frac{\text{Increase in biological yield}}{\text{Irrigation water applied}}$$

W.U.E (irrigation) for T1, T2, and T3 was 2.39, 3.08, and 3.03 kg/mm (Table 7). Insignificant difference between T1, T2, and T3 was observed. W.U.E (irrigation) for D1 and D2 was 3.14 and 2.53 kg/mm, respectively. Insignificant difference between D1 and D2 was found (Table 8).

4-6-10 Actual evapotranspiration of wheat by depletion method (ETa).

Actual evapotranspiration (ETa) values of wheat determined by depletion method were 474.8 mm, 427.8 mm, 445.54 mm, and 375.54 mm, for T1, T2, T3 and T4, respectively (Table 7). Wheat ETa of T1, T2, and T3 was significantly higher than T4. Insignificant difference between T2 and T3. Wheat ETa of T1 was significantly higher than T2 and T3. Total ETa increased with increase of applied water. An increase of 99.26 mm in ETa from T4 to T1 resulted in an increase in yield from 3.38 to 4.75 ton/ha (140.5%).

Wheat ETa of D1 (453.82 mm) was significantly higher than D2 (408.02 mm) as shown in Table 8.

The wheat ET-grain yield relationship as affected by ETa is described by the following linear equations (Figure 11):

For D1, $Y = -2.65 + 0.016\ ET$ $\qquad R^2 = 0.95$

For D2, $Y = -1.10 + 0.012\ ET$ $\qquad R^2 = 0.96$

Where,

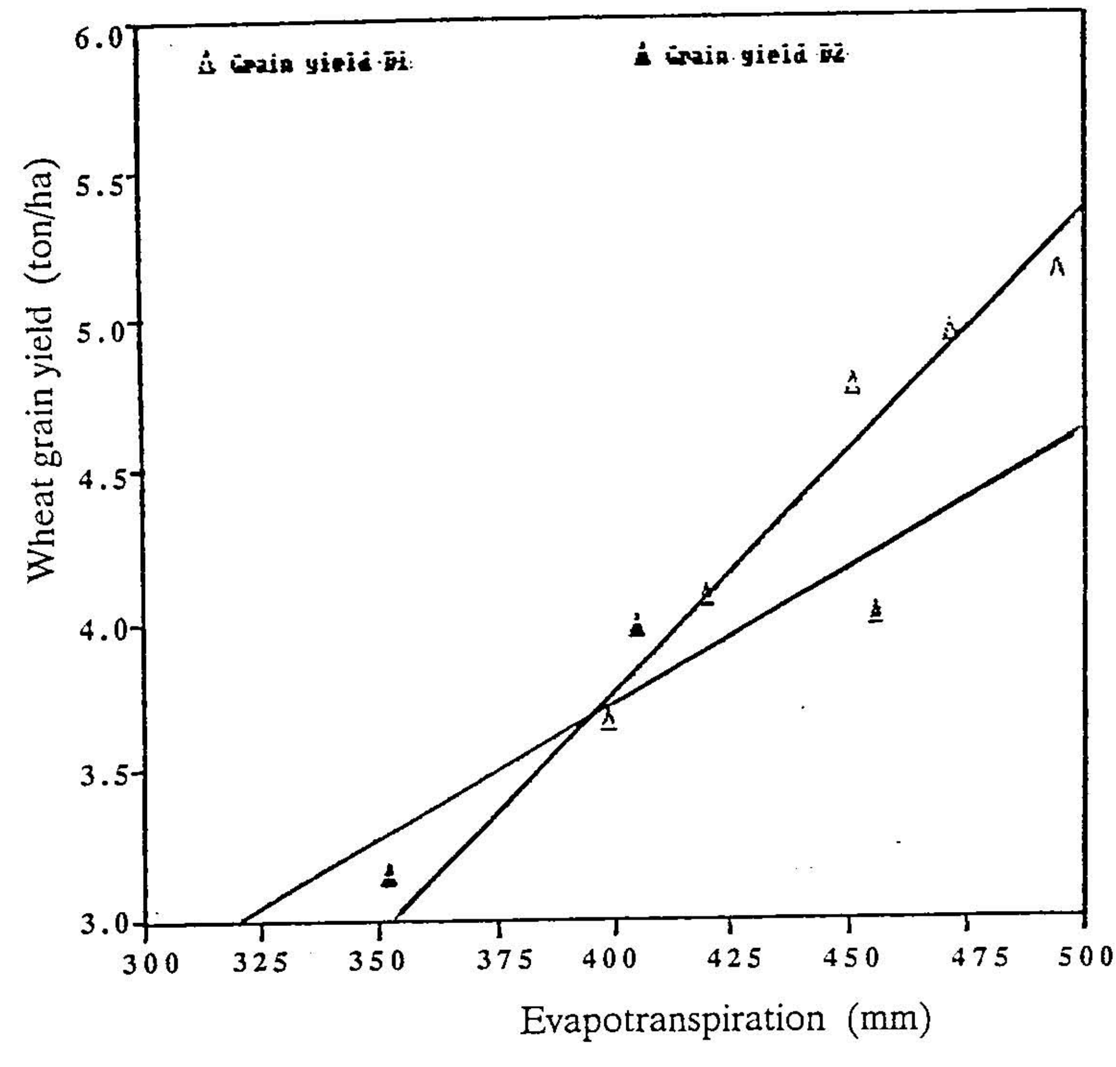

Figure 11 : Relationships between wheat grain yield and actual evapotranspiration under early planting (D1), and late planting (D2).

Y= wheat grain yield, (ton/ha)

ET= actual evapotranspiration, (mm).

Wheat ET-straw yield relationship could be described by the following linear equations (Figure 12):

For D1, Y= - 0.82 + 0.02 ET R^2=0.95

For D2, Y= 0.43 + 0.016 ET R^2=0.98

Where,

Y= wheat straw yield, (ton/ha)

ET= actual evapotranspiration, (mm).

The linear relationship between yield and ET was found by many researchers (Shatanawi et al. (11), Hanks et al. (16)).

The relative ET-grain yield equations were as follows:

For D1, Y/Ym= -0.52 + 1.54 ET/ETm R^2=0.95

For D2, Y/Ym= -0.25 + 1.27 ET/ETm R^2=0.96

Where, Ym= maximum grain yield, (ton/ha)

ETm= maximum evapotranspiration, (mm).

The relative ET-straw yield equations were as follows :

For D1, Y/Ym= -0.09 + 1.11 ET/ETm R^2=0.95

For D2, Y/Ym= 0.05 + 0.96 ET/ETm R^2=0.98

Where, Ym= maximum straw yield, (ton/ha)

ETm= maximum evapotranspiration, (mm).

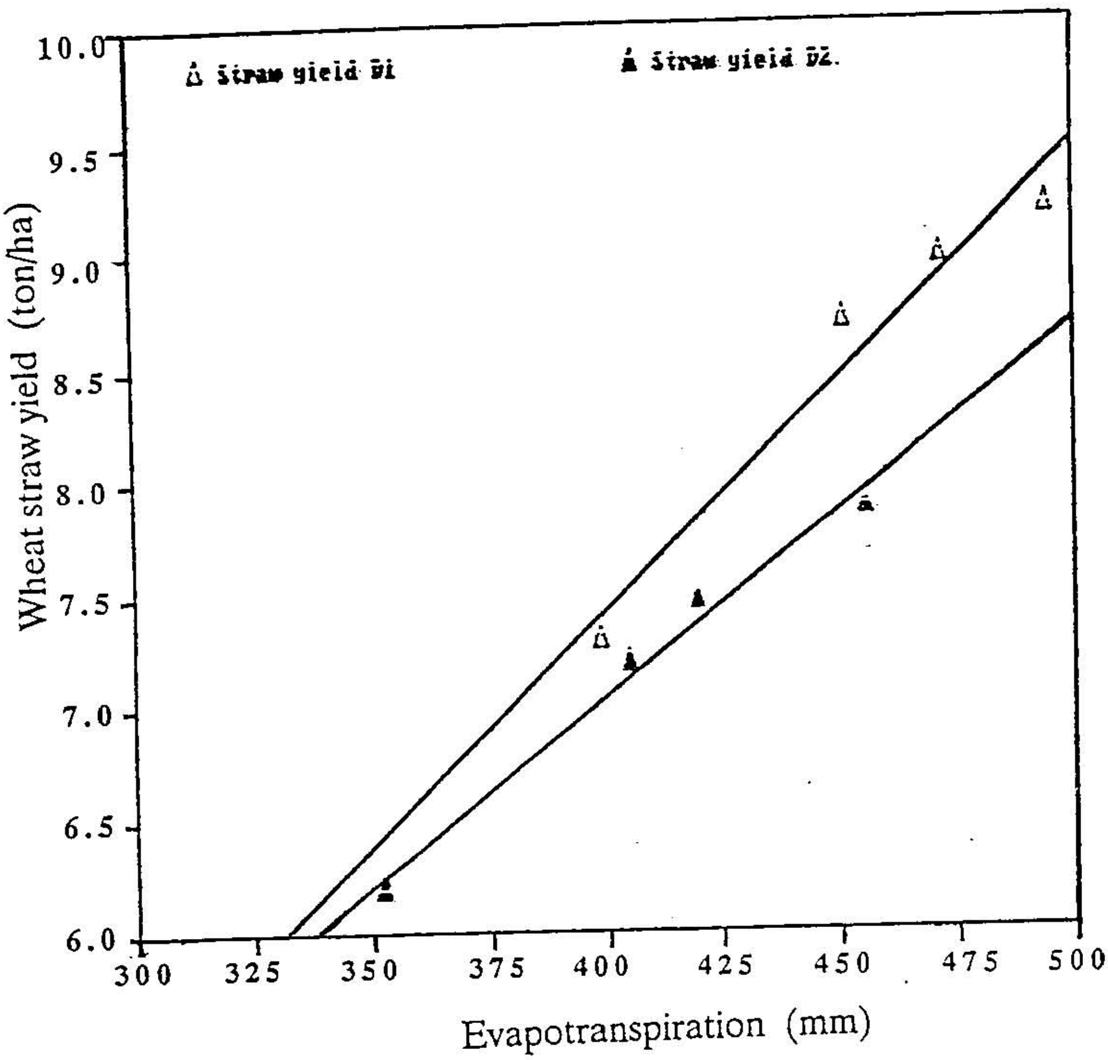

Figure 12 : Relationships between wheat straw yield and actual evapotranspiration under early planting (D1), and late planting (D2).

The average daily ETa values as affected by the irrigation treatments for each planting date on 10-days period and on monthly basis are shown in Tables 9, 10, 11, and 12. Monthly ETa values for the whole growing season are shown in Figures 13a, and 13b.

The results showed that ETa values for the different treatments had the same trends with close values during Nov., Dec., Jan., Feb., Mar which are the rainy months with low temperature and incident solar radiation. Differences are clear after supplementary irrigation was initiated (during Apr. and May).

Figures 13a and 13b show that ETa values for different treatments were low at the beginning of the season, then increased until they reached maximum values during April to May followed by gradual decline until they reached minimum values during June. These fluctuations in ET values are attributed to the climatic changes during the growing season.

4-7 Potential evapotranspiration (ETP) and crop coefficients (Kc).

Potential evapotranspiration (ETP) was measured by class-A pan evaporation. Average daily ETa for wheat plant, potential evapotranspiration (ETpan), and the corresponding crop coefficient (Kc) values, under both planting dates are shown in Tables 13, 14 on monthly basis.

The variation of Kc values with the growing season on monthly basis for different planting dates are shown in Figure 14.

Table 9 : Average actual daily evapotranspiration (mm/day) measured by depletion method for early planted wheat (D1) under different irrigation treatments during 1991/1992 growing season .

Period	Days	T_1	T_2	T_3	T_4
11-20 Nov.	10	1.14	1.21	1.31	0.60
21-30 Nov.	10	1.29	1.36	1.41	1.03
01-10 Dec.	10	1.63	1.75	1.68	1.71
11-20 Dec.	10	0.94	1.06	1.13	1.27
21-31 Dec.	11	0.99	1.01	1.06	1.01
01-10 Jan.	10	0.91	0.90	0.88	0.90
11-20 Jan.	10	0.54	0.47	0.54	0.49
21-31 Jan.	11	1.58	1.57	1.57	1.53
01-10 Feb.	10	1.81	1.81	1.84	1.87
11-20 Feb.	10	1.34	1.37	1.36	1.48
21-29 Feb.	09	1.14	1.19	1.16	1.23
01-10 Mar.	10	2.03	2.04	2.04	2.02
11-20 Mar.	10	3.23	3.08	3.14	2.63
21-31 Mar.	11	3.95	3.89	3.94	3.53
01-10 Apr.	10	3.21	3.32	3.22	3.32
11-20 Apr.	10	4.02	3.75	3.50	3.45
21-30 Apr.	10	4.36	3.45	3.54	3.11
01-10 May.	10	3.71	2.67	3.12	2.55
11-20 May.	10	3.22	2.49	2.95	1.68
21-31 May.	11	3.31	2.82	3.09	1.91
01-10 Jun.	10	2.81	2.34	2.61	1.57
11-20 Jun.	10	0.79	0.43	0.72	0.19
21-28 Jun.	08	0.79	0.43	0.72	0.19
Total		494.09	450.84	471.44	398.90

T_1 = 100% of estimated ETa
T_2 = 50 % estimated ETa
T_3 = 100% of estimated ETa only during critical periods
T_4 = Rainfed (not irrigated) .

Table 11 : Average actual daily evapotranspiration (mm / day) for early planted wheat (D1) on monthly basis under different irrigation treatments .

Period 1991/1992	Days	Supplementary irrigation			
		T1	T2	T3	T4
NOV.	20	1.22	1.28	1.36	0.82
DEC.	31	1.18	1.26	1.28	1.32
JAN.	31	1.03	1.00	1.02	0.99
FEB.	29	1.44	1.47	1.46	1.54
MAR.	31	3.10	3.03	3.07	2.75
APR.	30	3.86	3.51	3.42	3.29
MAY.	31	3.41	2.67	3.05	2.04
JUN.	28	1.51	1.11	1.40	0.68
Total		494.09	450.84	471.44	398.90

T_1 = 100% of estimated ETa

T_2 = 50 % estimated ETa

T_3 = 100% of estimated ETa only during critical periods

T_4 = Rainfed (not irrigated) .

Table 12 : Average actual daily evapotranspiration (mm /day) for late planted wheat (D2) on monthly basis under different irrigation treatments

Period 1991/1992	Days	Supplementary irrigation			
		T_1	T_2	T_3	T_4
DEC.	8	0.92	0.86	0.92	0.86
JAN.	31	1.03	1.00	1.05	0.98
FEB.	29	1.54	1.40	1.52	1.44
MAR.	31	2.44	2.33	2.45	2.28
APR	30	3.13	3.00	2.89	2.83
MAY.	31	4.34	3.50	3.68	2.73
JUN.	28	2.45	2.03	2.16	1.15
Total		455.51	404.75	419.63	352.17

T_1 = 100% of estimated ETa

T_2 = 50 % estimated ETa

T_3 = 100% of estimated ETa only during critical periods

T_4 = Rainfed (not irrigated) .

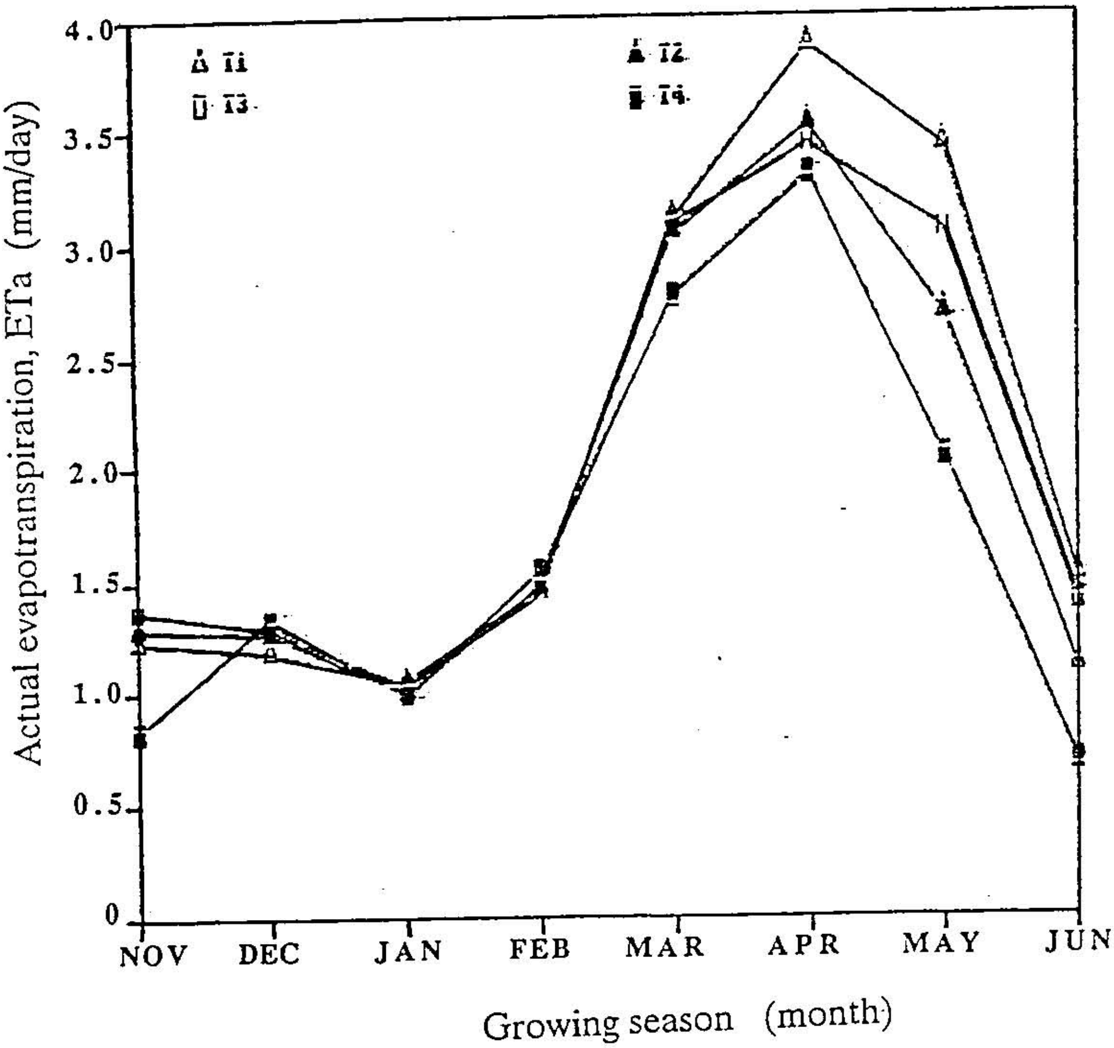

Figure 13a : Average daily actual evapotranspiration (mm/day) for early planted wheat on monthly basis under the four irrigation treatments.

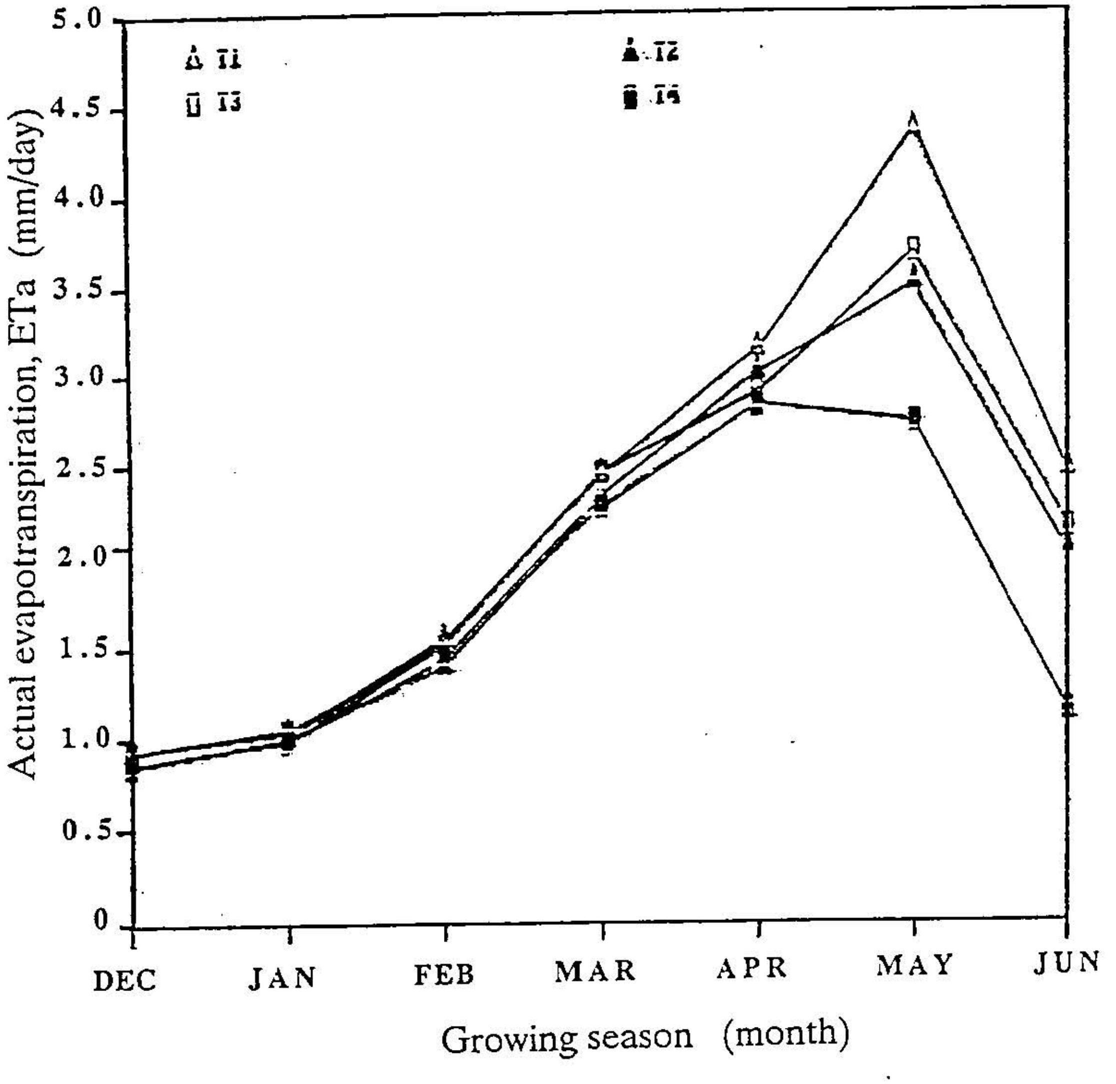

Figure 13b : Average daily actual evapotranspiration (mm/day) for late planted wheat on monthly basis under the four irrigation treatments.

Table 13 : Average actual daily evapotranspiration (ETa) measured by depletion method for early planted wheat (D1) with 100% of estimated ETa , average daily potential evapotranspiration (ETpan), and the corresponding Kc values during the growing season .

Period 1991/1992	**Days**	**ETpan** (mm/day)	**ETa** (mm/day)	**Kc** (ETa/ETpan)
Nov.	20	2.98	1.22	0.41
Dec.	31	0.87	1.18	1.36
Jan.	31	1.00	1.03	1.03
Feb	29	1.26	1.44	1.14
Mar.	31	2.08	3.10	1.49
Apr.	30	3.63	3.86	1.06
May.	31	4.52	3.41	0.75
Jun.	28	5.73	1.51	0.26
Total		628.04	494.09	

Table 14 : Average actual daily evapotranspiration (ETa) measured by depletion method for late planted wheat (D2) with 100% of estimated ETa , average daily ETpan, and the corresponding Kc values during the growing season .

Period 1991/1992	**Days**	**ETpan** (mm/day)	**ETa** (mm/day)	**Kc** (ETa/ETpan)
Dec.	08	0.62	0.92	1.48
Jan.	31	1.00	1.03	1.03
Feb	29	1.33	1.54	1.16
Mar.	31	2.08	2.44	1.17
Apr.	30	3.63	3.13	0.86
May.	31	4.52	4.34	0.96
Jun.	28	5.73	2.45	0.43
Total		548.50	455.51	

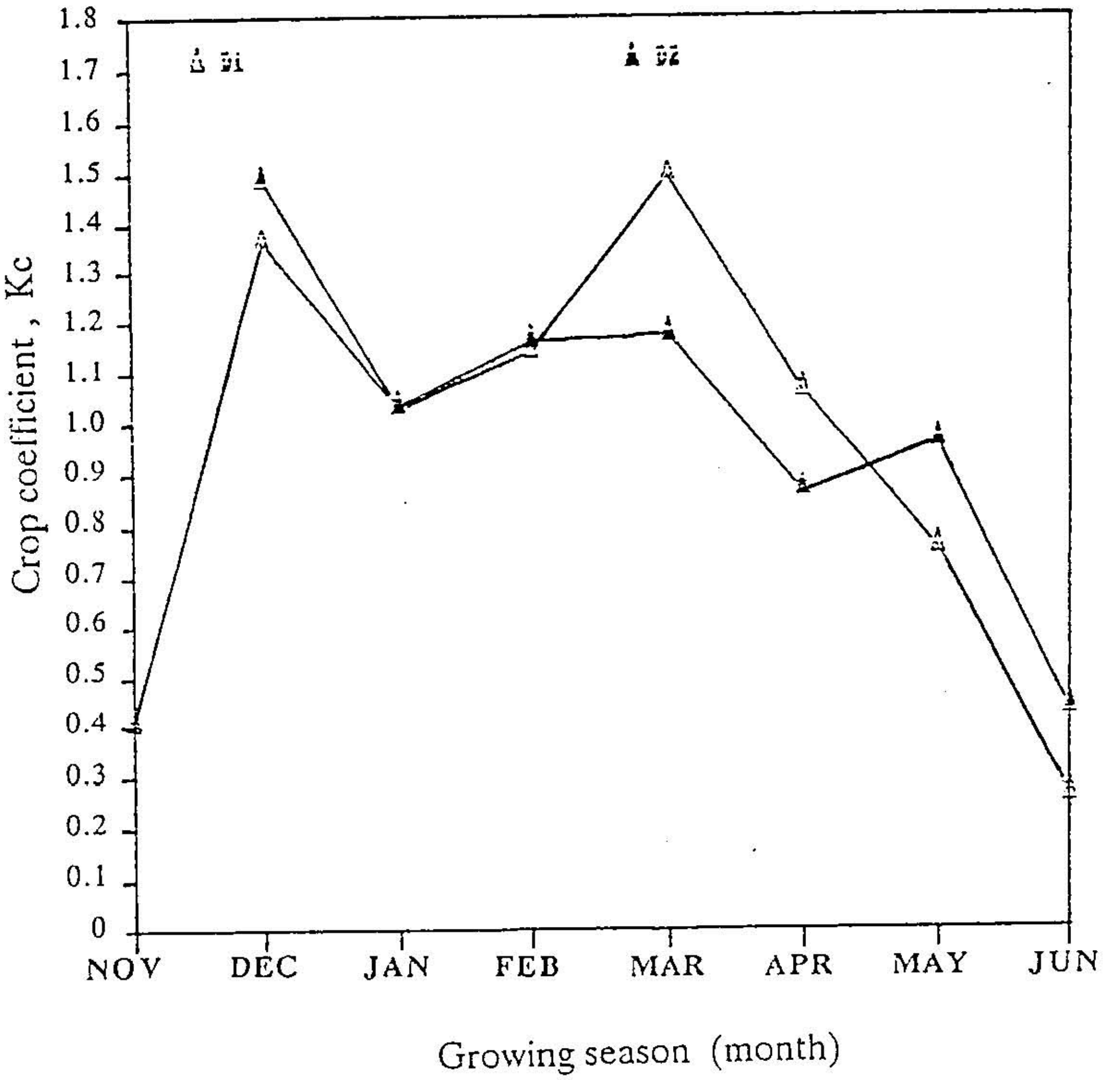

Figure 14 : Crop coefficient values variation with the growing season on monthly basis interval for early planted (D1) and late planted (D2) wheat.

Figures 15 and 16 show the cumulative evapotranspiration for ETa, ETpan, estimated ETa (using class-A pan), with the growing season for the two planting dates. The close values of ETa and estimated ETa during the growing season proves that class- A pan is a good estimate for ETa, and consequently a good method for scheduling supplementary irrigation. In fact, evaporation pans provide a measurement of the integrated effect of temperature, radiation, humidity, and wind on evaporation from a specific open water surface where in a similar fashion the plant responds to the same climatic factors.

4-8 Wheat crop water use at different growth stages.

Table 15 shows crop water use of wheat during different growth stages for different treatments. Results indicate that the maximum amount of water used by wheat crop grown under different treatments, occurred during tillering, heading-flowering, and grain formation growth stages, which was about 62% to 74% of the total water used. These results emphasizes the needs for supplemental irrigation during these critical periods coinciding with diminishing rainfall.

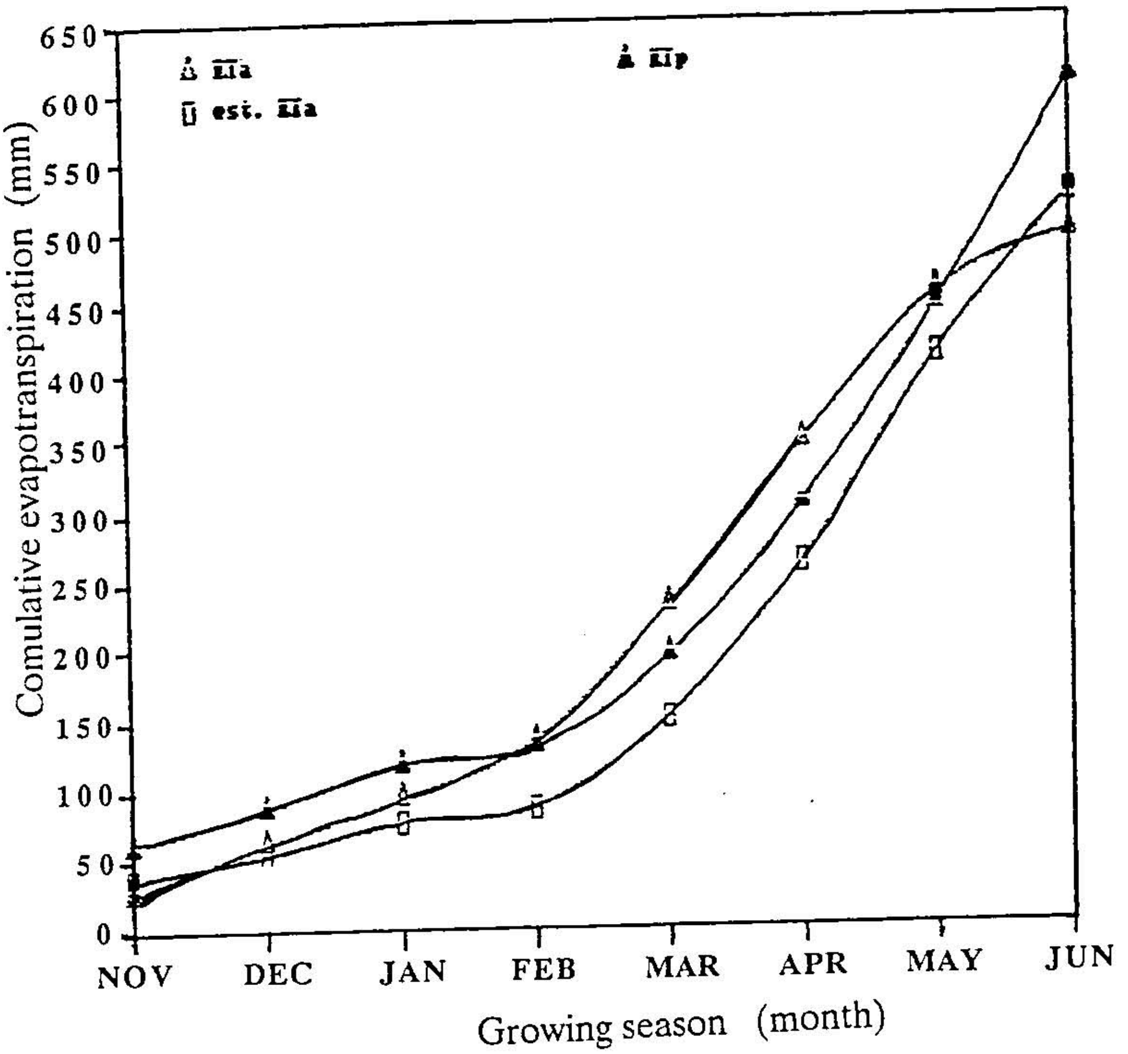

Figure 15 : Cumulative actual evapotranspiration (ETa), potential evapotranspiration (ETpan), and estimated actual evapotranspiration (est. ETa) for early planted wheat during the growing season.

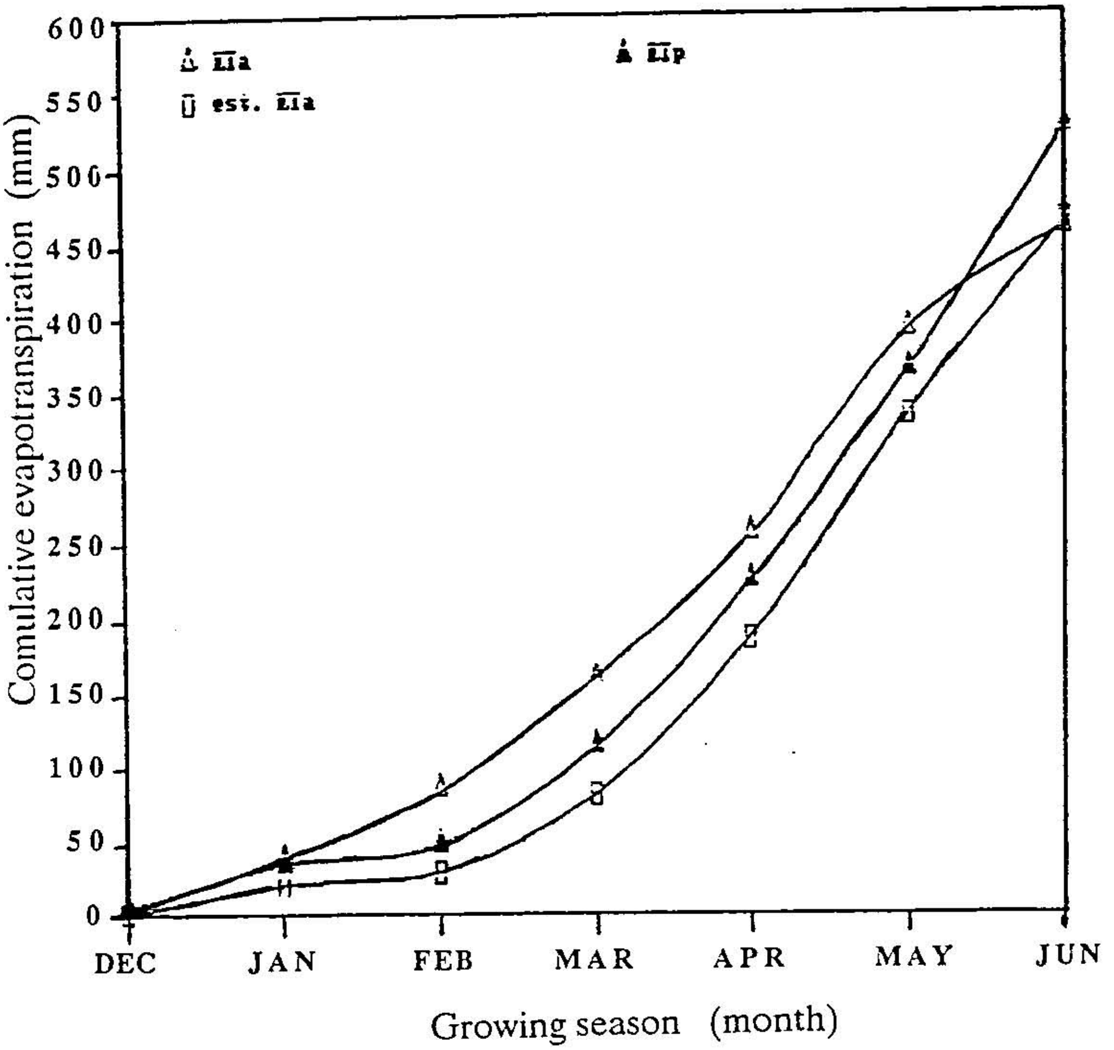

Figure 16 : Cumulative actual evapotranspiration (ETa), potential evapotranspiration (ETpan), and estimated actual evapotranspiration (est. ETa) for late planted wheat during the growing season.

Table 15 : wheat crop water use (mm) during the different growth stages for all treatments, during 1991/ 1992 growing season .

Growth stages	Early planting				Late planting			
	T1	T2	T3	T4	T1	T2	T3	T4
Planting to emergence	31.48	33.16	34.88	24.32	28.99	27.88	29.41	27.46
seedling stage	70.07	71.32	72.38	72.93	94.00	87.88	93.78	88.04
Tillering stage	198.70	190.92	190.31	179.89	152.2	142.45	141.85	132.75
Heading and flowering	83.83	71.49	74.59	61.92	78.12	63.00	66.24	49.14
Grain formation to milk ripe	81.79	63.39	73.60	46.92	66.57	54.39	57.52	36.79
Milk ripe to maturity	30.20	22.20	28.00	13.60	39.20	32.48	34.56	18.40
Total (mm)	494.09	450.84	471.44	398.90	455.51	404.75	419.63	352.17

T1 : 100% of est. ETa **T2** : 50 % of est. ETa

T3 : 100% of est ETa at critical stages **T4** : Rainfed

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A study was carried out during 1991/1992 growing season at Mushaqqer Agricultural Experiment Station, located approximately 28 km south west of Amman to study the effect of supplementary irrigation on wheat yield as related to evapotranspiration and planting date.

The experiment was laid out in a split plot in randomized complete block design with four replications. The main treatments were early planting (D1) and late planting (D2) dates. The subplot treatments were four levels of irrigation treatments (T1 = 100% of estimated ETa, T2=50% of estimated ETa, T3 = 100% of estimated ETa at critical stages, and T4 = rainfed). Each subplot size was 4.0 x 4.0 m . Supplementary irrigation was initiated on April, the first, 1992.

Actual water consumption of wheat plant (ETa) was measured by depletion method using neutron scattering techniques for the different treatments. Potential ET was measured by class-A pan evaporation method during the growing season in addition to corresponding crop coefficients values (Kc). Estimated ETa was determined by potential ET and Kc values obtained from F.A.O, and was then used to schedule supplementary irrigation.

Wheat yield and many yield parameters were measured. Continuous record of plant phenology was made during the growing season.

Amounts of water applied as supplementary irrigation for T1, T2, T3, and T4 were 127.3, 71.12, 92.05, and zero mm under early planting, and 138.04, 69.02, 76.38, zero mm under late planting, respectively.

The results obtained can be summarized as follows:

1. Total ETa of wheat plant increased significantly with water applied. Total ETa for T1, T2, T3, and T4 were 474.8, 427.8, 445.54, and 375.54 mm, respectively. Total ETa of D1 (453.82 mm) was significantly higher than D2 (408.02 mm). An increase Of 99.26 mm in ETa from T4 to T1 resulted in increase in yield from 3.38 to 4.75 ton/ha (140.5%) .

2. Wheat grain yields and corresponding water use efficiency (W.U.E) responded significantly to the lowest amount of supplementary irrigation. Average wheat grain yield of T1 (4.75 ton/ha) , T2 (4.35 ton/ha), and T3 (4.49 ton/ha) were significantly higher than T4 (3.38 ton/ha). W.U.E increased from 0.9 kg/mm under T4 to 1.02 kg/mm under T2.

3. Early planting date increased the grain yield (4.61 ton/ha) of wheat significantly compared to late planting (3.88 ton/ha).

4. Supplementary irrigation showed significant difference compared to rainfed treatment with respect to wheat yield parameters measured, namely: straw yield, biological yield, 1,000 kernel weight, number of heads per m^2, plant height, grain yield/straw yield, and grain yield/biological yield.

5. Significant difference was obtained between early planting and late

planting with respect to straw yield, biological yield, 1,000 kernel weight, number of heads per m^2, plant height, and W.U.E based on biological yield.

6. The relation between wheat grain and straw yield with evapotranspiration was linear. On the other hand, the relation between grain and straw wheat yield with water applied could be described by a second degree equation.

7. The maximum amount of water used by wheat crop occurred during tillering, heading-flowering, and grain formation stages. The later two stages commonly coincide with diminishing rainfall, so the need for supplementary irrigation during these stages is essential.

8. Class-A pan evaporation method is a good estimate of actual evapotranspiration. Consequently, it is considered as a good method for scheduling supplementary irrigation

These results lead to the following recommendations:

1. Supplementary irrigation is highly recommended during critical growth stages in order to stabilize and increase wheat yields, especially in rainfed areas with high seasonal rainfall variability

2. Early planting is recommended for sowing wheat in Madaba and similar regions.

3. Further research studies on supplementary irrigation in the fields of economical feasibility, wheat varieties, and waste water use are needed in dry land areas of Jordan.

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APPENDICES

Appendix 1 :Maximum temperature (Tmax), minimum temperature (Tmin), wet bulb (Wb), dry bulb (Db), wind velocity (U), class-A pan evaporation (Ep), relative humidity (RH %), and rainfall (Rn) taken from Mushaqqar Meteorological Station .

DATE	Tmax (°C)	Tmin (°C)	Wb (°C)	Db (°C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/11/91	26	09	11.8	19	3	7	36.81	
02	26	10	12	18.2	3	8	43.41	
03	19	11	14	18	5	7	61.97	
04	15	08	9.4	10.4	6		87.18	11
05	16	10	11.4	12	2	1	92.69	1.5
06	19	07	12	14	3	2	77.74	
07	24	11	13	16	4	4	69.19	
08	25	11	10.4	14.6	5	6	55.70	
09	22	10	9.2	13	3	7	57.42	
10	19	08	12.6	14	3	4	84.27	
11	21	06	10	12	3	5	76.16	
12	23	10	10.6	15.4	6	5	51.13	
13	18	10	14	16	3	3	79.13	
14	21	11	13	14	6	5	88.692	
15	22	08	1.6	17	5	5	8.09	
16	25	06	10.4	15	6	6	52.41	
17	14	10	13.4	16	4	3	73.13	
18	20	05	10	12	4	3	76.16	
19	18	08	12	15	5	3	68.19	
20	19	05	9.6	11	3	4	82.54	
21	21	10	12	15	3	4	68.19	
22	22	11	13	16	5	5	69.19	
23	24	09	12	17	4	7	51.77	
24	24	10	10.4	15	6	8	52.41	
25	25	10	10	15	6	5	48.58	
26	22	12	09	14	4	5	46.83	
27	18	07	09	15	3	3	39.21	
28	17	03	10	12	5	3	76.16	
29	18	07	08	11	5	3.5	63.46	11.5
30	18	06	8.8	9.4	6	3	91.96	

Appendix 1 Continued

DATE	Tmax (°C)	Tmin (°C)	Wb (°C)	Db (°C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/12/91	10	6	9	9.6	7		92.02	9.2
02	09	7	8	9	5		86.48	72
03	10	6	6	8	4		72.27	62
04	09	5	6	7	6		85.36	09
05	11	5	5	8	3	1	58.97	
06	12	4	6.8	9	4	1	70.76	
07	14	3	7	8.4	5	3	80.74	
08	14	2	4.8	6	3	5	81.74	
09	09	5	4.4	6.6	5	5	67.78	
10	11	5	4.8	5.8	3		84.61	
11	12	2	5.2	7	4	2	73.94	
12	10	5	5.4	6	7		90.79	7.5
13	07	3	4	6	4		69.88	15
14	08	2	4.2	5	3		87.22	17
15	10	1	3	4	4	2	83.35	
16	10	1	3.8	4.8	3	1	83.93	
17	11	1	4	5	2	2	84.07	
18	11	-1	2	4	3	2	67.12	
19	12	0	2.4	5	2	1	59.43	
20	12	3	4.2	5.8	4	1	75.57	
21	10	2	4	6	3	1	69.88	
22	12	0	3	3.8	4	3	86.52	
23	13	1	4	6.4	4	3	64.65	
24	13	3	5	7.6	2	2	63.66	
25	08	5	4	6	7		69.88	1.5
26	10	1	4	4.6	3	1	90.22	
27	12	3	4.5	5.6	4		82.95	11
28	09	3	5	6	8	1	84.74	
29	09	-2	2	3	2	1	82.58	
30	10	-2	1.6	2	4	1	92.64	6.5
31	10	1	3	5	6	1	68.55	

Appendix 1 Continued

DATE	Tmax (˚C)	Tmin (˚C)	Wb (˚C)	Db (˚C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/1/92	04	1	5	6	10		84.74	20.5
02	04	-3	2.4	4.6	8		64.88	40
03	05	-3	0.8	1.6	4		85.08	06
04	08	-4	0.6	1	3	2	92.28	
05	07	-3	0.4	1	4		88.45	
06	08	-2	1	1.8	2		85.22	
07	09	0	1	2.4	3		75.04	
08	05	-1	3	4	4	1	83.35	
09	08	-1	1	1.8	5	4	85.22	
10	08	1	2.6	4	4	5	76.81	
11	09	-1	2	3.8	3	2	70.06	
12	10	0	3	5	3	1	68.55	
13	10	3	6	6.8	4	1	88.16	
14	10	5	5.2	6	3		87.76	
15	08	5	6	7	5		85.36	01
16	07	4	4	5	5		84.07	2.8
17	05	3	4.2	4.8	4	4	90.31	17
18	08	3	4	5	2	1	84.07	04
19	10	4	5.2	7	5	1	73.94	0.5
20	08	5	4	6	5		69.88	01
21	08	3	4.5	5.2	3		88.90	12.5
22	08	1	5.4	6.2	2		87.86	
23	07	3	4.6	5	3	2	93.57	
24	08	-3	0.6	2.4	3	3	68.06	
25	07	-2	0	1	4	3	80.84	
26	09	-3	0.6	1	5	5	92.28	
27	06	-4	-0.2	0.4	6	2	88.10	
28	07	-5	-0.6	0	7	2	87.87	
29	10	-2	0	1.2	6	3	77.29	1.5
30	06	0	5	6	7		84.74	05
31		1	2	4.2	7		64.24	

Appendix 1 Continued

DATE	Tmax (˚C)	Tmin (˚C)	Wb (˚C)	Db (˚C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/2/92	03	1	1.4	2	8		88.99	28
02	07	0	0.4	1	3		88.45	06
03	10	1	4	6	5		69.88	1.7
04	03	-1	0.2	0.8	7	4	88.34	44
05	07	-1	2.2	3.4	8		79.52	67
06	07	3	3	5.4	9		63.10	
07	08	3	2.8	4.8	6		68.27	28
08	07	2	3	4	5		83.35	06
09	03	1	3	4	8		83.35	3.5
10	03	-4	-1.4	0.1	5		70.13	14.5
11	07	-2	2.8	3.8	4		83.20	01
12	08	-2	5	6	5		84.74	01
13	08	0	5.8	6.6	3		88.06	01
14	11	-1	4.8	6.8	4	1	70.88	0.5
15	14	0	6	7	3	4	85.36	
16	12	3	4.6	5.8	6		81.58	
17	11	5	6	8	3	1	72.27	04
18	13	-1	5	6	2	2	84.74	
19	14	4	8	9	2	3	86.48	
20	12	6	6.6	8	6		80.43	18
21	12	4	5.8	9.6	6	2	51.75	
22	16	3	6.6	1.4	6		205.64	6.5
23	07	5	5.6	6.8	5		82.34	11.5
24	03	0	0	2	8		63.92	20
25	03	-1	0	1.4	7		73.82	15
26	03	-2	0.4	1.4	4		81.21	08
27	05	0	2.2	2.8	3		89.39	3.5
28	07	0	1.2	2	4		85.36	
29		-2	2	3	3		82.58	

Appendix 1 continued

DATE	Tmax (°C)	Tmin (°C)	Wb (°C)	Db (°C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/3/92	07	1	3.2	4.2	3	1	83.50	2.5
02	10	0	4.2	6	2	2	72.82	
03	10	0	5.4	6	3	2	90.79	
04	10	0	4.8	5.6	2	2	87.55	
05	11	5	6	7	3	1	85.36	3.5
06	12	2	4.8	6.2	3	1	78.93	
07	11	0	5.6	7.2	2	2	76.96	
08	11	1	5	7	3	2	71.12	
09	10	7	3	4.4	4	2	77.22	
10	11	-1	1	4	6	7	51.28	
11	13	1	0	5.4	8	10	20.01	
12	14	0	1	6	9	5	27.52	
13	15	3	4	7	4	5	57.25	
14	12	1	5	8.4	3		54.49	
15	11	5	8	9	3	1	86.48	2.8
16	17	2	8	9	4	3	86.48	
17	14	4	8.2	10.2	2	2	74.54	
18	17	4	7.8	10.4	3	5	67.43	
19	14	6	9	10	3	2	86.98	
20	11	2	5.8	8.4	3		64.82	
21	10	0	6	8	4		72.27	2.8
22	07	3	6	7	5	1	85.36	28
23	09	3	3.6	4.4	4		86.88	0.1
24	11	1	5.4	6.6	2	2	82.19	
25	17	5	7	9.2	5	6	70.99	
26	20	7	7.2	12	5	6	45.08	
27	23	8	9	15.4	4	6	36.39	
28	22	9	12	17	3	7	51.77	
29	23	3	8	13.2	2	6	43.32	
30	15	5	8.4	14	4	4	40.97	
31	17	6	8	10	3	4	74.35	

Appendix 1 Continued

DATE	Tmax (˚C)	Tmin (˚C)	Wb (˚C)	Db (˚C)	U (km/h)	Ep (mm)	RH (%)	Rn (mm)
01/4/92	17	03	8	10	5	2	74.35	
02	19	03	9.2	13	5	5	57.42	
03	20	08	9.5	14	3	6	51.79	
04	18	06	8	13	2	6	44.96	
05	18	02	8	12.6	4	7	48.34	
06	21	05	9.8	14	5	6	54.80	
07	25	09	9	14	3	8	46.83	
08	25	13	11	14.2	2	8	65.27	
09	18	08	11.4	14	4	4	71.33	
10	23	04	8.6	10	5	5	81.89	
11	30	14	10.4	17	3	10	37.88	
12	14	16	14	22	2	7	36.29	
13	18	08	10.4	13	3	5	70.34	
14	15	07	10	11	4	3	87.45	
15	16	06	9	10	3	3	86.98	
16	15	04	8.4	10.4	2	4	74.73	
17	16	05	8	9.8	3	4	76.67	
18	19	03	9.8	10.4	3	4	92.26	
19	17	08	9	14	4	9	46.83	
20	15	13	10	14.4	5	4	53.42	
21	20	05	10	16	2	7	41.17	
22	17	07	9.4	12	4	3	69.28	
23	16	02	8	11.2	3	4	61.42	
24	17	04	8.4	12	4	5	58.09	
25	16	06	8	10.2	3	4	72.07	
26	17	02	10	12	3	4	76.16	
27	19	08	11	12.4	5	4	83.39	
28	24	08	10.2	13	3	7	68.15	
29	20	11	12.4	18	2	7	48.09	
30	21	10	11	14	4	8	67.12	

الصفحة غير موجودة من أصل المصدر

ملخص

تأثير الري التكميلي على انتاج محصول القمح وعلاقته بالإحتياجات المائية للمحصول ومواعيد الزراعة

إعداد : عمار محمد جرار

إشراف : د. محمد رشيد شطناوي

يعتبر القمح من المحاصيل الاستراتيجية في الأردن، ويشكل الانتاج القومي من القمح حوالي ٢٨٪ فقط من الاحتياجات المحلية، ويعتبر سوء توزيع الأمطار وكمياتها خلال الموسم اضافة الى تذبذبها من موسم الى آخر من أهم العوامل المؤدية الى انخفاض الانتاج، ويمكن معالجة هذه المشكلة من خلال مايعرف بالري التكميلي والذي أظهر كفاءة عالية في زيادة الانتاج الزراعي وديمومته في المناطق المطرية.

أجريت دراسة في محطة المشقر للأبحاث الزراعية الواقعة على بعد ٢٨كم جنوب غرب عمان. هدفت التجربة الى دراسة تأثير الري التكميلي على انتاج القمح في المناطق البعلية، دراسة تأثير مواعيد الزراعة المختلفة على انتاج القمح، و تحديد الإستهلاك المائي لمحصول القمح إضافة الى تحديد قيم معامل المحصول .

تم استخدام التصميم الإحصائي (SPLIT - PLOT) بأربعة مكررات، حيث كانت هناك معاملتان رئيسيتان تمثلان الزراعة المبكرة والزراعة المتأخرة. قسمت كل معاملة رئيسية الى أربعة معاملات تحت رئيسية تمثل أربعة مستويات من الري هي ١٠٠٪ من الاستهلاك المائي الفعلي المقدر، ٥٠٪ من الاستهلاك المائي الفعلي المقدر، ١٠٠٪ من الاستهلاك المائي الفعلي المقدر خلال المراحل الحرجة للنبات ، و معاملة بدون ري معتمدة على الأمطار. استخدمت طريقة الاستنزاف الرطوبي للتربة بواسطة المجس النيوتروني في حساب الإستهلاك المائي الفعلي الموسمي للقمح (ETa). تم قياس الاستهلاك المائي

انكامن بطريقة حوض التبخر.

أظهرت النتائج ان الاستهلاك المائي الفعلي لمحصول القمح ازداد بدلالة معنوية نتيجة لاضافة المياه، كما أن الاستهلاك المائي الفعلي للمعاملات ١٠٠٪، ٥٠٪، ١٠٠٪ (خلال المراحل الحرجة) من الاستهلاك المائي الفعلي المقدر، اضافة الى المعاملة المطرية كانت ٤٧٤.٨، ٤٢٧.٨، ٥٤ .٣٧٥ ملم على التوالي. وقد تبين ان زيادة ٩٩.٢٦ ملم في الاستهلاك المائي الحقيقي من المعاملة المطرية الى معاملة ١٠٠٪ من الإستهلاك المائي الفعلي المقدر قد أدت الى زيادة في انتاج الحبوب من ٣.٣٨ الى ٤.٧٥ طن/هكتار أو مانسبته ٥ .١٤٠٪. لقد دلت النتائج ايضاً أن انتاج الحبوب استجاب بدلالة معنوية لأقل كمية من مياه الري التكميلي المضافة (٦٩.٠٢ ملم). وقد تبين أن انتاج الحبوب للمعاملات ١٠٠٪ من الاستهلاك المائي المقدر (٤.٧٥ طن/هكتار)، ٥٠٪ من الاستهلاك المائي المقدر (٤.٣٥ طن/هكتار)، و ١٠٠٪ من الاستهلاك المائي المقدرخلال المراحل الحرجة (٤.٤٩ طن/هكتار) قد تفوقت بدلالة معنوية على المعاملة المطرية (٣.٣٨ طن/هكتار). كما أن الزراعة المبكرة أدت الى الزيادة في انتاج الحبوب من ٣.٨٨ الى ٤.٦١ طن/هكتار تحت الزراعة المتأخرة والمبكرة على التوالي .

دلت النتائج على أن العلاقة بين الانتاج و الاستهلاك المائي هي علاقة خطية، بينما وجدت علاقة من الدرجة الثانية مابين الانتاج و كميات المياه المضافة.

إن مرحلة التسبيل والإزهار و مرحلة تكوين الحبوب هي مراحل حرجة بالنسبة للنبات كما أنها تتزامن مع توقف الأمطار، لذلك فإن الري التكميلي خلال هذه المراحل هو أمر حيوي لزيادة وتثبيت الانتاج .

أظهرت النتائج بأن حوض التبخر يعتبر طريقة جيدة لتقدير الاستهلاك المائي وبالتالي يعتبر من الطرق الجيدة لبرمجة الري التكميلي.