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Abstract

Groundwater resources are a crucial driver of development. Since the 1970s, the expansion of irrigated land on the margins of the existing 'traditional' oases has been encouraged by the Tunisian authorities to enhance local development. As a result, oases in Southern Tunisia are currently facing sustainability concerns. This situation requires alternative water management approaches, in which local actors collaborate and contribute to the design of new rules. To understand Tunisian oasis farmers' perceptions of water rules and public organisations, in 2021, we conducted an online survey in Jemna, an oasis in the Kebili region in Southern Tunisia. The picture that emerged from the online survey is that farmers in extension areas have distinctive characteristics but also similarities with farmers in the traditional oasis. Both types of farmers mainly cultivate date palm (monoculture), and, like farmers in the extensions, many farmers in the traditional oasis have a private borehole. All farmers in the Jemna oasis clearly perceive the limited availability and poor quality of the groundwater resource. However, they do not believe these problems cause conflict among farmers. They consider that, to solve possible conflicts and to ensure better water management in the oasis, collaboration among farmers is more effective than changes to rules issued by existing organisations. These preliminary results, if confirmed, can have important policy implications, as the farmers' perceptions of water rules and organisations, as well as farmers' willingness to collaborate, are crucial for a possible new approach to water management in the oasis.

Keywords: *Farmers' perceptions, Institutions, Oasis, Public organisations, Rules, Tunisia, Water management.*

1. Introduction and rationale

Today, groundwater resources are a crucial driver of development (Shah, 2009; Shah *et al.*, 2007). A large proportion of food production systems and consequently food security, depend on them. Groundwater exploitation has enabled improvement of local living conditions in many arid and semi-arid areas around the world, but also promoted agricultural practices that require irrigation (Changming *et al.*, 2001; Konikow and Kendy, 2005; Ross and Martinez-Santos, 2010).

The intensification of irrigated agriculture, fostered by policies aimed at improving local livelihoods, led to the emergence of what is called the 'groundwater economy' (Kuper *et al*., 2016; Amichi *et al.*, 2015). Recent trends are now jeopardizing groundwater resources in many areas, lead-

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ing several authors to talk about the 'collapse' of some groundwater economies (Petit *et al.*, 2017).

Groundwater is an example of a Common Pool Resource (CPR) (Ostrom, 1990), which need appropriate local policies and rules to avoid overexploitation and depletion, that can be irreversible and ultimately cause the collapse of the entire system.

Oases are 'exceptional entities' (Fassi, 2016) where groundwater availability and peculiar ecological conditions are met, which allow humans to live and practice agriculture in very arid zones, such as deserts. In the past, oases have proven their ability to adapt and shown their resilience in the face of harsh conditions (Fargette *et al.*, 2016). Their role in the development and management of arid zones is widely recognized (Kassah, 2009). At the same time, maintaining the delicate balance among the different components of these fragile socio-ecosystems requires integrated management of the resources, including groundwater, to ensure sustainable development (Fassi, 2016).

Recent studies (Trigui *et al.*, 2021) show the growing stress to which the complex terminal aquifer in Kebili, Southern Tunisia, is subject. This stress is mainly due to demographic and agricultural developments. According to the authors, since the 1950s, the region has experienced a perpetual evolution of the number of deep boreholes exploiting the aquifer to meet the growing water needs. The growth of domestic and productive water uses "has caused a considerable intensification of water exploitation which rose from 47.40×10^6 m^3 in 1950 to 297.77×10^6 m^3 in 2015. […] The excessive increase of exploitation resulted in a change of the hydrodynamics of the aquifer" (Trigui *et al.*, 2021).

The oases in Southern Tunisia have a very long history. In the distant past, access to water resources was collective (Mekki *et al*., 2013) and free of charge. Traditional community level assemblies defined management rules and resolved conflicts. In 1885, the Tunisian government appropriated springs and became the sole owner of oasis zones (Attia, 1983). In the past half century, the Tunisian government has implemented a variety of policies to incentivize local development through more intensive use of natural resources (Attia, 1983). The land reform between 1964 and 1969 imposed collectivist organisation, and the 1975 water code completed the transfer of water ownership to the State (Brochier-Puig, 2004). In addition, in the last 50 years, water users associations were created and progressively started to collaborate with regional organisations, named CRDA (French acronym for the Regional Agricultural Development Commission) (Mekki *et al.*, 2013). Water users associations, today called GDA (French acronym for Agricultural Development Groups), originally functioned under public directives and control, but underwent several changes in status and in their mandates over time. In particular, there was a progressive transfer of responsibilities to farmers and increased involvement of the members of water users associations in collective water management.

Many GDA experienced from the beginning a number of problems, such as the lack of acknowledgment by the member farmers of the GDA water management capacity (Farolfi *et al.*, 2018). Farmers consider often GDA as a simple tax collector. This resulted in weak commitment by member farmers in the functioning of the organisation, and often in their unwillingness to contribute financially to it through the payment of water fees. As a consequence, many GDA face today serious financial problems and cannot implement properly water management actions. Moreover, a recent study (Mahdhi *et al.*, 2021), points out the inefficiency of GDA in Tunisia, resulting from both management and engineering factors.

Since the 1970s, the expansion of irrigated land on the margins of the existing 'traditional' oases has been encouraged by Tunisian authorities in order to enhance local development, particularly the production of the internationally renowned Deglet Noor date, the main local product (Ghazouani *et al.*, 2009). However, expansion exceeded the government's expectations through the digging of 'illicit' boreholes by private farmers, and to continued planting of increasing numbers of date palms. As a result, oases in Southern Tunisia are currently facing sustainability concerns due to "uncontrolled expansion of irrigated areas, overexploitation and degradation of groundwater resources, and soil degradation" (Ghazouani *et al.*, 2009; Mekki *et al.*, 2013).

This situation raises a number of questions. How should public policies be revised to tackle overexploitation of oases in Southern Tunisia (Mekki *et al.*, 2013)? Are GDAs the appropriate entity to manage groundwater resources? Can alternative management approaches, as proposed by Petit *et al.* (2017), improve local groundwater management? And particularly, is there a potential for endogenous governance systems (Ostrom, 1990), e.g. the establishment of rules and institutions emerging through the water users' cooperation, that could complement the public sector's water management framework?

To assess the potential for introducing new water management pathways in Tunisian oases, we have to understand farmers' perceptions of and attitudes to existing water management systems, rules and public organisations,[1] their willingness to cooperate as well as their attitudes to other farmers' practices and water uses. The exploratory nature of this work did not call for an attempt to deeply understand the current formal and informal rules. The goal was rather to get a rapid assessment of local farmers' views on the GDA institutional setting, ask whether or not they consider it appropriate for local water management, and whether arrangements among farmers can be useful.

Hence, the objective of this study, undertaken in the framework of the IDES research project[2] is twofold. The first aim was to identify the profile of farmers who have plots in both traditional and extension areas of a typical Tunisian oasis,[3] to check for possible differences in the farming models, and consequently, in water uses, in the two zones. The second aim was to understand farmers' perceptions of water problems and possible remedies, to understand whether there is room in Tunisian oases for new water management approaches originating from cooperation between farmers and the co-construction of rules.

To achieve these aims, in 2021, we conducted an online survey of 65 farmers in both the traditional oasis and extensions in Jemna oasis, Kebili region, Southern Tunisia. Information was collected on farm structure and dynamics, water uses, the farmers' perceptions of water governance rules and organisations, and analysed to understand the attitudes of local farmers towards the current water management system, and their potential willingness to change to more appropriate local water policies.

The survey results showed that farmers with plots located in extension areas have distinctive characteristics but also share similarities with the farmers with plots located exclusively inside the traditional oasis. All the farmers in Jemna oasis clearly perceive the limited availability and poor quality of the groundwater. However, they do not believe that these problems are at the source of conflicts among farmers. They consider that potential future conflicts can be solved more effectively through farmers' informal collaboration than by new rules imposed by existing organisations. Farmers in Jemna oasis are willing to collaborate with other farmers, and have more confidence in collaboration among themselves than they have in the public organisations when it comes to identifying more effective and sustainable water management in the oasis.

The remainder of the paper is organized as follows. In section 2, we describe the study area and the methods used to collect and process the data. In section 3 we present the results of the survey and the estimates of a probit model. In section 4, we discuss our findings and their implications in terms of pathways for new groundwater governance tools and methods in Tunisian oases.

[1] The terms institution and organisation are used here following Bromley (1982). Institutions are collective conventions and rules that establish acceptable standards of individual and group behaviour. Organizations are defined by institutions: the organization is the operationalization of the institutions.

[2] Funded by the Institute for Agricultural Research and High Level Training (IRESA) Tunisia.

[3] While traditional oases today correspond to GDA areas, the term 'extensions' refers to plots established since the 1970s that occupy land at the edge of the traditional oases, and obtain water through illicit private boreholes that are not declared to the local authority for water management (CRDA).

2. Materials and methods

2.1. *The study area*

Jemna oasis is situated in the Governorate of Kebili, Southern Tunisia (33.30°-34.15°N; 8.30°-9.10°E). It is formed of two urban sectors, North Jemna and South Jemna, located in the South Kebili delegation, which occupies an area of 1,182 Km^2 (5.26% of the Kebili Governorate) and has 32,270 inhabitants (INS, 2018) (Figure 1).

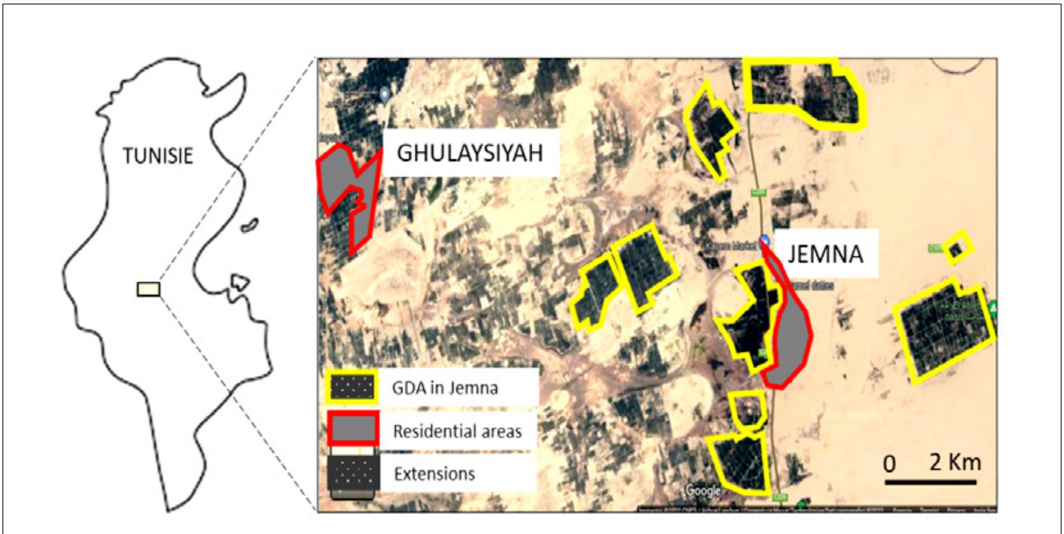
Nine water users' associations (GDA) exist in the oasis. They account for an irrigated area of 747 Ha, and 1,727 member farmers (data provided by the local farmers' association for the development of Jemna oasis and obtained in a study conducted in 2021 as part of the IDES project). Farmers who belong to water users' associations get their water from collective boreholes through a collective distribution system based on water delivery turns, and pay a fee to the GDA for access to water. The GDAs manage the irrigated areas in the 'traditional oasis'. Outside the traditional oasis, new farms have more recently been established and occupy the land at the margins of the existing farms. These farmers get their irrigation water from private boreholes that are not declared to the regional water management authority (CRDA). These farms correspond to what we term 'extensions'. Due to the rapid development of these farms, and to the informal nature of the arrangements underpinning this irrigated land, it is impossible to obtain accurate information on their number and size. The local farmers' association for the development of the Jemna oasis estimated that about 900 farmers only cultivate plots in the extensions of the Jemna oasis. Many farmers who belong to the GDA farm plots in both the traditional oasis and the extensions. In the remainder of the paper, these farmers are referred to as "mixed farmers", while farmers who have plots only in the traditional oasis are referred to as "GDA farmers", and those who have plots only in the extension are referred to as "extension farmers". The first two groups are both members of the GDA.

Like the other oases in the Kebili Governorate, the main product cultivated in Jemna oasis is dates. Monoculture is dominant, but 2-layer (palms and fruit trees) and 3-layer (palms, fruit trees and vegetables) cropping systems are also present.

2.2. *Survey and data analysis*

Due to Covid-19 pandemic constraints, we had to conduct our survey online instead of the originally planned face-to-face survey. A total of 65 farmers, identified through the local farmers' association for the development of the Jemna oasis, responded to an online ques-

Figure 1 - Geographical location of Jemna oasis.



tionnaire directly on their smartphone. The two criteria of selection for our non-stratified sample were to be located in the Jemna oasis and to be able to answer an online survey. The latter criterion influenced particularly the process of sample selection. A list of 89 farmers was provided to the research team, who contacted all of them. 13 farmers did not agree to participate in the survey (rate of rejection of 15%). Additionally, 11 farmers who only had a simple mobile phone could not participate in the survey. This left the team with 65 respondents.[4] Our sample was not built following a randomized or a systematic process. It was rather based on an available and ready-to-use database of farmers. For this reason, our results cannot be considered unbiased and definitive, but rather a first picture from which we can implement further studies.

The 65 respondents of our sample cultivate a total area of 122 ha and represent 2.5% of the total number of farmers in the oasis and 2.6% of the estimated total cultivated area.[5]

Out of the 65 interviewed farmers, 24 only cultivated plots in the traditional oasis ("GDA farmers"), 31 cultivated plots in both the traditional oasis and the extensions ("mixed farmers"), and 10 only farmed plots in extension areas ("extension farmers").

The questionnaire[6] was in Tunisian Arabic and contained 50 closed questions and one open question, the latter was not used in this analysis. The questionnaire was organised in sections around the following topics: general data (membership of the GDA, location of the plots in the oasis, etc.), cropping system, water use and irrigation system, demographic and socio-economic data, and the respondent's perception of the rules, organisations, and governance system of the oasis.

To help us understand the farmers' perceptions of and attitudes to water management in the Jemna oasis, the second part of the questionnaire contained a series of multiple choice statements to which respondents had to answer by choosing one of the following: 1 = I strongly disagree; 2 = I disagree; 3 = I agree; 4 = I strongly agree, corresponding to a four-level Likert scale. We chose to not have a 5-level scale in order to avoid a central tendency bias.

The investigator first contacted each respondent by telephone, and invited him (all the respondents were male) to use his mobile phone or computer to open a dedicated link on a server (Heroku) to complete the questionnaire. After checking the answers, the investigator again contacted each respondent to check the accuracy of the data, correct possible anomalies in the information provided and remove aberrant data.

Anonymity of the data was ensured by a protocol validated by CIRAD personal data protection system, which is based on the European general regulation on personal data protection (Regulation EU 2016/679). The survey was also declared to the Tunisian National Authority for the Protection of Personal Data (INPDP).

[4] Using the formula to calculate the size of the sample in a population where the proportion of the character to estimate is unknown (p=0.5), our sample (65 subjects) would allow to estimate the proportion at a confidence level of 95% with a 12% margin of error.

[5] To estimate the irrigated area in the extensions, we first multiplied the average area farmed by the extension farmers included in our survey (2.5 ha) by the total number of farmers located in the extension areas (900) previously assessed by the association for the protection of the Jemna oasis. This corresponds to an area of 2,250 ha. In the absence of precise data on farm structure in the area, we use information collected through local surveys and interviews to hypothesise that half the farmers who farmed plots in the traditional oasis (GDA members) also farmed plots in the extensions. This corresponded to 863 farmers (rounded to the nearest integer). We estimated that the average size of the plots in the extensions cultivated by mixed farmers was 1.97 ha = 2.4 ha (average size in our survey of a farmer with plots in both areas) – 0.43 ha (average size of plots in GDA according to an IDES study currently underway in Jemna). We then multiplied the two terms (863 x 1.97 ha) to obtain the area cultivated in the extensions by GDA members = 1,700 ha. By summing the two above areas, we obtained the total area in the extensions of 2,250 ha + 1,700 ha = 3,950 ha. This area was then added to the cultivated surface area in the nine GDA (747 ha) giving a total estimated area cultivated in Jemna of 4,697 ha.

[6] Available online in French and in Arabic at: https://newmedit.iamb.it/bup/wp-content/uploads/2022/07/Questionnaire-Jemna.pdf

Table 1 - Age of the farmers, size of their farm and year of beginning of farming for the three groups of farmers in Jemna.

	*Freq.**	*Mean area (ha)*	*Mean age (years)*	*Mean starting year*
Extension farmers	10	2.5	47	2005
GDA farmers	24	0.9	58	1989
Mixed farmers	31	2.4	48	2000

** According to previous surveys quoted in section 2.1, extension farmers represent 34% of the population of farmers in Jemna. Therefore extension farmers are underrepresented in our sample (15%).*

The database resulting from the survey contains 63 variables and 65 observations.

Statistics and tests of significance were conducted to describe the characteristics of the sample and the farmers' attitudes to water management. We then used a probit model (Gujarati and Porter, 2009) to analyse the behaviour of a dichotomous dependent variable (farming plots only inside the traditional oasis vs outside[7]). Probit models make it possible to perform regressions with binary dependent variables i.e. dependent variables that are coded "0-1". These models provide an estimate of the probability that the dependent variable takes the value 1. Probit analyses usually require larger samples to be meaningful. However, given the exploratory nature of our study, we considered appropriate to use this econometric method in this case.

3. Results

We split the sample into three groups that emerged from the survey: 1) farmers who only had plots inside the traditional oasis ("GDA farmers"), 2) farmers who only had plots in the extension areas ("extension farmers"), and 3) farmers who had plots in both zones ("mixed farmers").

3.1. *Population, agricultural production and water use in the traditional oasis and in the extensions*

All the farmers interviewed were men, which is the usual situation in Tunisia. GDA farmers were on average 10 years older than the farmers in the two other groups, their farms are smaller (less than ½ the size of the farms in the other groups), and they began farming more than 10 years earlier (Table 1).

Age was an important factor affecting the willingness of farmers to invest and innovate. Only 17% of GDA farmers were willing to buy an additional plot of land. The proportion rose to 40% for extension farmers and to 61% for mixed farmers. A chi2 test on the frequency distributions showed that the difference between the three groups was significant (p value = 0.005).

All the extension farmers we surveyed declared that agriculture was their main activity. In contrast, 21% of the GDA farmers and 32% of mixed farmers declared that agriculture was not their main activity. In the latter two cases, farmers whose main activity was not agriculture worked in public administration. The educational level of extension farmers and mixed farmers was higher, respectively 30% and 26% had a secondary school leaving certificate, whereas only one surveyed farmer among GDA-farmers had a secondary education. In contrast, none of the extension farmers had received practical agricultural training, whereas 26% of mixed farmers and 33% of GDA farmers had.

The main production system in both the traditional oasis and the extensions is date palm monoculture. Our results suggest that two or three layer production systems that were still present in the traditional oasis a decade ago (Mekki *et al.*, 2013) are now disappearing rapidly, and that farmers in the extensions only grow date palms in simplified cropping systems. According to the survey, 80% of the production systems of extension farmers are date palm monoculture, versus 71% for GDA

[7] In other words, "GDA farmers" vs the combination of "mixed farmers" and "extension farmers".

Table 2 - Number of boreholes per farmer, depth of the borehole, and year of drilling for the three groups of farmers in Jemna.

	Number of private boreholes/farmer	*Mean depth of the borehole (m)*	*Mean year of drilling the borehole*
Extension farmers	1.0	161.0	2009
GDA farmers	0.3	123.6	2008
Mixed farmers	0.7	129.0	2008

farmers and 74% for mixed farmers. Livestock production is not an important source of income in Jemna. Only 24 out of the 65 farmers surveyed raise goats (159 goats out of a total of 347 goats in the sample were raised on one farm), 17 farmers raised sheep (23 sheep out of a total sample of 149 were raised on one farm), and 11 raised chickens (103 chickens out of a total sample of 166 were raised on a single farm).

Farmers in the extension areas only get water from private boreholes. One third of the GDA farmers interviewed claimed to have a private borehole. Surprisingly, one third of the mixed farmers reported having no private borehole. This could be due to the unwillingness to declare ‘illegal’ activities in an online survey. Mixed farmers may also irrigate their plots in the extension with water from the collective network, if these plots are close to the traditional oasis. The picture that emerged from the survey in terms of water extraction shows a diffused practice of digging private boreholes, mainly in the extensions, but also in the traditional oasis.

Table 2 summarizes some statistics concerning boreholes. The average depth of boreholes is considerably deeper in the extensions, while the date of drilling is very similar for all types of farmers.

Solar pumps are the most popular way of extracting water used by the farmers (44.4% of extension farmers, 62.5% of GDA farmers, and 71.4% of mixed farmers, based on our surveyed sample). These systems are certainly less expensive in terms of energy, and were subsidized through public policy initiatives in recent decades. Both inside the oasis and in the extension areas, non-solar electrical pumps are preferred to diesel pumps for their higher power (33.3%, 12.5% and 23.8% by GDA farmers, extension farmers, and mixed farmers, respectively).

Irrigation systems differ significantly in the three groups of farms (chi square p-value = 0.000 based on the distribution frequency of the following systems: drip irrigation, sprinkler irrigation, flooding, and mixed systems). In extension areas, the most popular technique is drip irrigation (60% of the farmers in this zone used drip irrigation), while, as expected, in the traditional oasis, it is flooding (79.1%). Almost half (48.9%) the mixed farmers used more than one technique and that sprinkler irrigation was only used in the traditional oasis (12.5% of the GDA farmers’ surveyed used sprinklers).

Farmers who are members of GDAs pay for their water which is available through the collective water distribution system and is based on water delivery turns. The fee paid by to the GDA by farmers in the region ranges from 650 DNT[8]/ha/year to 1,500 DNT/ha/year. The farmers surveyed in Jemna paid an average of 93.5 DNT/month to the GDA. These farmers said the time between two water turns was more than 12 days. The duration of the irrigation turn is between 7 hours (GDA farmers) and 10 hours (mixed farmers) depending on the GDA. According to the CRDA, the average water flow is 20 l/s, but is subject to variations from case to case. The majority of farmers were not satisfied with either the frequency or the length of the delivery turn (only 12% of GDA farmers and 30% of mixed farmers were satisfied), and 60% of GDA farmers and 92% of mixed farmers would be willing to pay more for a more frequent and longer delivery turn.

[8] Conversion rate for DNT to Euro is 0.306.

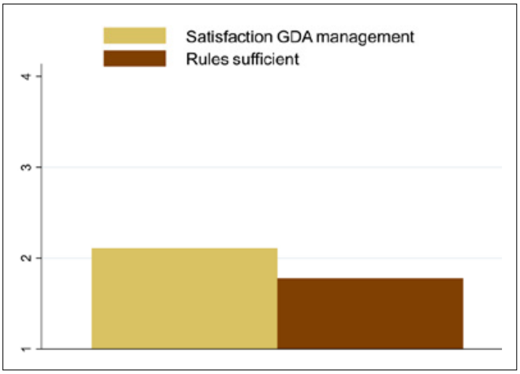
Table 3 - Characteristics of water turns and GDA farmers' and mixed farmers' level of satisfaction.

	Time between two turns (days)	*Hours/turn*	*Satisfied with turn (% of yes)*	*Willing to pay for better turn (% of yes)*
GDA farmers	>12	6.9	10%	60%
Mixed farmers	>12	10.0	30%	90%

3.2. *Farmers' perceptions of water management in the oasis*

The first two sentences concerning the farmers' perceptions of water management only addressed farmers who were members of a GDA (i.e. GDA farmers and mixed farmers). The sentences were: "*I am satisfied with the GDA's water management in the oasis*" and "*current GDA rules are sufficient to guarantee enough water for everyone at the right price*".

Figure 2 - Level of satisfaction concerning GDA water management and perception of GDA rules designed to guarantee enough water for everyone at the right price.



The bar graph in Figure 2 shows the average choices of the surveyed farmers who are members of a GDA on a 1-4 scale. The overall perception of farmers of GDA water management and rules was poor (average = 2.11 and 1.77, respectively). This result is in line with the results obtained by Farolfi et al. (2018) who reported farmers did not recognize the role of the GDA in Tunisia.

The second group of sentences concerned the farmers' perception of water availability ("*There is enough water for everyone in Jemna oasis*"), access to water ("*In addition to being available, water is accessible to everyone in Jemna oasis*"), and water quality ("*I am satisfied with the quality of the water in the oasis*").

The bar graph in Figure 3 shows that the farmers' perception of water quality, availability and access in the Jemna oasis is quite poor (average = 1.93, 1.74, and 1.68, respectively, for quality, availability and access, when all respondents are considered). The perception is the same for the farmers in the three groups (Kruskal-Wallis test, p-value = 0.902, 0.597, 0.689, respectively, for quality, availability and access), and consequently both in the traditional oasis and in extensions. Complementary qualitative interviews to understand why people in Jemna consider that there is not enough water (e.g.: decrease of water

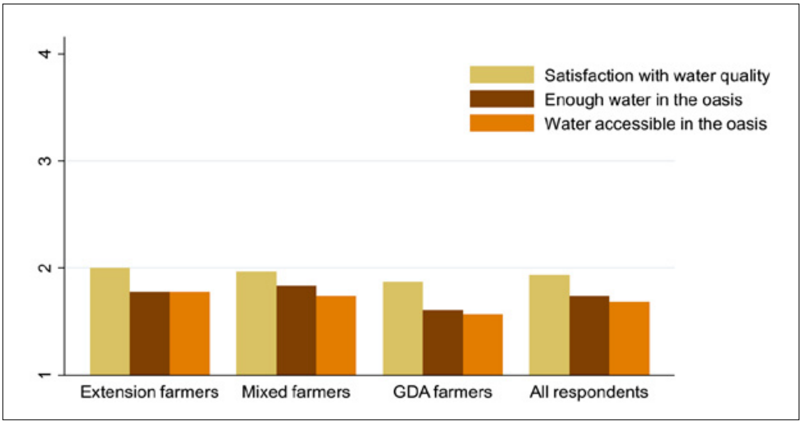
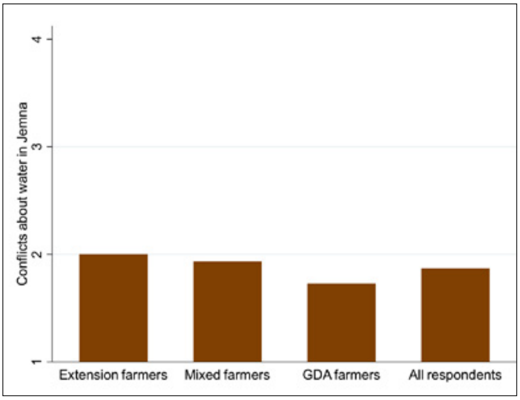


Figure 3 - Perception of water quality, quantity, and access in the oasis.

Figure 4 - Perception of conflicts concerning water in the oasis by the three groups of farmers.



flows in GDAs, decrease of groundwater levels and flow in extensions, etc.) would have been useful. They are foreseen in a future work.

The third group of sentences concerned conflicts about water in the Jemna oasis. First, the farmers read the following sentence: "*There are conflicts concerning water in Jemna oasis*". Figure 4 shows that farmers in the Jemna oasis do not consider conflicts over water to be serious (average = 2.00, 1.93, and 1.72 respectively for extension farmers, mixed farmers and GDA farmers). Although the perception of conflict by GDA farmers was lower than in the other groups, the Kruskal-Wallis test shows that the difference between groups is not significant (p-value = 0.556). In other words, farmers in the Jemna oasis are perfectly aware of water scarcity and the fact that water availability and access are not sufficient, but they consider that this scarcity is not a source of conflict among water users.

Farmers then had to react to two sentences about how to solve conflicts over water in the oasis. The first sentence was "W*ater conflicts can be solved through better management rules*" and the second was "*Water conflicts can be solved if farmers collaborate*". When reacting to these sentences, GDA farmers may refer to conflicts about water turns and possible water stealing or no respect of rules in the GDA, while extension farmers may refer to conflicts arising from land appropriation or discussions about farm borders.

The bar graph in Figure 5 shows that farmers gave a higher score to collaboration among themselves than to better management rules in resolving conflicts over water in the oasis (average = 3.08 and 2.77 respectively, when all respondents are considered). A Mann-Whitney test on the whole sample indicated this difference is significant (p-value = 0.045). Extension-farmers had a higher perception of the two means of conflict resolution than farmers in the other two groups (although the Kruskal-Wallis test was not significant: p-value = 0.521 and 0.257, respectively, for rules and collaboration). However, all the groups of farmers scored collaboration among themselves higher than better management rules.

The two next sentences concerned the farmers' willingness to collaborate with other farmers to manage water: "*I am ready to collaborate with the other farmers for better water management*" and "*I know other farmers who would be willing to collaborate for better water management*".

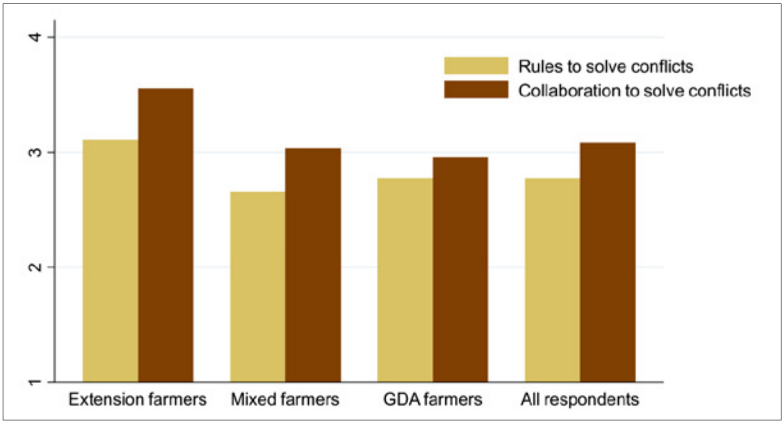


Figure 5 - How to solve the conflicts in the oasis: better rules vs collaboration among farmers.

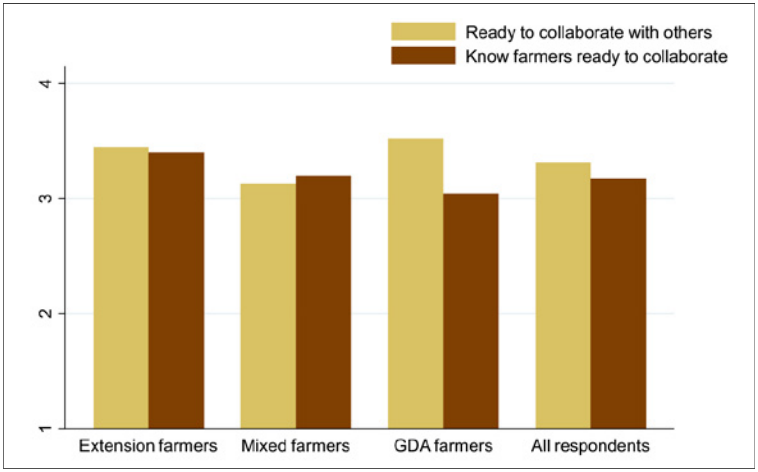


Figure 6 - Willingness to collaborate with other farmers and perception of other farmers' willingness to collaborate in better water management in the oasis.

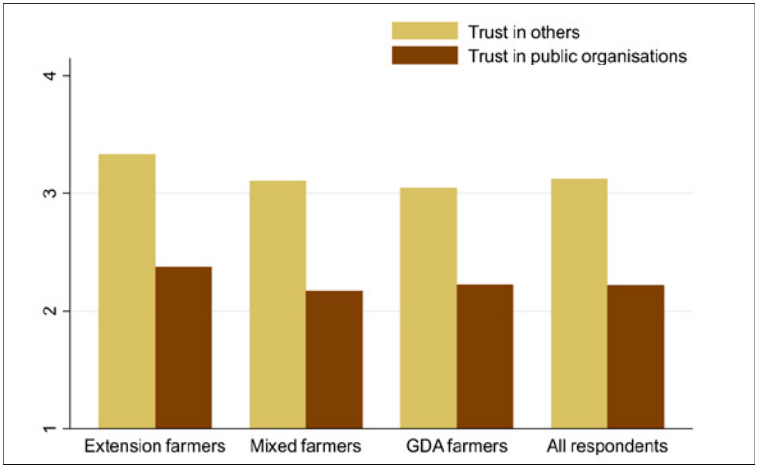


Figure 7 - Trust in public organisations and in other farmers for better water management.

The bar graph in Figure 6 shows that farmers in the Jemna oasis are willing to collaborate and know other farmers who are equally willing to collaborate with them (average = 3.31 and 3.17 respectively, when all respondents are considered). This is equally true for all three groups of farmers (the Kruskal-Wallis test was not significant: p-value = 0.136 and 0.622, respectively, for readiness to collaborate and knowing other farmers willing to collaborate, and the average answers are all above 3).

Finally, the two last sentences concerned the farmers' trust in public organisations and in collaboration with other farmers "*I trust collaboration among farmers for water management*" and "*I trust public organisations*[9] *for equitable water management*".

The bar graph in Figure 7 shows a clear difference in favour of farmers' trust in collaboration among themselves for water management rather than trust in public organisations (average = 3.12 and 2.21 respectively, when all respondents are considered). A Mann-Whitney test on the whole sample indicates that this difference is significant (p-value = 0.000).

This difference is present in all groups of farmers with no significant variability between groups (the Kruskal-Wallis test was not significant: p-value = 0.569 and 0.907 respectively for trust in others and in public organisations).

[9] The term 'institutions' was used in the survey.

3.3. *Discriminating characteristics of farmers who cultivate land in the traditional oasis and in the extensions*

The descriptive analysis reported in the previous section clearly revealed significant differences among the three groups of farmers in the Jemna oasis both in socio-economic characteristics, perceptions of and attitudes to water management.

The objective of this section is to identify the variables that distinguish farmers who only cultivate land inside the traditional oasis (GDA farmers) and farmers who have all or some of their plots in extension areas. In the latter group, we include both farmers who only have plots in extensions (extension farmers) and farmer who have plots in both areas (mixed farmers).[10]

To apply the probit model presented in the materials and methods section to this sample, we defined the dependent variable as a dichotomous variable taking the value of 1 when farmers only have plots in the traditional oasis, and the value of 0 in all other cases. The explanatory variables chosen for the probit model were based on the descriptive analysis presented in the previous sections. We selected some of the demographic, socioeconomic and behavioural variables that revealed significant differences between the groups of farmers. These variables are the age of the head of the household (numerical), the education level of the head of the household (1,2,3 for the three levels ”primary”, ”secondary”, and ”higher”), surface area of agricultural land (numerical), presence of a borehole (0 for ”no” and 1 for ”yes”), willingness to buy additional land (0 for ”no” and 1 ”yes”), year of start of farming activity (numerical), production system (two variables coded 0 for ”monoculture” and 1 for ”2 layer” or ”3 layer systems”) , member of the local farmers’ association for the development of the Jemna oasis (0 for ”no” and 1 for ”yes”), farming is their main activity (0 for ”no” and 1 for ”yes”), and variables concerning the perception of conflicts over water and access to water (1,2,3,4 according to the Likert scale). As all the farmers interviewed were men, the variable “gender” was not included.

Table 4 shows the average marginal effects of a probit model using different specifications. The specifications in the first two columns focus on the role of farmers’ characteristics, while the specifications in the last three columns show the importance of farmers’ perception of conflicts about water, and how to resolve them. More precisely, the first column underlines the role of farming characteristics; the second column adds the household head’s characteristics; the third column shows the same specifications but using a reduced dataset so as to properly compare these coefficients with the following ones; the fourth column adds two variables about farmers’ perception of conflicts and access to water. Finally, the last column adds a variable on the farmers’ perception of cooperation as a way to solve water conflicts.

Over 65 observations, one observation was missing for *willingness to buy additional land* and three were missing for the *year the farming activity started*. Consequently, only 61 observations were used in the first column. Despite choosing perception variables with the least missing values, the sample in the third column was reduced to the 53 observations available for conflict perception variables. In fact, eight more observations were lost when perception variables were added in the fourth and fifth columns.

We first observed that the variables *willingness to buy additional land* and *year of farming activity started* were negatively and significantly correlated with the probability of only having plots inside the traditional oasis. When *willingness to buy additional land* moved from 0 to 1, it reduced the probability (0-1) of only having plots in the traditional oasis by about 0.2. *Willingness to buy additional land* is an important factor for a farmer to have a plot in the extensions, whatever the specification considered. The effect of

[10] We did so having in mind a broader empirical model of water extraction (see recommendations for future research below). If unobserved variables determine both the probability of having plots only in extension areas and water extraction, then a two-step procedure is needed (Heckman, 1979). The first stage of the Heckman procedure is a probit model.

Table 4 - Variables that distinguished farmers who only farmed plots in the traditional oasis versus farmers who farmed plots in extension areas - Probit estimation with average marginal effects.

	1	*2*	*3*	*4*	*5*
VARIABLES	*Dependent variable: plots only in the traditional oasis (1) versus plots in the extensions (0)*				
	dy/dx	dy/dx	dy/dx	dy/dx	dy/dx
Farm size	-0.103*	-0.101*	-0.124*	-0.116*	-0.114
	(0.0553)	(0.0562)	(0.0695)	(0.0698)	(0.0697)
Year farming activity started	-0.00947***	-0.00988***	-0.0107**	-0.0105**	-0.0102**
	(0.00243)	(0.00370)	(0.00438)	(0.00446)	(0.00409)
Willingness to buy additional land	-0.239***	-0.241***	-0.223**	-0.211**	-0.183**
	(0.0765)	(0.0801)	(0.0899)	(0.0981)	(0.0882)
Production system:					
Two layer system	0.149	0.147	0.111	0.115	0.0779
	(0.147)	(0.150)	(0.157)	(0.162)	(0.156)
Three layer system	0.0820	0.0914	0.353	0.376	0.269
	(0.217)	(0.233)	(0.597)	(0.493)	(0.845)
Borehole	-0.120	-0.124	-0.114	-0.104	-0.0827
	(0.0752)	(0.0800)	(0.0864)	(0.102)	(0.0937)
Farming main activity	0.178*	0.181*	0.193*	0.169	0.150
	(0.0926)	(0.0946)	(0.104)	(0.125)	(0.114)
Member of the association	0.293**	0.297**	0.310**	0.289**	0.306**
	(0.124)	(0.127)	(0.135)	(0.145)	(0.139)
Age		-0.00654	-0.0173	-0.0171	-0.0167
		(0.0373)	(0.0416)	(0.0421)	(0.0410)
Education		-0.000839	0.0156	0.0290	-0.0258
		(0.0761)	(0.0825)	(0.0925)	(0.0867)
Water conflict				-0.0199	-0.00755
				(0.0582)	(0.0496)
Access to water				-0.0237	-0.0188
				(0.0893)	(0.0825)
Cooperation to resolve conflict					-0.0873**
					(0.0417)
Observations	61	61	53	53	53

*Note: Robust standard errors are in brackets. * denotes significance at the 10-percent level, ** at the 5-percent level and *** at the 1-percent level.*

the *year the farming activity started* on the absence of plots in the extensions was small but significant, regardless of the specification considered. However, it was negative, showing that farmers who had plots in extension areas started agricultural activities later than GDA farmers. *Farm area* was negatively correlated with the group of GDA member farmers, indicating that farms in this group are significantly smaller than farms with plots in the extensions. We observed no effect of the *cropping system* (date palm monoculture versus the two mixed 2-layer and 3-layer cropping systems) nor of the presence of a *borehole*. These results are in line with descriptive statistics underlining the similarity of the cropping system (monoculture) in the two zones, and a tendency to drill boreholes not only in the extension areas, where no water is supplied by the GDA, but also within the traditional oasis. *Farming* appeared to be more often the *main activity* of GDA farmers than of extension or mixed farmers, as the estimation coefficient was positive and significant. However, it should be noted that this coefficient was not robust to all specifications. In fact, looking at the descriptive statistics in the previous sections, while the main activity of all extension farmers was agriculture, this was only true of 68% of mixed farmers and of 79% of GDA farmers. As expected, being a *member of an association* was positively correlated with farmers who only farmed plots in the traditional oasis. When *association membership* moved from 0 to 1, it increased the probability of only having plots in the traditional oasis by almost 0.3, and was significant in all specifications. While the negative sign for *age* is intuitive, surprisingly is was not significant. However, this variable was closely correlated with *year the farming activity started*, which may explain the lack of significance. *Education* did not appear to differ with the group of farmers, as the coefficient was not significant.

Turning now to farmers' perceptions of and attitudes to water, the only variable that appeared to differentiate farmers who cultivated plots in extension areas from farmers who only cultivated plots in the traditional oasis was *cooperation to resolve conflicts*. GDA farmers showed less preference for cooperation to solve water conflicts than farmers with plots in extension areas. To better understand this result, we need to recall that both farmers in extensions and in the traditional oasis gave a higher score to cooperation between farmers than to "better management rules" to solve conflicts about water. However, the tendency towards cooperation seemed to be even higher in farmers with plots in the extensions than in farmers who only had plots in the traditional oasis. This result is consistent with the right-hand bar graph in Figure 5, where the bar corresponding to extension farmers is visibly higher than the bar corresponding to GDA farmers. Neither the perception of *water conflict* nor the perception of *access to water* was significant, confirming the findings of the previous section, i.e., the global similarity of perceptions of water by farmers who cultivated plots in both areas of the oasis.

To sum up, the results of the probit model indicate that, compared to farmers who only cultivated plots in the traditional oasis, farmers with plots in extensions started their activity later, were more willing to buy additional land, had larger farms, and were not members of the association for the protection of the oasis. These were the main variables that distinguished "extension and mixed farmers", on one hand, and "GDA farmers", on the other. Conversely, the cropping system (monoculture in both areas), the presence of a borehole, the type of irrigation and the water extraction system did not seem to distinguish farmers with plots in the extension from GDA farmers. In terms of perceptions about water, the only significant difference was more confidence in cooperation as a way to solve water conflicts by farmers with plots in the extensions. However, this result is mitigated by the fact that conflicts are not considered to be a major problem in the oasis, and furthermore, farmers in both areas give a higher score to collaboration among themselves than to "better management rules" for solving water conflicts.

4. Discussion and conclusion

The rapidly evolving dynamics around groundwater exploitation in the Mediterranean region, particularly in Tunisia, call for a thorough analysis of the causes of the water resources depletion as a result of the so-called 'groundwater economy' (Kuper *et al.*, 2016; Amichi *et al.*, 2015). Oases are highly productive and delicate ecosystems which, in recent decades, have undergone a radical change in trends in terms of intensification of the agricultural systems and groundwater use.

The Governorate of Kebili, Southern Tunisia, with over 140 palm oases, is the main date producer in the country with 61% of the overall national production in 2016 (Agence de Promotion de l'Industrie et de l'Innovation, 2017).

Trigui *et al.* (2021) consider that agricultural water uses are among the main reasons for water depletion of the Complex terminal aquifer in Kebili, which is the main source of water in the studied area. According to some authors (Petit *et al.*, 2017), the overexploitation of groundwater resources confirmed in this case by Trigui *et al*. (2021) will lead to the collapse of the system in the short or medium term if drastic measures are not taken rapidly.

One potential measure is a new approach to water management, in which water users (mainly farmers, in the Tunisian oases) collaborate and define rules through collaboration among peers rather than complying with rules imposed by the existing organisations. Indeed, previous studies (Farolfi *et al.*, 2018; Mouri and Marlet, 2007) have shown that in Tunisia, farmers do not perceive the actual decentralised water management organisations (the GDA) as legitimate and as capable of guaranteeing adequate and sustainable management of the resource. Other studies (Hassen *et al.*, 2021) underline the fact that most Tunisian water user associations are in crisis and offer poor service to their members.

The rapidly evolving dynamics in Tunisian oases apply particularly in the so-called extensions, in which farms were established more recently, and that occupy the land on the margins of farms located in the traditional oasis, where the official water management organisations (GDA) operate (Ghazouani *et al.*, 2009; Mekki *et al.*, 2013). Farms in the extensions get their water from private boreholes which are not declared to the local water management authority (CRDA). These farms are often considered as the main cause of groundwater overexploitation in Tunisian oases (Mekki *et al.*, 2013).

The results of the survey conducted in Jemna oasis showed that farmers who cultivated plots in extension areas had distinctive characteristics such as having started their farming activity more recently, their willingness to buy additional land, and the fact their farms are larger. In contrast, the values of some variables such as the type of cropping system (monoculture) and the presence of a borehole on the farm were similar in all three farmers' groups.

The differences between farmers who farmed plots in the extensions and those who only farmed plots in the traditional oasis are less obvious when it comes to farmers' perceptions of water problems and possible solutions. All the farmers in the Jemna oasis clearly perceive the limited availability of, access to, and the poor quality of the water resource. However, they do not believe that these problems are a source of conflicts among farmers. Their trust in collaboration between farmers is greater than their trust in better rules produced by existing organisations to solve possible water conflicts and achieve better water management. They are willing to collaborate and think that other farmers are as willing as they are. The location of farmers' plots in the traditional oasis or in the extensions had no significant effects on these perceptions.

These preliminary results, if confirmed, would have important policy implications, as cooperation and trust are key ingredients in a possible new approach to water management. Following Ostrom's sustainable governance principles (Ostrom, 1990),[11] one can consider management of groundwater as a common-pool resource (CPR) problem, where dialogue, information sharing and communication between farmers are crucial to reach sustainability. In the resource economics literature, mechanisms have recently been proposed (Yao *et al.*, 2021) to reduce the over-exploitation of CPR through communication among resource users and the introduction of CPR management rules, such as the approval mechanism (a system where CPR users first propose extractions and then approve or disapprove them to decide their implementation). These mechanisms can be imposed by the existing organisations (in this case, the GDA) or defined by the group of farmers themselves through a process of discussion and negotiation. The approval mechanism, along with other forms of CPR management, could be tested

[11] Where institutions are rules agreed by all in a society, and where the best rules are those that emerge from actors' concertation, negotiation, and not those imposed exogenously by the existing organisations.

in the Tunisian oases to assess its acceptability and possible effectiveness in the management of groundwater resources.

This work has several limitations. First, due to the limited time and resources available, and because the Covid-19 pandemic further constrained the survey, the sample on which this paper is based is small, and the procedure for its selection is potentially conducive to statistical biases. Additionally, only farmers who were able to read and who owned a smartphone or a personal computer were able to take part in the online survey. This may have caused an auto-selection bias. Second, the survey, based on an electronic form filled in by the farmers on their smartphone, was not an ideal context to ask open questions. For this reason, all the questions were closed (yes/no, or multiple choices). On the one hand, this format considerably reduces the risk of errors and the time of completion of the questionnaire, also limiting the risk that the respondents give up and do not complete the survey. On the other hand, closed questions are less informative, and do not offer the respondents the opportunity to explain the reasons and the motivations for their responses. Quick interviews are perhaps not the right method to elicit conflicts, especially if no specific issues such as conflicts about water turns, water thefts, or pipeline damages are mentioned in the survey. Furthermore, farmers advocating less rules and more dialogue can be those currently benefitting more from weak or/and unclear rules. The format of the survey is thus another limitation of the study. Finally, this work is based on a single oasis located in Southern Tunisia. The generalization of our results to other oases in Tunisia and elsewhere is therefore not possible at this stage, and this study should therefore be considered as an exploratory and preliminary work, open to future developments. In particular, the existence of an association for the defence of the oasis in Jemna, which is not the case in all oases, may have an influence on the degree of trust the farmers have in collaboration to improve water management.

Future research pathways along the lines of this work therefore involve surveys based on larger and differently selected samples, in other oases in Tunisia and in North Africa to identify the socio-economic characteristics of farmers who cultivate plots in traditional oasis and in extension areas, as well as their perceptions of water problems and possible solutions to improve water management. More detailed and qualitative interviews, to avoid the potential biases coming from quick interviews as discussed above, are needed as well. These surveys will confirm or invalidate the findings of the present work and possibly allow their generalization. Another important perspective for future research, if these preliminary findings are confirmed, is the design and testing of governance mechanisms, such as the approval mechanism (Yao *et al.*, 2021), to improve groundwater management in Tunisian oases.

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