Food and Agriculture Organization of the United Nations

Special Session

Water Productivity & Water Accounting

WATER
Efficiency, Productivity, and Sustainability
in the Near East and North Africa countries

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Program, Special Session “Water Productivity & Water Accounting”

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11:40-11:50 **Activities of the WEPS project on WA and WP in Tunisia**, H. Habaieb

Theme : Water productivity

11:50-12:00 WP and gaps for cereal crops

ID 1-233 **Yields, water productivity gaps and farmers’ perception of vulnerability factors, in irrigated areas with contrasting climates,** A. Lasram, F. Yakoubi, R. Nabli, H. Maaroufi, A. Maki, M. M. Masmoudi, N. Ben Mechlia.

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ID X-XXX **Regional Evapotranspiration Network,** V. Nangia

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12:40-13:00: Discussion & closing

ID 2-317 **Water Productivity and Yield of barley and vegetable crops, irrigated with low quality waters in arid Tunisia,** K. Nagaz, F. ElMokh, M. M. Masmoudi

ID 2-229 **Production gaps in Tunisian arid and sub-humid irrigated perimeters: Diagnosis and causal factors** A. Lasram, R. Nciri, F. Yakoubi, R. Nabli, H. Maaroufi, A. Maki, M. M. Masmoudi, N. Ben Mechlia

Food and Agriculture Organization
of the United Nations

FAO-SIDA WEPS project

Special Session

Water Productivity & Water Accounting

SHORT PAPERS

Papers revised and compiled by
Prof. M. M. Masmoudi

June 2022

Farmers' perceptions of vulnerability factors and their adaptation intentions in irrigated areas with contrasting climates

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Highlights

Farmers'perceptions of vulnerability factors were investigated in two contrasting climatic zones sub-humid and arid located in northern and central Tunisia.

The availability of water and fertilizers were the main concerns of farmers who were not well aware in general about environmental threats such as climate change and loss of soil fertility.

Efficient farmers are more likely to be aware about risks associated with climate change such as water scarcity and plant disease threats and willing to receive technical assistance

The main adaptation intentions and requests expressed by farmers were the improvement of water and inputs management in the sub-humid area and the improvement of the reliability of water and fertilisers supply in the arid zone.

Less efficient farmers' intentions and requests for adaptation moved towards more subsidies and access to credit and the use of adapted varieties.

Keywords: *farmer perception, vulnerability factors, technical efficiency, aridity.*

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1. Introduction

Enhancing the adoption of adaptive strategies is the major concern of agricultural extension services to cope with emerging environmental threats. Exposed to many environmental constraints, such as climate change (CC) and soil fertility loss (SFL), and under the increasing pressure of market demand, farmers are more than ever asked to be efficiently and durably productive in irrigated Tunisian areas. However, despite the considerable efforts deployed by extension services to disseminate strategies and technologies having proven their effectiveness for water-saving and better resource management, extension gaps still exist (Lasram et al., 2021). The majority of farms are still below optimal technical efficiency levels (Lasram et al., 2015; Jovanovic et al., 2020).

Farmers are the key actors in the success of any improvement measures, actions and strategies. They have to be convinced of the importance of these environmental threats before they align agricultural technological packages with appropriate adaptive measures. The experiences of farmers with risks and the perceptions of their potential impacts are the main drivers of their commitment to take actions instead of privileging immediate economic benefits (Nadagijimana, 2021).

Although farmer perception studies about climate change have gained ground (Fierros-González and López-Feldman, 2021), local investigations have still to be made for all vulnerability factors in order to explore specific problems and target relevant actions. With the unprecedented environmental change speed in Tunisian irrigated area, time-saving is imperative, thus adaptations intention of farmers must also be explored and redressed in case of deviation from the national strategy adaptation targets. Aridity risk and technical efficiency levels could shape farmers' perceptions and intentions to act differently. Although the aridity factor has received more attention, technical efficient level influence on farmers' intentions to adapt has not been sufficiently studied.

The main objective of this work is to explore farmers' perception of vulnerability factors affecting yield gaps and their adaptive intentions to cope with the restrictive factors in relation with the aridity risk and the technical efficiency levels of farmers.

2. Material and Methods

The data used for the analysis were collected from an exhaustive survey, which was carried out in 2020 by the National Institute of Field Crops (INGC), in two irrigated areas, Brahmi in Jendouba-northern Tunisia and Houareb in Kairouan-central Tunisia, and which covered 51 and 49 randomly selected farmers, respectively.

Relative risks analysis estimated by the ratio of conditional probabilities of positive responses for Houareb vs Brahmi farmers was calculated to assess aridity risk on farmer perceptions. Odds ratios of logistic regression were used to assess the effect of technical efficiency level on farmers' perceptions.

3. Results and Discussion

The results showed that production factors availability was the leading concern of farmers. Technical efficiency levels rather than aridity conditions prejudiced farmer perceptions about the negative effect of CC, SFL, and lack of technical assistance (LTA) on production.

Favorable convictions of CC and SFL limiting effects doubled the probability of farmers' intention to change crops. The main options of adaptation intentions were the improvement of water and inputs management in the sub-humid area and their reliability in arid zones. Low technical efficient farmers have moved towards subsidies and access to credit alternatives besides adapted variety use.

4. Conclusion

The present study explored farmers' perceptions of vulnerability drivers and their adaptation intentions in relation to climate risk and their levels of technical efficiency. Low awareness among farmers exposed to aridity risk, especially among the less technically efficient do not sufficiently motivate their adaptation intentions.

Further efforts to raise awareness of the tangible effects of climate change are needed to boost the adoption of approved technologies for improving technical efficiencies and water productivity in irrigated Tunisian areas.

Acknowledgments

This study was supported by the WEPS-FAO/SIDA project. The contribution of INGC by providing raw data of the survey is acknowledged.

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Combining Remote Sensing data and AquaCrop for Assessement of yield and water productivity of Durum Wheat in Semi-arid Conditions in Tunisia

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Highlights

The suitability of AquaCrop model using weather and remote sensing (RS) data for simulating yield and water productivity of durum wheat has been assessed under semi-arid conditions and results compared to FAO WaPOR output and in-situ observations.

Canopy cover (CC) of durum wheat derived from RS-NDVI have been used as input to AquaCrop model

Performance of AquaCrop model fed by RS CC, in estimating yield and water productivty was better than WaPOR.

WaPOR tends to overestimate actual evapotranspiration and underestimate actual biomass and water productivity. A validation and adjustement of its outputs is required before its use for decision making.

Keywords: NDVI, AquaCrop, WaPOR, Yield, Water productivity, Durum Wheat, Semi-arid conditions.

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1. Introduction

Wheat is among the strategic crops in Tunisia. However, owing to recurrent and increasingly severe droughts exacerbated by anthropogenic climate change (Sadok et al., 2019), the situation of low wheat production in the Middle East and North Africa Region (MENA), including Tunisia, is becoming severely alarming. From 2012 to 2016, the average total wheat production was 1.26 Million tons obtained mainly from durum wheat (Khaldi et al., 2017). Meanwhile, regional wheat yield averages never exceed 5t/ha as maximal yield estimated nationally (ONAGRI, 2018). As the competition among water-consuming sectors intensifies, policymakers are challenged to improve the efficiency of water use by the agricultural sector (Foster et al., 2020).

Improvement in water productivity reflects the decrease in water consumption with maintaining or increasing crop production. Thus, to assess the impact of different management strategies on water productivity and crop production, the Food and Agriculture Organization of the United Nations (FAO) has developed AquaCrop as a model presenting a balance between simplicity, accuracy, and robustness (Raes et al., 2009).

With the development of remote sensing technology and data, estimation of WP is becoming easier (Jin et al., 2018). Recently, the FAO has, also, developed a platform (WaPOR) to monitor water productivity via the open access of the remotely sensed derived data which are available from 2009 to the present time and covering the entire continent of Africa and the Middle East region.

The main objective of this study is to assess the accuracy of different FAO tools, particularly, WaPOR and AquaCrop for estimating durum wheat yield and water productivity under semi-arid conditions in Tunisia.

2. Material and Methods

Datasets used for this study were collected from 16 farmers' fields, growing durum wheat in North East Tunisia under semi-arid rainfed and irrigated conditions. Farmers' plots, followed up by the local extension services, were managed during three consecutive cropping seasons (2012-2015) under various growing conditions and using different agricultural practices. A set of parameters previously determined by a calibration of AquaCrop model for semi-arid conditions in Tunisia (Sghaier, 2014), was used in the simulation. Canopy cover determined from Landsat Normalized Difference Vegetation Index (NDVI) was used by AquaCrop and its outputs were compared to in-situ observed yields. The plateform WaPOR was also used for evapotranspiration (ET), yield and biomass estimation and its outputs were compared to those obtained by AquaCrop based on regression analysis and statistical indicators.

3. Results and Discussion

For all growing seasons, the canopy cover values estimated by AquaCrop model and those obtained from Landsat NDVI were in a good fit, with a forced regression slope through the origin equal to 1.08 and an R2 value of 0.78. However, AquaCrop model tends to slightly overestimate canopy cover with an MBE value equal to 3.4%. This overestimation was noticed, in particular, when canopy cover is higher than 25%.

The regression slope line of the estimated yields vs. measured ones is close to 1, with R2 of 0.87 and MAE equal to and 0.35 t/ha. For Water Productivity, the correlation between measured values and those estimated by AquaCrop model resulted in an R2 of 0.63 and MAE equal to 0.2 Kg/m3. Considering an optimal WP value equal to 2 Kg/m3, the yield and WP gaps estimated by AquaCrop were within the same order of magnitude as those obtained from the measured WP. Regression slope line between observed and estimated gaps is close to 1 and R2 equal to 0.66. These results reveal that AquaCrop model is a reliable tool for estimating durum wheat yield and WP.

WaPOR tends to underestimate actual biomass (MBE= - 2.83 t/ha) and biomass WP (-1.03 kg/m3) compared to AquaCrop. However, it overestimates ETa with MBE values equal to 75.9 mm/growing season. In addition, considering the biomass as the product of the normalized water productivity by the ratio of actual to reference evapotranspiration, from sowing until heading, resulted in better estimations of biomass than WaPOR with slope regression line equal to 1.06.

4. Conclusion

In this study, using NDVI derived from LANDSAT remote sensing data by AquaCrop model resulted in reasonable estimations of durum wheat water productivities and yields.

WP gap to the potential and attainable levels is about 0.8 kg/m3, which underlines the improvement potential which can be achieved by a better technical assistance of farmers and training for adoption of adequate practices.

A comparison between AquaCrop model and WaPOR platform outputs suggests the necessity to calibrate and adjust WaPOR outputs to the local conditions before they can be used by the stakeholders.

Acknowledgments

This study was supported by the WEPS-FAO/SIDA project. Datasets were collected from the EU-ACLIMAS project outputs.

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Production gaps in Tunisian arid and sub-humid irrigated areas: Diagnosis and causal factors

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Highlights

Production gaps are estimated in two contrasting climatic zones : arid and sub-humid in north and central Tunisa.

Average values of technical efficiency and resource efficiency for all grown crops were about 60% and 78%, respectively.

The difference in climatic risk between the two regions resulted in differences in crop and irrigation management behavior and efficiency.

The technical efficiency of water seems to decrease when the aridity increases

Keywords: *Yield gap, water productivity, technical efficiency, aridity.*

1. Introduction

In irrigated arid zones, where water scarcity has often been highlighted as the main risk affecting cultural management and yield gaps, actual farmer yield levels vary depending on local environments and management practices. In these areas, water scarcity is expected to intensify with climate change and required yields have to be achieved with water supply restrictions (Drobinski et al., 2020). Water productivity, the ratio of water production to water consumption per unit area, is currently the most widely used indicator to assess the appropriate irrigation scenario that fits water resource constraints (Adetoro et al., 2021). Many researchers have then invested in quantifying the effect of irrigation management on increasing water productivity (Kamdi et al., 2020). Calibrated agrometeorological models such as AquaCrop are also being used as consistent tools for making irrigation strategies and management decisions (Amiri et al., 2022).

In Tunisia, farmers were often found halfway efficient or less in the irrigated area (Lasram et al., 2015; Kamiyama et al., 2021). Nevertheless, yield gaps data are still lacking and estimated based on global or simulated datasets. These data are too broad to provide an accurate dashboard for stakeholders to identify relevant management, technology, and policy interventions and to take locally relevant actions. Aggregate yield data at the field level with related technical itineraries could help build a comprehensive picture to diagnose and analyze the major causes of yield and productivity gaps.

The objective of this work is twofold: (1) to decompose wheat yield gaps in smallholder farming systems in two contrasting climate irrigated areas in Tunisia corresponding to yield gaps in terms of efficiency, resources, and technology and (2) to assess the climate risk impact on these yield gaps.

2. Material and Methods

The data used for the analysis were gathered from an exhaustive survey and experimental data sets during five successive cropping seasons (2015-2020). The survey was carried out in 2020 by the National Institute of Field Crops (INGC), in two irrigated public areas (PPI) : Brahmi in Jendouba-northern Tunisia classified as sub-humid and Houareb in Kairouan-central Tunisia classified as arid region. A total of 51 and 49 farmers were randomly selected in Brahmi and Houareb districts respectively for the survey. The experimental datasets were obtained from in situ crop and weather monitoring carried out in the INGC demonstration platforms in the same regions.

AquaCrop model was used to estimate yield and water productivity gaps and Tobit censored regression was used to analyze the technical gap sources in the both areas. AquaCrop parameters were taken from a previous calibration work carried out in Tunisia by Sghaier (2014). The cultivated crops in the region were wheat, oat, sugar beet, potato, onion, tomato, fababean and pea.

3. Results and Discussion

Average values of technical efficiency and resource efficiency gaps considering all crops were around 40% and 22%, respectively. Besides wheat, sugar beet and tomato are associated with the highest technical efficiencies. This is related to the fact that most farmers in Brahmi PPI are monitored and technically assisted by the transformation factories that also supply them with seeds and inputs. Leguminous crops have the lowest efficiencies. Aridity increased technical, water resource and technology yield gaps and technology water productivity gap

Tobit analysis showed that the factors that had a significant positive impact on technical efficiency were: level of education, farm area, rotation, use of adapted varieties, access to information, professional technical assistance, use of drip irrigation, availability of agricultural equipment, and use of pesticides. Farmers who have another source of income are significantly less efficient than those whose only source of income is agriculture.

The integration of livestock into the farm decreases the technical efficiency. Leguminous, does not significantly improve yields when used as a previous crop, especially in the Houareb area. Leguminous, which are moderately demanding in terms of potassium, are often not fertilized and not irrigated, which can accentuate the soil potassium deficits that are already medium to poorly fertile.

4. Conclusion

The present study assessed yields and water productivities in Houareb and Brahmi irrigated area, characterized by contrasting rainfall patterns. For durum wheat, the dominant crop in both areas, the global yield gap is about 4.8 and 5.8 t/ha for Brahmi and Houareb respectively. The contribution of technological, water resource and technical aspects to these gaps are respectively 35%, 40% and 25%. The difference in climatic risk between the two regions result in differences in crop and irrigation management behavior and an efficiency decrease due to the pronounced aridity in the Houareb perimeter. The technological gap can be improved by the use of improved varieties, particularly with regard to their harvest index.

Acknowledgments

This study was supported by the WEPS-FAO/SIDA project. The contribution of INGC by providing yield, water and weather data collected in its demonstration platforms is acknowledged.

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Water Productivity and Yield of barley and vegetable crops, irrigated with low quality waters in arid Tunisia

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Highlights

Water productivity of barley and some vegetable crops (carrot, pepper, faba bean and potato) was determined under arid conditions of southern Tunisia.

Experimental work was carried out over the period 2012-2016 within farmer fields and under different water suppplies using deficit irrigation and low quality water.

Irrigation scheduling based on soil water balance and deficit irrigation improved WP with values ranging from 5 to 9 $kg.m^{-3}$

Economic WP was between 3.0 and 5.8 $TND.m^{-3}$ with an advantage for short cycle crops that profit from rainfall period.

Keywords: *barley, vagetable, carrots, potato, fababeans, pepper, irrigation, deficit, economic, water productivity, arid.*

1. Introduction

In the arid regions of southern Tunisia, the development of irrigation has been increased around shallow wells having high salinity levels ranging between 4 and 6 dS/m while their use in agriculture demand continuous management and monitoring. Local practices give to vegetable and cereal crops an important place in small-scale irrigation schemes, however, crop productivity remains low (El Mokh el al., 2011). To overcome the effects of water shortage and the use of low quality water in small scale agriculture, the introduction of low cost water-saving irrigation technologies have been identified as key and realistic components of reducing agricultural water demand in many similar regions in the world (Horst et al., 2005, Webber, 2008 and Erkossa et al., 2009). To this end, there is a necessity to study and evaluate the farmer's practices in order to improve their practices and ensure the crop systems sustainability. To attend these objectives, there is a critical need to increase water productivity through the use of more efficient methods and the development of new irrigation scheduling techniques such as full irrigation and deficit irrigation, which is not necessarily based on full crop water requirement. In the same way, the choice of the suitable crops could be an interesting alternative to better valorize the unfavorable climate and water conditions and to insure durable revenue for farmers. This study was conducted in southern Tunisia over the period 2012-2016 within farmer fields and with farmer's participation to evaluate their management's practices using saline waters (4 to 6 dS/m) on barley and vegetable crops yield, biophysical (WP), Irrigation (IWP) and economic water (EWP) productivities.

2. Material and Methods

The experiment was conducted on-farm fields situated in the arid regions of southern Tunisia characterized by a dry climate. No rainfall was received during first season (2012-2013) and 145 and 84 mm were recorded, respectively, for 2013-2014 and 2015-2016. A randomized complete block design was adopted with three replicates for each experiment. Each plot included a specified number of rows depending to the crop and farmer conditions. All plots were drip-irrigated using well waters having a salinity of 4 to 6 dS/m. Soil texture is sandy to loamy sand with total available water ranging between 74 and 80 mm.

Four vegetable crops (carrot, pepper, faba bean and potato) were considered over two-years experiments in a demonstration pilot field while, potato, considered as a high economic value crop, was also replicated in 9 neighboring private farms with the objective to push farmers to use and adopt efficient irrigation practices (Figure 1). Barely was sown in December and harvested in the end May-beginning of June, Potato was planted in September and harvested in December, Carrot and Faba bean were sown in October and harvested in February and pepper was transplanted in May and the first fresh harvest took place at the end of November for both years. Three irrigation strategies were applied during the two years of demonstration, full (FI) and deficit (DI70) treatments based on soil water balance (SWB) method and local farmer method (FM). In order to conduct dissemination exercise, a guideline of irrigation scheduling of potato considering two irrigation strategies FI and DI 70 was developed and provided to farmers. The guideline was based on results obtained in the field pilot. Fertilizers were supplied for all field experiments according to common farmer's practices for vegetable crops in the region of Medenine, Tunisia (ElMokh et al., 2016).

Figure1: Field pilots used for demonstration purpose

Irrigation management practices for the selected crops was evaluated in terms of yield, biophysical water productivity (WP=Y/I+P), Irrigation water productivity (IWP=Y/I), and economic water productivity (EWP=WP*PP) and irrigation economic water productivity (EIWP=IWP*PP) where Y is the crop yield (t/h), I+P is the total water supply (Irrigation and precipitation) and PP is producer price. The average of producer prices for the period 2012-2016 for each crop were used (FAOSTAT, 2016). Analysis of variance was performed using the Statgraphics (www.statgraphics.com). The LSD test at 5% level was used to evaluate the difference between treatment means.

3. Results and Discussion

The highest values of both yield and WP were observed for potato, faba bean and carrot crops compared to the other crops. Total water supply for these short period crops was between 300 to 500 mm (figure 2). Pepper and barley have lower water productivity values as they used more water resulting from their longer cropping cycles that cover high evaporative demand period. For pepper, only the first fresh harvest was considered in the calculation, yield varied between 1.6 and 3.2 t.ha^{-1} (figure 2). Despite the relatively low fresh yields, farmers are using this variety, probably for its better adaptation to the local conditions and for its suitability to be dried and conserved as higher price dry pepper or paprika. For barley the low levels of yields are attributed the fact that only dry grains at harvest are considered in the calculation.

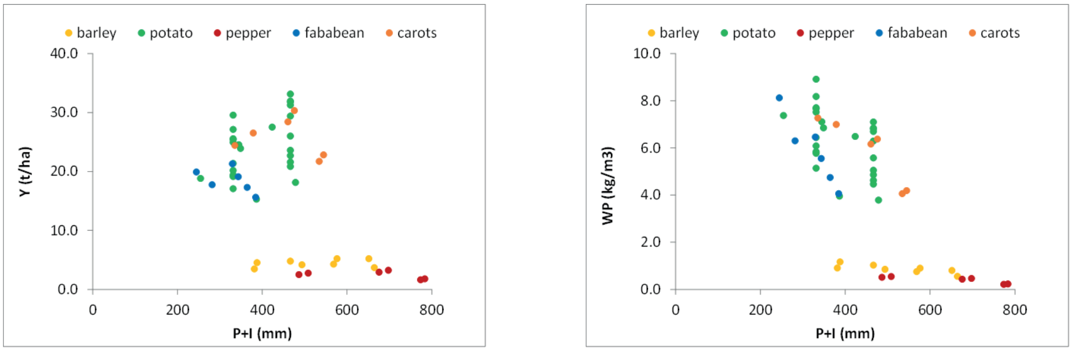

Figure 2: Yield (Y) and total supply (I+P) water productivity (WP) of barley, pepper, potato, carrots and fababean crops obtained under different irrigation strategies in arid region of Medenine-Tunisia

The economic water productivity calculated for total and applied irrigation water confirm that carrot, faba bean and particularly potato, resulted in high water profit per cubic meter of applied irrigation water that exceed 5 TND.m^{-3} for potato (Figure 3).

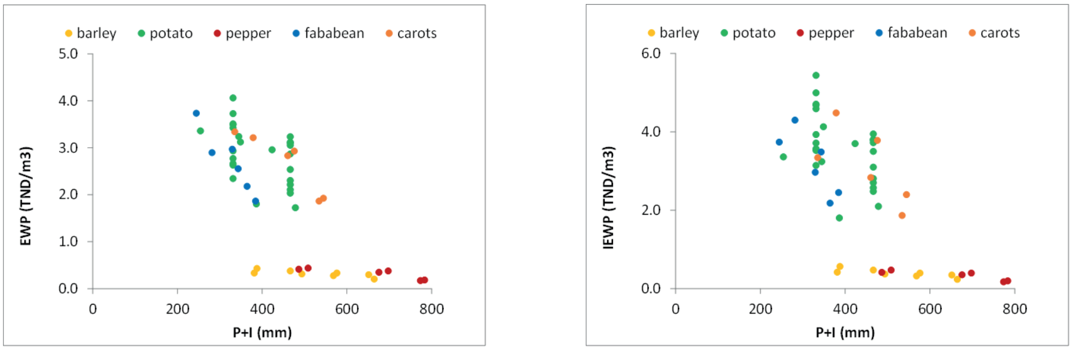

Figure 3: Economic total water (EWP) and irrigation water (IEWP) productivity of barley, pepper, potato, carrots and faba bean crops obtained under different irrigation strategies in arid region of Medenine-Tunisia

The water application under FI and DI resulted in higher yield and WP compared to farmer method (figure 4). In fact, with DI (200 to 350 mm) yield varied between 15 to 30 t.ha^{-1} and increased to 20-35 t.ha^{-1} under FI with a water supply between 350 and 500 mm, while for FM application of 350 to 550 mm produced 15 to 22 t.ha^{-1} (figure 4). Therefore, the FI treatment improved considerably the yield, WP and EWP, compared to FM. These results confirm the finding of Ataklti (2019) for sesame crop who indicated that high economic water productivity is obtained with full irrigation treatment.

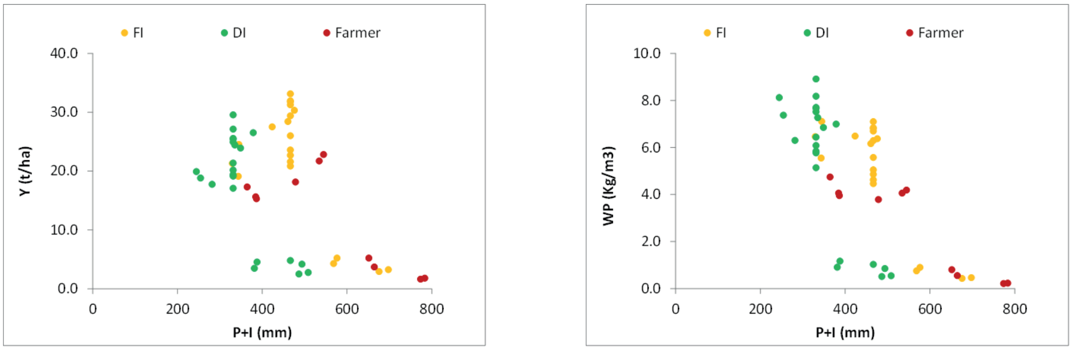

Figure 4: Yield (Y) and total water supply water productivity (WP) of barley, papper, potato, carrots and fababean crops under SWB full (FI) and deficit (DI) irrigation compared to farmer's method (FM).

The reduction by 30% of water supply resulted in small yield reduction for most crops, and in high WP and IEWP for some crops ranging between 3.0 and 5.8 TND.m^{-3} compared to FI with 2.0-3.0 TND.m^{-3} and FM within the range 1.8-2.2 TND.m^{-3}. For FM although more water was used (50 to 100 mm), significant yield reductions were observed which may be attributed to relatively high soil salinity observed under this method (El Mokh, 2016).

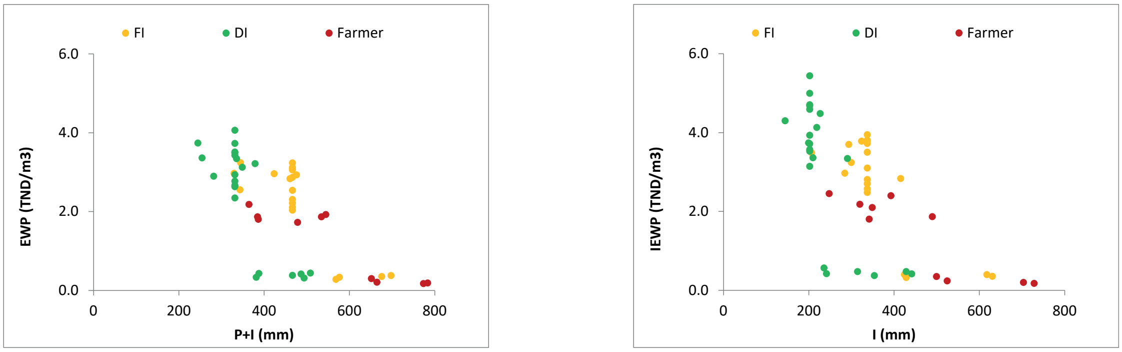

Figure 5: Economic total water (EWP) and irrigation water (IEWP) productivity of barley, papper, potato, carrots and fababean crops under SWB full (FI) and deficit (DI) irrigation compared to farmer's method (FM).

Water productivity-yield relationship (Figure 6) showed that yields obtained for short cycle crops, potato carrot and faba bean, was in the range 15-33 t.ha^{-1} with WP values varying between 1.8 and 9.0 kg.m^{-3}, while, longer growing cycle crops, barley and pepper, have lower yield, WP and EWP.

Short cycle crops such as potato, carrot and faba bean seem to have better soil salinity status and benefit more from rainfall events that alleviate the salinity impact, therefore, results in higher yields and crop water productivities. This support the idea to grow high economic crops whose cultivation cycle coincide with rainfall season (autumn and winter) and low evaporative demand period.

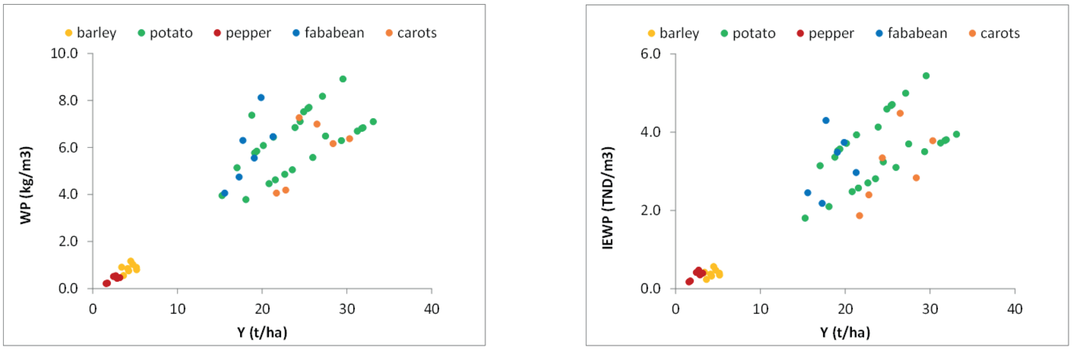

Figure 6: Yield (Y)-Water productivity (WP, IEWP) relationship for short (potato, carrot, fababean) and long (pepper, barley) growing cycles irrigated with saline water under arid conditions.

Crops with high water demand such as pepper can be combined with others crops (cucumber, water melon and melon) as mixed crops to increase its water productivity. Exploiting its value chain for paprika production, pepper could realize high EWP which make its cultivation economically viable. According to our study, barley should be cultivated only on a small plot to secure family and the animal needs. Obviously, both irrigation and crop management should be adapted or adjusted according to environmental changes.

4. Conclusion

The small scale irrigated areas represent the main sources of income for an important number of farmers in the region. Thus, the improvement of farmer's crop water and economic productivities are related to the sustainability and the enhancement of these small crop systems. The irrigation scheduling is the key to improve the crop water productivity and to reduce the environmental impact of saline water. The results showed the importance of this technique in the increase of yield, WP and EWP compared to the farmer practice. The deficit irrigation with small reduction 30% can be useful strategy with low yield reduction and high WP, EWP and IEWP. The choice of the crop as well as the crop management is key factors to improve farmers' economic irrgation water produtivity and ensure farm sustainability. The short cycle's crops such as potato; carrot and faba bean benefited more from rainfall events where the impact on soil salinization is low especially in wet season. In addition, these crops provide reasonable return for farmers. The possibility of mixing long cycle crops crop with other crops such as cucumber, water melon and melon can be a good alternative that could be studied to identify the efficiency of this combination. The farmers consider barley as essential cereal for their nutrition and for animal feeds, although its presence in the system shouldn't be yearly and minimized in small plot to conserve water for cash crops.

Acknowledgments

This work is supported in part by WADIS-MAR project (water harvesting and Agricultural techniques in Dry Lands: an Integrated and Sustainable model in Maghreb regions and the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'.

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Literature review on Water Productivity of date palm treesin Tunisian oasian agro systems

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Highlights

The sudy, , aims to assess the water productivity for date palm cultivation in Tunisia.

A literature review of the previously published scientific papers and documents related to works carried out in these regions for the evaluation of the different aspects of water productivity.

The outcome of this review indicates that (i) the date palm plantations surfaces are expanding, they cover 58.000ha with a total production of 355.000t in 2021(ii) the distribution of irrigation water is variable and irregular. iii) The reported water supply for date palm is from 20,000 to 30,000 m3/ha while a number of scientific-based calculations estimate the crop water requirement for regular date palm production between 10,000 and 18,000 m3/ha (iv) The common irrigation systems are the traditional surface methods (v) Soil salinization, alkalization and loss of soil permeability is growing and may impact productivity of date palms and sustainability of the production system (vi) There is an important overexploitation of conventional water resources reaching 250 % in Nefzaoua Oases for example (v) Biophysical water productivity is not mentioned in most documents, estimations based on reported data revealed that it is not exceeding 0.66kg/m3.

Keywords: *date palm, oasis, Tunisia, water productivity, bibliographic review*

1. Introduction

Ensuring sufficient and sustainable agricultural production for a growing population despite the emerging challenges related to climate variability and environmental degradation is the main objective of management strategies and the backbone of social and economic development. This productivity and food security is closely related to natural resource exploitation namely water resources continuously used for irrigation as the major part of agro-based countries are located in the hot dry areas under semi-arid and arid climate. Thus, to supply the increasing demands, different adaptation techniques and innovations have been adopted to sustainably increase agricultural production, guarantee equitable access to scale global and local and reduce the loss of natural resources. The paradigm shift towards more productive and sustainable agricultural systems relies on a careful evaluation of currently adapted practices taking into account their ecological impacts and their economic benefits. The vicious circle that characterizes agricultural development and its consequences on the sustainability of agro-ecosystem services has been the subject of several multidisciplinary studies in recent decades. These works have confirmed that the factors influencing food insecurity have increased with the extension of the abusive exploitation of natural resources. This alarming situation is amplified by the COVID19 pandemic crisis and climate variability. According to the different medium and long-term development scenarios, more appropriate management of the agricultural sector is required especially in the most prone agro-based countries namely the regions of North Africa and the Middle East (NENA regions). Despite the multiple development actions and adaptation projects to implement the most productive structures in these regions, including the regional project WEPS, GCP/RNE/009/SWE, executed by FAO and funded by the Swedish International Development Cooperation and Assistance Agency (SIDA), different emerging issues still constraining the sustainable agricultural development in these s regions. Thus, an assessment of the previously adopted strategies is essential to outline further fruitful management actions, especially for the water resources. In this context, the present study aims to evaluate water productivity in agricultural systems of southern Tunisia. Water productivity: the water productivity of an agricultural production system is the ratio of the output of the system to the input, the latter being taken in terms of the volume of water. In other words, it should move from an objective of increasing yields (Kg/ha) to an objective of increasing the quantity produced per cubic meter of water consumed (Kg/m3). Different criteria can be used to evaluate this productivity of which, four main indices are often designated to properly quantify the efficiency of the use of water resources in agricultural activity namely Biophysical water productivity (WP) is the ratio between the weight of the agricultural products and the amount of water consumed (ET) per unit area (EWPET). For fully irrigated crops, one can consider the biophysical productivity of irrigation water (WPIRR). In the same way, economic water productivity (EWP) is defined as the ratio between the value of the product or the gross or net revenue and the volume of water consumed (EWPET) or irrigation water applied (EWPIRR) per unit area. The usual units are Kg/m3 for biophysical productivity and US$/m3 or DT/m3 for economic productivity. To assess the biophysical and economic water productivity of a crop, the study aims to make a concrete analysis of different factors and practices influencing the water productivity of date palms. In fact, besides the various aspects of productivity and technical and practical inputs, this paper attempts a thorough review of the evolution of biophysical and economic productivity from previously published works concerning the productivity of water under palm trees in southern Tunisia.

2. Material and Methods

The literature review on water productivity must respond to a large number of parameters and productivity assessment indices predefined by the FAO including, agronomic parameters (phenological stage, irrigation system, climatic (temperature, evapotranspiration), economic (yield, production, cost, etc.), and environmental (salinity, etc.) indices. The work includes a preliminary work of inventory and synthesis of the state of the art concerning the biophysical and economic productivity of the water of the date palms in Tunisia before starting surveys and field work which make it possible to study the current cultural practices and identify the strategies and the measures allowing the improvement of the productivity of the water in the oases. This task requires a careful evaluation not only of work published in the form of scientific articles, theses, and master's theses, but also of internal reports, studies and diagnoses of organizations and technical sheets, and guides that have been produced and not yet published.

3. Results and Discussion

Date palm oases in southern Tunisia

Arid climate conditions, spatio-temporal variability of rainfall, and frequency of extreme events, in particular long periods of drought, define major challenges for stable and sustainable agricultural production in southern Tunisia. These constraints, amplified by poor land management and overexploitation of water resources, require the development of crops increasingly adapted to severe climatic conditions and resistant to the progressive degradation of agricultural soils and loss of fertility. In this context, oasis systems are of crucial importance as they constitute one of the most efficient crops in terms of productivity and persistent irrigation. The cultural value attributed to the date palm is as important as that of an economic or environmental nature. The oasis systems play a key role in the settlement of the local population since they provide a means of subsidence with such great resilience that it allows defining a clear contrast with the desert landscapes, the dry conditions, and the saline lands. This continuous expansion of these agro-systems is associated with increased risks of degradation of natural water and soil resources used mainly for different agricultural activities. Tunisian oases are distributed in the governorates of Kébili, Tozeur, Gabes, and Gafsa (Figure 1). The areas have increased from 16,720 ha in 1974 (Sghaier 2010) to 58,055 ha in 2021 (DGPA 2021). The geographical distribution of the oases shows that 65% of these areas are located in the governorate of Kébili, 17% in Tozeur, 13% in Gabes, and 5% in Gafsa. This variability is mainly due to the expansion of the achievements of private extensions in Nefzaoua outside the public irrigated perimeters (Sghaier, 2010; Mekki, 2021). These agrosystems are classified into two main types: traditional and modern:

- Traditional oases are oases characterized by a high density of date palms (over 200 plants/ha), the predominance of common varieties, a high density of fruit trees and great diversity of species, and a traditional irrigation system. 126 traditional oases are covering a total area of around 16,138 ha (28% of the total area of Tunisian oases). 45% of these oases are located in Gabes, 28% in Kébili, 22% in Tozeur, and only 5% in Gafsa. The agricultural production system in these oases is a"Multi-stage" system: Palm trees, fruit trees, and vegetables. The sustainability of these systems is threatened by many problems among others; fragmentation, the decline of biodiversity, and the scarcity of water resources. These oases also encounter technical problems related to supply, distribution and drainage networks, as well as those related to submersion or basin irrigation systems characterized by a loss of water resources. All of these problems result in low productivity and a gradual loss of soil fertility.

- The modern oases occupy an area of 41917ha (DGPA): These oases are represented by two production systems, namely:

The irrigated perimeters (33%): monoculture agrosystems of date palms (especially Deglet Ennour) and of less importance the irrigated perimeters with two and three different levels recently appeared. The development of these oases faces challenges mainly related to the distribution of water by agricultural development groups (GDA). Indeed, the delivery of the quantities of irrigation water to the plots does not depend on the real needs of the crops (types, stage of growth, climate, soil, etc.) but fixed about the area allocated to farmers (Omrani, 2009; Dhaouadi 2021).

Private extensions (67%): These oases, based on the monoculture of the Deglet Ennour variety, nevertheless contribute directly and with a high percentage to the production and export of date palm products across the country. These agricultural lands are characterized by abusive exploitation of water resources, facilitated by almost free energy, due to the irrational use of solar energy for pumping. The uncontrolled development of these agricultural lands defines serious environmental issues for the sustainability of the region's agricultural systems.

Water productivity under date palms in Tunisia

The Tunisian oases are continually the subject of detailed studies concerning the risks of degradation of these systems and the impact of developments on the various environmental components. Despite this variety of multidisciplinary research work (biological, pedological, agronomic, hydrogeological, chemical, etc.), the concrete evaluation of efficiency in the management of natural resources has not been the subject of a targeted study both locally and nationally. Thus, the evaluation of water productivity in agriculture, and especially in the irrigation of the oasis system, is only partially addressed by a few indices and criteria that lead to an often individual and poorly expressed interpretation. Between technical reports, scientific papers, research work, masters, and theses, these studies focus on a few aspects relating directly or indirectly to water productivity.

The study carried out by Abidi in 1991 on the evaluation of the water balance for the water tables of Djérid, estimated the total contributions of irrigation water the percentage of the real evapotranspiration, the losses by drainage, and the contributions to the water tables in the oases of Djérid (Table 1).

Table 1: Areas, water supplies and irrigation rates of the various oases studied (Abidi, 1991),

Region	Area (ha)	Irrigation (l/s)	Irr. Rate (l/s/ha)
Tozeur	1150	735	0.6
Nefta	900	580	0.6
El Oudiane	1000	710	0.7
ElHamma	400	240	0.6
Hezoua	418	270	0.6
Draa (Djérid Nord)	855	690	0.8
Draa (Djérid Sud)	848	570	0.7
Autres oasis	762	465	0.6
Total	6333	4260	0.7

Abidi's work, however, showed that the actual evapotranspiration is around 66% of the total volume of irrigation water supply, drainage losses were 20% and 14% of this volume fed into groundwater. Unfortunately, the absence of production data for these regions and in the same period did not allow the calculation of water productivity.

In the same region of Djérid, and at the level of different localities (Degueche, Tozeur, Tamerza, Guifla, Nafta, Hezoua, and El Hamma), the diagnosis of the fight against desertification carried out by "the consulting company in community development and business management" for the benefit of MED in 2004 also estimated the water deficit of the study area by analyzing the balance between water inflows from precipitation and the impacts on groundwater renewal.

The study conducted by Sellami and Zayani (1997) focuses, on the other hand, on the analysis of the effect of the water regime, on the production, and the yield of date palms irrigated by a channel (Séguia) from the terminal to the basin with water of 3 ds/m. This study estimated the biophysical productivity at a value ranging from 0.42 to 0.59 Kg/m3 and the efficiency of the water transport network to the basin of 70% of the watering rate oscillating between 47 to 68mm.

The research carried out by Battesti (1998) at Nefta examined the variation in the productivity of water used in irrigation for different products and date palms. Water productivity of total production was about 0.31 kg/m3 and was 0.25 kg/m3 if only dates palm production is considered. He attributed this variation to the layout at the scale of the plot (alignment, density, a variety cultivated, etc.). Battesti (1998) evaluated the economic productivity of the total oasis production which varies from in addition to the economic productivity which oscillates between 0.205 and 0.219 DT / m3 for dates and productivity varying from total production and between 0.193 and 0.196 Dt DT / m3 for dates. Although minimal, the variation in productivity assessed in these two plots highlighted that agricultural practices and management structures are the most influencing factors more than the cultivated area and the physical aspects of agrosystems.

The work of Belloumi and Matoussi (2006) also specifically assessed the variability of date palm yields between public and private oases. He showed that during the years 2002 and 2003, production in the Nefzaoua region varied between 5 and 80 Kg/palm and 10 and 100 Kg/date palm for public and private oases respectively. This work also examined the various factors that can have a direct or indirect influence on productivity, including the salinity of the irrigation water, the rate of irrigation, the supply of fertilizer, and the cultivated area.

The results obtained indicate that in 2002 and 2003, the expansion of private agricultural land is still limited respectively to public land which is well managed in terms of quantity, use of fertilizers, and extension. These results make it possible to estimate the biophysical productivity per palm tree which varies between 0.08 and 0.16 Kg/m3/palm tree (Table 2). This work has also made it possible to understand the efficiency of fertilizer application by estimating the productivity of phosphate-based fertilizers, which is around 6% for both systems.

Table 2: Comparison of productivity factors of private and public oases (Belloumi et Matoussi 2006)

Oasis	Water supply (m3/tree)	Production kg /tree	Fertizers kg/ tree	Water Salinity (g/l)	WP (Kg/m3)
GIC	151. 20	24.50	1.677	4.120	0.16
Private	462.83	38.39	2.272	2.288	0.08

Dhaouadi et al. (2017) have also mentioned that the choice of irrigation system largely influences water productivity. It showed that the productivity of the irrigation water of the palm tree irrigated by the bubbler technique is of the order of 0.66 kg / m3 while that per basin is not exceeded 0.34 kg / m3. The quantities of water supplied and the irrigation system is among the factors that most influence the productivity of date palms according to published works. The work of BelHadj Amor et al. (2017), Dhaouadi et al. (2017), and Ben Aissa et al. (2019) proved that the variability of irrigation water requirements of date palms also spatially, biophysically, and temporally depends on the irrigation system, agricultural practices, drainage systems. The values of annual irrigation water requirements would be between 9,000 to 15,000 m3/ha according to Dhaouadi et al. (2017), from 12,000 to 13,000 according to Ben Aissa et al. (2019) would exceed 24,000 m3/ha according to Hadj Amor et al. (2017); Although these works also estimated approximately the quantity delivered, they do not make it possible to evaluate the productivity of the water since they do not contain information on the agricultural yields obtained under the different experimental conditions considered.

The distribution of irrigation water for the date palm in southern Tunisia has on average one and a half times the real needs of the palm and can locally reach 4 or 5 times the desired limits. Irrigation water productivity of palm trees in Djemna, Rijim Maatoug, and Tozeur was 0.23, 0.23, and 0.25 kg m−3 respectively (Dhaouadi et al.2021a). The quality of irrigation water is a determining parameter for obtaining fruitful yields from date palms. It is a limiting factor in the productivity of agricultural land. As a result, several works have focused on the evaluation of this quality and its suitability for agricultural uses used for agricultural purposes as well as its economic and ecological impacts. The synthesis work carried out by Dhaouadi al. (2021c) revealed that the salinity of irrigation water in the oases exceeded 9g/l for some boreholes as well as the SAR (Sodium Absorption Ratio) reached 23 which increases the risks of salinization and alkalinization and consequently rapid degradation of natural resources and plant cover.

Almost all water induces progressive soil salinization for one when used for irrigation continuously and for a long period. Progressive soil salinization. This aspect of soil salinization has been the subject of several studies. In fact, according to the work carried out by Ben Aissa et al. (2011) on the assessment of the water and salt balance in the oases, irrigation water brought more than 28t/ha of salts to agricultural land for 900 mm of water. This degradation is also mentioned by Besser et al. (2021) who showed that this increasing salinization of agricultural land which affects more than 1.25 ha/year; also causes a loss at the same time an economic result due to the fall of the current low productivity and constitutes a threat responsible for the degradation of that future the sustainability of these agrosystems.

4. Conclusion

In Tunisian oasis, the imminent scarcity of water resources is amplified by the successive droughts that have raged over the past two decades. As a result, the evaluation of the efficiency of the use of water resources and in particular the valorization of irrigation water by date palm and different associated crops is necessary to be the subject of scientific research and institutional development works.

This project of "Water Efficiency, Productivity and Sustainability in Near East and North Africa" constitutes the answer to these necessary and urgent questions, especially in this context of climate change and extreme events which amplify the challenges linked to the shortage of water resources and their qualitative and quantitative degradation in this arid semi- laughed at. It will therefore serve as a baseline study that can fill in the gaps related to the exploitation-yield duality, and therefore at the "food security-climate change-human survival" nexus.

Acknowledgments

This study was supported by the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'.

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Water productivity of date palm trees under two irrigation systems: Case study in a Tunisian oasis

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Highlights

The objective of this study is the estimation of water productivity of date palm Deglet Nour Variety via field survey and experimental work on two irrigation systems implemented in a private farm in southern Tunisian oasis. The considered systems are submersion irrigation system (SIS) and Bubbler Irrigation System (BIS).

The obtained results from field investigation indicate that the biophysical water productivity (WP) of date palms was, in average, 0.30 Kg/m^3 under traditional submersion irrigation and around 0.94 Kg/m^3 for the bubbler system. During the experimental years for the selected farmers and additional field observations during 2018-2020 reveals that (i) After 4 years of the BIS implementation, The use of BIS with appropriate scheduling reduced water supply to 40% and improved yield to 125% in comparison to SIS system (ii) the fruit quality in terms of size, Water activity, pH, sugar content (TSS) and antioxidant activity was not affected. In fact, the BIS have decreased fruit firmness (55%) and increased phenolic compounds content by 24%.

The BIS system showed a high capacity to improve water use and sustainability of date production in Tunisian oasis.

Keywords: *palm trees, production, irrigation, bubbler, water productivity, quality suastainability, tunisia, oasis*

1. Introduction

The date palm (Phoenix dactylifera L.) is a monocotyledon angiosperm plant that perfectly adapts with difficult climatic conditions in arid and semi-arid regions (Munier, 1973, Ibrahim, 2010). The date palm was identified as early as the second period of the Secondary Era, at the end of the Jurassic in Europe, While, in the recent centuries the distribution of the date palm has changed. Currently according to Djerbi, (1994), the Arab world is the cradle of date palm cultivation. Indeed, Iraq occupies the first place in terms of production and cultivated area followed by Egypt, Iran, Saudi Arabia, Pakistan, Algeria, Yemen, Sudan, Morocco, Libya, Oman, Tunisia, Bahrain, Mauritania, Somalia and Kuwait (Johnson et al., 2015). Tunisia is one of the date producing countries. The date palm is cultivated over an area of 58000 ha (DGPV, 2022). The production obtained for the year 2020 is around 332,000 Tons. Tunisia exports large quantities of their production, during the same year the quantity exported is about 118,890 tons for an economic value of 266,225 thousand dollars (FAOSTAT, 2022). The Date Palm plays a very important role both socially and economically, particularly in Djérid and Nefzaoua where it is the main cultivated crop (Hamza et al., 2015). In these regions this heritage crop is a source of life, through its value chain process. Indeed, the date fruit production has numerous uses both as a natural product or transformed one. It is an important factor for the prosperity of the country's export performance and, therefore, it decreases the largely negative trade balance (Ben Amor, 2015). Despite its export performance and its importance in terms of meeting a growing local and international demand, quality of Tunisian dates should be improved in order to remain competitive on the international market. Quality and quantity assurance, traceability and cost efficiency are all essential factors to remain competitive in demanding markets, and require well-managed supply and marketing systems. But essentially, improving the farming practices to achieve sustainable good production (Sarraf, 2021). During the last decades, many oases agricultural practices showed their high performances among quality and quantity field production of dates (Mazahrih, 2018). Irrigation practices have an important influence on the fruit quality at the scale of the farm (ALnaim, 2022). This study aimed to evaluate the bubbler and the immersion surface irrigation systems taking into account water productivity, yield, and fruit quality of dates palms (cv. Deglet Nour) irrigated with these system under Tunisia conditions.

2. Material and Methods

The study area is the oasis of Hazoua which is located about seventy kilometers from Tozeur. This region is administratively attached to the delegation of Tozeur. The perimeter is represented geographically by the coordinates 33° 44′ 19 N and 7° 36 01 EST (CRDA, 2015). Both experimental work and field surveys for 30 farmers were conducted during two seasons 2018/2020. Field Survey: the main questions were around irrigation practices and yield production. Experimental work: assessment of quantity and quality indicators of Date samples which were taken from the products of three plots both for SIS and BIS systems. Twenty fruit samples were taken of each batch. Different analyses were carried out on the fruits to determine the weight, the fruit size and fruit quality including moisture content, total soluble solids, water activity, pH, phenolic compounds and antioxidant activity (Jemni et al., 2014).

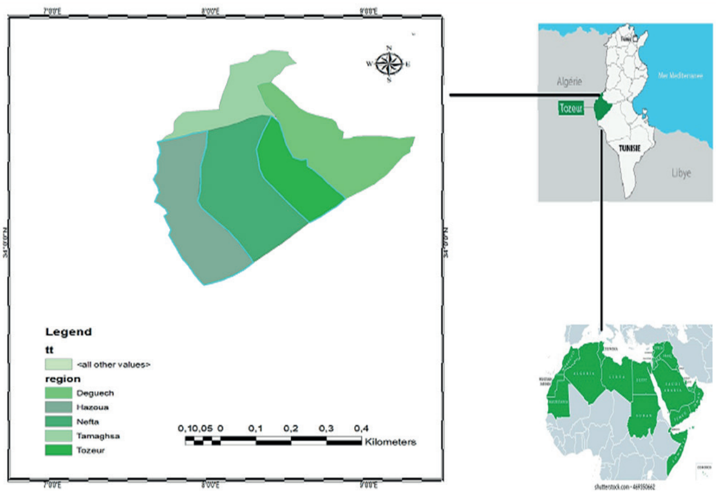

Figure1: Study area localization

3. Results and Discussion

The majority of farmers who adopt the first method use both sources of water; public and private. Only 3.7% use public sources. While the other farmers who have plots irrigated by the bubbler method, all use both sources of water. Public irrigation water is considered insufficient by farmers in this region. Of those, they were forced to create wells to support their crops (Fig.2). Figure 3 summarizes irrigations practices of the surveyed farmers. The water ride was very variable in the surveyed oases (between 6 and 13 days). Moreover, farmers adopting the BIS one (Fig.3) have close water rides (6 or 7 days). The duration of irrigating using the SIS is variable, but it is generally in the order of 6 hours with 12L/s and more.

The previous results make it possible to determine the mean of water quantity consumed annually by the two systems. It is 25.348 m3/ha/year for the SIS and 10.286 m3/ha/year for the BIS system.

The harvest is done by the exporter. The quantities of dates estimated for the SIS vary between 5 and 12 t/ha with more than 40% of the farms producing less than 8 t/ha. For the BIS, production is always higher than 8 t/ha with 30% of the farms producing 12 t/ha.

The calculated production weight average was about 7.745 t/ha for palm trees under SIS system and 9.666 t/ha for under BIS system. The estimated irrigation water and date production allowed determination of the biophysical water productivity of date palm trees of the surveyed farms which is estimated to 0.30 Kg/m3 for trees irrigated with the SIS system and 0.94 Kg/m3 for those irrigated with BIS system.

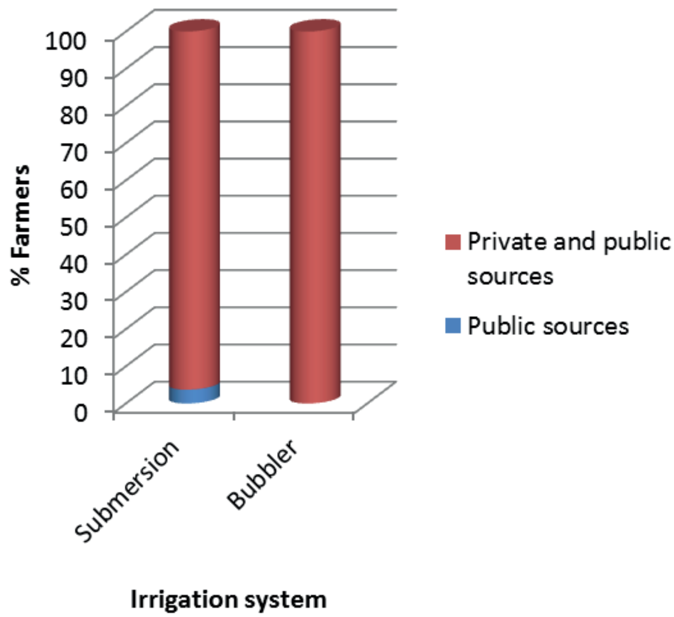

Figure 2. Water irrigation sources

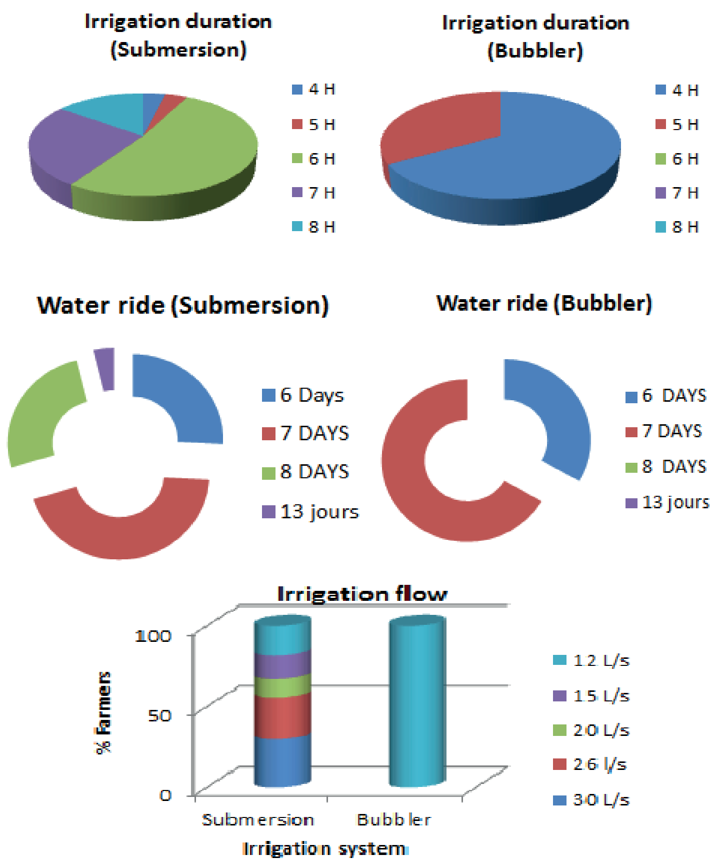

Figure 3. Irrigation practices of the surveyed farms

The study of date fruits quality on samples taken from the same category (category I) of palm trees irrigated by the two irrigation systems revealed that two-years averages does not show any significant differences in terms of quality for the same fruit category (Table.1). Furthermore, significant differences were observed for the parameters firmness and phenolic compounds richness. Thereby, BIS has been shown to be able to improve fruit firmness by up to 55%. In addition a 24% increase in the phenolic compounds accumulation was observed in fruits of the trees irrigated with BIS system.

Table.1. Effect of irrigation system on properties of date palm cv Deglet Nour.

Parameter Irrigation system	Submersion	Bubbler
Fruit weight (Gm)	8.25 ±1.42	9.35 ±0.86
Firmness (N)	6.08 ±0.19	3.38 ±0.87
Moisture content (%)	15.41 ±1.15	16.34 ±1.95
Water activity	0.593 ±0.031	0.629 ±0.031
pH	5.37 ±0.038	5.43 ±0.044
Total Soluble Solids (Brix)	73.86 ±3.06	74.42 ±1.83
Phenolic compounds (mg/100g FW)	2592.3 ±164.91	3237.8 ±222.80
Antioxidant activity (mg/100 FW)	42.59 ±0.63	40.64 ±2.45

4. Conclusion

Due to its positive impact on water productivity and commercial yield without changing fruit quality the BIS seems to be the good choice to overcome water scarcity in arid climate region and in particular in the South of Tunisia.

Acknowledgments

This study was supported by the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'.

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Yield and water productivity of olive trees and significance of farmers' behaviour on water productivity of irrigated olive farms in arid regions (Kairouan-Tunisia)

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Highlights

A survey seeking the analysis of water productivity of olive is conducted in central Tunisia covering 40 farmers.

Only 25% of the surveyed farmers grow olive as monoculture and provided required information for WP estimation

Biophysical and economic water productivities were within the range 0.45-1.28 kg/m^3 and 0.31-1.05 TND/m^3 respectively

Water availability and reliability seems to be the most significant source of yield and water productivity losses.

Farmer field schools initiated by the WEPS project may be an operational solution to improve the situations and reduce yield gaps

Keywords: *olive trees, yield, water productivty, farmer, behaviour, central Tunisi*a

1. Introduction

Water productivity (WP) is a concept used in evaluation of crop water management methods and sustainable development of agricultural production systems. It is defined as the ratio between yields and "water consumed" by crops. The term "water consumed" has been interpreted as "actual evapotranspiration", "raw irrigation plus rainwater", "evapotranspiration plus water lost to the plot but beneficial to other uses", etc. This parameter, which has long been considered to be the value of transpiration (Viets, 1962) has been interpreted by some authors as being water delivered, applied, or available for transpiration etc. In contrast, another group of authors (IWMI, 1997; Dembélé et al., 2001) presents the irrigation water productivity (IWP) indicator as the ratio of production to the volume of irrigation water. In this context, the concept of water productivity is used in the irrigated system to seek an objective of "Producing more grains per drop of water" (FAO, 2002; Giordano et al., 2006). This review of the literature shows: i) in one hand, the large scientific debate that gave rise to this notion and the large divergence around its understanding and interpretation, ii) in the other, the flexibility around this notion. Probably there is no single definition of water productivity and it is the context that can guide the choice of parameters to consider. The present work attempts to analyze farmers' behavior, considered as a key component in food production, and the way strategies, practices and decision making impact water productivity are studied. The farmer decision making impact on farms' business profitability is also addressed in this paper in an attempt to understand the relation between different water productivity levels and different farmers' behaviors and agronomic practices observed on a sample of 40 olive growing farmers in central Tunisia. The estimated biophysical and economic water productivity values will be analyzed in view of the adopted agricultural practices and socio-economic factors.

2. Material and Methods

Water productivity has been associated with multiple components considering both social and economic aspects as well as technical and environmental issues. The study concerns four districts in the region of Kairouan-Central Tunisia, the districts of Chbika, Manzel Mhiri, Sbikha and Chrarda (Figure 1). This region is classified as an arid zone, with an average temperature of 5-21 °C in winter and 25-42 °C in summer and average annual rainfall of about 300 mm.

Forty (40) farmers growing irrigated olive trees were surveyed with the objective to evaluate the efficiency of irrigation and the entire production process of olive. Several parameters were estimated from the collected data, including: water biophysical productivity expressed in kg of olive per m3 of water and the water economic productivity expressed in TND (Tunisian Dinars) per m3 of water.

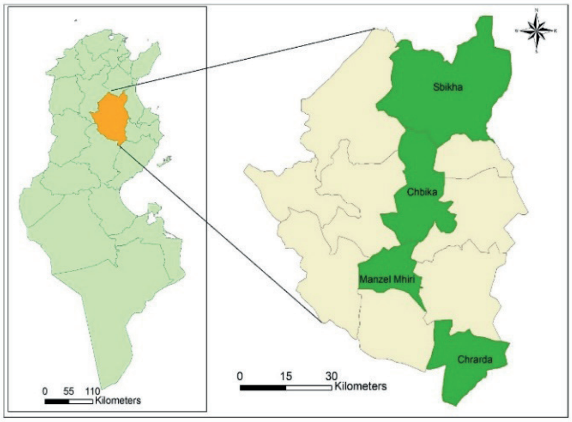

Figure 1. Localization Map of the study area

The survey covered the following aspects: personal socio-economic information, agronomic practices, water resources and management, economic information (production costs, income, and commercialization). The collected information concerned the three agricultural seasons of the period 2017-2020.

Biophysical (WP) and economic (EWP) water productivities were calculated by equation (1) and (2).

$$WP = Y/WS \quad (1)$$

$$EWP = GM/WS \quad (2)$$

Where:

WP : biophysical water productivity (Kg/m^3)

EWP : economic water productivity in Tunisian dinars (TND/m^3).

Y : fresh olive yield (Kg/ha)

WC : water supply covering irrigation and rainfall (m^3/ha).

GM : gross margin (TND/ha) equal gross product value minus corresponding variables costs per ha.

3. Results and Discussion

The results show the existence of several production systems covering rainfed, irrigated, monoculture or intercropping systems growing seasonal or annual crops with the olive trees (Figure 2). Only ten farms growing olive tree in monoculture and which provided all information needed for WP and EWP calculation are considered in this study.

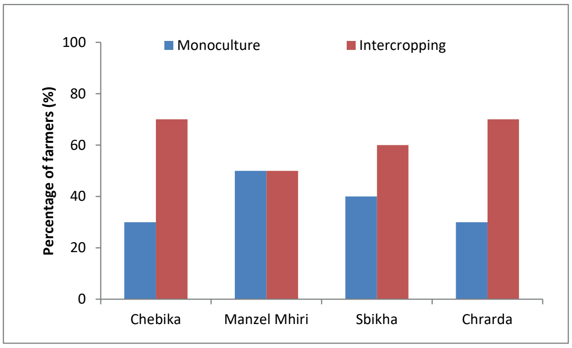

Figure 2. Percentage of farmers growing olives under monoculture and intercropping systems.

Large differences in biophysical water productivity values were among the surveyed farmers, ranging between 0.45 Kg/m3 and 1.28 Kg/m3 (Figure 3). Economic water productivity values were between 0.31 DT/m3 and 1.05 TND/m3 except for young olives trees of farm ID 3 that have negative EWP because they are still not productive (Figure 3). This variability is attributed to the differences of farmers' attitudes to deal with water scarcity and the lack of financial resources in some cases. Differences between farmers are mainly related to the type of the irrigation system used and its efficiency as well as to the irrigation scheduling, the adopted technical package and to the marketing strategy.

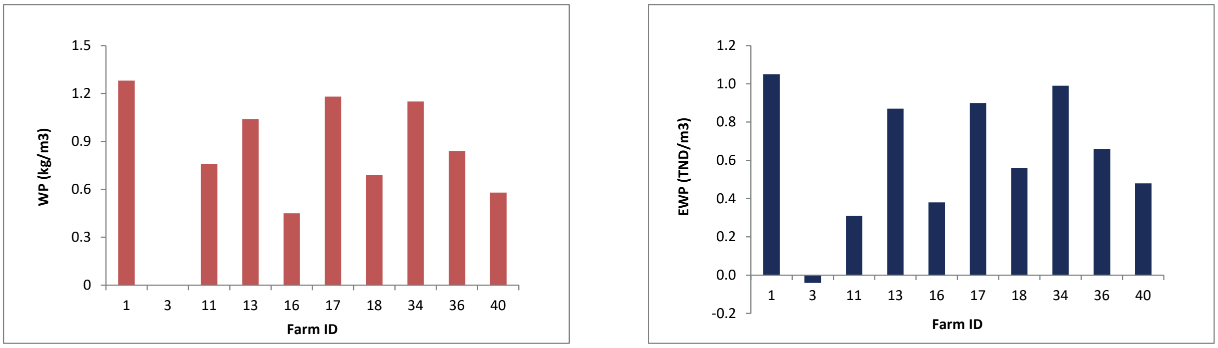

Figure 3. Biophysical (WP) and economic (EWP) water productivities of olive trees conducted in monoculture in ten farms in central Tunisia.

Three different strategies and behaviors were observed among farmers' and typical representative farms are presented here. Farm of type 1 covers 10 ha equipped with drip irrigation, considered as an efficient case. It obtained the best results in terms of biophysical and economic water productivity. The head of this farm is well educated with a university degree and was already involved in the trainings of the Farmers' Field Schools (FFS) organized by the WEPS project. The farmer applies an adequate technical package and use drip irrigation system with a good irrigation scheduling (Table 1).

Table 1. Technical packages used by the farmers growing olive in monoculture system.

District	ID	Irr. System	Irr.Period	Pruning Y/N	Trad. / Mechanized tillage	ways/yr	Manure Y/N	Fertilizer Y /N	Trt. Disease /pest
Chbika	1	Drip	Feb.-Sept.	Y	T	5	Y	Y	Mites
	3	Drip	Mar.-Aug.	Y	M	-	N	Y	Mites
Manzel Mhiri	11	Pipe	Jan., May, July, Aug.	Y	M	4	N	Y	Olive fly
	13	Drip	Winter +Summerr	Y	T	3-4	Y	N	-
	16	Drip	Winter-summer	Y	T	3	Y	Y	Olive fly
	17	Pipe	Feb., Jun., Aug, Oct.	Y	T	3	N	Y	-
	18	Drip	Winter-summer	Y	T		N	N	-
Chrarda	34	Drip	Dec., July., Oct.	Y	T	4	Y	Y	-
	38	Flood	Feb., Jun., Aug., Oct.	Y	M	3	N	N	Olive fly
	40	Drip	flowering & pruning	Y	T	2	N	N	-

The application of the good practices allowed him to achieve the highest values in terms of biophysical and economic productivity of water while obtaining good yields and good economic benefit per hectare. The typical farms of type 2 covers 24 ha, where the farmer, is facing a serious problem of water availability preventing him to fully irrigate all trees. The farmer used a strategy of supplemental irrigation only during three critical periods in December, before the start of the plant growth cycle, in June during the period of fruit growth and in October during the period of lipogenesis. This strategy allowed the farmer to have acceptable levels of olive yields and economic profitability per hectare. Taking into account the lowest levels of applied irrigation water (Figure, 3) the observed values of biophysical and economic water productivity of this farm are considered very satisfactory compared to other farms where more water is applied annually.

The case representing the third type is a farm which covers an area of 10 ha with a density of 40 trees/ha, and good soil properties. The farmer adopted a strategy to apply irrigation water to the olive trees based on the visual appearance of the leaves. He considers irrigation as an essential element to have good yields in addition to tillage and pruning.

Despite the high yields per ha observed in this farm, water productivity values are low compared to those observed in the other farms. This is attributed to the large quantities of applied irrigation water and the possible losses resulting from the use of the submersion irrigation method used by this farmer.

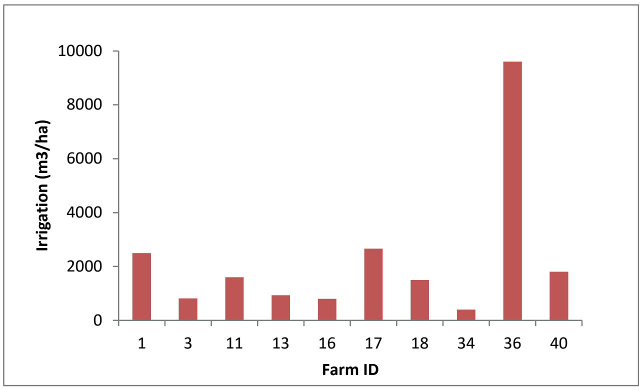

Figure 4. Annual irrigation amounts applied for olive trees grown as monoculture in ten farms in central Tunisia.

The large differences between the surveyed farmers are used to identify attainable values of yield and WP in the region and the improvement potential and possibilities of water productivity by analyzing water and crop management practices of the most efficient farmers.

4. Conclusion

This study highlights the importance of understanding how farmers make their decisions. Indeed, farmer's decision making involves a multitude of criteria to be optimized under a set of constraints: geographic characteristics, resources availability, business plans, marketing strategies, social conditions, farmer's education level, etc. At the same time, these decisions are based on the experiences acquired through a continuous process of exchange and experimentation, the search for solutions to deal with daily problems, but also thanks to the training carried out and the supervision received from development agents. In this context, the experiences of the Farmers' Field Schools (FFS) organized by the project WEPS can be a good alternative placing farmers at the center of learning processes through interactive methods to go toward better levels of water productivity.

Farmers are key elements in improving water productivity, and the improvement of water management must start at the farm scale. However, constraints imposed by both local and national socio-economic environment and resources availability and reliability impact their behaviour and decisions. In this global equation, both the management of water supply and water demand must to be considered at the same time. In the region of Kairouan, water management based on the offer is possible through the intervention of the public authorities. Maintenance and renewal of the public irrigation infrastructure and technical and financial assistance of farmers for modernization of their irrigation systems are also needed. As for demand water management: farmers must be aware of the importance of adapting their needs to water availability. This can be possible through: i) better control of water supplies to olive trees based on site specific data on soil, crop and actual weather situations in order to meet the needs of the tree without loss of water, (ii) assistance and training of farmers and in-situ supervision concerning the entire technical package.

Acknowledgments

This study was supported by the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'.

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Estimation of wheat actual evapotranspiration using in-situ CORDOVA-ET system

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Highlights

CORDOVA-ET is a station developed by the University of Cordob-Spain for measurment of evapotranspiration. It makes use of low cost electronics, sensors and wifi and internet technology for measurement, transmission, and sharing of collected data.

A station installed in the INGC plateform of Kodia, northwest of Tunisia, was used to estimate the actual evapotranspiration (ETa) of durum wheat.

The collected data, covering a period of three months corresponding to development-mid season, shows that daily ETa was in the the range 0.8-4.8 mm/day while reference evapotranspiration (ETo) varied between 1.0 and 5.8 mm/day during the same period.

In ordrer to compare in-situ measurement with remotely sensed estimation of ET, the Wapor plateforms output corresponding to the experimental plot was extracted and used.

A good correlation between CORDOVA-ET and Wapor was observed during the considered period for both ETo and ETa.

Keywords: *evapotranspiration, durum wheat, CORDOVA-ET*

1. Introduction

The combined effect of climate change and populations' growth leads to an increasing water demand and an accelerating water shortage. Facing the challenge of producing more food under water scarcity, a sustainable agricultural system requires a wise water management, which involves an accurate monitoring of crop water consumption (Nunes et al., 2017, Tantawy et al., 2018). Among a wide variety of actual evapotranspiration (ETa) determination methods, CORDOVA-ET system is developed to be a low-cost alternative for ETa monitoring at field level. As part of the system calibration and validation, this study aims to evaluate CORDOVA-ET outputs for a durum wheat cover in Tunisian conditions.

2. Material and Methods

This study was conducted at the experimental station 'Kodia' of the Field Crop institute (INGC), located in Bousselem-northwest Tunisia (36°32'47.83''N; 9°00'50.00''E). The area has an average annual rainfall of 525mm, a mean annual temperature of 18 ° C, and a mild winter season. The site has an altitude of 148 m but in flat area with a non-saline, calcareous soil, having a clay loam texture.

The CORDOVA-ET system (COnductance Recording Device for Observation and VAlidation of ET), developed by the the Institute for Sustainable Agriculture and the University of Cordoba-Spain (IAS-CSIC), allows the estimation of actual and reference evapotranspiration. The system is deployed at the moment in eight different countries with an ongoing work of calibration and validation over field crops and orchards.

The equipment is designed to calculate ETa at a daily time step and based on the energy balance method. The reference evapotranspiration (ETo) is also determined with weather data measurements using the FAO Penman-Monteith equation. CORDOVA-ET data are transmitted and stored into an open-source time series database using wireless communication technology. The system is composed of a base station, a weather station for ETo monitoring and four sensing nodes (Fig. 1). Each node integrates four sensors (Air temperature and humidity sensor, pyranometer, Canopy Temperature sensor and Soil temperature Sensor) used for ETa determination.

During this experiment, a CORDOVA-ET station was installed in a 2.4 ha plot. During 2020 winter season durum wheat was cultivated under rainfed condition on the plot and the plot was managed according to the standard conservation (no-till) practices.

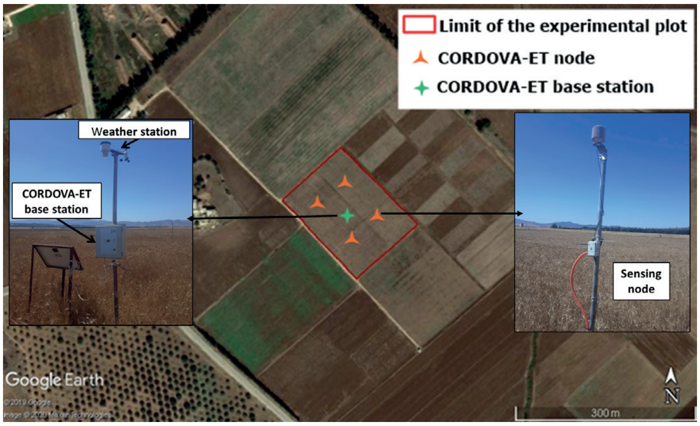

Figure 1. Location of the experimental plot (From Google map) and experimental design

In addition to the in-situ evapotranspiration data, we also examined the performance of the remotely sensed (RS) derived ET products of the FAO portal WaPOR. From this RS dataset we used the reference evapotranspiration ETo_WaPOR available at a 10-days time step and a spatial resolution of 0.00223° (~250m, level 1). The Actual evapotranspiration and interception data (ETa_WaPOR) are also available at 10-days time step with a resolution of a resolution of 0.000992° (~100m, level 2). The calculation procedure of ETa_WaPOR is based on the ETLook model (Bastiaanssen et al., 2012) applying the Penman-Monteith (P-M) equation with adaptation to remote sensing input data.

The WaPOR data are used to assess the irrigation performance (Chukalla et al., 2022) and the water-food nexus (Tantawy et al., 2018) with some works in the evaluation of its products over arid and semi-arid regions (Blatchford et al., 2020; Geshnigani et al., 2021; Javadian et al., 2019).

3. Results and Discussion

The installation of CORDOVA-ET system took place during the growing season 2019-2020 in mid-February. The collected ET data covered a period of three months coinciding with the development and mid-season stages.

The resulting dataset given in Figure 2 shows a daily variation of ETa between 0.8 and 4.8 mm and ETo between 1.0 and 5.8 mm. The two considered variables have a high temporal variability without a clear evolution trend. The cumulated ETa corresponding to the period mid-February-mid-May 2020, is around 200mm. During the same period, cumulated ETo was 230 mm, resulting in an average Kc of 0.87.

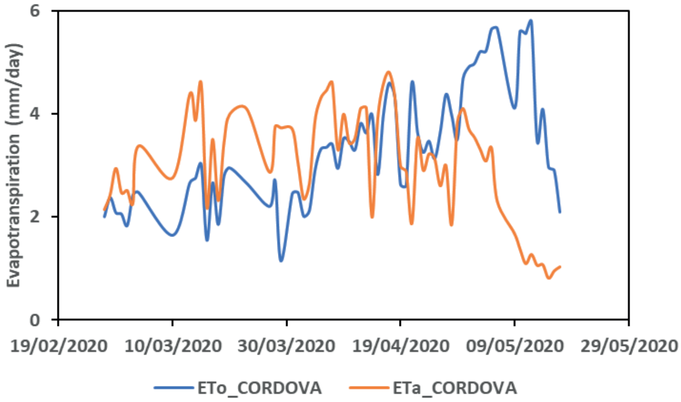

Figure 2. Temporal variation reference (ETo) and actual (ETa) evapotranspiration measured by CORDOVA-ET station on rainfed wheat during the period February-May 2020 at the INGC experimental station of Kodia-Boussalem

In another hand, 10-days average values CORDOVA-ET data are compared to the corresponding ET values extracted from WaPOR portal. The ETa_WaPOR dataset is extracted from one pixel covering the central part of the experimental plot while ETo_WaPOR values were derived from a larger area than the experimental plot.

Figure 3 shows temporal variation of reference evapotranspiration (ETo) measured by CORDOVA-ET and estimated by WaPOR and comparison of the 2 methods. The ETo_WaPOR shows a higher value than the in-situ measurements and quasi systematic over-estimation that could be related to the low spatial resolution of the RS product (Figure 3).

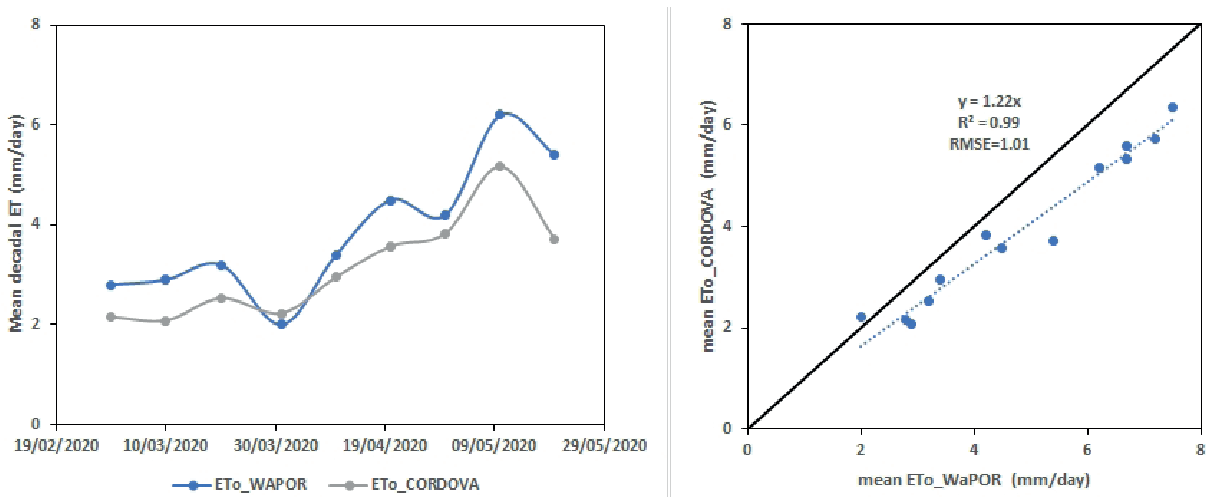

Figure 3. Temporal variation of 10-days average values of reference evapotranspiration (ETo) measured by CORDOVA-ET and estimated by WaPOR and comparison of the 2 methods.

Concerning actual evapotranspiration, both methods showed good correlation and time course of ETa followed the same variation trends (Figure 4). The slightly lower values of ETa_WaPOR agrees with the results of ETa_WaPOR evaluation under annual crops and citrus orchard under semi-arid climate in northeast Tunisia (Alaya et al, 2021; Belgacem et al, 2021).

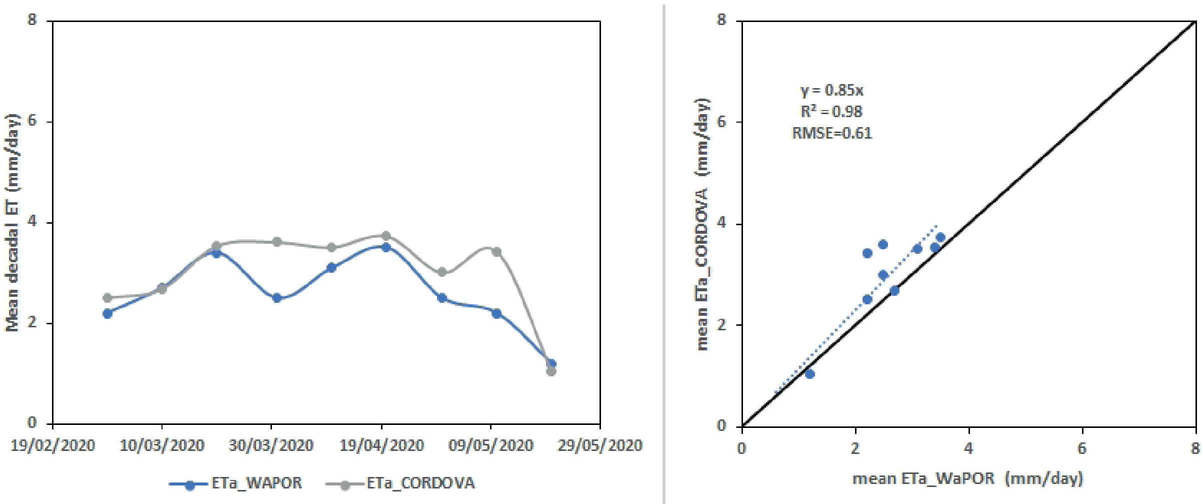

Figure 4. Temporal variation and comparison of actual evapotranspiration measured by CORDOVA-ET (ETa_CORDOVA) and estimated by WaPOR plateform (ETa_WaPOR).

4. Conclusion

In this experiment, data obtained by CORDOVA-ET system covered mid-season of wheat growing cycle corresponding to the period of high evapotranspiration of the crop. The ETa peak extends from March to late April. This period was characterized by a gradual increase of the atmospheric evaporative demand, maximum vegetation density and good watering conditions. Comparison between CORDOVA-ET outputs and WaPOR's ET products shows a good correlation for both reference and actual evapotranspiration with a similar evolution trends.

Acknowledgments

This study was supported by the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'. The contribution of the Field Crop Institute (INGC) in providing and managing the experimental plot is acknowledged.

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Validity of shirps rainfall data and its use for rapid water accounting in an irrigated perimeter in northern Tunisia

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Highlights

With its highly spatial and temporal variability, rainfall measurement in Tunisia is a crucial operation that requires financial as well as human efforts to cover the whole country in a representative and continuous way. Satellite rainfall data can be a freely accessible solution that came as an alternative information source. Climate Hazard Groups Infrared Precipitation with Stations (CHIRPS) is a global set of rainfall data calibrated with in situ rain gauge stations from national and regional authorities starting from 1981 until today. The study aims to compare and validate this database with 294 ground stations in Tunisia for the period from 1981 up to 2015 with the monthly time step in a station to pixel basis. Both statistical analysis and goodness of fit statistics are used for the comparison including the Coefficient of correlation (r), the coefficient of determination (R^2), Probability of BIAS (PBIAS), RMSE-observations standard deviation ratio (RSR) and Nash-Sutcliffe efficiency (NSE). Results show a good fit of CHIRPS data for the coastal zones as well as the subhumid and humid bioclimatic stages located in the Northern and North-western part of the country with RSR<0.7, r>0.75, NSE>0.7 and |PBIAS|>0.2. For the semi-arid, arid and Saharan bioclimatic stages located in the central and Southern part of Tunisia, CHIRPS tends to overestimate the amount of rainfall with a lower estimation accuracy. This study concluded that CHIRPS dataset can be used in the coastal and the rainy parts of Tunisia located in the North, North-West and the Est without further calibration but for the Centre-West and the South parts there is a need for an adjustment before the use.

Keywords: *CHIRPS, Rainfall, comparison, validation, Tunisia, Statistics*

Acknowledgments

This study was supported by the FAO-SIDA WEPS project, 'Water Efficiency, Productivity and Sustainability in Near East and North Africa'.

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