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CHART FOR MONITORING WHEAT IRRIGATION IN REAL TIME

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SUMMARY - A range of irrigation scheduling methods has been developed to assist farmers to apply water more efficiently taking into account crop evaporation and rainfall. However at small farmers' level, such methods can not be applied in a practical manner as they require sophisticated monitoring equipment and data processing. Moreover, the irregularity of rainfall, and the absence of guidelines at a short time-step often complicate decision-making during the irrigation season.
First, the paper presents a procedure for developing irrigation charts to help farmers in their day-to-day decisions. The charts are developed by considering the specific climate and soil characteristics of the region, the irrigation method and local irrigation practices. The chart guides the user in the adjustment of the irrigation interval to the actual weather conditions throughout the wheat growing season.
In a second step, the paper evaluates, how well the chart expects irrigation interval comparing it to a more advanced irrigation scheduling software. The climatic data for six growing season are used to test the chart. In all case, the correspondence is remarkably good. The developed irrigation guideline accurately predicts the mean water balance components and the dynamic processes of the mean soil moisture for wheat. It is believed that the simplicity of the chart makes it a useful tool to help decision-making for all actors involved in irrigation management.

Key words: wheat, irrigation, scheduling, chart, real time.

INTRODUCTION

Wheat is a central agronomic crop in the Tunisian economy, accounting for approximately 30% of all harvested acreage. Its production is characterized by an annual variability (from 0.3 to 2.0 Mg/ha). It is mainly due to the climatic factors, particularly, the uneven distribution of rainfall and the high level of evapotranspiration. At the site of the study (region of Tunis), average rainfall during the growing season of wheat (from November to June) ranges from approximately 140-400 mm. Supplemental irrigation is required because the reference evapotranspiration is about 420 - 510 mm (Sahli *et al.*, 2000). Therefore, under these conditions, wheat plants generally suffer a midseason drought stress that reduces spike number and fertility while kernel weight may suffer a terminal stress caused by high temperatures that increase evaporation from the soil. Because of these severe limitations imposed by drought, irrigation of wheat in Tunisia is encouraged by the government. However, low yields in irrigated areas still obtained: 3.3 Mg/ha for the last ten years, compared to a potential yield of 7.0 Mg/ha (Mailhol *et al.*, 2004). This is due to the inappropriate irrigation strategies of farmers. Indeed, when wheat is irrigated, farmers generally supply water one to two times in spring, with 60-120 mm of the total water application for each season. In this light, methods that increase water use efficiency of wheat, farmer profitability and that reduce environmental impact, are not longer simply commendable but required in Tunisia.

Good practice of irrigation scheduling consists in applying water to the root zone in the right quantity and frequency to reduce the low yield and low quality that results from water stress. There are different commercial devices to estimate the irrigation timing based on direct information from usually one variable of the soil–water–plant system. Nevertheless, all such devices present problems when they are used in large irrigation areas due to temporal and spatial variability of measurements and high costs of installation and management, in addition to sample alteration and low sampling volume. An alternative method widely used in scheduling irrigation is the water balance applied at the root zone to estimate indirectly the soil water content (Ojeda-Bustamante *et al.*, 2004). There are many irrigation scheduling computer programs developed based on the water balance (e.g. Fox *et al.*, 1992; Smith, 1992; Ojeda-Bustamante *et al.*, 1999; Sahli and Jabloun, 2005 and 2006). The slow acceptance of irrigation scheduling models may be attributed to many reasons. One of the critical problems of these models is the availability of the reference evapotranspiration and crop parameters, which define crop water use and water stress sensitivity. Furthermore, many of these models can only be used by technicians and managers in charge of irrigation scheduling. Thus, there is a need to develop tools that can be readily used by farmers.

Indicative irrigation calendars have proved useful for small holder farmers using mean climatic data and standardized crop and soil data. Fixed irrigation intervals and fixed application depths are recommended to the farmers with or without some empirical adjustments to actual weather conditions. Fixed calendars however are less reliable in conditions of varying rainfall. Guidelines at a short time-step often complicate decision-making during the irrigation season. The corresponding irrigation applications are often characterized by periods of over and under-irrigation. Excess watering may cause water logging, excessive vegetative growth and loss of valuable nutrients out of the root zone. Withholding irrigation, especially during crop sensitive periods, will result in limited growth and reduction in crop yield.

This paper outlines a methodology to develop wheat irrigation calendars that give farmers simple guidelines on how to adjust their irrigation during the growing season (i) to the actual weather condition and (ii) when shortage in the supply of irrigation water occurs (Raes *et al.*, 2000; De Nys *et al.*, 2001). Each chart presents guidelines for a particular region, soil type, growing season and irrigation method. In order that farmers adopt the guidelines, the calendar should be easy to consult. To present the methodology, we have focused our paper on a specific type of soil and climate (region of Tunis) and irrigation method (sprinkler irrigation). In the second step, the paper evaluates, for six growing season, how well the chart expects irrigation interval comparing it to a more advanced irrigation scheduling software.

METHODS

Chart development Procedure

Climatic data

The development of irrigation calendars requires a good knowledge of the meteorological conditions for the region and more in particular of the reference evapotranspiration (ET_o) and rainfall levels that can be expected in a 10-day period. The reference evapotranspiration is derived from 10-day climatic data of the region by means of the software MABIA-ET_o (Jabloun and Sahli, 2004) according to the FAO Penman-Monteith equation (Allen *et al.*, 1998).

Since the objective of the irrigation chart is to give farmers the possibility to adjust their calendars to the actual weather conditions, different alternative irrigation calendars are developed by using various probability levels for rainfall and ET_o. Rainfall and ET_o levels that are exceeded in 2 (20%), 5 (50%) and 8 (80%) years out of 10, were statistically derived from the 10-day rainfall and ET_o records of the last 25 years with the help of RAINBOW (Raes *et al.* 1996). By combining the various probability levels of ET_o and rainfall, four weather conditions are distinguished; hot weather conditions without any rainfall (20% ET_o and No Rain), dry (20% ET_o and 80% Rain), normal (mean ET_o and Rain) and humid (80% ET_o and 20% Rain) weather conditions. The mean 10-day ET_o and Rainfall as well as the dependable levels are presented in Fig. 1.

Soil data

In this study the characteristics of a typical clay-loam horizon for a fluvisol in the region of Tunis are used. The volume water content at field capacity and wilting point are respectively 39.3% and 25.5%. The corresponding Total Available soil Water (TAW) is 138 mm(water)/m(soil depth).

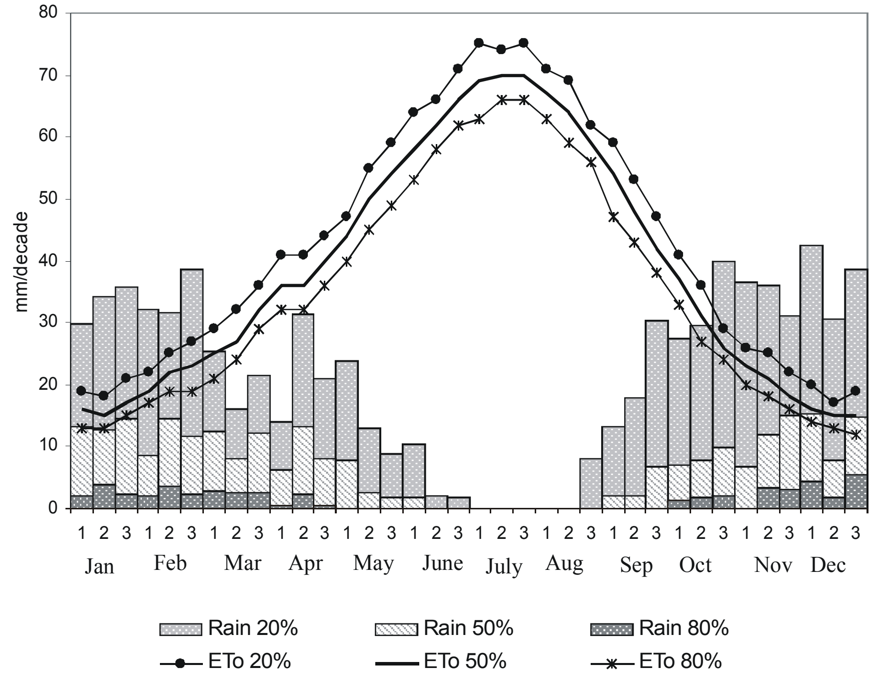

Fig. 1. 10-day Rainfall and ET_o levels with various probability levels (%) of exceeding for Tunis (Tunisia).

Crop data

Four distinct growth stages can be distinguished during the growing period: the initial, crop development, mid-season and late season stage. The basal crop coefficients (K_{cb}), rooting depth (Z_r) and depletion factor (p) for the growth stages are presented in *Table 1*. The values published by Allen *et al.* (1998) for K_{cb}, Z_r and p were adjusted to the local climatic and soil conditions.

The effects of characteristics that distinguish field crops from the reference surface are integrated into the crop coefficient. Crop evapotranspiration (ET_c) is calculated by multiplying ET_o by K_{cb} + K_e, K_e designed the soil evaporation coefficient. The allowable depletion p is the average fraction of TAW that can be depleted from the root zone before moisture stress occurs. It is the ratio between the Readily Available soil Water (RAW) and TAW. The factor p is a function of the evaporation power of the atmosphere. For hot dry weather conditions, p is 10-25% less than the values presented in *Table 1*. When the crop evapotranspiration is low, p will be up to 20% more than the listed values.

Table 1. Wheat crop characteristics for the four growth stage (modified from Allen *et al.*, 1998)

Period	Development stage (GDD,°C day)	Growth stage	K_{cb} basal crop coef.	Z_r rooting depth (m)	p allowable depletion
Nov. – Dec.	Sowing-beginning of tillering (500)	Initial	0.15	0.3	0.60
Dec. – Jan.	Tillering (400)	Crop development	0.15 – 1.10	0.3 – 1.0	0.60
Jan. – Mar.	Jointing (700)	mid-season	1.10	1.0	0.60
Mar. – May	Flowering-Ripening (900)	late season	1.10-0.25	1.0	0.60

Irrigation application depth

For the design of the alternative irrigation calendars, the irrigation application depth is considered as fixed. Fixed application depths in combination with a variable irrigation interval result in an efficient use of the irrigation water. The selected value for the fixed application depth depends on the soil type, crop type, irrigation method and equipment. The gross application depth, the irrigation depth applied by the farmers, will be larger and will be determined in a later stage when considering the irrigation efficiency at field level.

Irrigation interval

Irrigation calendars are developed by means of a soil water balance technique. It consists in first calculating the net irrigation requirement, which is obtained by subtracting from the crop water requirement (ET_c) the expected gains of water through rainfall. Given the fixed net irrigation application depth, the irrigation interval can subsequently be derived by plotting the root zone depletion along the time axis (Fig. 2). At sowing the soil water content is often at field capacity (root zone depletion is zero) as a result of a pre-irrigation. The rate of root zone depletion at a particular moment in the season is given by the calculated net irrigation requirement for that period. Each time irrigation water is applied, the root zone depletion decreases with the applied net irrigation depth. Generally the irrigation will be frequent during peak periods when the crop water demand is high and rainfall small. On the other hand, the applications are less frequent at the end and beginning of the season when ET_c is small or rainfall frequent (Raes *et al.*, 2000). As shown in Fig. 2, by altering the irrigation interval during the season, one is able to keep the root zone depletion between the lower limit (threshold value) and the upper limit (field capacity).

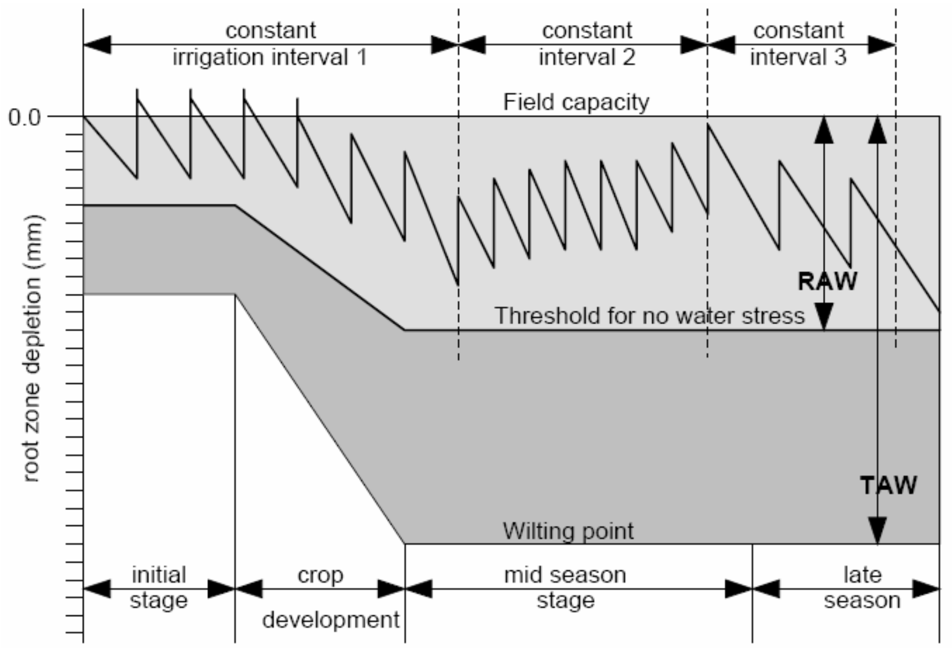

Fig. 2. Root zone depletion (broken line) for a schedule with a fixed irrigation application depth

By means of MABIA (Sahli et Jabloun, 2006) the irrigation interval is determined for the four weather conditions for each 10-day period of the growing season.

MABIA is a simple software tool for performing irrigation scheduling under various irrigation criteria (fixed depth, fixed interval, variable depth and variable interval) for both single and multiple field cases. The calculation procedures used by this model are based on dual crop coefficient approach as described by Allen *et al.* (1998). It offers the possibility to plan irrigation schedules for different operational conditions. By means of a simple soil water model, MABIA keep track of the water depletion in the root zone. The initial soil water content for the topsoil at the period of planting is assumed to be close to field capacity as a result of rain or pre-irrigation. This assumption is dictated by the fact that small seedlings are very sensitive to water stress. In order to simulate the optimal soil water conditions under sprinkler irrigation, the irrigation interval is adjusted so as to keep the soil water content in the root zone close to field capacity. This rule was not applied during the ripening stage (May), the irrigation was somewhat stopped at the end of the second decade of April.

In order to develop a simple irrigation calendar that is easy to apply, adjustments of the irrigation intervals were only realised at the beginning of a month or 10-day period.

Analysis of chart use

In order to assure the performance of developed chart to guide irrigations in real conditions, we consider six consecutive growing seasons with differing weather. For each season, analysis assumes the following steps: (i) With the help of the chart and information on the actual rainfall, the irrigation calendar is developed; (ii) Given the proposed irrigation calendar, the root zone depletion along the growing season is computed by means of the soil water balance model MABIA. It is done to see if the proposed calendar is able to keep the root zone depletion between the lower and upper limit during all the growing season. Indeed, to avoid crop water stress, the root zone depletion should not exceed the readily available water for no stress (lower limit). If so, the depletion will be larger than RAW and the crop will experience water stress. On the other hand, to avoid water losses, the soil water content in the root zone after an irrigation event should not exceed field capacity (upper limit);

RESULTS AND DISCUSSION

Irrigation chart

The simulation results are presented on an irrigation chart (Fig. 3) which is distributed to the farmers. The chart presents guidelines (i) to adjust the irrigation interval to the varying climatic conditions during the growing season; and (ii) to select the irrigation duration as a function of type, layout and efficiency of the sprinkler system. The guidelines are based on information concerning the actual weather conditions, local and technical aspects of the irrigation system and the crop response to water. The combination of all this information results in an irrigation calendar that is specific for a given farm and adjustable to the actual weather conditions.

Guidelines to adjust the irrigation interval to the actual weather conditions throughout the growing season are presented in the table on top of the chart (Fig. 3a). As a reference, the 10-day rainfall amounts expected during dry, normal and wet weather conditions are plotted on the backside of the chart (Fig. 3b). Since during the summer period little or no rainfall is expected, the farmer is advised to irrigate weekly in April. During the ripening stage (May), the crop is less sensitive to water stress and the irrigation could be stopped (Kang *et al.*, 2002). From the sowing date to the beginning of March, during the crop development stage, the irrigation interval will depend on the actual weather conditions. When it is wet and the rains are well distributed, no irrigation is required during this period of growth since rainfall compensates the crop water requirements. When it is hot and does not rain or when it is rather dry it is recommended to irrigate every twenty days during this period. The interval between two irrigations could be reduced to ten days in February. Under normal rainfall conditions, the irrigation interval might increase to thirty days in the first four decades ant to fifteen days in February. In addition, at least two irrigations are needed for the four weather conditions and this between March and April. Indeed, any water shortage during this period, yield formation period, should be avoided since the crop is sensitive to very sensitive to water deficits during this crucial period.

At the bottom of the chart (Fig. 3a) information concerning the duration of the irrigation application is presented. For the selected net irrigation application depth of 300 m^3/ha, the corresponding irrigation duration was calculated by considering various irrigation efficiencies and characteristics of the sprinkler system. The duration was calculated for two gross applications; namely 400 and 500 m3/ha. The irrigation duration corresponding with the two selected gross depths are presented for a range of pressures. Given the type of installation and the diameter of the nozzle, the irrigation duration can easily be calculated.

Irrigation chart

Wheat – Sprinkler irrigation

Sowing date : 15th November
Soil type : Clay - loam
Region : Tunis
Net application depth : 300 m^3/ha

Irrigation interval in days

<table>
<tr><td colspan="2">Month</td><td colspan="2">Nov.</td><td colspan="3">December</td><td colspan="3">January</td><td colspan="3">February</td><td colspan="3">March</td><td colspan="3">April</td><td colspan="3">May</td></tr>
<tr><td colspan="2">Decade</td><td>2*</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td rowspan="4">Weather conditions</td><td>Hot+ Dry</td><td colspan="3">15 days</td><td colspan="4">20 days</td><td colspan="4">10 days</td><td colspan="5">7 days</td><td colspan="4"></td></tr>
<tr><td>Dry</td><td colspan="8">20 days</td><td colspan="6">10 days</td><td colspan="2">7 days</td><td colspan="4"></td></tr>
<tr><td>Normal</td><td colspan="4">30 days</td><td colspan="4"></td><td colspan="6">15 days</td><td colspan="2">7 days</td><td colspan="4"></td></tr>
<tr><td>Wet</td><td colspan="12"></td><td colspan="4">20 days</td><td colspan="4"></td></tr>
<tr><td colspan="2">Growth period</td><td colspan="5">Sowing-Beginning of tillering</td><td colspan="3">Tillering</td><td colspan="6">Jointing</td><td colspan="6">Flowering-Ripening</td></tr>
</table>

* Initial soil wetness: Optimal soil water conditions (rainfall or pre-irrigation)

Irrigation duration in hours and minutes

<table>
<tr><td colspan="3">Sprinkler system 12 m × 12 m</td></tr>
<tr><td rowspan="2">Pressure and diameter</td><td colspan="2">Irrigation efficiency</td></tr>
<tr><td>Good (400m³/ha)</td><td>Medium (500m³/ha)</td></tr>
<tr><td>Pressure : 2,5 bars</td><td></td><td></td></tr>
<tr><td>nozzle = 4 mm</td><td>6 h 00 min</td><td>8 h 30 min</td></tr>
<tr><td>nozzle = 5 mm</td><td>3 h 30 min</td><td>4 h 15 min</td></tr>
<tr><td>Pressure : 3,0 bars</td><td></td><td></td></tr>
<tr><td>nozzle = 4 mm</td><td>5 h 30 min</td><td>7 h 00 min</td></tr>
<tr><td>nozzle = 5 mm</td><td>3 h 00 min</td><td>4 h 00 min</td></tr>
</table>

Fig. 3a. Irrigation chart for sprinkler irrigated wheat for the region of Tunis.

Although the presented alternative irrigation calendars assume that for each irrigation application the irrigation duration is identical, farmers may prefer to adjust both the duration and interval of their irrigation during the season. Under such conditions, the chart still provides valid guidelines for irrigation planning as long as the link between the duration and interval is respected. If a farmer doubles the proposed irrigation interval he also has to double the presented irrigation duration. If an irrigation application last only one third of the presented value, the interval between irrigations should also be one third of the proposed interval.

Dependable rainfall (mm/decade)

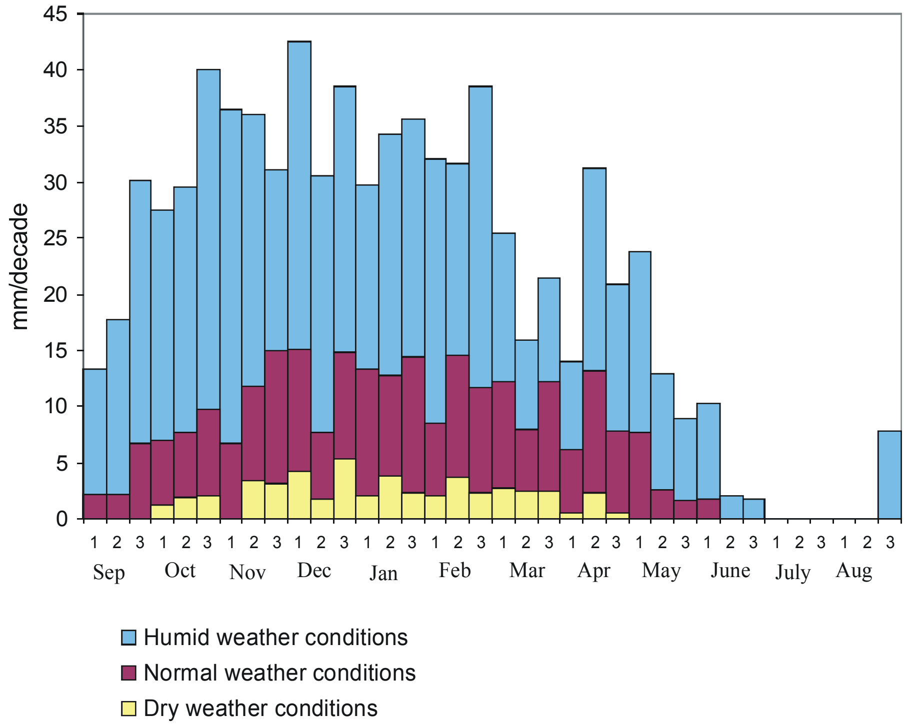

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Fig. 3b. Backside of the chart for sprinkler irrigated wheat for the region of Tunis.

Chart use

According to actual rainfall records and to the reference 10-day rainfall amounts expected during dry, normal and wet weather conditions plotted on the back of the chart (Fig. 3b), the weather condition of each 10-day was identified and then the indicative values for irrigation intervals was extracted from the front of the Chart (Fig. 3a). Figure 4 shows results of this basic application of the "Irrigation Chart" for the 6 selected years.

Scenario analyses for this soil–crop–climate combination studied, proved that irrigation was required in 100% of the years. Also, year-to-year differences between rainfalls caused great variability of wheat irrigation planning. The number of water applications was 4 in rainy years (seasons C_1 and C_5), 5–6 during medium ones (seasons C_2 and C_6) and 9–10 in dry ones (seasons C_3 and C_6). For example, for the rainy seasons C_1, only four applications of 30 mm each are suggested by the "Irrigation Chart": 120th, 135th, 144th and 151th days after sowing however, for the dry seasons C_3, ten irrigations are suggested 25th, 45th, 106th, 113th, 120th, 127th, 134th, 141th, 148th et 155th days after sowing.

	Month	Nov.		December			January			February			March			April			May		
Season C_1	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	2	59	61	9	19	0	3	52	3	42	22	13	1	12	16	13	10	3	0	32
	Weather condition	H	H	H	H	H	D	D	H	D	H	H	N	D	N	H	N	N	N	D	D
	Irrigation interval												15			7					
	Number of application												2			2					

	Month	Nov.		December			January			February			March			April			May		
Season C_2	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	15	0	27	24	43	42	0	0	7	3	20	26	8	20	1	1	1	65	16	0
	Weather condition	H	H	H	H	H	H	Wr	Wr	N	D	H	H	N	H	D	D	D	H	Wr	Wr
	Irrigation interval							20	10	15				15		7					
	Number of application							0	1	1						3					

	Month	Nov.		December			January			February			March			April			May		
Season C_3	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	13	34	8	0	7	17	15	1	43	34	0	0	0	0	5	3	4	0	9	0
	Weather condition	N	H	N	D	D	H	H	D	H	H	Wr	Wr	Wr	Wr	N	D	N	D	N	D
	Irrigation interval	30			20				20			10	7								
	Number of application	1			1				0			1	7								

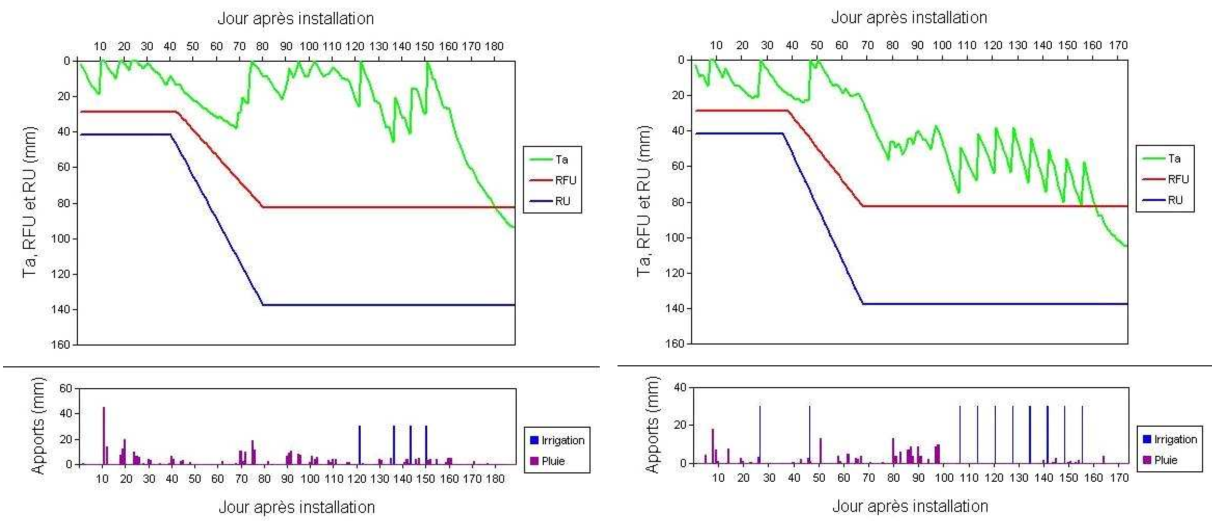
	Month	Nov.		December			January			February			March			April			May		
Season C_4	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	14	2	0	10	9	39	35	0	0	0	3	22	6	1	0	11	9	0	1	1
	Weather condition	H	D	D	H	N	H	H	D	D	D	D	H	N	D	D	N	H	D	N	N
	Irrigation interval		20						10				15		7						
	Number of application	0	1		0				4				1		3						

	Month	Nov.		December			January			February			March			April			May		
Season C_5	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	4	13	6	6	17	14	34	7	48	8	134	14	10	1	15	22	47	50	4	0
	Weather condition	D	N	D	N	N	N	H	N	H	N	H	N	N	D	H	H	H	H	N	Wr
	Irrigation interval	20											15		10	20					
	Number of application	1											1		1	1					

	Month	Nov.		December			January			February			March			April			May		
Season C_6	10 - days	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Rainfall (mm)	2	11	11	3	17	10	46	26	25	7	0	1	2	0	11	10	2	0	0	7
	Weather condition	D	N	N	D	H	N	H	H	H	N	Wr	D	D	D	H	N	N	Wr	Wr	H
	Irrigation interval	20									15	10				20	7				
	Number of application	1									1	3					1				

Fig. 4. Irrigation calendars for the selected six years derived from Chart application.

Soil water depletion (Dr) induced by the application of the resulted irrigation schedule of each growing seasons was computed with MABIA software. Fig. 5 shows the results for the two wheat seasons C_1 and C_3. The model simulations indicate that the proposed calendars are able to keep the root zone depletion between the lower and upper limit during all the growing season. Similar results were also obtained for the other studied years.



(a) (b)

Fig. 5. Simulated values of root zone depletion induced by the application of the irrigation programs given by the calendar for the two wheat season (a) C_1 and (b) C_3.

CONCLUSION

To provide Tunisian wheat growers with some guidelines, a procedure was presented to develop 'Irrigation Charts' which can be distributed to farmers with the help of the extension service. The charts give farmers indicative values for irrigation intervals for four different weather conditions. Its simplicity makes it a useful tool to help decision-making for all actors involved in irrigation management.

The use of Irrigation Chart under different weather conditions have shown that the irrigation schedules cover well the plant requirements during the peak period, when wheat crop evapotranspiration is high and rainfall is scarce (late winter and early spring). In addition, outside this peak period, the chart irrigation strategy responded correctly to the prevailing weather conditions. The derived calendars have shown a good adjustment to the unreliability of rainfall observed during these periods.

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