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FINAL REPORT

PROJECT TITLE: CONTRIBUTION TO THE IMPROVEMENT OF IRRIGATION MANAGEMENT PRACTICES THROUGH WATER-DEFICIT IRRIGATION

BY

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ABSTRACT

The study aimed at identifying irrigation management practices which could result in water savings through-water deficit irrigation. Two field experiments, one on wheat and the other on sugar beet, were conducted and consisted of refraining from supplying water during specific stages of the cycle so as to identify the period(s) during which water deficit would have a limited effect on crop production.

The year was exceptionally dry with a climatic deficit throughout the growing season.

In the case of wheat, high water deficit occurred during the early stages and irrigation during these stages was the most beneficial for the crop. However. one water application during the tillering stage allowed the yield to be lower only to that of the treatment with three irrigations.

Irrigation during the stage of grain filling caused the kernel weight to be as high as under three irrigations. However, this advantage could not make up for the loss with respect to the other yield components which were higher under good watering conditions during the stage of tillering.

The highest water-use efficiency value was obtained with one irrigation during the tillering stage, although it was not very different from that of the treatment with three irrigations. The lowest value corresponded to the treatment with one irrigation during grain filling and that under rainfed conditions.

For sugar beet, when water stress was applied early in the crop cycle, its effect could be almost entirely recovered with adequate watering during the rest of the growing season. On the opposite, good watering early in the cycle, followed by a stress, resulted in the second lowest yield. Water deficit during the maturity stage had also a limited effect on yield.

The most crucial periods for adequate watering were those which correspond to late foliar development and root growth which coincided with the highest water requirements period.

Resuming irrigation late in the season, after a long period of stress caused the formation of new leaves at the expense of the sugar already stored in the roots.

Stress throughout the crop cycle resulted in the highest yield reduction per unit of water deficit. Nevertheless, for the same amount of water savings through deficit irrigation, it was better to partition the stress throughout the cycle than during the critical stages of the crop.

From the economics standpoint, maximum profit for farmers was obtained with the fulfillment of the entire crop requirements. However, at the national level, it would have been more important to practice deficit irrigation and increase the irrigated area.

For both crops, high yields as well as high water-use efficiency values could have been obtained

I. INTRODUCTION

The study was conducted on wheat and sugar beet and had the following objectives:

- Conduct field trials aiming at identifying crop stages during which the crops could withstand water stress with limited effect on yield and quality;
- Draw conclusions on ways of managing irrigation so as to increase water-use efficiency and limit water loss;
- Make inferences on water savings on a large scale (irrigation projects), through adequate irrigation management.

In addition, a variety of by-products were expected to come out of the study, such as:

. identify appropriate means of estimating water requirements of the crops used, within the context of the study region,
. contribute to assessing the crop coefficients associated with the empirical and semi-empirical models identified,
. contribute to establishing the water response function of the two crops used, both for the entire growing season and for each stage of these crops,
. identify appropriate means of irrigation scheduling and management which could be used at the farm level and by the agency in charge of project management.

II. SUGAR BEET

MATERIALS AND METHODS

The experiment was conducted in the Doukkala region, west of Morocco, where an area of 0.8 hectare served for the trial. During the previous growing season, the field was cropped by wheat and remained follow between the harvest in June and the soil preparation for the present trial, in October.

Sowing took place manually in mid-November, with a spacing of 50 and 20 cm, respectively between and along the crop rows, i.e., with a cropping density of 100 000 plants per hectare. Fertilization consisted of bending 100 UN, 150 UP and 300 UK. To enhance germination, an irrigation was applied right after the crop installation.

Throughout the crop cycle, the production techniques were such as recommended for maximum production in the region.

Irrigation water was first lifted into a large calibrated reservoir from which it flows under gravity, which made it possible to measure the amount supplied to each treatment with accuracy. During the irrigation periods (ETa = ETM), the treatments were receiving one water application every 15 days, on normal conditions, and every 10 days on peak water requirements period.

Each irrigation regime was equipped with three access tubes for monitoring soil water content at different depths. Measurements of this parameter were taken every three to four days, from February 7[2] through harvest and served for determining crop water use.

At harvest which took place on the 6th of June, root yield was measured in all treatments within all four repetitions. Moreover, the sugar content of the roots as well as their technological quality were measured.

The soil physical and chemical characteristics were also determined on samples taken at different locations of the field.

Precipitation was measured with a rain gauge installed inside the experimental field, while the other climatological parameters were monitored in a station located in the study region.

The water consumptive use of the crop was determined by means of the water balance method, neglecting the drainage term. It was also estimated using the two methods described by Doorenbos and Kassam (1980) in the FAO bulletin number 33. For a better accuracy of these methods, all the necessary parameters were determined in situ. Moreover, the soil water reservoir in the root zone was monitored through the measurements of soil water content with the neutron probe, and the rooting depth was measured occasionally until it reached the maximum of 60 cm by the end of March.

The crop water requirements (ETM) were estimated by means of three methods: Blaney-Criddle, Radiation and Penman.

RESULTS AND DISCUSSION

SOIL CHARACTERISTICS

Table 2 shows the soil characteristics as determined through analysis in the laboratory. With respect to these characteristics, there seems to be no limitation with regard to sugar beet production.

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[2] This date corresponds to when the crop density was thinned.

Table 3: Depths of water applied to the different treatments (mm) and corresponding dates of application

Date	Crop age (days)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
9/12/92	23	35	-	35	-	35	35	35	-	35	35
23/12/92	37	30	-	-	-	30	30	30	-	30	30
6/ 1/93	51	35	-	40	40	-	35	35	-	-	35
20/ 1/93	65	30	-	-	30	-	30	30	-	-	30
19/ 2/93	95	45	-	-	45	-	45	45	-	-	45
22/ 3/93	126	60	-	-	60	70	-	60	70	-	-
2/ 4/93	137	65	-	80	65	65	-	65	65	-	-
14/ 4/93	149	70	-	-	70	70	-	70	70	-	-
25/ 4/93	160	65	-	65	65	65	-	65	65	-	-
9/ 5/93	174	60	-	60	60	60	-	60	60	-	-
20/ 5/93	185	60	-	-	60	60	75	-	60	75	-
29/ 5/93	194	70	-	-	70	70	70	-	70	70	-
TOTAL	203	625	0	280	560	525	320	495	460	210	175

REFERENCE EVAPOTRANSPIRATION (ETo) AND CROP WATER REQUIREMENTS

Reference evapotranspiration as estimated by three different methods known to be well adapted for the conditions of the region amounted to 705, 687 and 715 mm, respectively for the methods of Penman, radiation and Blaney-Criddle. Maximum crop water requirements were obtained by multiplying the reference evapotranspiration values with the sugar beet crop coefficients previously determined in the region. ETM values were low in the beginning of the crop cycle and increased gradually to attain the maximum during April and May. Then, they started to slowly decrease in late May. Their evolution was practically the same independently of the estimation method which attest of the validity of all three methods within the context of the region. Total ETM of the sugar beet crop amounted to 610 mm, for a growing period of 205 days. Assuming the irrigation efficiency to be 80 % which is too optimistic, gross water requirements were 7625 m^3/ha. If we consider that all precipitations benefitted for the crop, By comparison, these values are very close to those identified by Doorenbos and Kassam (1980) and which are as follows: 0.45 for the initial stage, 0.8 for the crop development stage, 1.1 for the mid-season stage and 0.95 for the late season stage.

WATER CONSUMPTIVE USE

Table 6 gives the crop water use, under the different irrigation regimes. The crop period 1 (initial stage) was completely dry. However, because of the low requirements during this stage and the irrigation applied after the crop installation, treatment 4 which was to be stressed during this period was subjected only to a minor stress at the end of the stage.

The maturity stage was also completely dry. As a result, treatment 7 which received no water application during this stage used only 73 mm during this period. This depth was almost 36 % below the maximum requirements.

Because of natural precipitation which amounted to 67 mm, stage 2 was only partially stressed. Total water requirements during this stage were 115 mm while actual evapotranspiration of treatment 5 which was to be stressed during this period was over 51 % below this requirement.

Treatment 6 which received no irrigation during the third stage was the most severely stressed. Its consumptive use during this stage (116 mm) was over 66 % below the requirements.

For the entire growing season, water consumptive use of treatments 3, 4, 5, 7 and 8 was over 74 % of ETM. That of treatment 6 was over 62 % of ETM, while treatments 2, 9 and 10 used less than 50 % of the maximum requirements.

In the case of treatment 2 which was conducted under rainfed conditions, total ETa is slightly higher than the total precipitation of the growing season, which means that the soil water reservoir has contributed to ETa.

Maximum values of ETa varied from 2.23 for treatment 2 and 5.7 for treatments 1, 7 and 8. They occurred at different moments, depending on the irrigation itinerary of each treatment.

During the period from February 7 through harvest where the in-situ water balance method was applied, all three methods of ETa determination gave close results, except for a slight overestimation by the in-situ water balance method due to drainage which was not accounted for by this method, but also to the lower accuracy of this method.

Table 7: Root and sugar yield and water-use efficiency of irrigation water applied to the treatments

Treatment	Irrigation		Yield		Water-use efficiency	
	Number*	Volume (m^3/ha)	roots (t/ha)	sugar (t/ha)	roots (kg/m^3)	sugar (kg/m^3)
T1	12	6250	81.38	14.72	13.02	2.35
T2	0	0	29.96	6.56	-	-
T3	5	2800	64.05	12.26	22.87	4.37
T4	10	5600	79.40	14.98	14.18	2.67
T5	9	5250	75.09	14.20	14.30	2.70
T6	7	3200	61.87	11.53	19.33	3.60
T7	10	4950	71.80	14.03	14.50	2.83
T8	7	4600	69.40	12.32	15.08	2.68
T9	4	2100	45.44	8.02	21.63	3.82
T10	5	1750	37.72	8.14	21.55	4.65

* The irrigation applied right after the crop installation is not included.

adequate watering conditions early in the cycle leads to the development of an important leaf cover, with a shallow root depth. When a severe stress follows, the crop depletes the soil water stored in the root zone rapidly and wilts before the completion of root development.

Treatment 9 received only four irrigations two of which during the initial stage and the remaining two during the last stage (maturity.) These last two water applications allowed the crop to partially recover since its yield (45.44 t/ha) was higher than that of T10. This ability of sugar beet to partially recover the effect of early water stress has also been identified during the previous growing seasons.

From these results and those of the previous growing seasons, it can be concluded that under limited water, it is better to start subjecting the crop to stress early in the cycle. By doing so, the period of stress is not concentrated in time on one hand, and the crop is adapted to limited watering conditions on the other. This conclusion is confirmed also by treatment 3 which received the same number of irrigations as treatment 10, with different timings, but which yield was over 70 % higher. The water consumptive use of this treatment was 345 mm lower than ETM, but this deficit was more or less evenly distributed along the growing season.

Treatments 5 and 8 were irrigated essentially during the second half of the crop cycle. However, the former received two water applications before the latter which allowed the crop to partially avoid the stress during the period of intensive foliar development, thus realizing a highly competitive yield of 75 t/ha.

Thus, about 90 % of the yield variability between treatments can be attributed to the difference in the amounts of water applied through irrigation, independently of the timing of application. When considering the depth of water actually used by the crop during the period february 7 - through harvest, the relationship is of the same kind:

ROOT YIELD = 13.29 + 0.12 ETa (r = 0.97)

SUGAR YIELD = 3.47 + 0.02 ETa (r = 0.96)

WATER PRODUCTION FUNCTION

The crop production function was determined for the entire crop cycle and for various periods of it depending on when the stress was applied. The highest yield response coefficient (0.86) was obtained when the stress took place during the entire cycle. This value puts sugar beet among the crops which require large amounts of water if the yield is not to be reduced by water stress. The same result has been found the previous year.

The second highest yield reduction took place when the water stress was applied during the last two stages of the crop cycle (root development and maturity) with a coefficient of 0.74. This was also the situation during the previous growing season. Intermediate but still important yield reduction resulted from the stress during the P2 and P3, with a coefficient of 0.64. Again the same result was found the year before.

The yield response coefficient corresponding to the first two stages (P1 and P2) was a bit higher than that of the previous growing season with a value of 0.42. During the previous campaign, the stress applied during these two stages had the lowest effect. It should be noted however that during the previous campaign, only limited stress could be applied during these stages due to precipitation. When the stress took place only during the last stage (maturity), it had only a limited effect on yield, with a coefficient of 0.38. Nevertheless, the lowest effect was that of the stress applied only during the second stage (P2).

In conclusion, the same tendency as that of the previous year was found during the present growing season. When water stress is applied early in the crop cycle, after the stage of 6 to 8 leaves, it could easily be recovered provided adequate watering conditions take place during the rest of the growing season. However, the water deficit during the early two stages should not be too high (over 50 % of the requirements) for a long period of time. In the same manner, limited effect on yield results from water deficit applied late in the cycle, during the maturity stage.

The most crucial periods for adequate watering are those which correspond to late foliar development and root growth. These periods coincide with the highest water requirements and the crop cannot withstand water deficits of more than 30 % without important effect on yield.

Sowing took place on the 17th of December and was performed with a mechanical sowing machine having six lines 30-cm apart from each other. Care was taken so as to have the same density for all genotypes which required the equivalent of 136, 125, 136, 128 and 114 kilograms per hectare, respectively for Isly, Marzak, Tassaout, Sarif and Acsad 59. Areas between genotypes and treatments as well as those around the blocks were also cultivated by wheat in order to avoid the border effects. In early January. a light irrigation of 40 mm was applied to all treatments to enhance germination, due to the lack of precipitation before and after installation.

Each treatment was irrigated separately. The depth applied during each irrigation was 60 mm. The irrigation system consisted of sprinklers with a nominal flowrate of 6 millimeters per hour, installed on a grid of 12 by 12 meters. The dates of the different irrigations applied are given in table 8.

Observations and measurements

The climatic parameters were monitored throughout the crop cycle by means of an automatic weather station installed near the experimental field. Recorded parameters included solar radiation, relative humidity, wind speed, insolation, precipitations and temperature.

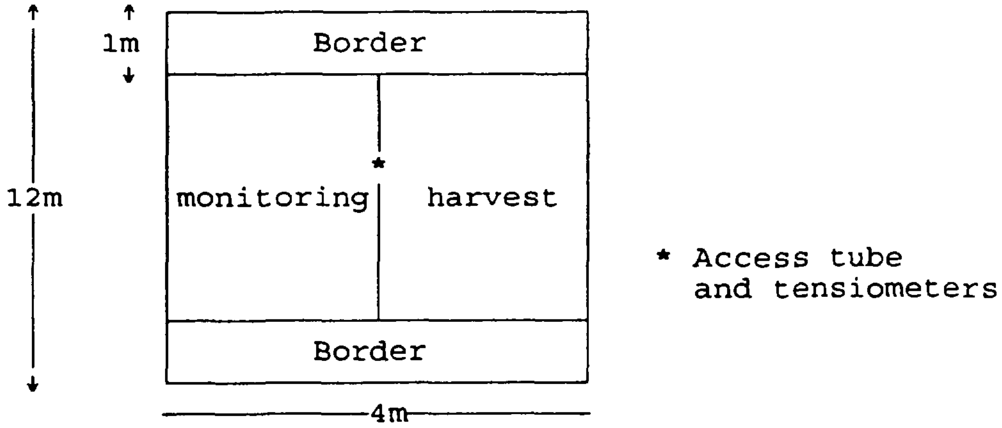
Soil water content was measured with a neutron probe, in all treatments of the first block. Measurements took place every two or three days, at the depths 20, 40, 60 and 80 cm, during the last 110 days of the crop cycle. Volumetric humidity was then obtained from the neutron probe calibration curve. The latter was determined in two sites located in the middle of the plots, during a period of two months. Soil bulk density was also measured in-situ, at different depths.

The crop water consumptive use was determined by means of the in-situ water balance method, during the last 115 days of the crop cycle. In addition, it was estimated using the method described by Doorenbos and Kassam in the FAO bulletin number 33 (1980) and the soil water status based on neutron probe measurements.

Table 8: Irrigation dates of the different treatments

Treatment	Irrigation date
Tillering (D)	21/02/93
Heading (C)	03/04/93
Grain filling (B)	28/04/93
Frequent (E)	21/02/93 - 04/04/93 - 29/04/93

To avoid the effect of crop destruction during measurements and monitoring of the various parameters on the final yield, each experimental plot was partitioned as indicated below. The left part (monitoring) served for all measurements performed on the crop, while the right part (harvest) was left undisturbed for estimating the final yield and its components.



The plants were monitored for the leaf area index, the stem height and the above ground dry matter. The leaf area was measured every fifteen to twenty days, in all blocks and for all genotypes. Samples were taken on two adjacent lines over a length of thirty centimeters and the area of all synthesizing leaves was measured with an electronic area-meter.

Crop water requirements as estimated by the Penman method varied from a minimum of 2.4 mm/day to a maximum of 6.9 mm/day.

Table 9: Soil physical and chemical characteristics

Depth (cm)	Constituents (%)					bulk density (g/cc)	pH
	CS	FS	CL	FL	C		
0-20	12.86	38.08	7.28	7.01	34.77	1.44	7.64
20-40	10.88	42.41	5.63	5.28	35.80	1.46	7.46
40-60	10.61	40.63	7.60	4.51	36.65	1.52	7.83
60-80	11.35	39.67	7.53	3.68	37.77	1.54	7.83

Depth (cm)	Exchang. cations (meq/100g)				P_2O_5 mg/kg	O.M (%)	EC 25°C sat.Pa. mmho/cm	FCC (%)	PWP (%)
	Ca	Mg	Na	K					
0-20	15.2	4.0	1.56	0.27	15.5	0.80	2.33	24.47	11.45
20-40	-	-	1.84	0.23	7.63	0.78	2.39	24.58	12.07
40-60	16.8	4.4	1.82	0.20	6.3	0.80	2.40	24.90	13.22
60-80	19.0	5.4	1.71	0.27	6.3	0.73	2.35	22.38	13.14

Table 10: Precipitation during the campaign (92-93) and the mean during the period 1976-93 (mm)

Month	Sept	Oct	Nov	Dec	Jan	Feb	Marc	Apr	May
92-93	1.5	24.3	11.0	26.8	23.1	29.9	51.7	25.5	5.6
76-93	2.3	31.7	51.0	50.0	54.8	45.45	35.6	28.5	10.7

YIELD ANALYSIS

GRAIN YIELD

Table 11 shows the grain yield obtained under the different irrigation regimes, for all five genotypes. Both factors as well as their interaction had a highly significant effect on this variable.

STRAW YIELD

As it was the case for grain yield, both factors as well as their interaction had a significant effect on straw yield. In addition, all five irrigation treatments resulted in different straw yields, with a decreasing order as follows: three irrigations, one irrigation during tillering, one irrigation during heading, one irrigation during grain filling and no irrigation (table 12.)

Table 12: Straw yield (100 kg/ha) under the different irrigation regimes and for all genotypes

Irrig. Treatment	Genotype					Mean
	Isly	Marzak	Tass.	AC.59	Sarif	
E	82.31	82.65	91.36	81.88	77.64	83.17 A
D	73.69	73.28	74.57	75.32	61.39	71.65 B
C	69.16	72.78	59.82	70.55	57.99	66.06 C
B	57.77	66.88	56.18	64.00	57.33	60.43 D
A	51.93	48.64	56.94	56.43	46.95	52.18 E
Mean	66.97A	68.85A	67.77A	69.64A	60.26B	66.70

Thus, the straw yield turned out to be highest when irrigation was applied during the vegetative stages. With respect to genotypes, only Sarif resulted in a relatively lower straw yield than the other four genotypes.

The interaction was such that the maximum straw yield (9100 kg/ha) was obtained with the genotype Tassaout under three irrigations, and the minimum (4700 kg/ha) with sarif under rainfed conditions.

TOTAL ABOVE-GROUND BIOMASS

The total biomass production (table 13) behaved in a similar fashion to both grain and straw yields taken separately. With respect to genotypes, and as it was the case for straw yield, only Sarif turned out to result in a relatively lower value than the other four. This difference is due to the fact that this genotype is smaller in height than the others. Moreover, it is relatively more sensitive to Xanthomonas-Translucens which attacked the crop during the vegetative stages.

In general, the early water applications resulted in an improvement of this parameter.

Table 14: Actual evapotranspiration (ETa) of the different treatments (mm) during the last three months of the cycle

Irrig. treatmnt	Genotype					Mean
	Isly	Marzak	Tass	AC 59	Sarif	
E	269.5	272.5	291.2	257.1	281.6	274.4
D	226.3	223.5	226.3	223.4	244.6	228.8
C	198.8	204.9	189.5	186.6	220.2	200.0
B	184.4	184.3	187.6	172.1	196.9	185.1
A	159.8	150.4	144.3	144.3	150.4	149.8
Mean	207.8	207.0	207.8	196.7	218.7	207.6

YIELD-ETa RELATIONSHIP

The best relationship obtained between grain and straw yields (YLD) and the depth of water used by the crop (ETa) is of the logarithmic form:

$$\mathbf{YLD = a + b \times ln(ETa)}$$

where the yield is in 100 kg/ha and ETa in mm.

The regression coefficients a and b as well as the correlation coefficient, obtained for the different genotypes, are reported in the table below.

	GRAIN YIELD			**STRAW YIELD**		
Genotype	a	b	R^2 (%)	a	b	R^2 (%)
Isly	-335.94	70.26	96***	-251.83	59.92	96***
Marzak	-239.91	51.74	87**	-224.37	55.18	93**
Tassaout	-230.04	49.91	94***	-216.22	53.49	84**
Acsad 59	-276.14	59.40	97***	-159.00	43.45	98***
Sarif	-249.05	52.36	86**	-177.29	44.25	87**

Thus for all genotypes, the yield variation between treatments can be explained essentially by variations in water consumptive use. It can also be concluded from these results that the crop

Table 16: Water-use efficiency for straw production (Kg/ha/mm)

Irrig. Treatmnt	Genotype					Mean
	Isly	Marzak	Tass.	Ac.59	Sarif	
E	52	49	49	53	44	49.4
D	53	53	52	54	43	51.0
C	51	51	50	56	40	49.6
B	47	48	44	52	40	46.2
A	48	48	52	54	43	49.0
Mean	50.2	49.8	49.4	53.8	42.0	49.0

IV. CONCLUSIONS

The growing season was exceptionally dry with a climatic deficit throughout the cycle of both wheat and sugar beet. Except for minor changes, the experiment was a replicate of that conducted the previous year and many of the results relative to the critical stages of the crops turned out to be similar to those of the previous campaign.

In the case of wheat, high water deficit occurred during the early stages (tillering and stem elongation) and irrigation during these stages was the most beneficial for the crop. Withholding irrigation during these stages subjected the crop to a severe deficit which amounted to over 60 % of the requirements for over two months and resulted in a low tiller and spike density. However, one water application during the tillering stage was enough to reduce this effect and to allow the crop to have a much higher density which is the first important yield component. The final yield under this situation was lower only to that of the treatment with three irrigations.

Within the treatments with one water application, that where the irrigation coincided with the stage of tillering resulted in a higher yield because mainly of its superiority in terms of most yield components.

Irrigation late in the growing season (grain filling) caused the kernel weight to be as high as under three irrigations. However, this advantage could not make up for the loss with respect to the other yield components, especially the density. The latter is higher under good watering conditions during the stages of tillering and stem elongation.

The highest water-use efficiency value was obtained with one irrigation during the tillering stage, although it was not very different from that of the treatment with three irrigations. The lowest value corresponded to the treatment with one irrigation during grain filling and that under the right choice of the period of water application is made. Under the conditions of the growing season, appropriate irrigation management practices would have allowed for the area cropped by wheat to be doubled and that of sugar beet to be increased by at least 30 % with no decrease in yield. With a limited yield reduction, the area cropped by sugar beet could have been also doubled, with a substantial increase in returns.

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