Wheat productivity under supplemental irrigation in Northern Iraq

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Wheat Productivity Under Supplemental Irrigation in Northern Iraq

A report on collaborative research undertaken by:

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and
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Foreword

The dry areas are characterized by water scarcity. Agriculture consumes most of the water, but the water available is not enough for sustainable crop production. Since other sectors are increasingly competing for water, agriculture is bound to be a loser from its share of available water. Therefore. the poor, who depend largely on agriculture, will be particularly affected by the increasing scarcity of water. Driven by this challenge, ICARDA's research program has a major focus on coping with the effects of water scarcity in the dry areas.

One promising area of research is concerned with improving the efficiency with which water is used in agriculture. Higher water-use efficiency means more production with less water. ICARDA is working on improving water productivity with its national agricultural research systems (NARS) partners, and is developing appropriate strategies and methodologies to achieve this goal across the dry areas. Supplemental irrigation has proved to be a highly water-use-efficient technique. Optimization of irrigation scheduling and its integration in the cropping systems are important areas of research in ICARDA's Natural Resource Management Program (NRMP). Early results indicate a strong potential for improvement in saving water by using appropriate schedules in conjunction with proper production inputs and systems management.

It is within this framework, and through fruitful collaboration with the Iraqi national research program. that the research presented in this report was conducted. We hope that the results of this 4-year research study on improving the efficiency of water use will benefit the farmers in northern **Iraq** and other similar environments.

Prof. Dr Adel El-Beltagy
Director General
ICARDA

INTRODUCTION

General

Iraq occupies an area of about 443,432 km^2 within the West Asia and North Africa (WANA) region, (latitudes 29° 5' to 37' 15' north and longitudes 38" 45' to 48' 45' east). The altitude of the country varies from sea level in the south to as high as 3500 m above sea level in the mountains of the northeast. In the central part of the country, the Mesopotamia plain (near Baghdad and Babylon) has altitudes of 30 to 30 m above sea level. Upper Mesopotamia (Al-Jazeera) varies in altitude from 100 to 450 m above sea level, with the northern part being flat or slightly undulating. The population of Iraq in the year 2000 was about 24 million, and has been growing at an annual rate of about 3%,.

The climate of Iraq is Mediterranean. The summer season is long. hot and dry. Winters are short, with mean monthly temperatures generally above zero. Intense cyclonic activities in the atmosphere are usually responsible for rainfall. The mean annual air temperature in the north is about 20 'C, increasing up to 25 °C in the south and south-west. Minimum temperatures occur in January, and can fall in the north to -14 'C. By contrast, maximum temperatures occur in July and range between 47 'C in the north and 52 C in the south.

Mean annual precipitation in the mountainous northern regions ranges from 850 to 950 mm, and can reach 1250 mm in the northeast. In the central part of the country, mean annual precipitation decreases to 125-150 mm (at Baghdad). In the western. southern and southwestern regions. precipitation is 100 mm or less. The prevailing wind blows from the west and northwest throughout the year. Mean annual wind speeds range from 2.1 to 3.9 m/s. and maximum speeds of around 30 m/s can be reached. Evaporation from free water surfaces varies from 1300 mm in the northeastern parts of the country to 2600 mm in central parts.

The major water resources of Iraq include the Tigris and the Euphrates rivers. These originate in the mountains of Turkey and Iran. and flow throughout Iraqi territory, joining in Shatt Al-Arab in the south. Historically. these two rivers have played a vital role in supporting civilization in Iraq. However. despite this fact. water availability is now the major constraint limiting agricultural development in that country.

The annual wheat production of the country is fluctuating. Total production was 0.491, 1.196, 1.376. 1.310, 0.911 and 0.854 million tonnes in 1989. 1990. 1991,

1992. 1993. and 1995. respectively. These figures should be compared with a national need of over 3.2 million tonnes Thus. there is a large disparity between local supply and national demand (Hakim and Mahmood 1995). Average yields during the six years considered ranged from 0.57 to I.l t/ha (Central Board for Statistics 1996).

Bread wheat (*Triticum aestivum* L.) and durum wheat (*T. durum*) are the most important cereal crops in Iraq. The total cultivated area of wheat in Iraq during the 1997198 growing season was 1.406 million ha. At the Nineva governorate (where this study was conducted, and where annual rainfall is 350-500 mm), the area planted with wheat during that growing season was 0.531 million ha. Wheat yields under rainfed conditions are rather low. The average dry-farming productivity of wheat in the Nineva governorate. was *0.5* t/ha during the 1996197 season. Both the amount and the inter-seasonal distribution of rainfall have a direct impact on wheat productivity. There is an urgent need for Iraq to improve and stabilize the production of this strategic commodity. Over the last decade, improving wheat productivity has been given the highest priority in development plans for the country.

Studies of irrigation requirements and scheduling in the northern part of Al-Jazeera have been limited, because until 1990 the whole area was under rainfed farming systems. In an extensive study on rainfed agriculture in Iraq (University of Mosul 1979) it was reported that the wheat crop in the northern Al-Jareera region requires 50 mm of rainfall at the beginning of the season (October-December) for germination and seedling establishment, and 130150 mm at the vegetative and head stages (March-April). Rainfall during January and February (the cold winter months) is generally adequate, hearing in mind that the growth of the crop is very slow during these two months. Adary and Al-Rasheedy (1993) indicated that the best time for supplemental irrigation is at sowing and during the months of March and April.

Water use efficiency. or water productivity, is defined as the ratio of grain or biomass yield to the amount of water used to obtain this yield. There is some confusion as to what is meant in this definition by 'the amount of water used' (Oweis *et* al. 1999a). The following interpretations are reported in the relevant literature: seasonal rainfall (under purely rainfed farming): seasonal evapotranspiration: net depth of irrigation: amount of water delivered to the farm inlet; total depth of irrigation application and sum of seasonal rainfall with irrigation applications. The efficiency of using water in supplemental irrigation can be calculated by dividing the increase in yield (compared with the yield under rainfed conditions) by the increase in evapotranspiration due to irrigation. In this study, however, the increase in yield is divided by the total amount of irrigation.

Alleviating soil moisture stress during wheat's critical growth stages is the key to improving its productivity. Supplemental irrigation is a highly efficient option. which can be used to achieve this goal. by providing the crop with the necessary amount of water **at** the required time. Supplemental irrigation is defined as: "the addition of a limited amount of water to otherwise rainfed crops. when rainfall fails to provide esseutial moisture for normal plant growth. in order to improve and stabilize productivity" (Arar 1992: Oweis *et al*. 1999b).

Other factors and procedure5 can enhance crop productivity. These include the use and adaptation of high yielding cultivars, and improved fertility and soil and water management. Important management factors include the selection of suitable sowing dates and the efficient use of rainwater in conjunction with supplemental irrigation. The ultimate goal is to maximize production and/or the net economic return per unit of water used.

Objectives

In view of the large shortfall in wheat production in Iraq, the low productivity of rainfed wheat and the potential for a substantial improvement in wheat productivity through the application of supplemental irrigation, research was initiated in order to improve the productivity of wheat in northern Iraq. This goal was to be achieved by optimizing the conjunctive use o frainfall and the limited water resources available, along with other production inputs such as improved cultivars. fertilizers and other soil and crop management strategies. Specific objectives included:

1. Defining the timing and amount of supplemental irrigation appropriate, in order to improve yield and water use efficiency.
2. Determining water application rates and nitrogen levels suitable for the conditions of the area.
3. Identifying wheat cultivars' response to supplemental irrigation practices.
4. Determining the relationships between sowing date and productivity under supplemental irrigation.

CHARACTERISTICS OF THE STUDY AREA

Experimental Site

In 1991, a large supplemental irrigation project, the North Al-Jazeera Irrigation Project, was established in order to serve approximately 60,000 ha of arable land, using a linear-move sprinkler irrigation system. The research presented here was conducted on a farm at the Rabiah Research Station, located inside the North Al-Jazeera Project. This is located about 80 km to the northwest of the city of Mosul, in northern Iraq, near the Syrian and Turkish borders (Fig.1).

The project extends between latitudes 36" 33'40" and 36° 53' 20" N and longitudes 42° 0' 20" and 42" 33'40" E. The area is defined as a moderate rainfall zone. having mean annual rainfall ranging from 350 mm in the south to 500 mm in the north. About 75% of the project land is cropped with wheat each year under a limited amount of irrigation, ranging from 100 to 150 mm. The wheat-growing season in this area generally begins during November and ends in early June. If the land is summer-cropped, then the sowing of the wheat is delayed until around mid-December.

Climate

The climate of the study area is Mediterranean, characterized by a cold rainy winter and a hot, dry summer. Long-term means of the climatic parameters of the experimental site are presented in Table 1. Rainfall in the area exceeds evaporation during the months of December through February, but these factors are balanced during the month of March. A moisture deficit is obvious in April and May, and may be the main cause of low productivity in rainfed crops. In years with below-average rainfall: the deficit becomes very significant and extends over a greater number of months during the growing season. The growth stages of flowering, heading and grain formation usually occur during the period of April to early May. This, of course. is affected by sowing date and weather conditions.

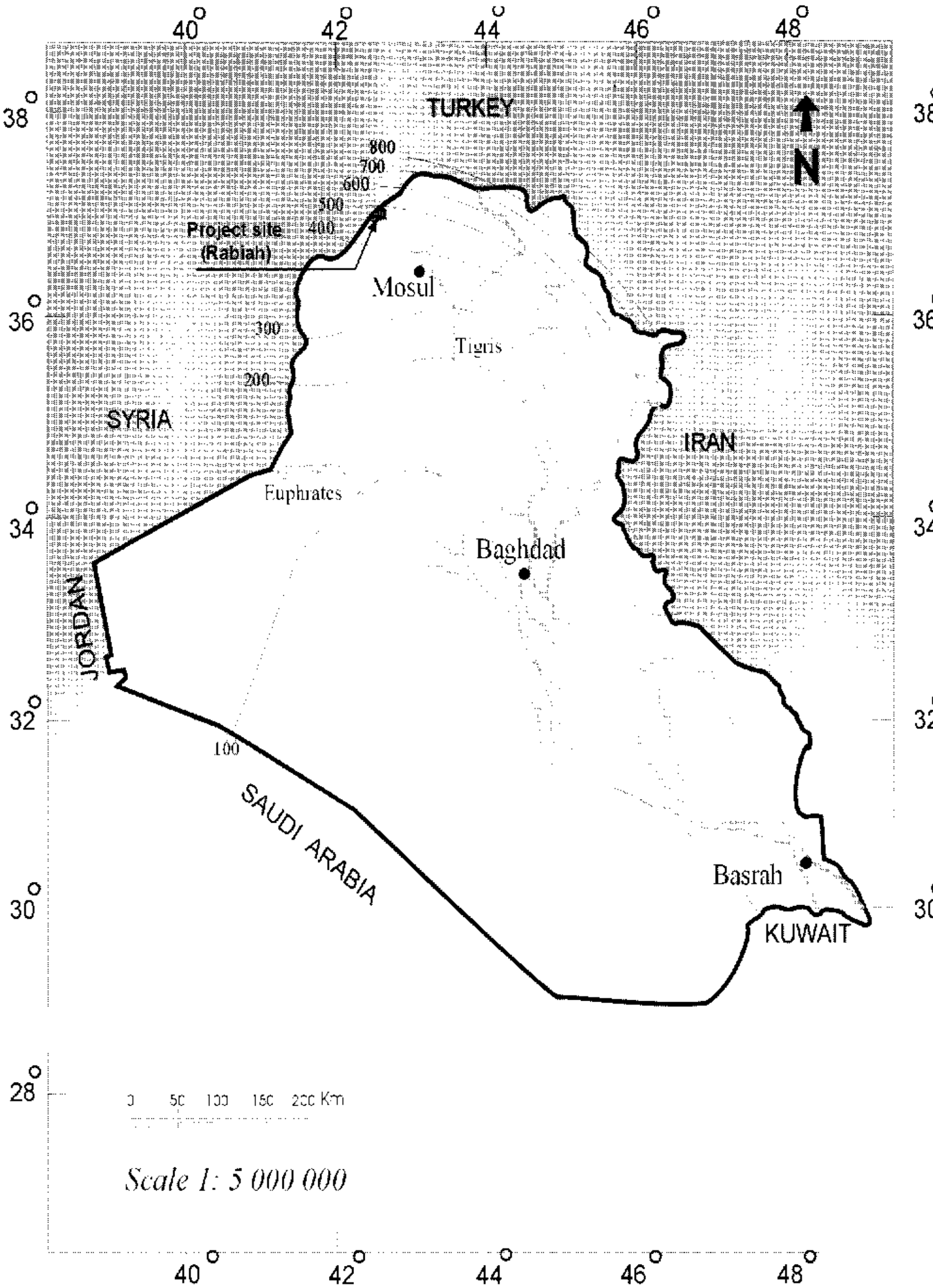

Figure 1. Location of North Al-Jazeera project-Rabiah where the supplemental irrigation research was conducted (1994-98)

Table 1. Long-term climatic data for Rabiah Research Station, northern Iraq: monthly and annual means, 1967-97.

Month	J	F	M	4	M	J	J	A	S	O	N	D	Annual
Rainfall (mm)	66.6	63.6	66.5	47.6	20.9	1.0	0	0	0.3	24.3	37.0	63.2	391[1]
Mean Rainfall (1990-97)	50	56	51	30	28	0	0	0	5	12	27	55	314
Mean Temp. °C	5.7	7.7	100	15.9	22.2	28.0	31.5	30.7	26.1	19.7	12.0	7.1	18.1
Mean Max. Temp. °C	11.3	13.0	17.2	23.7	30.5	37.0	41.2	40.6	36.9	29.0	19.1	12.9	26
Mean Min. Temp. (C)	0.8	1.9	4.3	8.5	13.0	17.6	20.7	20	14.9	10.8	5.3	1.8	10
Mean relative humidity *(%)*	81	77	71	66	51	32	29	30	32	46	69	81	55.4
Evaporation (Pan-A). mm	**24**	37	70	120	216	329	363	332	242	139	53	27	1951
Mean rind speed (m/s)	1.8	2.0	2.0	2.0	2.5	2.4	2.7	2.4	2.2	2.0	1.9	1.8	2.1
Mean daily sunshine(hr)	4.6	-1.8	7.6	7.6	9.9	11.4	11.8	11.7	9.1	8.8	6.3	4.7	8.2

[1] ***Underlined figures represent annual totals***

Soils

Buringh (1960) classified Iraq's soils into eight types, two of which represent the soils of the study area: the brown-reddish soils and the brown soil. The brown-reddish type is usually found in the limited rainfall zone (200-350 mm), and is characterized by light vegetative cover and low biological activity. Brown soil represents most of the project area. and has a pH > 7.0 and organic matter of 1 to 2 %. Table 2 presents some of the characteristics of the soil in the project area.

Table 2. Soil characteristics at the experimental site at Rabiah.

Depth	pH	Texture	EC	P	K	Gypsum	Ca^{2+}	Mg^{2+}	Na^{+}	SAR
(cm)			dS/m	- -ppm	- -	%	------------	meq/L	- - - - -	———
0-15	7.4	SCL	1.5	30	200	1.2	2.1	1.9	0.3	0.21
15-30	7.3	SCL	1.0	27	180	0.8	1.9	1.1	0.4	0.35
30-60	7.6	SC	0.6	24	180	1.1	2.3	0.8	0.5	0.43
60-90	7.5	SC	0.8	22	170	0.7	2.0	0.9	0.5	0.35
Average	7.5		1.0	26	183	1.0	2.1	1.2	0.5	0.31

SCL= Silt Clay Loam, SC= Silt Clay, EC= Electrical Conductivity, **P=** Phosphorus (available). **K=** Potassium. Ca= Calcium, Mg= Magnesium. Na= Sodium, SAR= Sodium Adsorption Ratio.

Generally, the soil is deep (> 2.0 m) with a hardpan layer about 50 cm below the surface (Buringh 1960). The weak alkalinity of the soil (pH 7.3-7.6) is suitable for growing various crops, including wheat. barley. potatoes. tomatoes. corn and sunflower. These. and others, are grown in the project area. Thr area has a few *wadies,* which act as natural drains. These were modified and shaped to collect surface runoff, and channel it into *WadiAl-Mur:* located along the lowest contour in the project area. Until the early 1990s. the average EC (Electrical Conductivity) of the project soil was less than I dS/m. However. during the last few years; signs of a salinity buildup, due to the absence of subsurface drainage. the presence of the hardpan layer and excessive irrigationhave been reported in some parts of the project. As a result. the productivity of the land has declined, as indicated by a recent study on the project (Al-Talib 1999).

The soil texture of the surface layer is generally silt loam to silt clay loam. while the subsurface layer is mostly silt clay. The average apparent specific gravity of the soil is 1.3. The average available water in the soil profile (difference between field capacity and permanent wilting point) is about 170 mm per meter of soil depth.

Irrigation Water

The North Jazeera Irrigation Project (Rabiah) is fedby the Tigris River via a large submerged pumping station located inside the reservoir of a large dam. 50 km to the north of Mosul city. Thecapacity of the pumping station is 45 m^3/s. Long delivery pipes convey the pumped water to the Project area. The quality of the irrigation water is 'good' according to the criteria of Rhoades and Loveday (1990). Average values of pH, EC. SAR (Sodium Adsorption Ratio) and ESP (Exchangeable Sodium Percentage) were 7.4. 0.41 dS/m. 0.09 and I. 15. respectively. In seasons with low rainfall. such as the 1998199 scason. when annual rainfall was only 164 mm. the water supply to the Project was reduced by 40% and an emergency agricultural plan was enforced. Rainfed wheat production in this year was negligible.

Farming Systems

The project area was entirely under rainfed farming before 1991 with the exception of small and scatterrd areas irrigatedfrom wells that had discharges ranging from 5 to 10 liters per second. The water from these wells may have contained as much as 5000 ppm of dissolved solids. The main crops grown were wheat and barley. About 50% of the land was usually left underfallow each year. However, the farming system in the project area changed drastically after the installation of a large-scale linear-move sprinkler irrigation scheme. Low productivity rainfed farming was transformed into an intensive agricultural system, with a cropping intensity of more than 100%.

Winter crops occupy, under supplemental irrigation, about 80% of the Project's cultivable land. In summer. however. the percentage cropped area is limited to only 30%. Thus, the overall cropping intensity of the Project is around 110%. Wheat is the major winter crop, covering 73% of the Project area. Other winter crops are barley, lentil and potatoes, which cover 3, 1.5 and *2.5%* of the area respectively. During the summer. tomato is the major crop. occupying ***22%*** of the Project. Other summer crops include spring potatoes (5.5%), sugar beets (1.0%), and vegetables (1.5%).

Before the implementation of the Project, farmers were not exposed to irrigated farming techniques: intensive production inputs or improved water management. The appearance of salinity in certain parts of the project area, and the reported decline in land productivity, motivated efforts both to evaluate water use efficiency on farms and to measure the technical and socio-economic aspects of the Project under present conditions.

MATERIALS AND METHODS

Treatments

The study included a series of experiments which tested four variables: the cultivar, the sowing date, the supplemental irrigation level and the nitrogen application rate. 'Waha' was the principal cultivar used in the trial, and was thus used during all seasons. However. other promising or newly released cultivars were also included in different seasons (Table 3). in order to test their response to supplemental irrigation. Two or three sowing dates were adopted each year, depending mainly upon the onset of rain. Two supplemental irrigation levels were adopted, in addition to a rainfed treatment (control). The full supplemental irrigation level (FSI) was the level that achieved rewetting of soil (back to field capacity level), in the effective root zone, when 50% of the available water had been depleted. The deficit supplemental irrigation level (DSI) was 50% of the water applied in the FSI level. Therefore, **DSI** represents a treatment with intentional deficit or 'stress-irrigation'. Generally, three levels of N fertilizer were used (0, 40 and 80 kg/ha), the only exception to this rule occurred during the 1997198 season

(Table **3). **The treatments were replicated three times. **As** will be described later, the experimental design was of the split-strip-split type (Gomez and Gomez 1984).

Table **3.** Summary of the experimental treatments implemented over **the** four cropping seasons at Rabiah.

Season	Rainfall (mm)	Cultivars oi wheat	Sowing date?	Nitrogen (kg/ha)	SI[1] (mm)
1994195	450	Waha (durum)	D_1= 29 Oct	0	Rainfed
		Om Rahi 5 (durum)	D_2= 26 Dec	40	DSI = 40
		Abu-Ghraib (bread)	D_3= 9 Jan	80	FSI = 80
1995196	316	Waha	D_1= 2 Jan	0	Rainfed
		Om Rabi 5	D_2= 7 Feb	40	DSI = 2x20=40
		Adnanya (bread)		80	FSI = 2x40=80
1996197	310	Waha	D_1= 1 Dec	0	Rainfed
			D2= 5 Jan	40	DSI =3x20=60
			D_3= 1 Fch	80	FSI = 3x40=120
1997/98	236	Waha	D_1= 31 Dec	80	Rainfed
			D_2= 19 Feb		DSI = 18+(2x25) = 68 **mm**

[1] Total rainfall over the growing season (see Table 4 for full deteils).

[2] SI= Supplemental Irrigation, DSI= Deficit Supplemental Irrigation and FSI= Full SupplementalIrrigation.

Weather

The mean monthly climatic parameters at Rabiah, over the growing seasons 1994195 to 1997/98. are presented in Table 4. The seasonal rainfall of 236 mm, in the 1997/98 growing season. was relatively dry, while the 450 mm seasonal rainfall of the1994195 period was relatively wet. During the other two seasons, seasonal rainfall values were near the long-term average.

Table 4. Climatic parameters at Rabiah over the four experimental growing seasons: mean monthly temperatures and humidity, and total monthly rainfall and evaporation.

Parameter	Nov.	Dec.	Jan.	Feb.	Mar	Apr	May	Total
			1994/95					
Max. Temp. (°C)	17.4	9.4	12.1	15.2	19.4	22.6	32.7	
Min. Temp. (°C)	9.4	1.8	3.0	4.0	6.9	12.4	16.9	
Rainfall (mm)	87	108	44	64	58	39	13	450[a]
Rel. Humidity (%)	84	87	89	80	73	72	51	
Pan Evap(mm)	45.2	33.5	16.3	44.0	76.8	114.0	155.0	585.0
			1995196					
Max. Temp. (°C)	19.6	15.2	11.1	15.2	16.1	71.6	32.8	
Min. Temp (°C)	5.3	2.1	3.1	3.1	4.1	7.5	13.1	
Rainfall (mm)	13	2	118	48	103	2 4	8	316
Rel. Humidity (%)	75	81	93	92	95	92	77	
Pan Evap. (mm)	53	27	20	42	42	101	241	526
			1996197					
Max. Temp. (°C)	23.0	14.5	12.4	12.1	14.6	21.6	32.2	
Min. Temp. (°C)	na	1.8	1.2	-1.1	2.7	6.7	12.9	
Rainfall (mm)	0	143	17	96	45	24	5	330
Rel. Humidity (%)	na	na	58	61	55	51	30	
Pan Evap. (mm)	na	na	na	na	na	na	na	
			1997198					
Max. Temp. (°C)	19.1	12.9	9.0	13.4	18.1	24.9	31.9	
Min. Temp. (°C)	5.1	1.9	0.8	0.8	3.8	9.4	13.7	
Rainfall (mm)	23	56	44	35	34	9	0	236[b]
Rel. Humidity (%)	na	na	na	na	na	na	na	
Pan Evap. (mm)	50	35	14	47	85	115	222	568

a: including 47 mm of rain in October 1994, **h:** including 35 mm of rain in October 1997.
na: not available (no data collected).

Wheat Cultivars

During the period of the study, several improved wheat cultivars were released and tested for their response to supplemental irrigation and other parameters. Most important were the following:

Waha

'Waha' is a durum wheat variety introduced into Iraq by ICARDA in 1980, and released for wide-scale use in 1995. It is a highly productive cultivar. with yields of 4-6 t/ha. It has been widely adopted by farmers at Rabiah; and in high rainfall areas. because of its lodging resistance when compared with the local varieties.

To schedule irrigation, water content of the soil was measured at five depths (10, 25. 50, 75 and 100 cm) in selected experimental plots during the growing season. Soil samples were taken using screw-type augers. The main objective of monitoring soil moisture was to ascertain when to irrigate and how much water to apply. Therefore, the interval between soil moisture sampling varied (between *2* and 5 weeks), depending on the amount and distribution of rainfall.

Experimental Layout and Procedure

As indicated above. the experimental design was of a split-strip-split type. However, the allotment of the various factors (cultivar, sowing date, irrigation, and nitrogen) to the different levels of the experimental plots was governed both by the nature of the linear-move irrigation system and by other unforeseen external factors; which necessitated annual adjustments to the treatments (Table 5). Unfortunately. it was not possible to maintain fixed experimental layout and parameters for all seasons. Therefore, these may be considered a series of related experiments. For example. during the 1995196 growing season. sowing dates were allotted to the main plots in a randomized complete block design (RCBD) over three replications (see Appendix A for the experimental layout for the 1995196 season). Each sowing-date main plot was divided, strip-wise. into three sub-plots, accommodating three levels of supplemental irrigation. Each sub-plot is subdivided into three sub-sub-plots to accommodate three crop varieties (the irrigation and cultivar treatments were oriented perpendicularly to each other). Each of the irrigation-variety sub-sub-plots was further divided to form three sub-sub-sub-plots, to accommodate three levels of nitrogen. Such a design can be termed a split-strip-split plot in RCBD. Adequate buffer rones (land strips) were established between the plots, to assure accurate water application by the linear-move sprinkler irrigation system used in the experiment, which moved continuously.

Table 5. Summary of the multi-split **design of** all the experiments in the study.

Plot Designation	Growing Season			
	1994/95	1995/96	1996/97[a]	1997/98[b]
Main plot	Cultivar	Sowing date	Sowing date	Irrigation
Sub-plot	Sowing date	Irrigation	Irrigation	Sowing date
Sub-sub-plot	Irrigation	Cultivar	Nitrogen	
Sub-sub-sub-plot	Nitrogen	Nitrogen		
Size of treatment plot (m^2)	15 x 10	15 x 10	YO x 4	S x l

a: Only one cultivar (Waha) was used in this year

h: Only **one** nitrogen level (80 kg ha^{-1}) was used in this year

Furthermore, Waha is suitable for preparation of traditional local food products such as *Burgul Jareesh* and *Huhia.*

***Om Rabi** 5*

'Om Rabi 5' is a durum wheat variety introduced into Iraq by ICARDA in 1989, and released in 1996. It is a highly productive cultivar (yielding 4-5 t/ha) in both the moderate and high rainfall areas. Om Rabi 5 is now widely adopted both by farmers and consumers of durum wheat products. It is very responsive to fertilizer and supplemental irrigation in the Rabiah area.

Adnanya

'Adnanya' is a new bread wheat variety, developed by IPA from a crossing of the local variety, *saberbeg,* and an Indian variety It is a good variety, with a high grain yield potential (4-5 t/ha under the moderate rainfall conditions of Rabiah).

Abu-Ghraib 3

'Abu-Ghraib ***3'*** is a local bread wheat variety, released in 1973 by the Ministry of Agriculture for use in irrigated and high rainfall areas. The variety has a yield potential of 4 t/ha but is susceptible to strip rust *(Puccinia striformis)* and stem sawfly *(Cephur pigmaeus).*

Irrigation Systems and Scheduling

Two types of linear-move irrigation systems are available in the North Jazeera Irrigation Project, the canal-fed and the hose-fed systems. Except for their water intake arrangements, the two systems have identical specifications. The canal-fed system was used in this research. This system consist.: of seven trusses interconnected near the supporting towers. A driving cart is placed at the inlet of the system. The spans between neighboring towers are equal, at 48.75 m. except for the first span; which has a length of 50.5 m. The machine has a total length of 350 m, including a 70 m cantilever extending from the end of the last tower.

The machine is equipped with 133 spray nozzles placed 2.5 m above the ground, and spaced at 2.5 m intervals. These operate at a low-pressure head (7 to 10m). The system can he operated at different speeds. The depth of water applied to the soil surface depends on the speed of the machine and the spray losses of the system. For example. a speed setting of 100% gives a travel rate of 112 m per hour and a design depth of application of 4.5 mm per pass. a 25% setting results in a 28 m per hour travel rate and a 16.2 mm depth of application.

Plot size and number of plots varied from year to year, depending on the number of cultivars and sowing dates (Table 3). The experiments were conducted on the same irrigation unit for all years. but on alternating fields within the farm. The summer crop preceding the wheat growing seasons was potato (in 1994195). sunflower (in 1995/96), corn (in 1996197). and fallow(in 1997198). Seeds were drilled in rows with 17.5 cm spacing and a depth of 4-6 cm. The seeding rate was about 140 kg/ha.

The soil's water content was measured at five depths (10, 25. 50. 75 and 100 cm) in selected experimental plots during the growing season. Soil samples were taken using screw-type augers. A sample of the data sheet used for soil moisture measurement is shown in Appendix B for the 1995/96 season. Soil tests on selected samples indicate that field capacity and wilting point are, respectively, approximately 26%)and 13% by weight. The average apparent specific gravity of the soil is 1.30.

In order to measure grain yield, a complete treatment plot was harvested mechanically. Samples of a one square meter area were harvested for the following yield components: biological yield (above-ground yield): grain yield; straw yield: number of heads/m^2; number of kernels/head and mass per 1000 kernels. The lengths of the phenological growth stages are given in Appendix C.

Modeling and **Simulation**

Simulation models are useful forpredicting the effects of environmental variables, soil and crop characteristics, and management practices on a soil water regime, and/or on salt balance. crop growth and yield. At a reasonable cost and overa reasonable length of time, models are able to assess the effects of management and environment on crop performance over a period. which is long enough to characterize the climatic variability of the region. and any potentially adverse impact on the environment of the technology being tested.

There is widespread agreement on how simulation models should be adapted, using the water balance concept. to study and evaluate crop water requirements and yield under different supplemental irrigation conditions. All available climatic, soil, crop and water management factors are usually integrated in the simulation process (Hachum and Sheet 1989: Perrier and Salkini 1991; Oweis *et al.* 1992 and Pala *e tal.* 1996). In this study. a crop-water use simulation model. based on the water volume balance concept, was adapted to schedule supplemental irrigation and estimate crop productivity. The simulation involved daily monitoring of soil moisture in the crop root zone.

In the simulation model, the actual daily crop evapotranspiration (Et_a) is calculated using the following equation:

$$Et, = Et_p \times K_c \times K, \qquad (1)$$

where:

Et_p = potential evapotranspiration
K_c = crop coefficient
K_s = soil water availability coefficient

Potential evapotranspiration is estimated using the Evaporation Pan Method, with the pan coefficient reflecting daily wind run and relatively humidity as detailed and summarized by Doorenbos and Pruitt (1977). The growing season is usually divided into a number of stages (Appendix C). The procedure proposed by Doorenbos and Pruitt (1977) for estimating the crop coefficient during each of these stages was adopted in the simulation model. The soil water factor (K_s), also known as soil water depletion factor, reflects the effect that available soil moisture in the root zone has on crop water consumption. Many relationships and formulae have been proposed to define this factor. The following relationship, proposed by Jensen et al. (1970), is the most widely used. and was incorporated into the simulation model:

$$K_s = \log (PAW + 1)/\log (101) \qquad (2)$$

where PAW is the percentage of the available water defined as follows:

$$PAW = (AVW \text{ I } TAW) \times 100 \qquad \mathbf{(3)}$$

where:

AVW = Available depth of water in the current depth of the root zone
TAW = Total available depth of water in the current depth of root zone

The current depth of the root zone (RZD) was estimated by the following equation developed by Borg and Grimes (1986):

$$RZD = RDm\ (0.5 + 0.5 \text{ Sin } (3.03(DAPIDTM))-1.47) \qquad (4)$$

where:

DAP = current day after planting
RD, = maximum rooting depth
DTM = number of days to maturity
Sin = a trigonometric function.

Irrigation management, and especially irrigation scheduling, requires knowledge of soil water balance. This necessitates an estimation of the amount of water in the crop root zone at any time. The soil water balance equation used in the simulation model is:

$$S_e = S_b + I + P + U - D - R - Et_a \quad (5)$$

Where S_e and S_b are the amount of water in the root zone at the end and beginning of the period: I is the net amount of supplemental irrigation; P is the precipitation; U is the upward flow Srom a shallow water table; D is drainage below the root zone: R is surface runoff and Et_a is the actual evapotranspiration.

Since there is no shallow water table in the experimental site component U was neglected. Furthermore. land preparation and experimental layout were such that no surface runoff was allowed to leave the plots. Also drainage, D, below the root zone was checked by monitoring the depth of water penetration in the soil. Direct soil sampling using augers. furnished the information necessary for this monitoring. No drainage below the root zone was detected. thus component D of the water balance equation was also neglected.

The simulation process began, for each planting date. by defining initial water distribution in the soil profile (in the root zone) on the sowing day. The effective crop rooting depth was assumed to increase according to equation 4. The predefined inputs for this equation are maximum depth of the root zone (RD_m) and number of days lo maturity (DTM).

The simulation model also included crop productivity. Undoubtedly, crop production depends upon many variables. However. under normal climatic conditions. good pest and disease control and a proper level of fertilization. the major role in the production process is played by water. Thus. the following simplified water-dependent crop production model has been proposed:

$$\text{Relative yield} = Y / Y_{max} = \Sigma ET_a / \Sigma (ET_p \times K_c) \quad (6)$$

in which:

- Y = Expected crop yield (grain) under prevailing conditions.
- Y_{max} = Maximum crop yield (grain) under optimum conditions.
- ΣET_a = Total actual seasonal crop evapotranspiration (consumptive use)
- $\Sigma (ET_p \times K_c)$ = Total potential seasonal crop evapotranspiration (seasonal water requirements).

Figure 2 shows the main components of the model

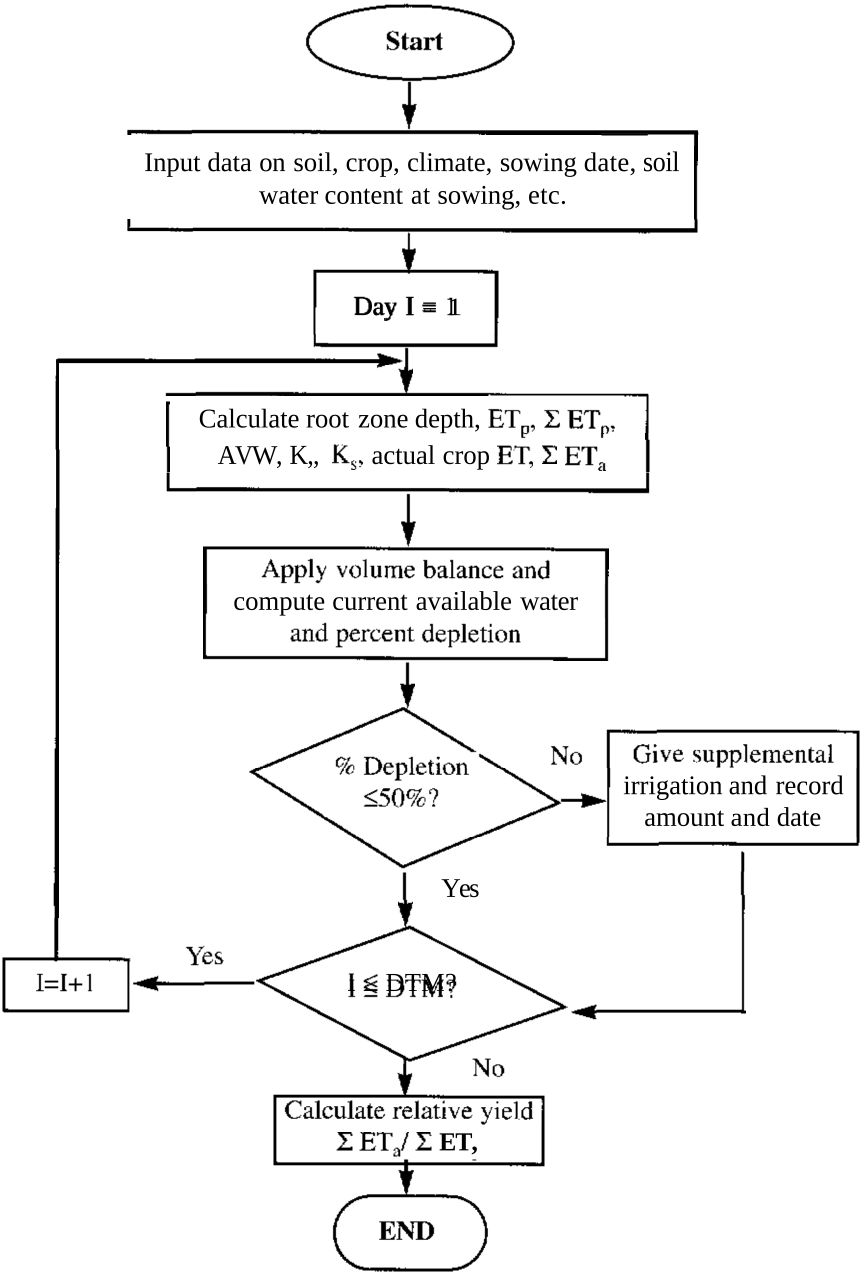

Figure 2. Flow chart of the main components in the simulation model for supplemental irrigation, Rabiah, Iraq.

RESULTS AND DISCUSSION

Due to the lengthy timespan of the experiment, and the use of different varieties in each year, the results emphasize only grain yield parameters. Here we emphasize supplemental irrigation and its interactions with sowing dates. cultivar. and nitrogen treatments.

1994/95 Season

During the 1994195 season, the total seasonal rainfall was 450mm. which is above average. However, its distribution was not optimal, since most of it fell very early in the season (Figure 3). Between March and May, there was a shortage of water in the crop root zone. Therefore. a small amount of supplemental irrigation was needed during this active growth period. Irrigation was given only after emergence in all of the treatments. The seeds were left to germinate and emerge under rainfed conditions. At grain filling, three levels of supplemental irrigation were maintained: (1) rainfed with no irrigation: (2) DSI with two irrigations of 20 mm each. one on 9 May and one on 20 May and (3) FSI with two irrigations of 40 mm each, on 9 May and 20 May.

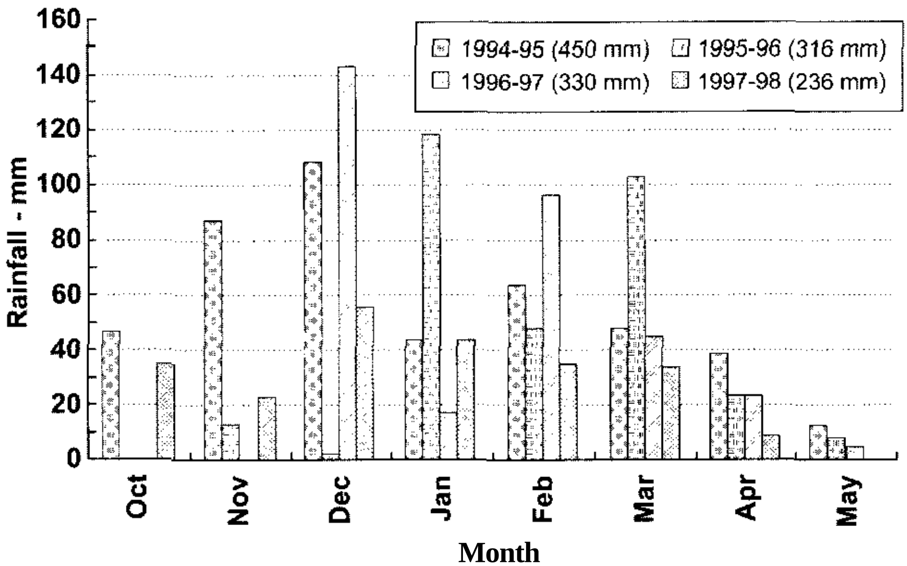

Figure 3. Monthly rainfall distribution over all experimental cropping seasons.

Though this year was relatively wet. yield was notably lower than the potential optimum. One possible reason for this low yield was the occurrence of abnormally high temperatures (a heat wave) during the periods 23 April to 30 April and 11 May to 20 May.

Statistical analysis of the grain yield data indicated no significant interactions among factors. The early sowing treatments (29 Oct) gave the highest grain yield of durum wheat varieties, especially for Waha-Iraq (2.96 t/ha) and Om Rabi 5 (3.04 t/ha), as shown in Table 6. These figures represent an increase of about 20% in yield at early sowing compared with late sowing. Late sowing (9 Jan) caused a significant decrease in grain yield for all cultivars. Results also confirmed that Abu-Ghraib 3 is not suitable for supplemental irrigation and/or rainfed conditions. Therefore, it was excluded from the experiment in subsequent years.

Table 6. Effect of sowing date, water management options and nitrogen application rates on wheat grain yield for the 1994195 growing season at the Rabiah experimental station.

Treatments		Wheat Cultivar			
		Waha	Abu-Ghraib 3	Om Rahi 5	Mean
		t/ha			
Sowing Date	29 Oct	2.96	2.39	3.04	2.80 a
	26 Dec	2.88	2.44	2.87	2.73 a
	9 Jan	2.50	2.14	2.42	2.35 b
	Mean	2.78 a	2.32 b	2.78 a	
Water Management[1]	Rainfed	2.66	2.32	2.83	2.60
	DSI	2.76	2.38	2.53	2.55
	FSl	2.93	2.28	2.97	2.72
	Mean	2.78 a	2.33 b	2.78 a	
Nitrogen Rate	0	2.69	2.37	2.66	2.57
	40	2.90	2.25	2.71	2.62
	80	2.75	2.35	2.95	2.68
	Mean	2.78 a	2.28 b	2.77 a	

[1] DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation. Means with different letters differ significantly at the 5% level (Duncan's Mulliple Range Test).

For the SI-treatments. there was no notable increase in grain yield **except in** the case of the Waha cultivar. The Waha cultivar gave. for the FSI. an increase of 10%; in grain yield in comparison with the rainfed treatment. as shown in Table 6. The limited response to supplemental irrigation was due to high rainfall (450 mm) and storage of winter rainfall in the soil (when the vapor pressure deficit was slow) and the subsequent utilization of this by the crop in the spring.

Table 6 also presents the effect of the N rate **x** cultivar interaction on grain yield. There was no clear trend regarding the impact of N on grain yield. One possible reason for this is that the field had high residual fertility from the summer crop (potato). which had received a high quantity of N-fertilizer (150 kg N/ha). Waha and Om Rabi 5 responded equally well to N application. while Abu-Ghraib 3 showed no response.

1995/96 Season

The experimental site had previously been under a sunflower crop in the summer of 1995. This had received 400 kg/ha of NPK compound fertilizer 27:27:0 plus 200 kg/ha **of** urea (40% ***N*** ***)***The onset of the first rain (called ***Balla*** in Iraq) came late in this season (on 2 Jan; see Fig. 3). and thus resulted in a delay in sowing and in the initiation of the growing season. The second sowing date was 7 Feb 1996 with good antecedent soil moisture conditions.

During January, February and March. the amounts and distribution of rainfall were relatively good for wheat growth (1 18. 48. and 103 mm. respectively). During April, rainfall was inadequate for the requirements of the crop. Moreover, there had been a hot southeastern wind during late April (the heading period of wheat). Thus. the season was exceptional both for the late start and the occurrence of drought during April and May

Table 7 presents a summary of the results of the analysis of variance (ANOVA) for the grain yield. along with other yield components. for the I995196 season. In this section, this discussion will focus only on grain yield. Other yield components will be discussed later. The results given in Table 8 show that the significant difference in grain yield found in this growing season was due only to cultivar effects.

Table 7. Summary of the results of mean squares analysis of variance for grain yield and other yield components for the 1995196 growing season.

Source of variation	Degrees of freedom	Grain yield	Biological yield	Head perm'	Kernels per spike	1000 kernel
Replications (R)	2	-				
Sowing date (A)	1	N.S		**	N.S	N.S
Error (a)	2	-		-	-	-
Supp. Irrigation (B)	2	N.S	*	N.S	N.S	N.S
A x B	2	N.S	**	*	N.S	N.S
Error (b)	8	-	-	-	-	-
Cultivars *(C)*	2	**	**	**	N.S	**
A x C	2	N.S	**	N.S	N.S	N.S
B x C	4	N.S	**	N.S	N.S	N.S
A x B x C	4	N.S	**	N.S	N.S	N.S
Fertilizer (D)	2	N.S	**	**	**	**
A x D	2	N.S	N.S	N.S	N.S	**
B x D	4	N.S	N.S	N.S	N.S	*
A x B x D	4	N.S	N.S	*	N.S	N.S
C x D	4	N.S	N.S	N.S	*	*
A x C x D	4	N.S	**	**	N.S	N.S
B x C x D	8	N.S	N.S	N.S	N.S	*
A x B x C x D	8	N.S	N.S	N.S	N.S	N.S
Error	96	-		-	-	-
Total	161					

N.S. = Not significantly different at the 5% probability level.
** = Significant at the 1% probdbility level.
* = Significant at the **5%** probability level.

Though the 1995196 rainfall (316 mm) was less than that of the 1994195 season (450 mm), the yield of the rainfed treatment for the 1995196 season was greater. This result is largely attributable to the better intra-seasonal distribution of the 1995196 rainfall (Fig. 3). In 1994. most of October's rain (47 mm) and part of November's rain (87 mm) had been lost by evaporation from the soil.

Table 8. Effect of sowing date, water management options and nitrogen application rates on wheat grain yield at Rahiah experimental farm during the 1995196 growing season.

Treatments		Wheat Cultivar		
		Waha	Om Rabi 5	Adnanya
		t/ha		
	2 Jan	4.47	3.81	3.54
Dale of Sowing	7 Fch	4.37	3.87	3.54
	Mean	4.42 a	3.84 b	3.54 b
	Rainfed	4.43	3.71	3.31
Water	DSI	4.36	4.01	3.51
Management'	FSI	4.47	3.80	3.78
	Mean	4.42 a	3.84 b	3.54 b
	0	4.11	3.89	3.58
Nitrogen Rate	30	4.60	3.82	3.52
	80	4.55	3.80	3.50
	Mean	4.42 a	3.84 b	3.54 b

[1] DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation. Means with different letters differ significantly at the 5% probability level (Duncan's Multiple Range Test).

1996197 Season

During this season. only the most promising cultivar. Waha, was sown on three separate dates (1 Dec 1996: 5 Jan 1997, and 1 Feb 1997). The previous crop in the experimental field was corn (summer planting) fertilized with 300 kg/ha of compound fertilirer (27:27:0 N/PK). Total rainfall was 330 mm at suitable times in December (142 mm) and February (96 mm). This was enough to secure good germination and emergence of wheat sown on 1 Dec 1996 and 5 Jan 1997. The first effective rain fell on 5 Dec 1996. The emergence dates were 18 Dec 1996, 22 Jan 1997 and 13 March 1997 for the first. second and third sowing dates, respectively. Below-zero temperatures were recorded during the period 27 Jan to 13 Feb 1997.

The first irrigation of 20 and 40 mm for DSI and FSI, respectively, were applied on 29 April 1997 (at the hooting stage of the Waha planted at D,). The second and third irrigations were applied. respectively. on 1 1May and 25 May 1997 (during heading and grain filling periods).

For wheat sown late (on 1 Feb 1997), seedling emergence was delayed until 13 March 1997. because of low temperatures (below 0 °C, reaching -13.9 'C) during the period 27 Jan to 13 Feb 1997. The rainfall during March (46 mm). April (23.9 mm) and May (5.2 mm) was not enough to meet the crop's water requirements. Therefore, supplementary irrigation was given at the end of April and during May, when the wheat was in the booting, heading and grain filling stages.

Table 9 presents a summary of the results of the analysis of variance (ANOVA) for grain yield. along with other yield components, for the 1996197 season. In this section. this discussion will focus only on grain yield. Other yield components will be discussed later. The results given in Table 9 show that the significant difference in grain yield for this season was due to supplemental irrigation (highly significant) and fertilizer (significant), and its interaction with the sowing date.

Table 9. Summary of the results of mean squares analysis of variance for Waha cultivar grain yield and other yield components fur the *1996/97* growing season.

Source of variation	Degree of freedom	Grain yield	Biological yield	Plant height	Heads per m^2	Kernels per spike	1000 kernel
Replication	2						
Sowing Date (A)	*2*	N.S	*	**		N S	
Error (a)	4						
Supp. Irrig. (B)	2	**	N.S	N.S	N S	* *	*
A x B	4	*	N.S	N.S	N.S	N.S	N.S
Error (b)	12						
Fertilizer (C)	*2*	*	**	N S	*	N.S	N S
4 x C	4	**	*	N.S	*	N.S	N.S
C x B	4	N.S	N.S	N.S	N.S	**	N.S
AxBxC	8	N.S	N.S	N.S	N.S	**	N.S
Error	***36***						
Total	*80*						

N.S. = Not significantly different at the 5% probability level
** = Significant at the 1% probability level.
* = Significant at the 5% probability level.

The average grain yields for the Waha cultivar in the 1996-97 growing season are presented in Table 10. The results show clearly that the early sowing date (1 Dec 1996) combined with high N and **SI** give the highest grain yield (5.61 t/ha). The lowest grain yield was given by late sowing under rainfed condition (2.59 t/ha). The results in Table 10 emphasize the importance of supplemental irrigation, since it greatly improved wheat crop production in a year with a 330 mm or near to average rainfall. As Table 6 indicates, rainfall during April (24 mm) and May *(5* **mm)** was below crop requirements. Therefore, one irrigation (of 20 mm) was given at the end of April for DSI, and two irrigations (2 x 20 mm) were given on II May and 25 May for FSI. However. irrigation of 20 mm was not enough to significantly increase crop yield relative to rainfed yield.

Figure 4 shows the interactions of nitrogen doses with the date of sowing. These results indicate that the effect of an **N** dose on grain yield increases with a delay in the sowing date. This effect may have been due to the fact that there was residual N in the soil (which had resulted from the large amount of N-fertilizer applied to the previous crop). Thus. there was no need for the application of N during the growing season. However. crops sown later may not have had access to the previously-applied N (which was presumably lost by leaching or through other processes). The N treatment applied at the rate of 40 kg/ha would therefore have been helpful in the case of later-emerging crops, which would have had a greater need than the crops sown earlier.

Table 10. Grain yield of Waha cultivar under various sowing dates, water management options and nitrogen fertilization rates for the growing season 1996197.

Sowing Dates	Nitrogen	Water Management Option'		
		Ranted	DSI	FSI
	Kg/ha	t/ha		
I Dec 1996	0	1.58 abcde	1.71 abcd	5.50 ah
	40	3.76 defgh	4.29 cdefg	5.13 abc
	X0	1.16 cdefg	3.91 defg	5.61 a
5 Jan 1997	0	1.76 defgh	4.56 abcde	5.47 ah
	40	4.56 abcde	1.38 bcdef	5.55 ah
	80	4.14 cdefg	4.22 cdefg	4.23 cdefg
I Feb 1997	0	2.68 hi	3.13 phi	3.49 fghi
	40	3.76 defgh	3.50 efghi	4.65 abcde
	80	2.59 1	3.31 fphi	4.53 abcdf

1 DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation Means with different letters differ significantly at the 5% probability level (Duncan's Multiple Range Test)

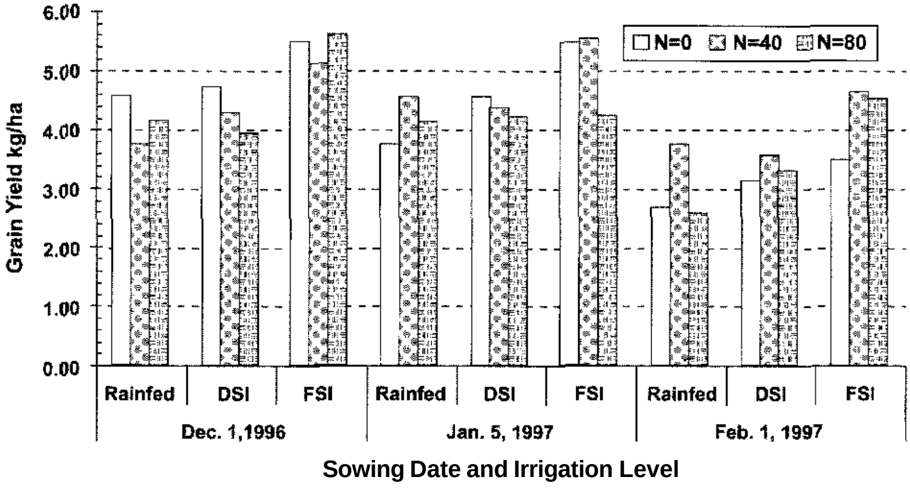

Figure 4. Grain yield of Waha cultivar for different sowing dates and levels of supplemental irrigation and nitrogen for the 1996197 season, Rabiah, Iraq.

1997/98 Season

During the 1997198 growing season. the rain came early, in October (35 mm). During November, December. January and February there were; respectively, 3, 56,44 and 34 mm of rainfall. However, this was actually the driest season of the study, because the rainfall during March (34 mm). April (9 mm) and May (0 mm) was insufficient for the crop's requirements. This situation necessitated the initiation of supplemental irrigation early, during March and throughout April and May, to supply moisture for the important stages of flowering and grain filling.

The amounts and timing of the irrigation applications were governed by the soil moisture conditions during March and April. Three irrigation applications were made: 18 mm on 3 March. 25 mm on 5 April and 25 mm on 12 May, 1998. Total rainfall at Rabiah during this season was 236 mm, thus the total amount of water received by the DSI treatment was 304 mm. Due to technical problems and a water shortage, the FSI treatment was not feasible in this year.

The results and discussion for this season consider the Waha cultivar only. In this year. all treatments were fertilizedusing the N=80 level. The results given in Table I I clearly show the positive impact that a limited amount of supplemental irrigation has on wheat yield. The pronounced impact of supplemental irrigation was probably the result of the fact that conditions were dry. Table 11 also shows the adverse ellect of delayed sowing on yield. Yields were 70% lower as a result of delaying the sowing from 30 Dec 1997 to 17 Feb 1998. Thus, each week that sowing was delayed resulted in a grain yield loss of about 220 kg and 520 kglha for rainfed and irrigated wheat respectively.

Table 11. Grain yields of Waha cultivar with different sowing dates in the **1997/98** growing season at Rahiah (with total growing season rainfall of **236 mm** and fertilization rate of **80** kg N ha^{-1}).

Sowing Date	Grain yield (t/ha)		% Yield Increase (under DSI. relative to rainfed control)
	Rainfed	Deficit Supplemental lrrig. (DSI)= 68 mm	
3 0Dec 1997	2.16 b[1]	4.61 a	113
17 Feb 1998	0.46 d	I.09 c	137
% Yield Decrease (later Sowing date relative to earlier sowing date)	74	76	

1 Means with different letters differ significantly at the 1% probability level

Water Use Efficiency (WUE)

Table 12 gives the WUE values over three growing seasons for Waha cultivar, averaged over all N levels. The results indicate that, for the rainfed treatment, the highest WUE is generally obtained with early sowing under most water management treatments. For the WUE for the total amount of water (rain + SI), the values are close to that of the rain-only WUE. For SI water alone, the WUE_{si} depends on seasonal rainfall and the water management treatment. Generally, WUE_{si} increases as seasonal rainfall decreases.

The WUE_{si} was highest for the 1997198 growing season. This season was the driest (rainfall = 236 mm) of the study period. Therefore, the positive impact of supplemental irrigation crop production was very significant. In two out of three years, the maximum return per one cubic meter of supplemental irrigation water was obtained in the case of the deficit irrigation level **(DSI).** The adverse effect that a delay in sowing has upon WUE is very obvious in Table 12.

Table 12. Water use efficiency (kg grain/m³ of water) for Waha cultivar for three seasons.

Season	Rainfall (mm)	Water Management[1]	Sowing date	WUE_{rain}	WUE_{total}	WUE_{si}
1995/96	316	Rainfed	2 Jan	1.36		
			7Feb	1.44		
		DSI	2 Jan		1.38	1.61
			7 Feb		1.15	-
		FSI	2 Jan		1.26	0.44
			7 *Fch*		1.12	
1996/97	330	Rainfed	I Dec	1.26		
			5 Jan	1.26		
			1 Feb	0.91		
		DSI	I Dec	-	1.11	0.27
			5 Jan	-	1.13	0.40
			I Feb		0.86	0.55
		FSI	1 Dec	-	1.20	1.06
			5 Jan	-	1.13	0.78
			I *Feh*		0.94	1.01
1997/98	236	Rainfed	30 Dec	0.91		
			17 Feb	0.27		
		DSI	30 Dec	-	1.52	3.61
			17 Feb	-	0.36	0.66

1DSI= Deficit Supplemental Irrigation and *FSI* = Full Supplemental Irrigation

Yield Components

In this section, the yield components of the Waha cultivar for the growing seasons 1995196 and 1996/97 will be presented and discussed. An area of one square meter was selected and hand-harvested from each plot to allow data estimates for the following: biological yield, straw yield, number of heads per m², number of kernels/head, mass per 1000 kernels, and grain yield.

Table 13 presents the means of the yield components for the growing reason 1995196. The nitrogen-fertilized treatments (+N) are compared with the non-fertilized treatments (NO) and denoted as (-N). These data clearly show that nitrogen increased the biological yicld of plants under all sowing-date and irrigation-level treatments, by promoting early vegetative growth. Moreover, early sowing resulted in higher biological and grain yicld due to the longer growing period, with a low vapor pressure deficit at the early growth stage. This provided more vegetative growth in the crop sown early. in comparison with the late sown crop. Table 7 shows a summary of the results of the analysis of variance (ANOVA) for grain yield, along with other yield components for the 1995196 season. This analysis shows that the main effects of sowing dates, irrigation, cultivar and fertilizer on straw yield are all significant. For other yield components. fertilizer and cultivar had the most significant effect.

Table 13. Mean results of yield components for Waha cultivar for the 1995/96 growing season, Kabiah, Iraq.

Sowing Date	Water Management[1]	Fertility	Biological yield (t/ha)	Straw yield (t/ha)	Heads / m 2	Kernel /head	g/1000 kernels
2 Jan 1996	Rainfed	-N	9.5	5.6	171	40	41.5
		+N	11.8	10.1	189	41	37.1
	DSI	-N	10.4	6.1	198	37	41.3
		+N	11.6	6.8	181	41	36.9
	FSJ	N	9.0	1.9	141	41	41.1
		+N	119	7.3	207	42	38.2
7 Feb 1996	Rainfed	-N	9.1	4.4	123	40	36.8
		+N	8.9	1.5	144	41	37.2
	DSI	-N	7.1	3.5	138	37	39.3
		+N	8.6	4.3	147	41	37.1
	FSI	-N	9.0	1.7	147	33	38.1
		+N	9.6	5.0	138	10	36.3

1 DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation

Table 14 presents the mean results of the yield components for the 1996197 growing season. Though irrigation had a highly significant effect on grain yield in this year. it did not have a significant effect on biological yield (Table 9). This was most probably because water was used for grain filling in preference to vegetative growth at the time of year that the water was applied (in the late spring). Fertility had the greatest impact on biological yield, as in the previous year.

Simulation Model Performance

Figure *5* illustrates the performance of the model used to simulate daily evapotranspiration and soil moisture levels in the crop root zone for the 1995/96 growing season. This is the season for which the most complete body of data was available for the simulation. The sampling frequency used to monitor soil moisture was increased to a weekly level during April and May. Water was added during the period 6 May to *2* June 1996 (the period in which heading and grain filling occurred in the wheat).

Figure 5 shows the water budget of the root zone. The figure illustrates that (for the first time in this season) the percentage depletion of available water in the root zone exceeded the allowable limit of 50%. This occurred at about the end of the tlowering stage, on 6 May. This is in agreement with the measured available water as indicated by the mark or symbol (☐) on 24 April and on 7 May 1996.

During the 1995196 season, the harvested grain yield of a number of individual plots was more than 6 t/ha. Although the maximum grain yield (Ymax) in the simulation model, described earlier. is taken to be 6 t/ha, this does not appear to have biased the model's prediction. Table 15 gives a summay of the predicted consumptive use (column 3) and the potential seasonal crop evapotranspiration, i.e. crop water requirements, (column 4). as well as the relative yield, according to Equation 6 (column 5), the expected, i.e. simulated, yield (column 6), and the actual or measured yield (column 7) using the model for the 1995/96 growing season.

A comparison of the yield values. shown in the last two columns of Table 15, indicates that the agreement between the two figures is good. Thus, the performance of the model proposed suggests that it is promising and worthy of further improvement and investigation, in order to check its validity under various conditions.

Table 14. Mean results of agronomic studies for Waha cultivar for the 1996197 growing season, Rabiah, Iraq.

Sowing Date	Water Management[1]	Fertility	Biological yield (t/ha)	Straw yield (t/ha)	Heads /m2	Kernel /head	g/1000 kernels
I Dec 1996	Rainferl	-N	15.4	10.8	234	52	32.7
		+N	13.5	9.5	275	49	38.7
	DSI	-N	16.5	11.7	270	55	36.8
		+N	12.6	8.5	320	52	39.4
	FSI	-N	15.3	9.8	266	47	38.1
		+N	16.6	11.2	281	53	38.7
5 Jan 1997	Rainfed	-N	15.5	11.7	162	51	34.0
		+N	11.5	7.2	149	45	37.6
	DSI	-N	14.6	10.0	199	53	45.6
		+N	13.4	9.1	232	47	43.2
	FSI	-N	15.0	9.6	224	52	40.2
		+N	12.6	7.7	203	58	41.2
1 Feb 1997	Rainfed	-N	5.6	2.9	117	48	42
		+N	9.7	6.6	128	44	41.6
	FSI	-N	7.5	4.4	141	42	40.4
		+N	10.3	6.9	122	48	43.2
	DSI	-N	8.3	4.8	170	55	45.7
		+N	14.3	9.7	166	61	43.4

[1] DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation.

Table 15. Comparison of Waha grain yield as estimated by the simulation model and actual yield for the 1995196 growing season.

Sowing Date	Water Management[1]	ΣET_a (mm)	$\Sigma(ET_p \times K_c)$ (mm)	$\Sigma ET_a / \Sigma(ET_p \times K_c)$	Grain Yield (t/ha)	
					Simulated	Actual
2 Jan 1996	Rainfed	220		0.71	4.3	4.7
	DSI	240	310	0.77	5.6	4.8
	FSI	260		0.83	5.9	1.7
7 Feb 1996	Rainfed	*200*		0.69	4.1	1.5
	DSI	231	290	0.79	4.7	4.3
	FSI	252		0.87	5.2	4.5

[1] DSI= Deficit Supplemental Irrigation and FSI= Full Supplemental Irrigation.

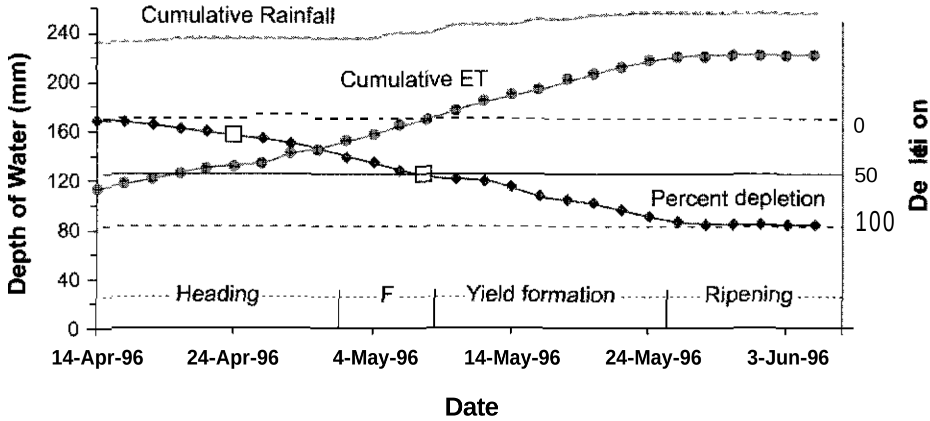

Figure 5. Cumulative measured rainfall, simulated crop ET and simulated percentage moisture depletion in the crop rooting zone, for 2 Jan 1996 sowing date, under rainfed conditions. F = flowering stage; (☐) = measured available water.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In the rainfed farming system of the West Asia and North Africa (WANA) region, a shortage of water is the major constraint placed upon agricultural production. Iraq is one of the WANA countries in which there is a large gap between local supply and national demand for wheat. Average wheat grain yields during the years 1989-97 fluctuated between 0.6 and 1.2 t/ha, which is far below the country's potential. Agronomic practices, therefore, should aim to utilize water available from rainfall and/or other sources for crop production **in** the most efficient way. Supplemental irrigation is an efficient practice used to stabilize and to improve crop production under conditions of variable amounts of rainfall and variable rainfall distribution. Therefore. that the country improves and stabilizes the production of wheat, this strategic commodity, is of the highest priority. The objective of the research presented in this report was to study the potential for improving wheat crop yields through the use of supplemental irrigation. in conjunction with other production inputs such as improved cultivars, fertility and management strategies. This report presents the activities and results for the 1994-98 period.

The experimental site is located within a 75.000 ha irrigation project. the North Jazeera irrigation project. Since 1991. the area has been converted from rainfed agriculture to supplementally-irrigated land, Irrigation is a new practice for the local people of Al-Jazeera. and research is needed to optimize this practice. The selected site lies within aunual winter rainfall isohyets of 350 and 500 mm. The main irrigation method in the project is sprinkling, by mechanized linear-move systems. About 75% of the project area is cropped with wheat every year. The climate is Mediterranean. with a growing season for wheat from November or December to early June.

The experiment included four variables: wheat cultivars, sowing date. supplemental irrigation levels and nitrogen application. Waha. a durum cultivar, was the principal cultivar used in the experiment, in conjunction with other bread and durum cultivars. Two or three sowing dates were chosen each year. depending mainly on the onset of rain. Three irrigation levels were used: zero irrigation (rainfed), 100% replenishment of the root zone soil moisture deficit (termed as full supplemental irrigation. FSI), and 50% replenishment of the root zone soil moisture deficit (termed as deficit supplemental irrigation, DSI).

Three levels of nitrogen fertilizer were used (0, 40 and 80 kg/ha). The treatments were replicated three times and the experimental design was of a multi-split type. The size (dimensions) of the basic plots. and their total number. varied from year to year, depending on the number of cultivars and sowing dates. From each sub-sub-sub plot; a sample of one square meter was harvested for the quantification of yield components. Such components included: above-ground biological yield, grain yield, number of heads per square meter. number of kernels per head and mass per 1000 kernels.

A simulation model for supplemental irrigation and crop productivity was adapted and tested. The model is based on the water volume balance concept. and was used to schedule irrigation and to estimate crop productivity. The simulation involves a periodic monitoring of soil moisture in the crop root zone.

While considering the conditions and limitations of the present study. the following conclusions and recommendations can he made. these are mostly in agreement with the results and trends of ICARDA 's research findings on supplemental irrigation of wheat in northern Syria (Oweis *et al*. 1998) and in the Central Anatolian Plateau (Oweis *et al* 2001):

I. In the Al-Jazeera area, applying relatively small amounts of supplemental irrigation can substantially enhance wheat production. However. the significance of this increase depended largely, in this research, on the amount and distribution of seasonal rainfall. In a relatively wet season (total rainfall of 450 mm), the yield increase, relative to rainfed yield, was around 10%; in a dry season (rainfall of *236* mm): the increase might exceed 100%
2. Early sowing resulted in higher wheat production per unit area. In the 1997198 season (which was very dry), for every week that sowing was delayed there was a resultant grain yield loss of 220 kg/ha for rainfed crops, and 520 kglha for crops under supplemental irrigation. However. it was observed that abnormally low (sub-zero) temperatures during January and/or February can adversely affect production under an early sowing regime. If irrigation facilities are available, farmers should be encouraged to sow wheat in early December, without waiting for the onset of the rain. Early sowing also helps the crop to escape the drought and high temperatures of late May by reaching maturity earlier, because of early growth under the low vapor pressure deficit in the winter period.
3. The main effect of fertilizer application, and its interaction with other factors on wheat grain yield. was not consistent. Probably the soil's high residual fertilizer level, from the previous crop, was one main reason for this. However. biological yield significantly increased with an increase in the level of fertilizer. It is strongly recommended that nitrogen levels in the soil be closely and continuously monitored for environmental and economic reasons.
4. Rainfall use efficiency was increased, from 9.1 kg/ha/mm to 15.2 kg/ha/mm, by supplementing rainwater with only 68 mm of irrigation. In practical terms, such a small amount of irrigation water cannot, alone, greatly affect crop production. However, when used in conjunction with rainfall, both rain and irrigation water productivity are increased substantially. It is strongly recommended that limited water resources be used to stabilize variable rainfed crop production, by supplying a minimum amount of water at the critical growth stages of the crop.
5. Among the wheat cultivars tested, Waha proved to be most responsive to supplemental irrigation. Adnanya and Om Rabi 5 cultivars are compatible, but are not as responsive as Waha. The Abu-Ghraib cultivar is, however, not suitable for rainfed and/or supplemental irrigation. It can be concluded that cultivars developed to perform well under fully irrigated conditions, such as Abu-Ghraib. do not perform as well under rainfed and/or limited supplemental irrigation. New wheat genotypes, with a higher genetic potential for yield and performance under supplemental irrigation in the moderate rainfall zone (350-500 mm), should be sought.

6. Maximum water productivity is obtained under a deficit irrigation strategy (DSI) in which only 50% of irrigation requirements are applied. Having water resources, which are not sufficient to irrigate all cultivable lands, it is recommended that Iraq adopts a deficit supplemental irrigation strategy in water deficient areas. particularly in dry years, thus supplying about half to two thirds of total irrigation requirements over and above that of seasonal rainfall. Such a strategy will not only stabilize wheat production, but will also allow a larger area to be cropped using the water saved through the use of deficit irrigation.
7. Farmers should be encouraged to irrigate their wheat crop fields during drought periods. in order to save their crop and increase its yield. Since vegetables grown in the spring compete for water with wheat. further research is needed to evaluate the benefits farmers derive from adopting any of the options available. A balanced cropping system and rotation should be used to achieve higher. sustainable. water productivity and a greater economic return for farmer.

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Appendix A

A Sample Experimental Layout for the 1995-96 Season

Irrigation Canal

D_1		D_2		D_2		D_1		D_1		D_2	
SI_0 DSI FSI		SI_0 DSI FSI		FSI SI_0 DSI		SI_0 DSI FSI		DSI SI_0 FSI		DSI SI_0 FSI	
61 58 55 N_{80} N_{80} N_{80}		142 139 136 N_0 N_{40} N_{40}		115 112 109 N_{80} N_{40} N_{80}		34 31 28 N_0 N_{40} N_0		7 4 1 N_0 N_{40} N_{40}		88 85 82 N_{40} N_{80} N_0	
62 59 56 N_{40} N_0 N_{40}	V_1	143 140 137 N_{40} N_{80} N_0	V_1	116 113 110 N_0 N_{80} N_0	V_1	35 32 29 N_{40} N_{80} N_{40}	V_3	8 5 2 N_{80} N_{80} N_{80}	V_2	89 86 83 N_0 N_0 N_{80}	V_1
N_0 N_{40}		144 141 138 N_{80} N_0 N_{80}		117 114 111 N_{40} N_0 N_{40}		36 33 30 N_{80} N_0 N_{80}		9 6 3 N_{40} N_0 N_0		90 87 84 N_{80} N_{40} N_{40}	
70 67 64 N_{40} N_{80} N_{40}		151 148 145 N_{40} N_{80} N_{40}		124 121 118 N_0 N_0 N_0		43 40 37 N_{80} N_0 N_{80}		16 13 10 N_0 N_0 N_0		97 94 91 N_0 N_0 N_{80}	
71 68 65 N_{80} N_{40} N_0	V_2	152 149 146 N_{80} N_0 N_0	V_3	125 122 119 N_{80} N_{40} N_{80}	V_2	44 41 38 N_{40} N_{40} N_0	V_1	17 14 11 N_{40} N_{40} N_{40}	V_1	98 95 92 N_{80} N_{40} N_{40}	V_2
72 69 66 N_0 N_0 N_{80}		153 150 147 N_0 N_{40} N_{80}		126 123 120 N_{40} N_{80} N_{40}		45 42 39 N_0 N_{80} N_{40}		18 15 12 N_{80} N_{80} N_{80}		99 96 93 N_{40} N_{80} N_0	
79 76 73 N_0 N_0 N_{40}		160 157 154 N_{80} N_{40} N_{80}		133 130 127 N_{80} N_{80} N_0		52 49 46 N_0 N_{80} N_0		25 22 19 N_{80} N_{80} N_{80}		106 103 100 N_0 N_0 N_{80}	
80 77 74 N_{40} N_{80} N_0	V_3	161 158 155 N_{40} N_{80} N_0	V_2	134 131 128 N_0 N_{40} N_{40}	V_3	53 50 47 N_{40} N_{40} N_{40}	V_2	26 23 20 N_{40} N_{40} N_0	V_3	107 104 101 N_{80} N_{80} N_0	V_3
81 78 75 N_{80} N_{40} N_{80}		162 159 156 N_0 N_0 N_{40}		135 132 129 N_{40} N_0 N_{80}		54 51 48 N_{80} N_0 N_{80}		27 24 21 N_0 N_0 N_{40}		108 105 102 N_{40} N_{40} N_{40}	

K_2 ---------- R_1

D_1 = 2 Jan 1996	V_1 = Waha	SI_0 = No Irrigation	N_0 =No N applied
D_2 = 7 Fcb 1996	V_2 = Om Rabi5	**DSI** = *50%* Irrigation	N_{40} = 40 **kg** N/ha
R_1 , R_2 , R_3 = Republications	V_3 = Adnanya	FSI = 100%Irrigation	N_{80} = 80 kg N/ha

AGRICULTURAL DEVELOPMENT UNDER SUPPLEMENTAL IRRIGATION IN RAINFED REGIONS

RABIAH. NORTH **JAZEERA IRAQ**
Experimental Layout (1995-1996)

Appendix B

A sample of data sheet used for soil moisture measurements at Rabiah, North Al-Jazeera, Iraq

6.4.1996	6.3.1996	6.3.1996	6.3.1996	25.2.1996	Date of Measurement
13	15	14	13	15	Plot No.
V1	V1	V1	V1	V1	Variety
D1	D1	D1	D1	D1	Sowing Date
N_0	N_{80}	N_{40}	N_0	N_{80}	Nitrogen Level
I_0	I_0	I_0	I_0	I_0	Irrigation Level
100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	Depth (cm)
22.9 24.1 23.7 26.8 27.2	22.9 24.2 24.2 24.4 24.4	21.6 22.7 23.7 24.6 25.6	21.6 22.4 22.6 24.4 24.4	23.0 23.1 24.8 25.5 27.0	% Water Content (on dry mass basis)

6.4.1996	6.4.1996	6.4.1996	6.4.1996	6.4.1996	Date of Measurement
87	86	85	15	14	Plot No.
V1	V1	V1	V1	V1	Variety
D2	D2	D2	D1	D1	Sowing Date
N_{40}	N_0	N_{80}	N_{80}	N_{40}	Nitrogen Level
I_0	I_0	I_0	I_0	I_0	Irrigation Level
100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	100 75 50 25 10	Depth (cm)
24.2 24.6 23.9 23.2 23.9	24.6 23.9 24.6 25.3 26.3	25.3 23.5 23.9 24.6 24.2	25.6 24.8 26.0 26.8 27.6	24.8 24.8 22.2 26.0 25.2	% Water Content (on dry mass basis)

Supplemental Irrigation Level (SI): *FSI = full supplemental irrigation; DSI = Deficit SI with 50% of FSI; Rainfed; zero SI.*
Nitrogen Level: N_{80} = 80 kg. N/ha; N_{40} = 40 kg. N/ha; N_0 = No fertilization
Wheat Variety (W V): V_1 = Waha, V_2 = Om Rabi 5 ; Sowing date (SD): D_1 = 2 Jan 1996; D_2 = 7 Feb 1996

Appendix C
Wheat Crop Phenological Growth Stages (days) for Waha cultivar
(According to FAO system)

		Growth stage				
Year	Sowing Date	Initial	Crop Development	&lid-Season (yield formation)	Late (ripening)	Total (days)
1994-95	29 Oct 1994 26 Dec 1994 9 Jan 1995	na	**na**	na	na	na
1995-96	2 Jan, 1996	32	68	31	**33**	164
	7 Feb 1996	20	43	27	**33**	123
1996-97	1 Dec 1996	I8	94	45	*35*	192
	5 Jan 1997	19	70	37	35	161
	I Feb 1997	47	40	18	34	139
1997-98	**30 Dec** 1997	41	61	28	39	169
	17 Feb 1998	23	37	19	36	115

na: not available (no data collected)