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Practical and Effective Approach for a Sustainable Agriculture of the Oases of the Algerian Sahara: Case of the Ouargla Oasis

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Abstract
Introduction: The oasis of Ouargla has economic, ecological, and social significance, and it has very significant groundwater potential. At the same time, it is facing conditions that may cause its degradation, even its disappearance. This study aimed to identify these constraints and propose an effective and sustainable solution to these problems. The second objective of this study was to propose an oasis production system which will enable the valorization of water resources, sustainable socio-economic development, and the preservation of the environment.
Method: This is a descriptive and analytical study that was conducted using a survey and measurements of soil, irrigation water, and phreatic aquifer water.
Results: The soils of the Ouargla Oasis are sandy in texture (85% sand) and very salty (electrical conductivity of 3.56 dS/m), and they have very low organic matter content (0.25% organic matter). The phreatic aquifer is very salty (electrical conductivity of 30.13 dS/m) and very shallow (96.16 cm deep). The date palm uses the uppermost layer, which it shares with a few other crops. The irrigation technique practiced is submersion with inefficient drainage.
Conclusion: To preserve Ouargla Oasis against degradation by salinization and waterlogging of the soil, and in order to preserve water and increase farmers' incomes, it is necessary to practice rational water management and crop diversification.
Keywords: Sustainable agriculture, Environmental sustainability, Groundwater, Soil, Phoeniciceae
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Introduction

In the Sahara, life is almost impossible outside the oases. The oasis is defined as cultivated land in desert or semi-desert environment. It is characterized by targeted mobilization of water resources and by the formation of unique ecosystems, resulting from human activity (1). It is in this space that humans subsist and develop various activities. Their diet depends a largely on the products of the oasis and their habitat is linked to oasis resources and by-products (2). The oasis is defined as an integrated development model combining the socio-economic and environmental dimensions (3). It also represents a unique reservoir of biological diversity, traditional local knowledge, and ancestral know-how. The oasis production system is based on the rational management of water and soil resources. The date palm creates a microclimate and ensures a marketable product. These productions are maintained through traditional palm groves (4). Farmers use biological pest control in these palm groves. Similarly, manure is used for soil fertilization. Therefore, phytosanitary products and chemical fertilizers are practically absent in these palm groves. Thus, these oases produce healthy foods that contribute to improving public health. In Saharan areas, the use of irrigation is a necessary practice for all agricultural development. The water supply for crops is mainly based on the exploitation of fossil, non-renewable groundwater extracted by deep boreholes with high flow rates. To be sustainable, agriculture must meet the needs of present and future generations, while ensuring profitability, environmental health, and social and economic equity (5). Sustainable agriculture must promote healthy ecosystems and sustainable management of the earth, water, and natural resources, while ensuring food safety globally. Agricultural sustainability implies a complementary and concomitant management of three dimensional levels: environmental, sociological, and economic (6).

The palm grove of the Ouargla Basin is one of the largest oases in the Algerian Sahara. It covers an area of 5,000 hectares (7). It has high potential for the production of dates and contains significant underground water reserves. At the same time, it faces problems and constraints related mainly to the rise of the phreatic water table, which has caused soil degradation through salinization and waterlogging, leading to the asphyxiation of crops. The significant increase in irrigation flow rates, combined with mismanagement of water resources, has led to considerable groundwater losses. According to Amrani (8), the inputs of water by irrigation can reach 45000 m^3/ha/year, while IDAS recommends 12500 m^3/ha/year, which means that there is an excess of 32500 m^3/ha/year. The large quantity of water from flood irrigation has caused the phreatic aquifer to rise despite the presence of a drainage ditch network. The excess quantities of water have accelerated the deterioration of environmental conditions and balances in the Saharan ecosystem (9). These environments are already weakened by very salty and often shallow surface aquifers, as well as by topographical conditions that do not facilitate water evacuation. These environments, which had always functioned as closed and well-balanced systems, are now suffering from excess moisture (10). According to Salhi (11), the rise of the phreatic aquifer in the palm grove of the Ouargla Basin has caused damage to its agro-system, resulting in the dieback of thousands of palm trees and the destruction of annual crops due to asphyxiation and high salinity. In the past, these systems functioned as balanced ecosystems, with the date palm forming the upper stratum, underlying crops (forage, vegetables, etc.), and livestock. Today, because of flood irrigation, farmers have often abandoned the underlying crops to prioritize date-palm cultivation. These practices have had negative repercussions on fodder production and, consequently, on livestock. These systems are simple compared to natural ecosystems and are therefore fragile and unstable. However, the rational management of these agro-systems for sustainable production implies that their functioning should be as close as possible to that of natural ecosystems through diversification of plant and animal species.

The objective of our research was to find an effective and sustainable solution to the problems of the rising phreatic aquifer in the Ouargla Oasis, in order to safeguard this disappearing ecosystem. The second objective on this present study was to propose a sustainable oasis production system based on plant and animal diversity, which would allow a valorization of water resources and sustainable socio-economic development of the study region.

Materials and methods

Study area

This study was carried out on the oasis of the Ouargla Basin, located in southern Algeria, about 800 km from the capital Algiers. The oasis of Ouargla is one of the main oases of the Algerian Sahara. It situated within a vast sedimentary basin. Ouargla (31°57'47" N and 5°20'31" E) is limited to the north by the Wilaya of Touggourt, to the west by the Wilaya of Ghardaia, to the south by the Wilayas of Tamanrasset and Illizi and to the east by the Wilaya of El-Oued and Tunisia (Figure 1). The palm trees are planted in the lowlands of the basin at an altitude of approximately136 meters. Geomorphologically, there are flood-prone areas consisting of sebkhas and chotts. During the Neolithic Period, this sebkha functioned naturally thanks to groundwater contributions (12). These depressions serve as outlets for the phreatic aquifer. From a climatic point of view, the Ouargla region is located in the mild Saharan bioclimatic zone marked by an almost permanently dry period that extends over all months of the year. The maximum and minimum temperatures are respectively 43.5 °C recorded in July and 4.8 °C in January. Rainfalls are rare and average 38 mm. The annual evaporation is very high, reaching an average of 3320 mm. In Ouargla, as in everywhere else in the Sahara, water resources are from an underground origin. These resources include two major aquifers (13):

- The intercalary continental, an Albian aquifer which extends over an area of 600,000 km^2 and is exploited at a depth of between 1100 and 1200 meters.
- The terminal complex covers an area of 350,000 km^2 and is composed of a Mio-Pliocene aquifer known as the sand aquifer and a Senonian aquifer known as the limestone aquifer.

The main objective of our study, which covered 120 farms, was to understand the production, irrigation, and drainage systems practiced in the Ouargla palm grove in order to identify the constraints arising from these practices. The collection of information was carried out in the different municipalities of the Ouargla Wilaya (Figure 2) through six representative areas (Table 1):

Similarly, to highlight the main causes of degradation of this agro-system and possibly to propose solutions for its sustainability, we conducted measurements on the phreatic aquifer, irrigation water, and soil (Table 2). Finally, to highlight the most influential variables affecting soil salinization risk, we used a principal component analysis (PCA) with a matrix of 6 variables. Among the variables considered, we included:

- Electrical conductivity of the phreatic aquifer: ECpl
- Depth of the phreatic aquifer: Dpl
- Electrical conductivity of irrigation water: ECiw
- Electrical conductivity of soils: ECs

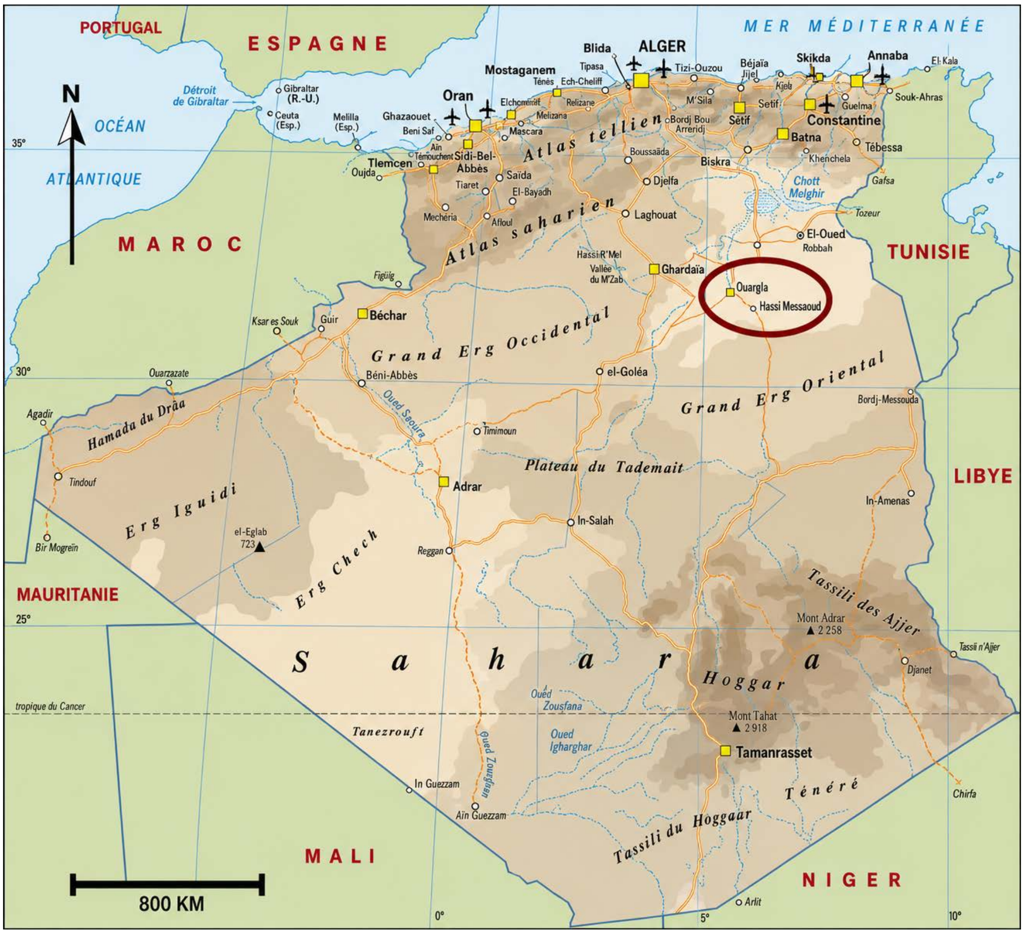

Figure 1. Location of the study area

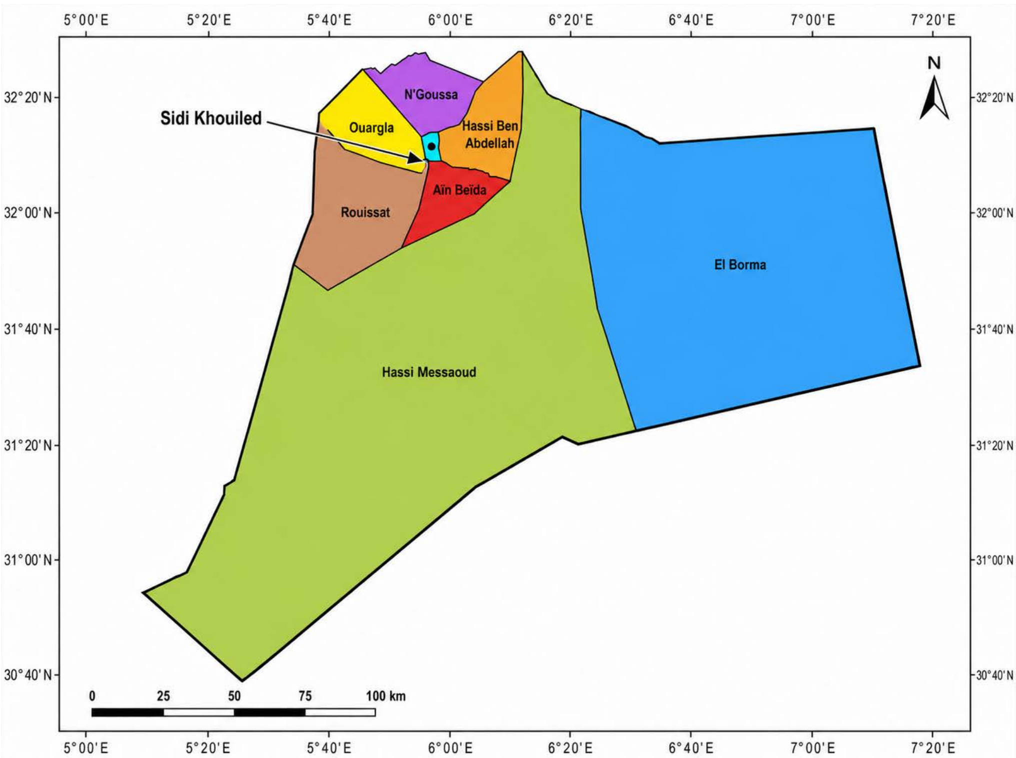

Figure 2. Municipalities of the wilaya of Ouargla

- The percentage of coarse sand: CS
- The percentage of fine sand: FS
- The percentage of silts + clays: S + C
- The organic matter content: OM

This principal component analysis was performed using XLSTAT software.

Table 1. Areas surveyed by municipality

Municipality	Areas
Ouargla	Ksar Mekhadma Bamendil
Rouissat	Rouissat
Ain Beida	Ain Beida Chott

Table 2. List of characters and variables measured

Measured characters and variables	Number of farms surveyed
1-Production system	120
2-Irrigation system	120
3-Drainage system	120
4-Irrigation water -Electrical conductivity	50
5-Phreatic aquifer -Depth -Electrical conductivity	50
6-Soil -particle size analysis -Electrical conductivity -Organic matter rate	50

Results

Production system

The production system of the palm grove of the Ouargla Basin is based on the cultivation of palm trees, which constitutes the upper stratum and creates a microclimate favorable to the development of annual crops. The results of our survey on the cultivation system practiced in the Ouargla palm grove revealed that 67.8% of farmers exclusively cultivate date palms. The remaining 32.2% grow fodder crops (alfalfa, green barley, and forage cabbage), market garden crops (onion, lettuce, beet, carrots, turnips, tomato, peppers, chili, watermelon, and local melon), and fruit trees (apricot, fig, and pomegranate) in addition to date palms. These plants are generally grown in submersion basins between rows of palm trees and/or in basins intended for irrigating date palms. Farmers that do not grow annual crops have reported that the irrigation time available to them remains insufficient to irrigate these annual crops. This forces most farmers to abandon annual crops to cultivate only date palms. In addition to date palms and annual crops, some farmers also raise small ruminants (goats and sheep). This type of livestock is ubiquitous in most of the areas studied and constitutes a key component of the oasis production system. It contributes to the production of milk and manure, thus improving the fertility of the palm grove soil. The survey results indicate that 88% of farmers practice goat and sheep farming, with a small number of animals, varying between 1 and 3. This number remains insufficient and is linked to the quantity of forage available in the palm grove. According to most farmers, flood irrigation does not allow them to grow forage crops between rows of palm trees; this is the main cause of reduced forage production. Consequently, this low fodder production constitutes the main cause of the decline in the number of animals raised in the palm grove. Moreover, our field surveys have revealed that cultivation in the oasis of Ouargla is traditional type, which makes it low-intensive and low-yield. The date palm, the main crop, yields an average production of 30 kg per palm or 3 tons per hectare, which generates an annual income of 300,000 Algerian dinars (which is equivalent to about 21,000 dollars). Agriculture in Ouargla's oasis cannot guarantee economic profitability, which is one of the primary pillars of sustainable agriculture. Motorized equipment ownership is not common, and no farm has a tractor.

Irrigation system

In the Saharan regions, the use of irrigation is a necessary practice for all agricultural activities and development. Irrigation of the palm groves in the Ouargla Basin oasis is supplied through collective boreholes drilled by the state. The irrigation system consists of a collective borehole and a network of underground and open-air pipes and distribution basins that ensure water distribution. Water sharing among farmers is entrusted to a manager chosen among the experienced farmers. This manager is responsible for distributing water among farmers, operating and maintaining the pump, and paying the electricity costs. In the Ouargla palm groves, irrigation is not on demand. In this management method, water shares are paid for, and the farmer receives water to irrigate his plot for a period of time expressed in hours, spread throughout the month and which can be two, three, or four times depending on the number of shares purchased. Our surveys conducted in the surveyed areas revealed that 98.8% of farmers are served by a collective borehole. Most of the farmers surveyed revealed that they receive water once or twice every two weeks. This shorter frequency, especially in summer, causes water stress for the palm tree and the underlying crops. The irrigation techniques used in all the palm groves of the oasis by farmers are of the traditional type using submersion basins.

This gravity technique consists of making submersion basins one meter wide along the rows of palm trees. Similarly, annual crops are grown in small earthen basins between rows of palm trees. These basins are then fed by a series of earth channels or 'seguias'. This irrigation technique leads to excessive water consumption because the soil is highly filtering and considerable water is lost through infiltration. However, when irrigating palm trees using this submersion technique, farmers do not control the flow rates and there is a tendency towards over-irrigation and the quantities applied during each irrigation are significantly higher than the recommended watering doses for sandy soils. This leads to considerable water losses at depth, which consequently causes the phreatic aquifer to rise. Similarly, the dilapidated state of the irrigation network causes enormous losses of water resources due to breaks in these pipes. These water losses also infiltrate into the soil and reach the shallow and very salty phreatic aquifer, causing it to rise towards the surface horizons of the soil. During the hot period, the water rises towards the surface of the soil by capillary rise and evaporates into the atmosphere, thus causing salt deposits on the surface and in the soil profile.

Drainage system

Agricultural drainage in arid zones aims to lower the phreatic aquifer far from the soil surface. The drainage system in the study area consists of a main open-air collector that encircles the entire basin, as well as primary and secondary collectors. The main collector discharges all drained water to natural outlets represented by sebkhas and chotts. Individual drains located on farms consist of open-air, trapezoidal ditches 1m deep, 0.5 m at the base, and 1 m at the surface. These drains are generally overgrown with weeds and require a lot of periodic maintenance work in order to remove the plants that grow inside these drains and which constitute a real obstacle to the flow of water in the drains, making them inefficient. Our observations revealed that these drains are not cleaned by farmers as they require very arduous work and constant maintenance; as a result, they are often ineffective and non-functional. Only the main collectors are periodically maintained by the State. The Ouargla Basin palm grove has undergone drainage cleaning programs in the past. Although these agricultural drainage development projects and programs have mobilized a lot of human and financial resources, they have not solved the problems of rising phreatic aquifer. Reality shows that drainage can in no way stop the rise of the phreatic aquifer and resolve the problems of salinity and water logging of the soil in the Ouargla Basin because of the very flat relief with a very flat slope of the order of 1% and the distance from the outlets (distance exceeding 20 km).

Environmental constraints

To highlight the main hydro-edaphic constraints that cause the degradation of the palm groves of the Ouargla Basin oasis, we carried out measurements on the soil, irrigation water, and the phreatic aquifer (Table 3).

The soil of the study region is characterized by a sandy texture, with about 85% coarse and fine sands, a very low organic matter content of around 0.25%, and high salinity, reaching an average of 3.56 dS/m. The classification of Durand (14) indicates that this water has high salinity. The soils of the Ouargla Basin are irrigated with water that has an average salinity of 3.48 dS/m. Flood irrigation on sandy and highly permeable soils has caused a rise in the groundwater table throughout the Ouargla Basin.

Our measurements, which covered all the surveyed areas, indicated an average groundwater depth of 96.16 cm. This groundwater is highly saline, with an average electrical conductivity of 30.13 dS/m. The widespread presence of this shallow and highly saline groundwater in all the palm groves of the Ouargla Basin has led to detrimental effects, causing soil salinization and waterlogging.

Principal component analysis (PCA)

To identify the variables that most strongly influence soil salinity, we performed a principal component analysis. We retained the first plane (F1 and F2), which explains 80.38% of the total inertia. The correlation circle is shown in Figure 3.

According to the position of the variables, it appears that the variables most related to the salinity of the basin soils are, in order:

- The depth of the phreatic aquifer;
- The electrical conductivity of the phreatic aquifer;
- A fairly good correlation with the electrical conductivity of irrigation water;
- An average correlation with the percentage of fine and coarse sands;

Discussion

Cropping system and livestock system

The results of surveys on the cropping system in the Ouargla Oasis are consistent with those obtained by Bouammar (15) in the El-Ksar palm grove located in the same study area, where he showed that nearly half of the farmers cultivate only date palms. The rest, in addition to date palms, cultivate underlying crops in very small areas. These crops are largely intended for self-consumption. Agriculture in the oasis of Ouargla is considered traditional and low-intensity, which leads to low yields. This observation is confirmed by Chaouch (16) who showed that these palm groves are unproductive and unsustainable due to poor irrigation practices that deplete water resources. The possession of domestic livestock is tradition among the inhabitants of Ouargla. This livestock consists of goats and sheep in very limited numbers (1 to 3 heads). Milk and milk products are produced for self-consumption. This finding is confirmed by Boummada

Table 3. Hydro-edaphic characteristics

Variables	KSAR	Mekhadma	Rouissat	Ain-Beida	Chott	El-Bour	Average ± standard deviation
Electrical conductivity of irrigation water (dS/m)	3.3	3.3	3.4	3.6	3.4	3.2	3.48 ± 0.13
Electrical conductivity of phreatic aquifer (dS/m)	29.5	26.2	28.2	32	30.6	34.4	30.13 ± 2.9
Phreatic aquifer depth (cm)	96	101	98	95	95	104	96.16 ± 3.6
Soil electrical Electrical conductivity of soil (dS/m)	3.6	3.3	3.4	3.7	3.6	3.8	3.56 ± 0.18
Soil organic matter (%)	0.5	0.2	0.1	0.1	0.2	0.2	0.25 ± 0.14
Coarse sand (%)	65.2	60.7	58.6	58.5	64.2	53.4	60 ± 4.3
Fine sand (%)	22.3	28.5	27.9	26.8	22.0	27.8	25 ± 2.94
Clay + silt content	12.5	10.5	13.5	15.7	13.8	18.8	15 ± 2.85

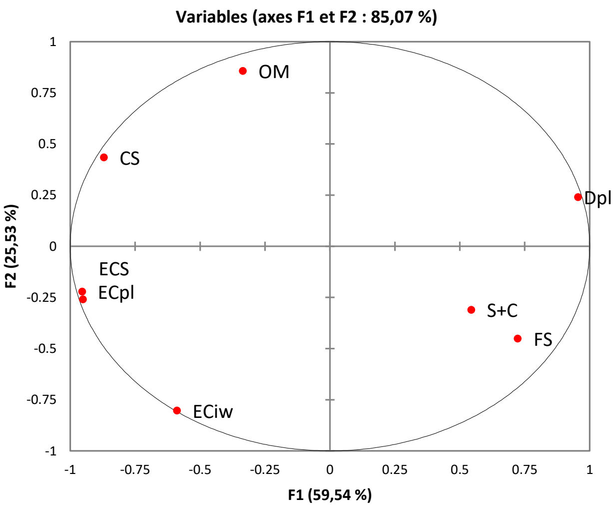

Figure 3. Representation of variables on the correlation circle

(17) in a study carried out in Ouargla and Oued-Souf, located 240 km from Ouargla.

Irrigation technique

Our study on the irrigation system in the Ouargla Oasis revealed that irrigation is carried out with very salty waters and from collective wells and that the most practiced irrigation technique is submersion. This observation is confirmed by Salhi (11) in a study carried out in the Ouargla Oasis. The practice of this irrigation technique causes considerable water losses. This excess water reaches the shallow phreatic aquifer and causes it to rise. The quantity of water lost by this technique is estimated at 12,712,489 m^3/year (18). Similarly, according to Chabacca (19), the obsolescence of the irrigation system causes losses estimated at 20%; the supply channels themselves cause losses in the order of 30%. All these losses are the main causes of the rising phreatic aquifer. To prevent this and combat salinization and water logging, specialists recommend installing a drainage network. According to El-Fergougui (20), drainage can only be effective and eliminate the accumulation of salts in the soil if the piezometric level exceeds 1.7 meters. Given the topographical conditions of Ouargla and the distance from the outlets, drainage will in no case be able to lower the phreatic aquifer to more than 1.7 meters.

Hydro-edaphic characteristics

The phreatic aquifer is characterized according to our results by a very shallow depth and very high salinity. These results confirm those obtained by Daddibouhoun (21) in a study carried out in the oasis of Ouargla. In this study, this author shows that the phreatic aquifer was in most cases very shallow, with an electrical conductivity ranging from 10 to 39.7 dS/m. Similarly, our results on soil salinity are consistent with those obtained by Idder (22) in the Ouargla Basin, which indicates that the electrical conductivity of the different soils of the Ouargla Basin are excessively high, exceeding 5000 mS/m. From a pedological point of view, our results show that the soils studied contain 85% sand and an organic matter content of around 0.25%. Khadraoui (23) reports that the Ouargla Basin is characterized by sandy-textured soils that are very poor in organic matter. This soil composition and the phreatic degradation phenomenon have led to very serious consequences, including the asphyxiation of palm trees and other crops as well as a drop in production.

Fight against rising of phreatic aquifer

The oasis of the Ouargla Basin is renowned for its significant phoenicicultural potential and its enormous underground water reserves. At the same time, it is experiencing constraints that hinder its development and contribute to its degradation. These constraints are linked more particularly to the poor management of water resources, which has caused a rise in the piezometric level of the phreatic aquifer. This phenomenon has led to a degradation of the palm groves through water logging and soil salinization. The implementation of measures and solutions to end this constraint requires a brief historical review of water resource management. According to Rouvillois-Brigol (24), the Mio-pliocene aquifer was artesian, and its exploitation dates back to a very remote past. This phreatic aquifer gave rise to the entire Ouargla palm grove. This gushing water, despite its low flow, made it possible to meet the water needs of the palm trees and the underlying crops. Drainage was not necessary at that time and there were few problems with rising phreatic aquifer. However, the use of pumping since the colonial period and after the country's independence has caused disturbances in the oasis. These disturbances resulted in a rise in the phreatic aquifer resulting from the manipulation of large flow rates by operators while maintaining gravity irrigation by submersion on highly filtering soils. With this gravity irrigation technique, the farmer applies quantities of water (4500 mm), which is significantly higher than the net doses recommended for date palm by the Technological Institute for the Development of Saharan Agriculture, totaling 1250 mm per year. This excess water seeps into the soil, reaches the phreatic aquifer, and causes it to rise. In light of this historical observation, lowering the phreatic aquifer to a sufficient depth to prevent both water logging and salinization of the soil must first begin with the reduction of water wastage to avoid replenishing the phreatic aquifer. To achieve this, we should replace the outdated gravity network with a pressurized irrigation network and introduce new irrigation techniques such as water-saving drip and sprinkler systems, where the farmer can manage low flow rates and control the watering doses. These methods are extremely effective and simple to use on small farms, such as those in the Ouargla palm grove, and will prevent 70% of water losses. The availability and relatively low prices of rigid PVC or high-density polyethylene (HDPE) pipes should undoubtedly encourage public authorities to launch development programs to install plastic pressure networks in order to preserve this very precious water resource. Experience from many arid and semi-arid countries indicates that pressure pipe irrigation techniques are successfully replacing traditional open canal irrigation methods at farm level (25). With this method, and unlike gravity-fed irrigation by submersion, the farmer will be able to handle low flow rates, as was the case in the era of artesianism. This will consequently eliminate the recharge of the phreatic aquifer. Determining irrigation doses and frequencies is also one of the most important factors to consider avoiding water waste. In this regard, we can refer to the water management computer program proposed by the FAO. This program, called CROPWAT, is an irrigation management assistance program. This can solve the problem of water waste, which is the main cause of the rise in the phreatic aquifer. This phreatic aquifer contained in the alluvial sands of the valley has the Sebkhat Sefioune as its outlet. Around the palm groves of Ouargla, there are also two other outlets: the chott of Ain Beida and the chott of Oum Raneb (26). These depressions reach a surface area of 25,000 hectares and constitute real evaporation sites. Estimates of evaporation from water bodies in arid zones are of the order of 2386 mm/year (27). As a result, these depressions could potentially evaporate more than 596 million cubic meters per year. Adopting such a solution can successfully replace the ditch drainage network and will consequently prevent the phreatic aquifer from rising.

Conservation of biodiversity

Oasis agro-biodiversity constitutes an important pillar for promoting sustainable agriculture. However, the application of sprinkler irrigation techniques, unlike submersion irrigation, will allow the exploitation of spaces between the rows of palm trees, which will lead to diversification and an increase in plant (fodder, market gardening, industrial crops, and fruit trees) and animal production (goats and sheep). These plant and animal products will certainly contribute to farmers' income. Livestock farming will therefore constitute a main component of the oasis production system. It will contribute to the standard of living of households through the provision of milk and meat and will also constitute a source of manure for enriching soils with humus. Livestock farming within palm groves also contributes to the valorization of fodder resources available at the farm level. The work of Chehma and Longo (28) on the valorization of agricultural by-products showed that Algerian palm groves offer an appreciable tonnage estimated at 135000 tons of dry palms, 5000 tons of date stalks, and 67500 tons of date waste. The exploitation of date palm by-products for animal feed will constitute an opportunity to develop the breeding of small ruminants in palm groves. The development of livestock farming and date production must automatically lead to the creation of milk processing units and the production of specific products (vinegar, alcohol, ointments, juice, sugar, handicrafts, etc.) from dates with low market value. The main phenomenon is that the local population has always had a potential demand for date products and goat's milk, which are highly appreciated. In addition, these products are highly sought after and sell at a good price. This will consequently lead to an increase in farmers' income, leading to overall socio-economic development, and will contribute to meeting the food needs of the local population.'

Conclusion

In Saharan areas, the use of groundwater resources is a necessary practice for any agricultural development activity. However, inefficient irrigation practices have caused significant losses of this precious and non-renewable resource and have resulted in a rise in the highly saline phreatic aquifer, which has led to waterlogging and soil salinization. This has caused ecological imbalances that were once well maintained.

The preservation of these fragile systems requires the rational management of irrigation water to prevent the phreatic aquifer from rising. This management must also involve the introduction of modern irrigation techniques, such as drip irrigation and sprinkler systems. The production system practiced in the Ouargla Oasis requires reconsideration in order to conserve and enhance water and soil resources and encourage farmers to diversify their production. This will make it possible to preserve these fragile systems and contribute to the improvement of household incomes and socio-economic development in the region.

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Competing Interests

There are no conflicts of interest associated with this publication.

Ethical Approval

No ethical issues were encountered during the writing of this article. The data presented are original and were collected in the Ouargla oasis. The authors certify that this article has not been published previously and is not currently under consideration by another publisher. No animals were used in this study.

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