Impact of water availability on agro-biodiversity of oases in the Kebili region of southern Tunisia.

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Abstract
Oases are fertile and cultivated lands in Sahara and dry areas due to the water source presence as rivers and deep aquifers. It was usually assumed that oases' agro-biodiversity level is linked to their history, type of cropping system, and their governance. Nevertheless, data collected from a survey carried out in 2020 on a referenced random sampling of 52 plots of farmers in Kebili, a southern Tunisian region, showed that water availability and irrigation practice are key factors determining agro-biodiversity level. Our results showed that plots that were irrigated by water turn were mostly organized on one layer (only date palm) while plots having drilling were mostly organized on three layers (palm date, fruit trees, vegetables, and/or forage and cereals). The plots that were irrigated at least once a week are those that were planted by more than 3 species, while those that were irrigated less than 3 times per month had the lowest agrobiodiversity level and were grown mostly by palm date only. Low water availability due to low water resources and drought and high gaps between irrigation are causing mortality for fruit trees and annual crops and therefore agro-biodiversity losses. These oases are heavily threatened.

Keywords: Water availability, water turn, drilling, irrigation frequency, agro-biodiversity losses.

INTRODUCTION

Oases are cultivated spaces within vast arid or even desert areas, found in most of the major dry regions of the world: around the Sahara, in the Maghreb and the Sahel, in the Middle East, on the west coast of Latin America and in Central Asia (Jouve, 2012). Oasis is also defined as "an area in the desert where both water and plants exist" (The Britannica Dictionary, 2022). In these areas, water has always played a key role. Since the survival of these oases is conditioned by the mobilization of water. From a technical point of view, this can be made in different ways, either by diverting water from rivers as in the Nile Valley in Egypt, or by exploiting underground water tables more or less by pumping deep as in the case of the Tunisian oases of Djerid, Nefzaoua or Gafsa, or by drainage using underground galleries of water tables located upstream of the oasis as this is the system of khettaras of southern Morocco, foggaras from Algeria (Touat, Gourara, and Tidikelt) or qanâts from Iran (Jouve, 2012). Moreover, according to Battesti (2005), the "founders" of these cultivation centers had a precise idea of the desert — or at least of the arid zones — since they had to be near it, people do not live in such regions without this environment having as much influence on the individual as on the group, on the content of knowledge and practices, notably and particularly about the question of water.

The Tunisian oases, as with all oases in the Maghreb, are traditionally mostly constituted by a palm grove under which there are, two other layers of vegetation like fruit trees and, below, cereals, forage, and vegetable crops. This organization owed oases an important environmental role in desert environments since they create a particular microclimate known as "the oasis effect". Especially, the vegetative cover is one of the key factors impacting the oasis microclimate effect (Han et al., 2010; Mao et al., 2016; Potchter et al., 2012). Moreover, the oasis microclimate

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participates in creating jointly evaporative cooling and humidifying effects (Hao et al., 2016; Potchter et al., 2012; Xue et al., 2019). This leads to decreasing temperature and increasing the relative humidity in the oasis compared to the surrounding desert and as a consequence of the advection of heat between the oasis and desert (Feng et al., 2009; Hao and Li, 2016; Hu et al., 1988; Xue et al., 2019; Zhang et al., 2003). In addition, in case of extreme weather events such as dust storms and blown sand, higher vegetal cover in the oasis successfully lowers the wind velocity (Xue et al., 2019) especially since those phenomena are frequent in the southern Tunisian region where oases are usually located. The same authors added that enhancing the oasis microclimate strongly participates in conserving the stability and sustainability of the oasis and underpinning human settlements in arid or very arid regions.

The oasis is an important socio-economic environment. Actually, it is estimated that around 150 million people live in oases, although most of these oases were created in sparsely populated regions, they are not islands lost in the middle of the desert and are endowed with a wealth and plant diversitylayers organization if water is available (Jouve, 2012). The role of water in such areas is therefore crucial. Hence, the use of water in the oasis is not only for growing production and the environment but also for industrial and living purposes (Zhao et al., 2010). In Tunisia, oases has also an important socio-economic role and provide every year a prosperous production of dates especially 'Deglet Nour' which is one of the most exported agricultural products. This production comes mainly from the oases of Kebili, our study area, i.e. 81% of national production and covering 64% of the total national area dedicated to palm groves (General Directorate for Agricultural Studies and Development, 2020, 2021). In Kebili as in all the Tunisian oases, the water resources come mainly from the exploitation ofunrenewable aquifers that could not be recharged. The management of these sources is important since they represent 34% of the underground water resources of Tunisia (Sghaier, 2010). Today, the exploitation of groundwater exceeds the capacity of water resources. The oasis aquifers of Kebili are exploited between 205 to 228% of their recharge capacity (Ministère de l'environnement et de développement durable and Direction générale de l'environnement et de la qualité de la vie, 2015). The management of this resource at the local level also represents a problem. Local associations called GDAs (Agricultural Development Groups) are in charge of sharing the water resources (Oases Associations Network, 2022) and they manage also the irrigation as water turn allowed to each farmer and from public drilling. The water turn is a distribution and sharing of water tool and where the water availability for growers could be fixed, modulated, and arranged in time and frequency and requires defining a valve operation schedule and a watering schedule. The time between irrigations by water turn is usually long and with low irrigation frequency in the governorate of Kebili, and was about one irrigation per month in 66% of oases and only 24% of oases in Kebili could irrigate twice a month (Elbekkay et al., 2016). These high gaps between irrigation could make oasis agroecosystems in crisis and decline and make them vulnerable to many threats that weigh on their future and raise the question of their sustainability. For that, we, carried out a field survey to investigate the impact of water availability and the irrigation frequency on the agrobiodiversity level of oases in Kebili

MATERIALS AND METHODS

Study site and survey

This study was carried out in September 2020 in the Kebili region located in southeastern Tunisia. A survey was performed on a random sample of 52 plots, and sampling was focused on family farming. The plots were located in the different oases of Kebili, such as Oum Somaa, Fatnassa, Ghidma, Sabria, Douz Nord, Nouaiel, Tarfaya Tambar Kelwemen, Blidette and Rjim Maatoug. The survey allowed us to gather data on agricultural practices and crops, including layers number, number of other species grown with date palms, irrigation system, irrigation water source, and irrigation frequency.

Data analysis methods

The Pivot Table method was used to analyze data and responses collected from the survey by computing frequencies and percentages while crossing the variables using functions in two packages, "tidyverse" (version 1.3.1) (Wickham, 2021) and "questionr" (version 0.7.7) (Barnier, 2022). To assess the correlation between the crossed variables, a Pearson's Chi-squared (Chi-2) test was used. A Multiple Component Analysis (MCA) was also carried out to characterize the study plots and to suggest a statistical typology for them. The MCA analysis was implemented by functions of the two packages "FactoMineR" (version 2.4) (Husson et al., 2020) and "Factoshiny" (version 2.3) (Vaissie et al., 2020). All these analyses were performed using the R programming environment (version 4.1.2) (R Development Core Team, 2021) that includes all functions of the used packages.

RESULTS

Although the organization of the plot did not differ with the water irrigation source (p-value of Chi-2= 0.4636 > 0.05), the plots that were irrigated by water turn (almost 80%) are organized in one and two layers while those irrigated with both water turn and drilling are mostly (88%) organized in two and three layers (Figure 1).

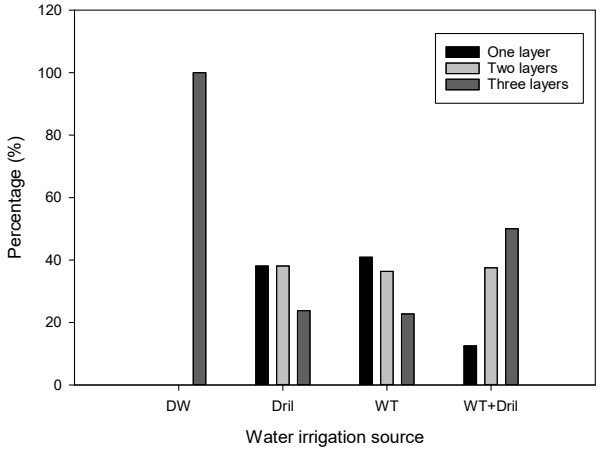

Figure 1 Cross between water irrigation source and the number of layers with DW: Drainage water and which is water recovered from the drainage channel, Dril: Drilling; WT: Water turn

Our results showed a statistically significant association between the irrigation frequency and the number of layers in the studied plots (p-value of Chi-2= 0.03402). The number of layers increases with the irrigation frequency (Figure 2, A). Plots that were irrigated less than one time a month are likely to be organized only on one or two layers while those that are irrigated 4 times or more a month are organized more on three layers (Figure 2, A).

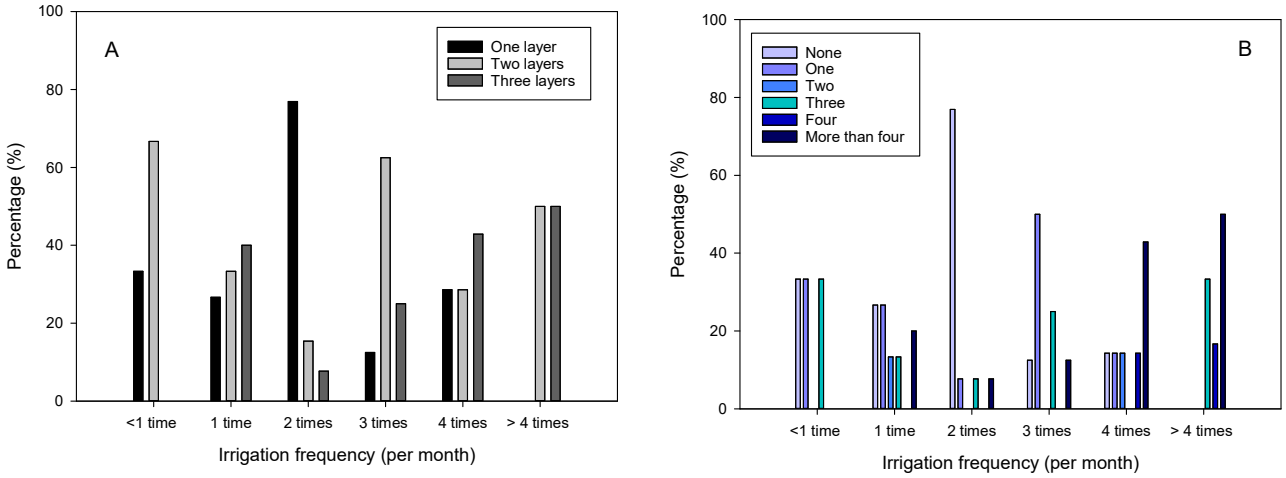

Figure 2 Cross between irrigation frequency and (A) layers number in oasis plots or (B) the species number grown with date palm in the plots

Moreover, the frequency of irrigation per month and the number of species grown with date palm were found to be significantly associated (p-value= 0.04804 <0.05). The more the frequency of irrigation per month increases, the more the number of species grown with the date palm increases (Figure 2, B). The plots that were irrigated more than 4 times a month are those that could be growing by at least three species with date palm while those that were irrigated less than 3 times per month have the lowest agrobiodiversity level and were grown mostly by only date palms (Figure 2, B). Growers were not encouraged to grow many species with date palms due to low water availability and high gaps between irrigations that could cause mortality for fruit trees and annual crops and therefore agrobiodiversity losses.

The results of the MCA analysis aimed to characterize the studied plots related to the irrigation showed that the number of species grown with date palm per plot, the layers number, and the irrigation frequency were the discriminant factors (p-values<0.001) (Figure 3, Variables graph). Irrigated 3 times or more per month by drilling, drainage water or water turn and drilling, using a drip or mini valve irrigation system, characterized plots organized into two and three layers and have one or more species grown with date palm. While irrigated between 1 time and twice a month by water turn using flood irrigation and mini valve, characterized plots organized into one layer with only date palm (Figure 3, MCA graph by modalities). The confidence ellipses around the barycentres are medium-sized and do not overlap, which indicates that the subpopulations are significantly separated. (Figure 3, MCA graph by individuals). This shows that plots are significantly different according to the source of water irrigation.

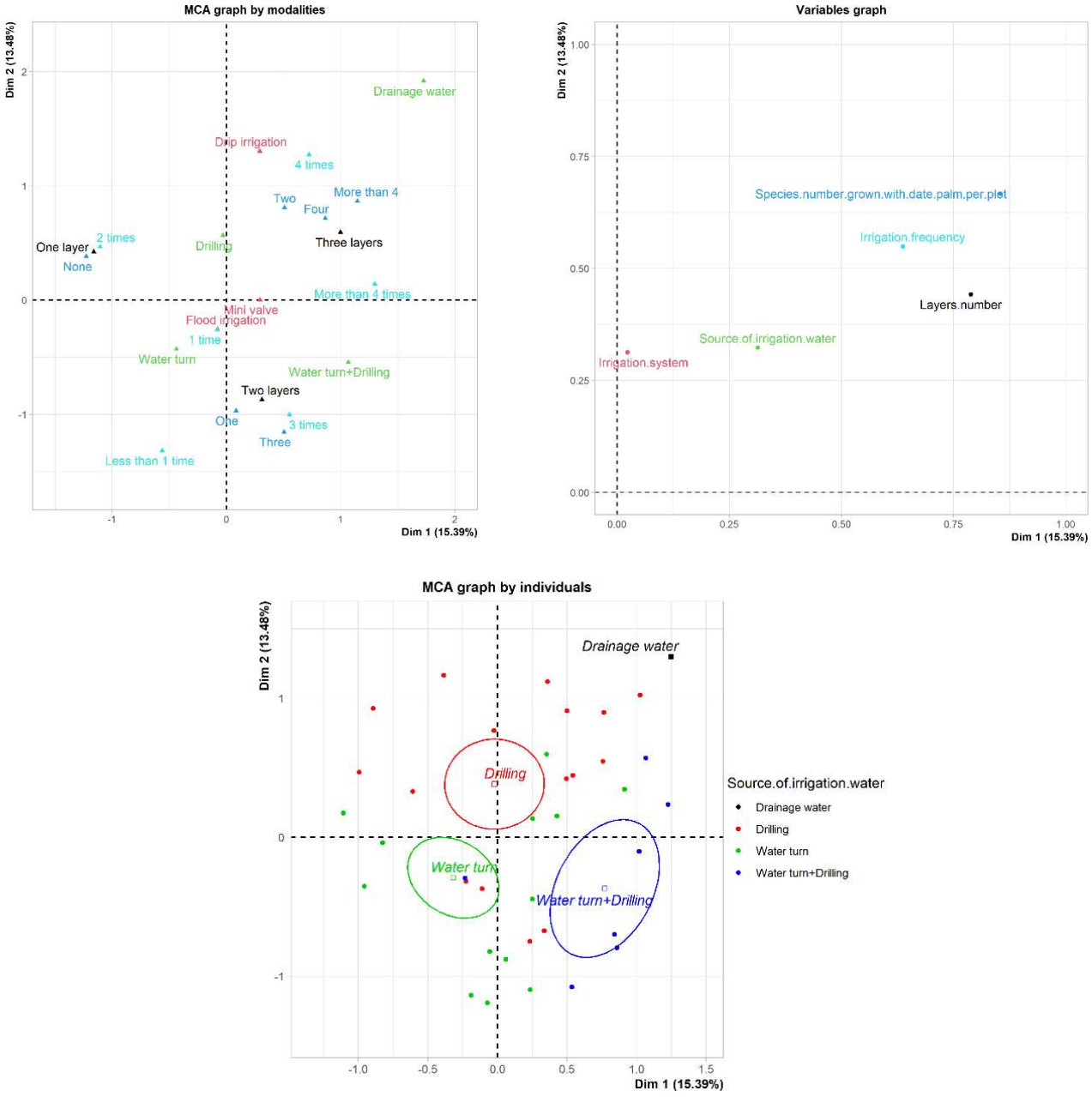

Figure 3 Multiple Component Analysis (MCA) representing characteristics of the studied plots and in relation to irrigation

DISCUSSION

Our results showed that the agrobiodiversity level was associated with water availability. The plots that were irrigated at least 3 times a month were those growing by other species other than date palms such as fruit species, cereals, vegetables, forage crops, and industrial and aromatic plants. While those that relied on water turn and with very low irrigation frequency (less than twice a month) lost their agrobiodiversity and where vegetables and cereals are becoming impossible to grow. Similarly, Peano et al. (2021) noticed in the oases of GDA El Erg in El Hamma (Southern Tunisia) that farmers were discouraged to grow vegetables due to the reduced water turn frequency, especially in summer. Indeed, water and oasis have a fundamental relationship, where the notion of the oasis is related to the presence of water. Since oases are defined by the

substantial and distinct existence of vegetation due to the control of irrigation and drainage system (Veyrac-Ben Ahmed and Abdedayem, 2017). An oasis is a common area for several usages and functions, where frequent elements are water/man/vegetation (Kassah, 1996, 2002; Veyrac-Ben Ahmed and Abdedayem, 2017). Moreover, the establishment of the oasis system could not occur without meeting a set of conditions such as the necessity of the available technical knowledge related to the control of water capture (by drilling wells, drilling foggara, spreading of water from a river, etc.), its distribution and economy (Battesti, 2005). In such areas as Kebili, where the rainfall rate is very low and surface water is limited, irrigation is still mandatory to grow crops and to preserve moisture levels in the soil (Veyrac-Ben Ahmed and Abdedayem, 2017). However, in Kebili region, irrigation water comes from the exploitation of the underground water resources of the Continental Intercalaire and the Complexe Terminal, which are fossil and non-renewable aquifers. Therefore, it presents unsustainable irrigation water source.

Our results revealed that a severe lack of water can profoundly change the landscape of the oases, turning from a traditional agricultural oasis multi-layered to a monoculture oasis with only date palms. In Kebili, faced with this situation, farmers have no choice other than to preserve the water source to maintain an acceptable level of biodiversity and the layered cultivation on which the oases have been based since their creation. Our results showed that the agrobiodiversity level is linked to the water source in the oases. The results of Benmoussa et al., (2022) showed that old oases ("traditional" oases) which relied on water turn have lost their agrobiodiversity and tend toward monoculture while the new oases ("modern" oases) are irrigated by drilling or by both drilling and water turn are more and more organized on two and three layers and therefore tend toward a gain of agrobiodiversity. Since, the groundwater governance system, in its formal and informal components, is one of the key factors in the sustainability and robustness of farming methods as oasis systems, i.e. their adaptive and maintenance (Daoudi and Lejars, 2016). A better irrigation schedule should be used by growers to improve water use efficiency andprevent agro-biodiversity losses. In fact, during the 2021-2022 season, we have installed capacitive probes to instantly measure soil moisture and follow irrigation management in different plots with one layer and three layers. The results showed that when water turn is used, growers tend to irrigate much more than needed and more than 50% of the irrigation water is wasted in the deep soil layers (Unpublished data). Therefore, it could be possible to reduce the irrigation time and shorten the intervals between irrigations, leading to a better water use efficiency. Moreover, the use of water-saving techniques such as drip irrigation and avoiding flood irrigation which promotes wastage and often water stagnation should also give some solutions to the growers. Improving water control in oases requires a more economical and rational use of the resource (Jouve, 2012).

The presence of date palm and crops or fruit trees is essential in an oasis due to their environmental and social and nutritional performances respectively. The date palm has not only an important role in the protection of growing lands by generating a more moistened microclimate compared to the outside of the oasis but also by minimizing the solar radiation and the drying effect of the wind, while the presence of the fruit species and crops is essential to feed both the family and animals (Veyrac-Ben Ahmed and Abdedayem, 2017). The first performance is what is called the oasis effect or also the "vegetation cooling effect" and this effect enhances the regional microclimate, especially by considerably decreasing the temperature in the oasis region (Feng et al., 2009; Hao et al., 2016). Nevertheless, the oasis agro-ecosystem could be deprived of its complexity and be exhausted while exposed to the pressure of an unfavorable environment and the hazard of climate change (Veyrac-Ben Ahmed and Abdedayem, 2017). Projections of average annual temperatures and rainfall in Kebili, according to the RCP 4.5 scenario, show an increase and a decrease by 2050 and 2100 in temperature and rainfall respectively (Belghrissi, 2018). The increase in temperatures will induce greater water demand due to an increase in evapotranspiration. Since evapotranspiration is the principal action in plant water consumption

(Zhao et al., 2010). Preservation of layered cultivation in oases can limit this phenomenon, as the desert environment oasis could be colder by 2-7°C than their neighboring during the summer (Hao and Li, 2016; Shi et al., 2012). The use and preserving of local and autochthones cultivars is also judicious due to their lower water requirements on one hand and their diversity and adaptive capacity for another hand.

Hence, the availability of water and the use of adaptive practices undoubtedly makes it possible to preserve the sustainability of the farming systems of the oasis environments, from the point of view of their agro-ecological reproducibility, their economic viability, and their social liveability.

CONCLUSION

The results of our survey showed that water availability and mainly water irrigation frequency are key factors of the agrobiodiversity level of the Kebilian oases. Plots that were irrigated frequently as those using water turn and drilling are mostly organized in three layers and grown by fruit species, vegetables, cereals, forage, medicinal and aromatic crops with date palms. Water-saving techniques, a better irrigation schedule and growing local germplasm and its conservation could be of great interest to sustain the oasis systems' biodiversity, especially facing climate change threats.

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