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Literature review on Water Productivity of date palm trees in Tunisian agro systems

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Abstract

The sustainability of agricultural productivity is closely related to the optimal exploitation of natural resources, namely the efficient water resources management. The evaluation of the effectiveness of the adopted strategies and the applied practices and systems relies on a number of criteria and parameters of which water productivity indices represent the most relevant criteria. In this context, the present study aims to assess the water productivity for date palm cultivation in Tunisia based on an accurate literature review of the previously published scientific papers and reports related to the different studies carried out in these agro-oases regions of the country for the evaluation of the different indices of water productivity. This review represents the main baseline document highlighting in an exhaustive way the challenging features related to water productivity for date palm agro-systems. The outcome of this review indicates that (i) the cultivated date surface is expanding, covering more than 58.000 ha with a total production of 355.000 tons in 2021(ii) the distribution of irrigation water is variable and irregular. iii) The reported water supply for date palm range from 20,000 to 30,000 m^3/ha while a number of scientific-based calculations estimate the crop water requirements for regular date palm production is between 10,000 and 18,000 m^3/ha (iv) the efficiency of water conservation techniques is related to numerous in farm factors related to the old traditional surface irrigation systems, to the soil salinization, alkalization and permeability loss and to the overexploitation issues of water resources that reaching is growing and may impact the productivity of date palms and sustainability of the production system (v) the estimation of the biophysical water productivity based on the reported data reaching barely 0.66kg/m^3. This overview highlights the need for an accurate evaluation of the ecological efficiency of the used management measures to a clear appreciation of the new strategies and policies to face the current constraints with regard to all different driving forces influencing water productivity both at the macro and micro scale.

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 (Green et al. 2014; Al Mulla and Gheilani 2018). Indeed, permanent productivity and safe food security is closely related to natural resource

exploitation namely water resources used increasingly 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 increase agricultural production in a sustainable way and to guarantee equitable access at global and local scales to the different ecological services and reduce the degradation of natural resources (Mhiri et al. 2013; Besser e al. 2019). To achieve these major objectives, and to outline the required management strategies and reglementary aspects, a careful evaluation of the currently adopted practices in terms of ecological impacts, economic benefits and social satisfaction is highly required. However, this assessment is coupled generally with relevant uncertainty related principally to the accuracy of the data and the used evaluation indices, tools and parameters.

In fact, the vicious circle characterizing agricultural development and the likely consequences on the sustainability of agro-ecosystem services has been the subject of several multidisciplinary studies in recent decades (Dhaouadi et al. 2017, 2021; Al Wahaibi et al. 2018; Al Muaini et al. 2019; Abdelhadi et al. 2020). These works have confirmed that the factors influencing food insecurity and natural resources degradation have increased with the extension of the abusive exploitation and the economic growth. This alarming situation is amplified by the COVID19 pandemic crisis and the climate variability. Consequently, 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) (Abdedayem & Boukchina, 2008).

In these arid to semi-arid regions, agriculture represents the main economic sector that supports huge socio-economic pressure and reveals important cultural dimension and environmental value. The expansion of agricultural lands, despite the local inaccessibility for water to irrigation or the quasi- permanent water deficit, relies principally on the most tolerant crops to these harsh conditions namely the date palm (Dhaouadu et al., 2017; Al Wahaibi et al., 2018) Al Muaini et al., 2019; FAO, 2020). However, according to the medium and long-term development scenarios, the resilience of palm agrosystems to the natural variable circumstances amplified by the mismanagement of natural resources and the anthropogenic stimulation shows a clear decrease challenging the sustainable productivity of the cultivated lands. Consequently, the assessment of the evolution of these agrosystems and the determination of the principal factors governing influencing or threatening the safe production is of paramount importance. The evaluation of the appropriateness of agricultural practices at farm scale level and the efficiency of natural resources exploitation measures are among the key success factors of these rehabilitation efforts. In this context, the FAO has introduced a number of objective multi-disciplinary methods commonly used that may accurately evaluate the exploitation of the natural resources namely irrigation water.

The present study aims, consequently, to evaluate water productivity in oasis agricultural systems of southern Tunisia under date palm. In fact, the water productivity of an agricultural production system is the ratio of the output of the system to the input, 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). Various 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. METHODOLOGY

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 (Abdedayem and Boukchina 2009).

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 (Fig.1).

agricultural soils and loss of fertility (low renewable water used for irrigation, saline poorly evolved soils generally covering the oases lands and increasing formation of gypsum crusts especially in the surface horizon of the cultivated lands (Besser et al. 2017; Dhaouadi et al. 2020, 2021)) Thus, 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 (Askri et al. 2014; Kraeim 2015; Fadzirul et al. 2020; Al Omran et al. 2019; Dhaouadi et al. 2020, 2021a, b). This continuous expansion of these agro-systems is associated with increased risks of degradation of

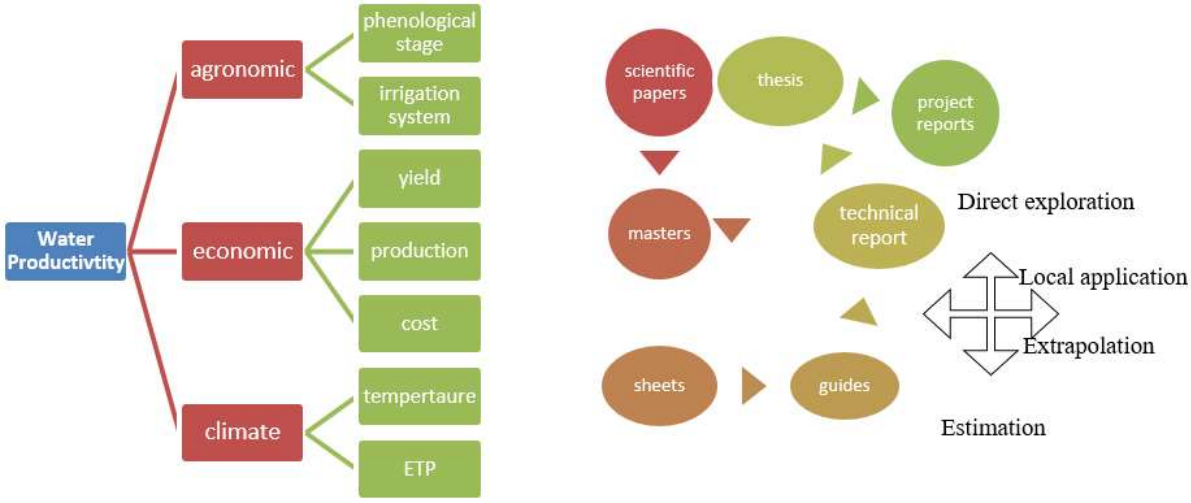

Fig. 1. the used methodlology and the key parameters controlling the water productivity at farm scale

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 adapted to severe climatic conditions (less of 100 mm of rainfall per year and elevated temperature of 45°C during the summer period (CRDA 2020) and resistant to progressive 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 (Sghair 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 (Sghair, 2010; Mekki, 2021). These agrosystems are

classified into two main types: traditional and modern (Fig. 2 and Table 1):

- 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 cover 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

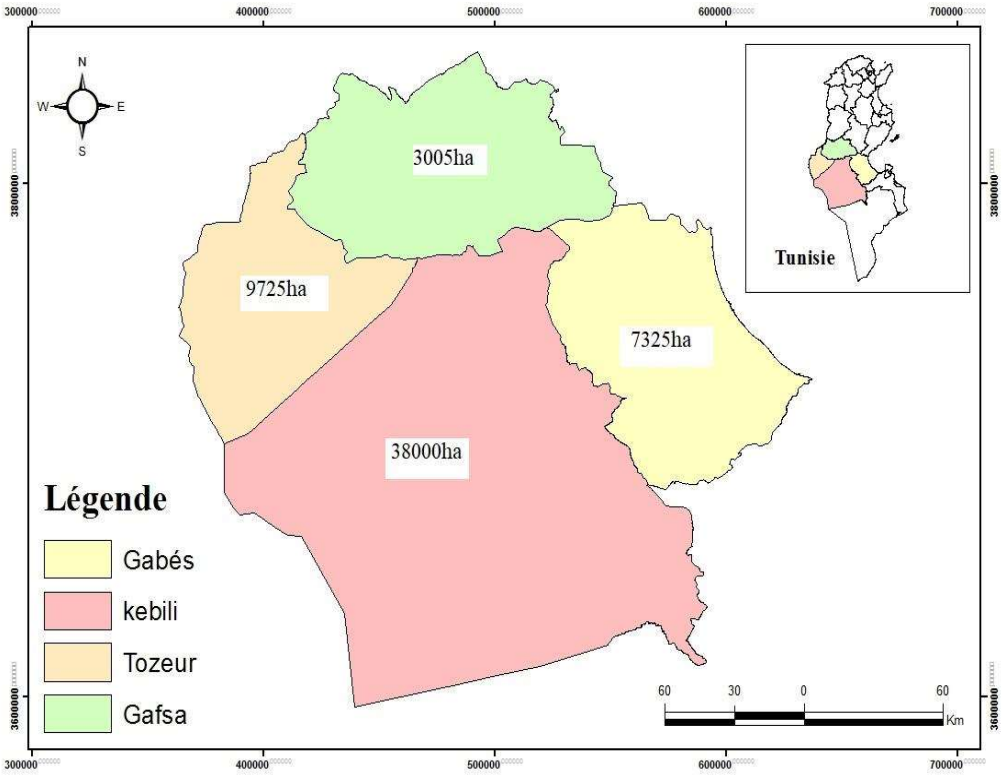

Fig. 2. The distribution of the oases agrosystems in Tunisia

Table 1. Oasis agrosystems in southern Tunisia

Localities	Classification	Varieties	Water exploitation
Gafsa	Public: 16,138 ha (28% of the total oases) Gafsa: 5%	Deglet Nour	Resources: 128 Mm3 Exploitation: 209Mm3
Tozeur	Gabes : 45% Tozeur : 22%	Deglet Nour Alig	Resources: 226Mm3 Exploitation:197Mm3
Kebili	Kebili: 28% Private: 41917ha	Deglet Nour	Resources: 242 Mm3 Exploitation:523 Mm3
Gabes			Resources: 180 Mm3 Exploitation:177Mm3

Table 2. the used methodologies in the estimation of water productivity in southern Tunisia

Methods	Parameters	References
Direct measures	Real ETP Drainage Productivity	Abidi (1991)
Estimation by ionic ratios	Water quality Soil productivity	Dhaouadi et al. (2021)
	Soil fertility loss	Besser et al. (2021)
Modeling	Water balance Chemical and physical parameters Soil moisture	Dhaouadi et al. (2017, 2020) Hadj Amor et al. (2017)
Economic evaluation	Productivity Yield quality	Battesti (2005)

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) (CRDA 2018-2020): These oases are represented by two production systems, namely:

The irrigated perimeters (33%): monoculture agrosystems of date palms (especially DegletEnnour) 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 is fixed about the area allocated to farmers (Omrani et Ouassar 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 (Hadj Amor et al. 2014, 2017).

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 development 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 for agriculture, and especially for irrigation purposes in the oasis system, is only partially addressed by some indices and criteria defining local, partial or inefficient interpretation or characterization of the system. Between technical reports, scientific papers, research work, masters, and theses, these studies focus on a few aspects relating directly or indirectly to water productivity (Table 2).

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 3).

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.

Table 3. Areas, water supplies and irrigation rates of the various oases studied (Abidi, 1991),

Region	Area (ha)	Irrigation water supply l/s	irrigation 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

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) (Table 4) at Nefta examined the variation in the productivity of water used in irrigation for different products and date palms (Table 4). 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

Table 4. Water productivity of the date palms and some associated crops (Battesti, 1998)

		Total production	Water productivity of total production	Water productivity of date palm
1	**Pb/Pr**	33050	0.311	0.255
2	**Pr/Pb**	14050	0.314	0.251

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. 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 5).

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, RijimMaatoug, and Tozeur was 0.23, 0.23, and 0.25 kg m−3 respectively (Dhaouadi & 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

Table 1. Comparison of productivity factors of private and public oases (Belloumi et Matoussi2006)

Oasis	Water supply (m3/palmier)	Production kg /palmier	Fertilisants kg/palmier	Water Salinity g/l	Biophysical Water productivity 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

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 increase 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.

Monitoring this issue at the plot level by systematic evaluation of the irrigation water use for the water-saving irrigation systems is conducted by Dhaouadi et al. (2015) showed that, for example, the bubbler irrigation technique makes it possible to reduce the effect of salinity (%) on the system and the agricultural soil by improving productivity under the palm tree by different water saving plans.

The literature review of these documents indicates the necessity of a critical evaluation of the evolution of the oases agrosystems in southern Tunisia. In fact, given the relevant importance of these agricultural lands with different dimensions, the succession of management strategies and technical improvements defined a heterogeneous environment of date palm cultivation, different at small scale and variable from a farmer to another. This heterogeneity is amplified by the individual practices and uncontrolled application of the indigenous knowledge of the local population. All these factors coupled with inefficient control and the lack of database make the required task hard of critical assessment and accurate examination of the effectiveness of the used methods and the adopted strategies hard. In other words, the amplitude of the challenges and the difficulty of dealing with the emerging issues is closely related to the absence of an accurate evaluation of the current state of these oases.

4. CONCLUSION

This synthesis highlights various main points that are of relevant references for date palm productivity and water resources management:

- The agrosystems in southern Tunisia reveal decreasing resilience against the climate and essentially the management of these cultivated lands. This increasing vulnerability is expressed by a reduction of the productivity of these trees;

- The water productivity is not yet addressed by exhaustive evaluation and detailed studies at local and national scales;

- The expansion of private oases coupled with inappropriate use of photovoltaic sources of energy has led to the inappropriate estimation and modeling of the evolution of date palm productivity and management issues due to the lack of accurate data base;

- The valorization of the local individual practices and the indigenous knowledge of farmers to face the challenging issues is highly required and the evaluation of their capacity to deal with the emerging challenges is the backbone of efficient management at different scales;

- The lack of appropriate evaluation of water productivity related to the different economic, ecological, and biologic aspects highlights the lack of accurate databases that may cover the quasi-total of the oases agrosystems in Tunisia. This outlines that, despite the numerous multidisciplinary studies carried out for the oases characterization in Tunisia, the estimation of the evolution of these systems and their resilience to the different aspects of degradation is still limited; aspects require baseline studies and data base collection.

The present study represents in this context, a preliminary synthesis of the previously carried studies about the productivity of water in the oases agrosystems of Tunisia. This literature review highlights that there are many uncompleted works to have a clear evaluation of this productivity. The partial evaluation assigned to local scale cannot reveal relevant data to be used as references. 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, 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.

Further works are required for experimental sites and data collection of the response of the oasis agrosystems to the different stimulations and under various agro-environmental conditions and issues.

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