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Effect of Irrigation Methods on Water Use Efficiency Applied to Citrus Crop in the Souss Region (Morocco) in the Context of Climate Change

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Abstract**—**This work was conducted in the Souss region, known by severe water scarcity and a high agricultural activity dominated by the citrus (representing 40% of the area of Morocco's citrus). The objective of this work is to diagnose the current situation of the water efficiency in citrus irrigation and analyze the impact of various production factors on water productivity and its sustainability in the context of climate change. A field survey was conducted on 65 farms with areas varying from 0.5 to 350 ha. The stratification method was adopted as a sampling frame. Initial result indicates that the use of water shows a huge shortfall, since 31% of farms in the region are still using the surface irrigation system and 67% of farms are still using only the experience of the manager to control and adjust irrigation. The assessment of water productivity showed a value of 1.2 kg/m^3 for surface irrigation and 3.8 kg/m^3 for drip irrigation. The use of tools for control and adjustment of irrigation increases the water productivity of drip irrigation by 25%. The availability of the technical staff (internal or external) allows an increase in productivity of 172.4% compared to farms without technical advice.

Keywords**—**Citrus, irrigation efficiency, water productivity, drip irrigation.

I. Introduction

THE Souss Massa region manifested on one hand an increased competitiveness in agricultural produce, on the other hand, it is marked by the scarcity of water resources and their over-exploitation. In this context, irrigation has acquired over the years strong economic and social dimensions. It stands out as an excellent means of agricultural development and thus has special attention of the authorities. Controversy was opened on water valorization and improvement of the water use efficiency. Therefore, any effort made to improve water use in irrigation practices will have a marked effect on sustainable agriculture and on conservation of soil and water resources. The improvement of irrigation management for the citrus crop in Souss Massa region requires good knowledge of system performance over long time periods.

Consequently, the objectives of this work are to determine the water productivity and the irrigation performance for citrus crop in Souss Massa region (Morocco), to diagnose the impact of several production factors on the water use efficiency.

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II. Material and Methods

A. Study Area

Study was conducted in the region of Souss Massa located in southern Morocco between the Atlantic Ocean and the mountains of the High Atlas and Anti-Atlas. The main plains are the Souss plain (4500 km^2), the plain of Chtouka (1260 km^2) and the plain of Tiznit (1200 km^2) [1]. Fig. 1 gives an overview of the geographical location of the area of the study. The region is certainly one of the main contributors of the economic development of the Kingdom [2]; it contributes to 12.3% of the total national GDP [3]. The economic structure of the region of Souss Massa shows a predominance of agriculture and services (Fig. 2). The analysis of the agricultural sector in the Souss Massa region, shows the fruit and vegetables production vocation of the region (Fig. 3).

B. Climate Context

The region is characterized by a semi-arid to sub-desert climate influenced by the ocean and the barrier effect of the mountains of the Anti-Atlas against the desert winds, hot summers and temperate to winters. Yearly average minimum temperature is 10 °C; the coldest month is January. Yearly average maximum temperature is 36 °C, the warmest month is August [4]. The total monthly rainfall for the last ten years (1995-2005) varies between 0 and 58 mm. The average annual evaporation is 1400 mm in the mountains and rises up to 2000 mm in the plains. In summer and autumn, hot eastern winds accentuate the evaporation. This makes irrigation and rational water management a necessity [5].

C. Water Resources

In Morocco, natural water resources are relatively scarce. Indeed, their potential is estimated at 22 billion m^3 per year, equivalent to 730 m^3/capita/year.

In the region of Souss Massa, intensive development of agricultural production is increasingly constrained by the water resources scarcity, exacerbated by prolonged droughts that are becoming recurrent. Water resources mobilized are limited and cannot follow the rhythm of economic and social development in the region. Thus, the groundwater situation has become alarming; it shows an average deficit of 150 million m^3/year, which concretizes the decrease in the level of the water by about 1-2 m/year [6]. Included the region of Souss Massa, six large dams regulate 364 million m^3/year (revised volumes) on total surface water intake amounting 668 million m^3/year. It is appropriate, consequently, to preserve this resource by its rational use, by an awareness of users and their involvement in its rationalization and economy, and by adopting more efficient irrigation techniques and less demanding crops and better rewarding water [6].

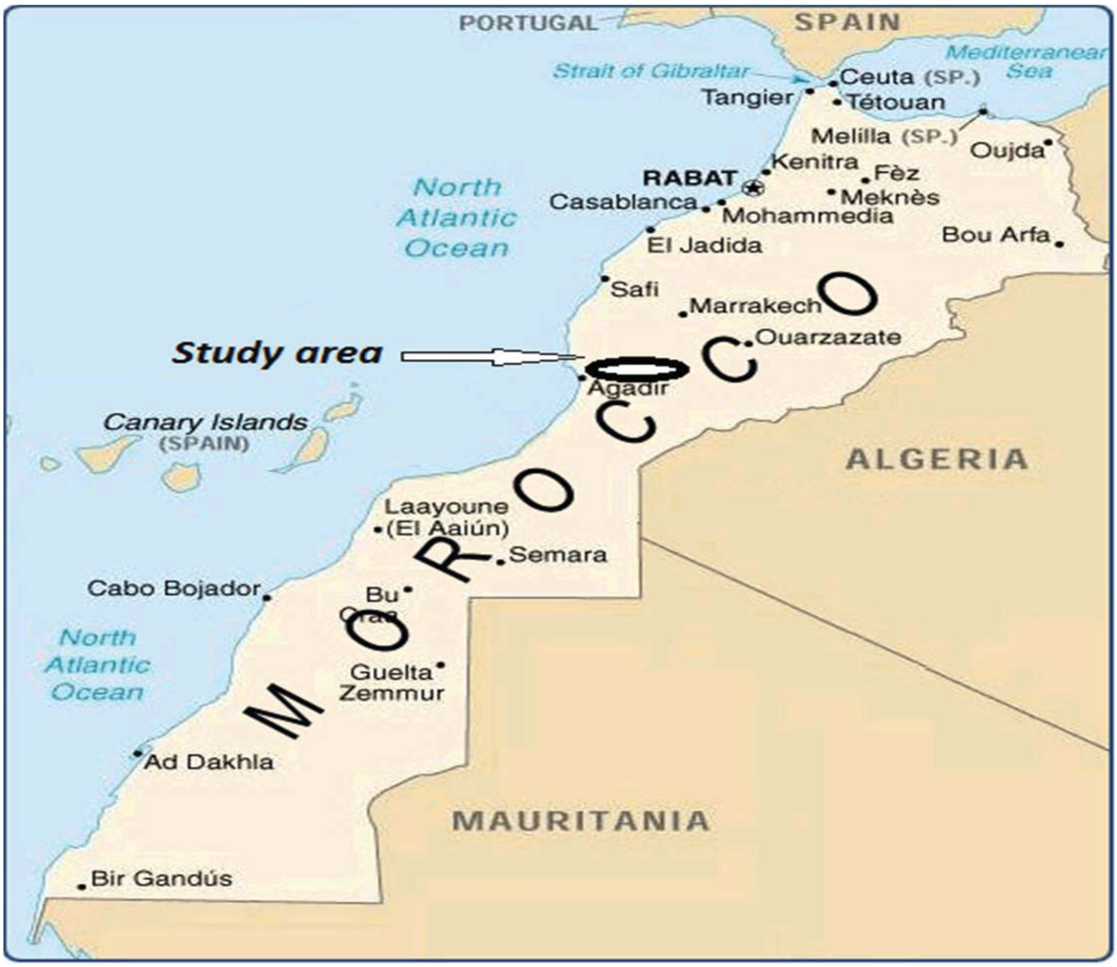

Fig. 1 Geographical location of the study area

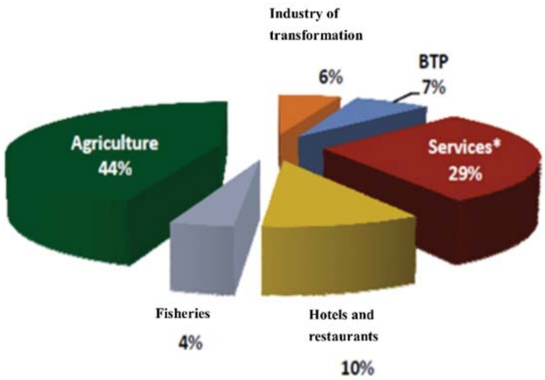

Fig. 2 Contribution to the added value by sector in the Souss Massa [3]

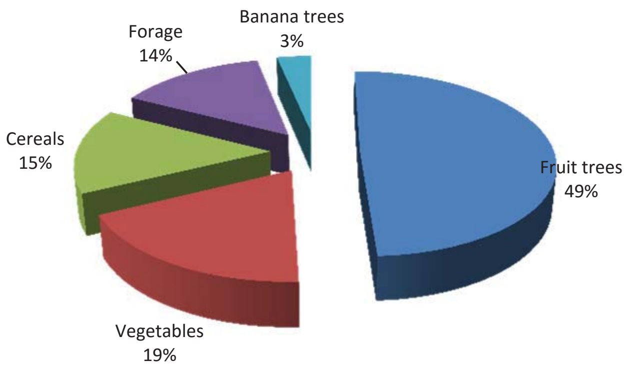

Fig. 3 Cropping within the perimeters of the Souss-Massa (Average seasons 2005-06 to 2009-10) [3]

D.Objectives of the Study

Considering the regional context marked by the scarcity and over-exploitation of water resources, and the national context that increases competitiveness for agricultural production, a debate has been initiated on water valorization and improvement of the water use efficiency. Therefore, to contribute with a scientific and rational analysis of this concept, this study focused on the evaluation of the irrigation water efficiency for the citrus crop in Souss Massa region with the following objectives:

- To characterize citrus farms methods for applying and monitoring the irrigation;
- To diagnose the current situation regarding the agronomic water use efficiency for citrus.

E. Methodology

To achieve the objectives, data collection was done by a survey using a detailed questionnaire, the following data were gathered:

- General Information: Identification of farms; grade and organizational sense of the farmer;
- Technical information: Characteristics of soil and water resources used, plant material and technical management of orchard, components of the irrigation system, tools of irrigation monitoring and the evolution of water consumption during the annual cycle of citrus.
- Economic information: Yield, productivity, production cost by varieties, destination of production and target markets, and the agronomic and economic valorization of water.

This study involved the population of citrus farms in the Souss region, this is the area known for its citrus plantations. It is about 3600 farms covering an area of 33000 ha [7]. Given the size and heterogeneity of this population, the use of stratified sampling was necessary. The surveys were done along the Souss Valley by examining a sample of 65 farms.

Crop productivity has often been reinforced by inputs, including water, fertilizer and pest control. However, these activities usually increase rather than reduce water consumption. It is therefore more logical to consider crop productivity per unit of water; it is called the water use efficiency (WUE) or crops water productivity [8].

The determination of the WUE or agronomic water use efficiency (AWUE) is based on two parameters: the yield of the variety of citrus and the amount of water consumed by the same variety throughout the season (a culture cycle). AWUE can be calculated by [9]:

$$\text{AWUE (kg/m}^3\text{)} = \text{(yield in Kg/ha) / (Volume of water brought to the orchard in m}^3\text{/ha)}$$

In the case of surface irrigation:

$$\text{water volume (m}^3\text{)} = \sum_i^N \text{ irrigations flow i} * \text{irrigation times I}$$

N: total number of irrigations during all the program.

In the case of drip irrigation:

$$\text{water volume(m}^3\text{)} = Q_P \sum_i^{12} DA_i * N_i$$

Q_P: flow calculated by multiplying the total number of the drippers and the flow by dripper; DA_i: average duration of irrigation during month i; N: number of irrigations during the month i.

F. Constraints Encountered During the Survey Work

Many constraints arise during our study; some of them are difficult to overcome. The principal constraints are summarized below:

- Detailed information missing on the level of the exploitations, for example, the quantities of irrigation water consumed per hectare;
- The majority of cases are not keeping accountancy to manage the financial standing;
- Certain producers do not accept the access to their farms. Those were eliminated from the sample;
- Difficulties to have precise information.

III. Results and Conclusions

A. Water Applied with Surface Irrigation Method

According the data collected from the survey, the volume of water applied in the case of surface irrigation can be resumed in Fig. 4.

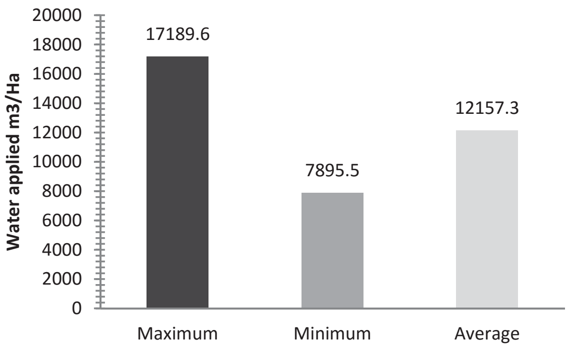

Fig. 4 Water applied m^3/Ha for farms with surface irrigation

Fig. 4 shows that the volume of water applied for citrus with surface irrigation in the Souss region is not very excessive compared to the volume of water applied to trees with traditional irrigation method (10000 to 18000 m^3/ha) [10]. This may be explained by the water availability that is related to (a) Water scarcity observed in the last years in the region; (b) the principle of the irrigation monitoring in surface irrigation consists in keeping the soil reserves between acceptable limits. The irrigation frequency varies according to the water demand related to the soil type and primarily according to the “water rights” in the scale of the water users association (WUA) and the common water resources distribution; (c) many farmers try to reduce irrigation frequency in order to minimize the cost of water salaries and irrigation time.

The average volume of water for surface irrigation during the three months of high demand (June, July and August) is 139 mm with an average frequency of 28 days. Yet, the

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average depth of roots of citrus trees is 110 cm [11], if we suppose that the irrigations start once the useful reserve is exhausted and that the moistened percentage of the orchard is 80%. Table I presents the water loss for the various types of soil, characterized by their Moisture within the field capacity (FC) and their moisture at the permanent wilting point (PWP), and for an average amount of irrigation of 139 mm/irrigation. In this context, if we knew that 66% of the surveyed exploitations with surface irrigation have a light texture of soil (sandy and sandy-loam soil), therefore 66% of exploitations carry out an average loss of more than 33.4 mm per irrigation.

B. Water Applied with Drip Irrigation Method

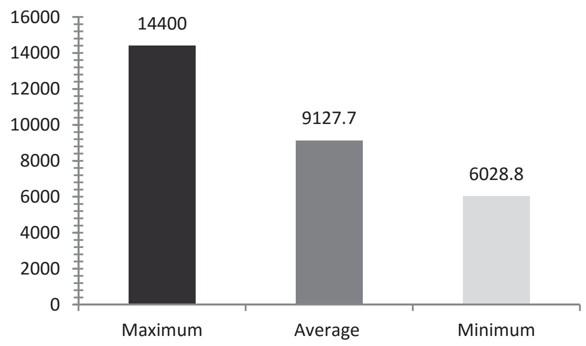

Fig. 5 Water applied m^3/Ha for farms with drip irrigation

Fig. 5 shows that the average water applied within drip irrigation is 9127.7 m^3/ha/year. This means a reduction of about 25% of irrigation water volume compared to surface irrigation in the same conditions. This is less than the value revealed in a World Bank report: “Drip irrigation uses 30-50% less water than surface irrigation, reduces salinization and waterlogging, and achieves up to 95% irrigation efficiency” [12]. This difference with the citation of the World Bank (5 to 25%) is due to the low volume of water applied within surface irrigation in our study because of the decrease in the availability of water for agriculture.

In another side, the average volume applied with drip irrigation is still high considering the volume of water applied for orchard with high technical team and without any restraint of water availability. This volume can be as low as 7000 m^3/ha/year. This situation reveals that the use of drip irrigation technology itself does not ensure a rational use of water in agriculture. In other terms, drip irrigation is only a tool, which might be combined with a modernization of all the irrigation practices. This modernization means “a process of technical and managerial upgrading (…) of irrigation schemes combined with institutional reforms, with the objective to improve resource utilization (labour, water, environment, economy) and water delivery service to farmers” [13]. This task consists of better matching water deliveries to crop water requirements, with water delivery conceptualized as a controllable natural-physical process that can be monitored and manipulated with technologies [14]. Thus, we will analyze the effect of monitoring way on the volume of water applied within drip irrigation.

C. Effect of Monitoring Ways of Irrigation on the Volume of Water Applied

Table II shows the percentage of use of each monitoring tools observed in the surveyed farms and with drip irrigation system. Note that two-thirds (± 67%) of farmers rely on their experience to manage irrigation of their farms without using measurement tools which help to take decision of water volume to apply. This can negatively influence the level of use of irrigation water efficiency. Furthermore, the underlying rationale of most studies relates to optimizing ‘crop per drop’, or to maximizing yields per unit of water [15]. In the same way, we will analyze the in the next step the yield (output) of the two irrigation methods.

TABLE II
PERCENTAGE OF USE OF DIFFERENT IRRIGATION CONTROL METHODS BY AREA CLASS

Area (S by ha)	Way to control irrigation					
	% using ET0	% using Tensiometer	% using Dendrometer	% using Pan A class	% using Capacitive probes	% using Experience
S ≤5	0	0	0	0	0	14.1
5 < S ≤50	5.2	0	0	0	3.5	43.8
S > 50	12 .3	1.8	1.8	1.8	6.9	8.8
All the sample	17.5	1.8	1.8	1.8	10.4	66.7

D. Yield for Drip and Surface Irrigation

TABLE I
WATER LOSS IN FARMS WITH SURFACE IRRIGATION FOR DIFFERENT SOIL TYPES [11]

Soil Texture	FC (% vol.)	PWP (% vol.)	Net maximum dose (mm)	Loss (mm)
Sandy	15	7	70.4	68.6
Sandy laom	21	9	105.6	33.4
Laom	31	14	149.6	0
Clay laom	36	17	167.2	0
Laom clay	40	19	184.8	0
Clay	44	21	202.4	0

Fig. 6 shows that drip irrigation gives 57% of additional yield while it uses minus 33% of irrigation water. This confirms that both under- and over-irrigation harms yields: “The purpose of irrigation is to keep the water status at a level that maximizes yield within the constraints of available irrigation water supply and growing season weather” [16]. This confirms also the potential of drip irrigation to precisely adjust water applications to pre-calculated crop water requirements, because drip irrigation allows more regular water applications as compared to surface irrigation and limits the wetted area. Moreover, if this is combined with the use of monitoring tools the positive effect on yield is amplified. To clarify this, we will analyze AWUE or the water productivity.

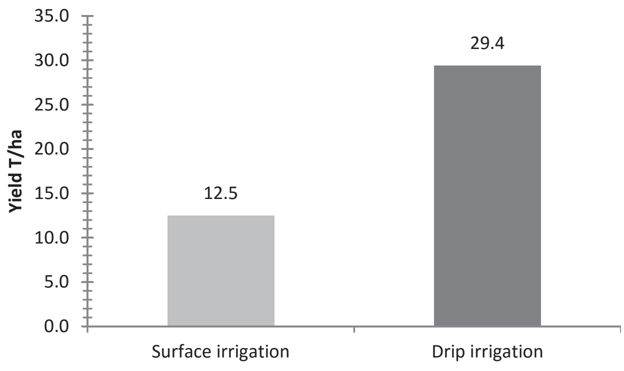

Fig. 6 Yield T/Ha for farms with drip and surface irrigation

E. Effect of the Irrigation System on the AWUE

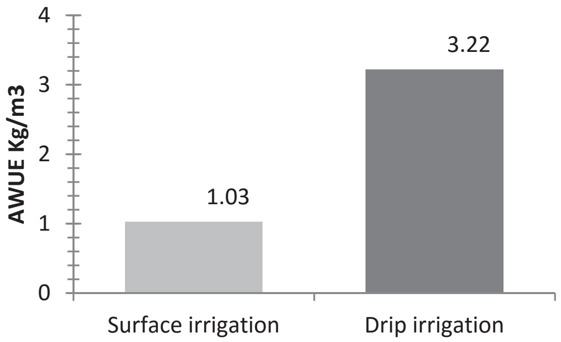

Fig. 7 Effect of the irrigation system on the AWUE

Drip irrigation allowed an increase in efficiency of 223.7% compared to the surface irrigation. Likewise, in an article in Nature, Gleick, 2002 asserts "Shifting from conventional surface irrigation to drip irrigation in India has increased overall water productivity by 42–255% for crops as diverse as banana, cotton, sugar cane and sweet potato [17]. Together, the greater water application efficiency and higher yields produce a doubling or tripling of water productivity [18].

F. Effect of Use of the Monitoring Tools on AWUE

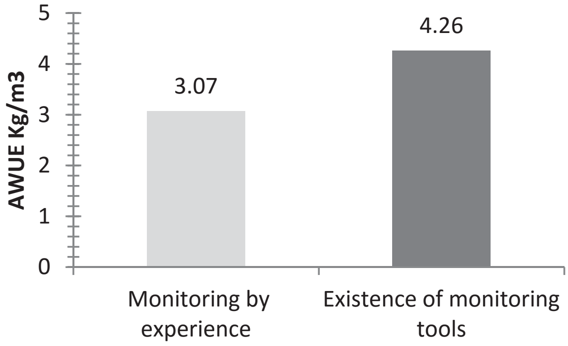

Fig. 8 Effect of use of the monitoring tools on AWUE

In addition to the effect of drip irrigation, the use of monitoring tools showed an increase of 24.5% of AWUE. Another factor, which can affect the AWUE, is the technical level of farmers. For that, we classified three technical levels:

- Technical level 1: Farms without technical team and without advice;
- Technical level 2: Farms without technical team but with external advice;
- Technical level 3: Farms with technical team.

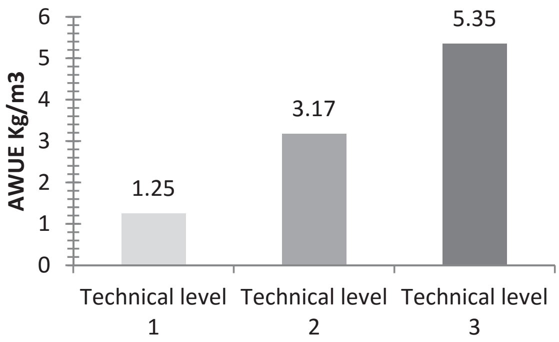

Fig. 9 Effect of the technical level of the manager on the AWUE

Fig. 9 reveals the important effect of technical level of farmers on AWUE. The AWUE is threefold if there is an external supervision and fivefold if the farm has its own technical team. In addition, if pass from external supervision to internal technical team we will have 69% of increase in AWUE. To show the combine impact of the technical level with the use of monitoring tools we present Fig.10.

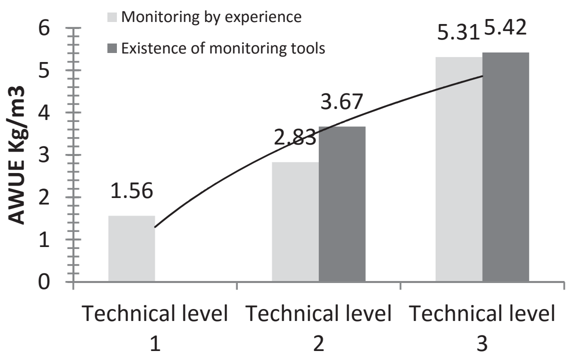

Fig. 10 Combine impact of the technical level with the use of monitoring means on the AWUE

We can conclude the low effect of the use of monitoring alone and a clear effect if the farm has its own technical team. This can be explained by:

- Technical tools are not used in a good way, so it has no effect on AWUE;
- Technical teams have not yet get the confidence in technical tools and it is used only for orientations. Therefore, the effect is not direct on AWUE

- Technical teams has accumulate a high experience in irrigation monitoring

IV. Conclusion and Recommendations

We conclude from the analyze of the effect of irrigation methods on AWUE (water productivity) that:

- We have the confirmation that (even all constrains) the transition from surface irrigation to drip irrigation ensures a minimum of gain in AWUE.
- With the drip irrigation system, we find several levels in AWUE due to many factors (technical level, monitoring technics…)
- In light of this, we recommend to generalize drip irrigation for all the citrus area and meanly a lot of effort to improve the technical level of farmers and the good use of irrigation monitoring tools.

For the next research, themes recommended to study the other factors that might affect AWUE like the crop itself (the varieties groups as oranges and mandarins, ages, densities…).

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