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Evaluation of Irrigation Efficiency in the Boghol Valley, Rural Commune of Dabaga, Aïr Massif, Niger

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The Aïr Massif is located in northern Niger. It is characterized by an arid climate that makes rain-fed agriculture impossible. To adapt, the population has developed irrigation from alluvial aquifers. The latter are dependent on rain and have a recurrent drying out. This results in the loss of crops or even abandonment of vegetable gardens leading to a subsequent decrease in production. In this context of aridity, the rational use of water is essential and necessarily involves knowledge of the water needs of crops and those delivered to these crops. The objective of this study is to assess the efficiency of irrigation water use in the Boghol Valley. The methodological approach is based on

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the calculation of water needs of crops using cropwat 8.0 software which required an inventory of soils, crops and areas they occupy according to the season. Then, the volume of water delivered at local scale was quantified using a volumetric meter. Finally, a comparison of the needs and quantities delivered at the valley level was made after extrapolation of data from the local scale. The results of the study show that irrigation is mainly carried out by gravity throughout the year. The quantities of water delivered are for all crops exceeding their needs. Overall irrigation efficiency of 71.07% was recorded. However, there are disparities with values of 80.75% and 49.70 % in the cold dry season and hot dry season respectively. This reflects considerable water losses in this arid environment. It is therefore necessary to improve efficiency by diagnosing irrigation practices.

Keywords: Irrigation; efficiency; aïr; boghol; alluvial water.

1. INTRODUCTION

Water remains the most vital element for the plant, since it is the liquid phase in which all the plant biochemical processes take place [1]. Plants typically absorb water from the soil through their roots and use only 1-1.5% of the volume of water absorbed for vegetative growth as well as some physiological and biochemical activities [2]. This need varies depending on the stage of development of the crop and climatic or soil factors [3, 4]. It is covered by natural rain in most cases. However, with climate variability, crops no longer receive the water needed for growth. Given the climatic variability that results in insufficient rainfall, irrigation has become the best way to limit the fluctuation of productivity from one year to another [4]. Indeed, with irrigation, a supplement of water is provided to the crops in order to allow them to function normally and complete their cycle. In many regions, such as the Boghol Valley, agriculture is entirely irrigated despite water resource challenges. In Boghol, the water resource available is mainly underground and has been heavily pumped in recent years, which contributes to the early drying of the water table. Indeed, water pumping observed on irrigated agricultural land is by far the most anthropogenic phenomenon that consumes water and causes its scarcity when demand exceeds available supply [5]. This shortage puts the plant in a situation of water stress with various consequences that can affect root activity, foliar and even yield reduction [6-8]. To overcome this difficulty, it is essential to guarantee the availability of sufficient quantities of water for their development. The warranty of these conditions for crops necessarily involves the carrying out of preliminary studies, including the determination of the water needs of the crops [9]. Indeed, the estimation of water needs ensures an optimum water consumption for quality production and good profitability [10]. It contributes to a good management of irrigation by avoiding potentially penalising excesses at different levels such as the depreciating effect on the crop, the cost of water and the impact on the environment [11]. In addition, it contributes to better management of water resources, especially in a context characterized by climate uncertainties. This is the context of the present study, which aims to assess the efficiency of irrigation for better management of water resources.

2. METHODOLOGY

2.1 Presentation of the Study Area

The Boghol Valley is located in the southern part of the rural town of Dabaga (Fig. 1). It is between 8°6' and 8°17' of eastern longitude and 17°4' and 17°20' of northern latitude and is bounded by the valleys of: Attri and Amdigra to the east, Teloua to the west and north and Tchintaborak to the south. With an elongated shape, the catchment area of this valley is estimated at 169.11 km2. The climate in the Boghol valley is semi-arid with a random rainfall pattern that varies considerably depending on the year from 24.2 to 225.10 mm/year [12]. Intense evaporation with strong wind (up to 20 km/h) and very strong insolation (3192.9 hours/year on average) which exacerbate the climatic drying with an ETP ranging from 2500 to 2600 mm/year [13]. Boghol has a random rainfall pattern that varies considerably from year to year, ranging from 24.2 to 225.10 mm/year [12]. It is characterized by two seasons: a long dry season of nine (9) months, from October to June and a short rainy season of three (3) months, from July to September. Agriculture is the largest economic activity in the Boghol Valley and consists mainly of irrigated crops during dry and rainy seasons. The development of this activity is conditioned by the availability of water in the alluvial table [14]. The estimated 12% of the watershed's irrigable potential is located along streams in the lowlands that constitute the lowest part of the watershed.

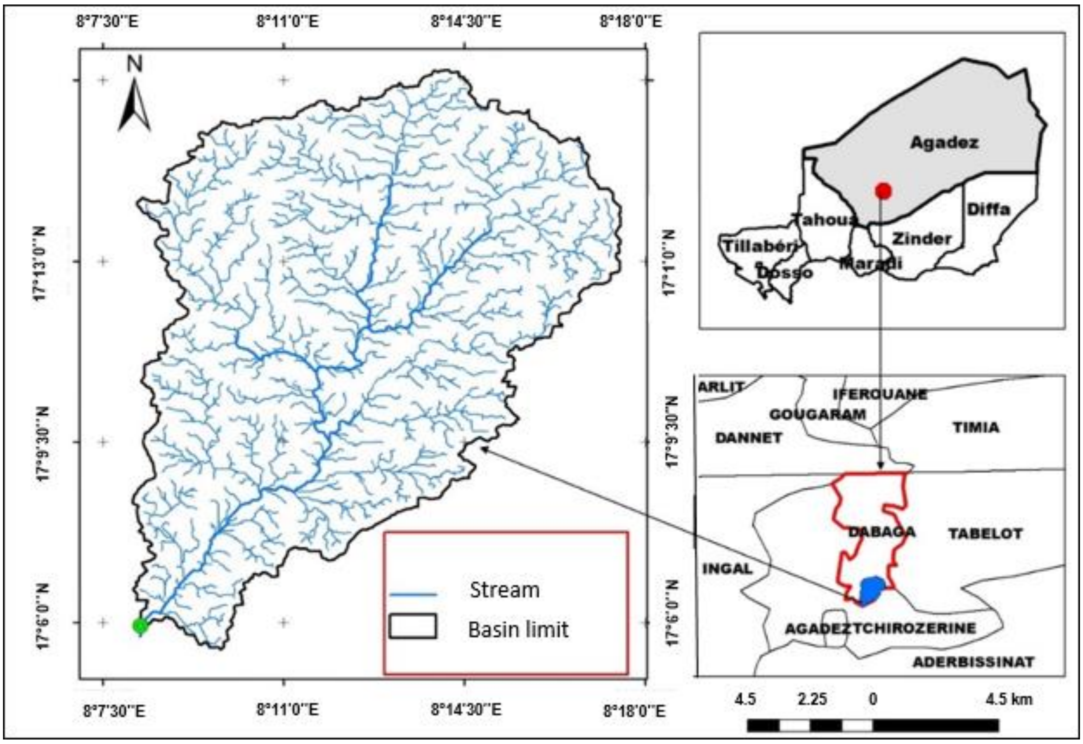

Fig. 1. Location of study area

2.2 Calculation of Crop Water Requirements

Water requirements were calculated using the FAO-developed Cropwat version 8.0 software based on Formula 1 [15]. This software requires the introduction of parameters such as ET0, effective rain, data on the crop in question and soil type including texture. This required the crop inventory and texture determination in sections 2.2.1 and 2.2.2 respectively. The climate data were obtained via ClimWat software, considering the meteorological station in the city of Agadez which is closest to the study area. After obtaining the water requirements of each crop, an extrapolation was made taking into account the total area it occupies, to have the need at the valley scale. The timing of seeding dates for each season's secondary crops was adjusted to the date of seeding of the main crops. The Corete (*Corchorus tridens L*) is a crop that has not benefited from scientific studies to have the Kc and the duration of vegetative phases, the characteristics of lettuce (*Lactuca sativa*) were taken by default. Only the actual vegetative duration was considered. The water requirement of the crop or evapotranspiration of the crop was calculated as follows:

$$ETC = PET * Kc \quad (1)$$

Where:

- ETC: Evapotranspiration of the crop in mm/d;
- PET: Potential evapotranspiration in mm/d;
- Kc: Cultural coefficient.

2.2.1 Inventory of crops and irrigation systems

An inventory of crops according to the seasons has been carried out. Crops were then ranked according to the area they took up in the season. The area is estimated by using land deeds issued by the basic land commission and GPS surveys for gardens without land deeds. Irrigation systems were identified by crossing the gardens and by talking to farmers.

2.2.2 Determination of soil texture

To determine the texture of the valley soil, 25 samples were taken at a depth of 50 cm, considered as horizon dominated by the roots of the crops practiced. Sampling points have been distributed so that the valley is covered in a representative manner. The samples were packaged in plastic bags and then sent to the laboratory of soil sciences at the Faculty of

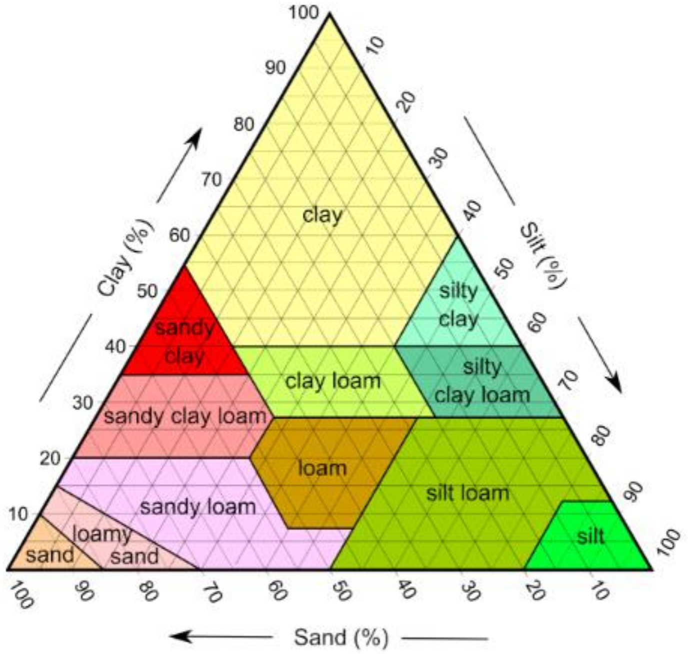

Fig. 2. Soil texture triangle diagram [17]

Agronomy of the University Abdou Moumouni of Niamey for particle size analysis. The latter was done by the Robinson pipette method described by [16]. After obtaining the particle sizes of the samples, the textural classes are determined using the texture triangle (Fig. 2) according to the USDA nomenclature [17].

2.3 Quantification of Pumped Water Volume

There are several methods for estimating local, regional and national water use for crop irrigation. The criteria used vary from one method to another and are based on the study of flows, catchment structures, rotation plan, crop water requirement or energy consumed by the pumping means [18-21]. The study established a relationship between the area under cultivation and the amount of water taken. For this, a flow measurement device was set up at the level of the plots of the dominant crops in the valley.

2.3.1 Monitoring of irrigation

Plots to be monitored were selected on the basis of the following criteria: (i) producer agreement, (ii) experience of the producer in gardening, (iii) availability of water, (iv) uniformity of speculation over a large part of the garden. Subsequently, a volumetric meter was installed from which all the water for irrigation of the plots of main crops passes. For secondary crops, water volumes are determined from the flow rate of the motor pump and the irrigation time. It should be noted that periodic water consumption surveys were carried out after watering throughout the crop cycle.

2.3.2 Calculation of pumped water volumes

The measured volumes on the plots are reported on one (1) hectare for each crop. It is calculated by the following relation:

$$\boldsymbol{P_{cult}} = \mathbf{V} \times \boldsymbol{S} \qquad (2)$$

Where:

- Pcult: Volume pumped for crop irrigation (m^3);
- V: Unit volume (m^3/ha);
- S: Area occupied per crop (ha);

The total volume taken (Pt) for irrigation is obtained by adding up the annual levies from each of the six (6) crops considered over the 2 seasons of the year.

$$\boldsymbol{Pt} = \sum_{i=1}^{i6} \boldsymbol{P_{cult\_i}}$$

Where :

- Pt : total pumping (m^3) ;
- V : unit volume (m^3/ha) ;
- S : Area occupied per crop (ha) ;
- i : Crop.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Cultures and spatial significance

This section presents the results of the inventory of the crops grown and the areas they occupy in the valley. It shows that the areas developed are estimated at 323.83 ha in 2019. The importance of crops according to seasons is presented as follows:

- in the rainy season, onions (*Allium cepa*) occupy almost 95% of the land developed;
- in the cold dry season, potatoes (*Solanum tuberosum L);*
- are the dominant crop in the valley with 74.75% of the area planted followed by tomatoes (*Solanum lycopersicum L*) and maize (*Zea mays*);
- in the hot dry season, onion and cornet occupy respectively 32.22 % and 27.82% of the area sown, followed by lettuce (*Lactuca sativa*), green pepper (*Capsicum annuum*) and watermelon (*Citrullus lanatus*).

The importance of development is a function of the seasons and follows the descending order which is: winter season, cold dry season and hot dry season. Crops are grown on soils with different textures.

3.1.2 Valley soil texture

Determination of soil texture after particle size analysis gives five (5) textural classes. The results of the soil particle size analysis for the Boghol Valley yield five (5) textural classes. The proportions of each texture are shown in Fig. 3. The dominant texture is sand-loam, representing about 52% of the valley's soils. Loamy sand texture is second, followed by sandy and loam textures in equal proportions. The sandy clay texture remains the lowest in the valley (4%). This texture contributes to the characterization of crop water needs.

3.1.3 Water requirements of crops in cold and hot dry season at valley scale

This section presents the water requirements of crops according to the seasons in which they are grown and the areas they occupy. The analysis in Table 1 showing the results shows that the need is proportional to the areas valued and varies by crop. So, the potato has the highest need of 1 387 003.8 m^3 and the smallest need is 17 276.7 m^3, with lettuce areas of 242.06 ha and 4.33 ha respectively. These requirements determine the amount of water to be delivered to crops from the water table.

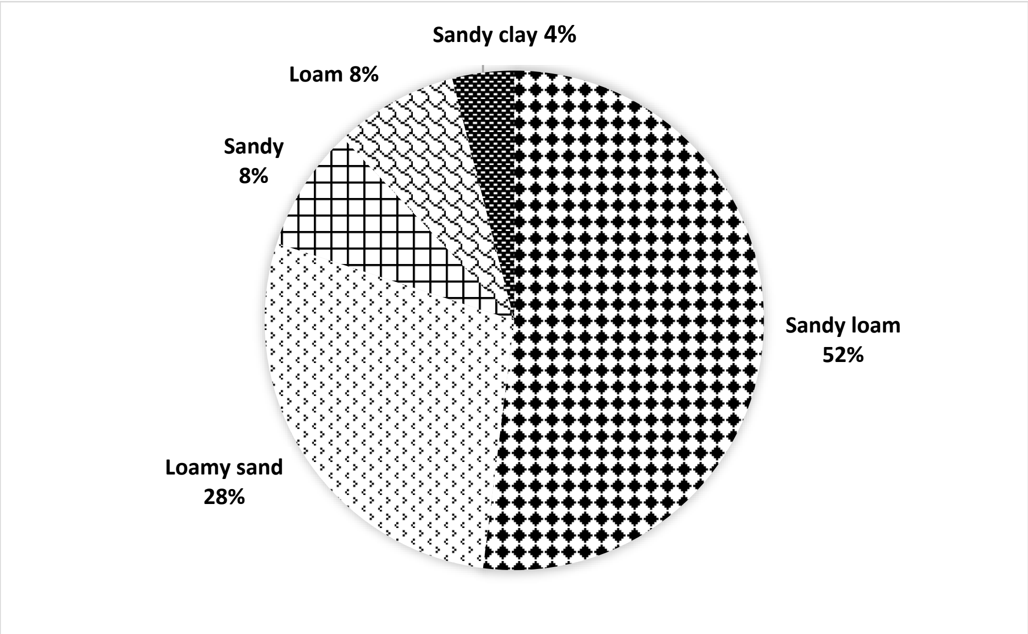

Fig. 3. Proportion of textures in the valley

Table 1. Water requirements of crops by area and season

Crops	Theoretical need (mm)	area occupied (ha)	Global need (m^3)
Cold dry season			
Potato	573	242.06	1 387 003.8
Tomato	464.7	21.72	100 932.84
Maize	605	16.19	97 949.5
Hot dry season			
Onion	483.6	11.47	55 468.9
Lettuce	399	4.33	17 276.7
Corete	399	9.9	39 501

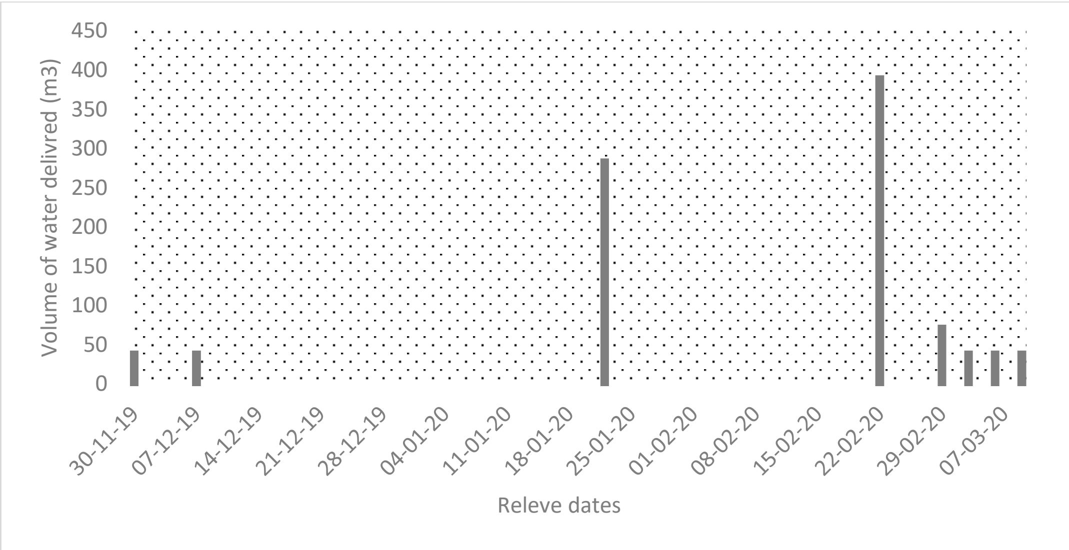

Fig. 4. Periodic report on quantities of water delivered to the potato

3.1.4 Amount of water delivered to crops in the cold dry season at local level

At this level, the volume of water delivered to crops is quantified from flow measurements and meter readings. Flow measurement operations give an average flow rate of 7.66 m^3/h in the cold dry season with a watering time of 31.86 h for an area of one (1) hectare. Quantities delivered to each crop are shown as follows:

Potato : The quantities of water taken before the meter is installed are 39 m3 per irrigation, corresponding to 195 m^3 for five (5) irrigations. The volume readings are estimated at 746 m^3. This results in a cumulative harvest of 941 m^3 throughout the season for an area of 0.13 ha. The volume of water pumped during the cycle is 7 101.88 m^3/ha for irrigation. Figs. 4 and 5 show respectively the volumes of water pumped by irrigation operation and a plot of potato under irrigation.

Tomato and Maize: In the cold dry season, crop watering is done every 3 days. For example, with a 90-day cycle for tomatoes and 120 days for maize, these crops receive 23 and 31 watering respectively. With the estimated flow of the pump at 7.66 m^3/h and the irrigation time of one (1) hectare which takes 31.86 h, the volume of water mobilized is 244.30 m^3 per irrigation operation. The annual harvest is 5 618.9 m^3/ha for tomatoes and 7 573.3 m^3/ha for maize.

Summary of local water delivery to crops in the cold dry season: The quantities of water pumped for crop irrigation are shown in Table 2. It is noted that the quantity delivered depends on the type of crop and the area developed.

3.1.5 Amount of water delivered to crops in hot dry season at local level

This section presents the water consumption for crops in the hot dry season. Flow measurement operations give an average flow rate of 10.72 m3/h in the hot dry season with a watering time of one (1) hectare estimated at 36.72 h. Quantities delivered to each crop are presented as follows:

Onion: The sum of the water volumes after each irrigation resulted in a cumulative water flow meter (Fig. 6) of 506.68 m^3 delivered to crops over an area of 0.68 ha. The largest dose was delivered at the 9th and 12th watering where it amounted to 35 m^3. While the smallest is 22 m^3 and is observed at the 11th watering. Fig. 7 shows the variations in the quantities delivered during the onion cycle. This results in a volume of approximately 7455.58 m^3 for the irrigation of one hectare.

Fig. 5. Potato plot under irrigation in Tachagor

Fig. 6. Tachagor water quantification meter

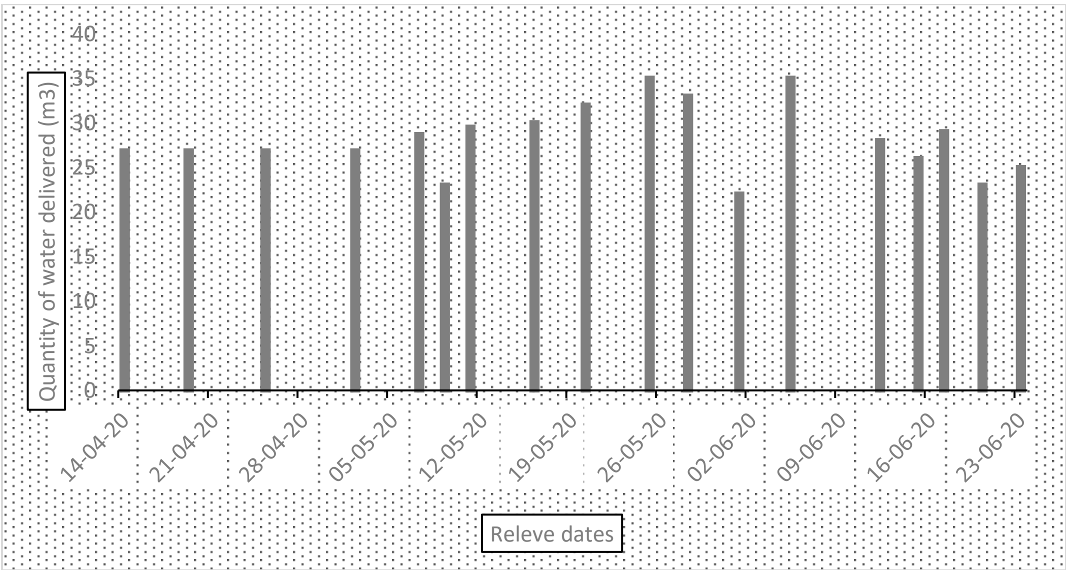

Fig. 7. Amount of water delivered to the onion during each irrigation

Table 2. Water Withdrawals in the Cold Dry Season

Crops	Area (ha)	Average volume (m^3)	Total volume (m^3)
Potato	0.13	-	7 102
Tomato	1	244.3	5 618.9
Maize	1	244.3	7 573.3

Table 3. Water Withdrawals in the hot Dry Season

Crops	Area (ha)	Average volume (m^3)	Total volume (m^3)
Onion	0.068	-	7 455.58
Lettuce	1	394.41	9 860.25
Corete	1	394.41	9 860.25

Lettuce and Corete: In the hot dry season, irrigation is done every 2 days. For a 75-day cycle, lettuce receives 25 irrigations. The corete also benefits from 25 watering for a cycle of two (2) cuts that lasts 75 days. Per irrigation operation it is mobilized 394.41 m^3/ha; from where for the whole production period of the cornet and lettuce a volume of about 9860.25 m^3/ha is taken for each crop.

Summary of local water delivery to crops in the hot dry season: The volumes of water delivered for irrigation vary from crop to crop. They also depend on the area planted. The breakdown of these quantities is shown in the Table 3.

3.1.6 Total valley pumping

This section presents the quantities of water delivered to crops after extrapolation of data from the results of the plots monitored. The results give a total volume estimated at 2 189 562.14 m^3. Fig. 8 shows the volume pumped for each crop according to the area developed in the valley. The analysis of the Fig. shows that crops grown in the cold dry season, such as potatoes, tomatoes and maize, have benefited from greater quantities of water than those cultivated in the hot dry season.

3.1.7 Ratio of water requirements and quantity delivered

Water requirements of crops and water taken from the groundwater are compared here.

Then, the overall pumping amounts to about 2 189 562.14 m^3 against a total estimated need of 1 698 132.74 m^3, or a «waste of water» of 491 429.4 m^3 corresponding to 28.93 %. The analysis in Fig. 9 shows that, for all crops, pumping is superior to the needs of the crop. Also, for water needs and pumping, the quantities are larger in cold season than in dry season.

3.2 Discussion

The drying up of water in the groundwater works can be equated with the increase in area harvested from year to year in the valley. This phenomenon is observed in the Timia valley located in the Aïr massif, with the invasion of rocky parts, clearing and exploitation of pastoral spaces to expand cultivation areas [22,23]. Then, the more land is exploited, the more water needs increase and the groundwater will no longer be able to cover demand. These results are comparable to those found by [24] which showed the influence of increased irrigated areas on groundwater in arid environments. In addition, the climate effects, including strong evapotranspiration recorded by the Aïr, require more water to meet the water needs of crops. The most worrying case is the hot dry season, when evapotranspiration is high and the water table is low. In addition, current crops are highly water-intensive compared to previous crops that were dominated by corn, wheat, barley and spices with small areas [25]. The water consumption of crops follows the rhythm of plant development and the climatic conditions that characterize the environment. Needs are higher in the hot dry season than in the cold dry season. This is justified by the high evapotranspiration values recorded in hot dry season where the plant's physiological activity is highly developed if water availability is guaranteed [26]. This means that the amount of water pumped per hectare in the hot dry season is greater than in the cold season to meet crop water needs. This confirms the work of [27] who found the same trend in terms of seasonal water consumption. However, taking into account the overall situation in the valley, the trend is reversed. This difference is due to the large areas that are highlighted in the

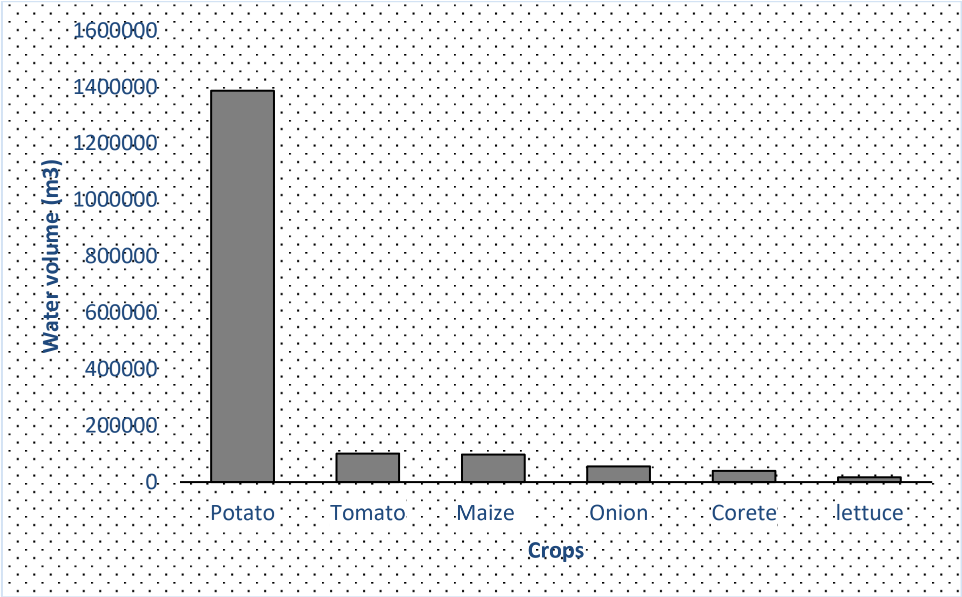

Fig. 8. Volume of water taken to meet crop needs

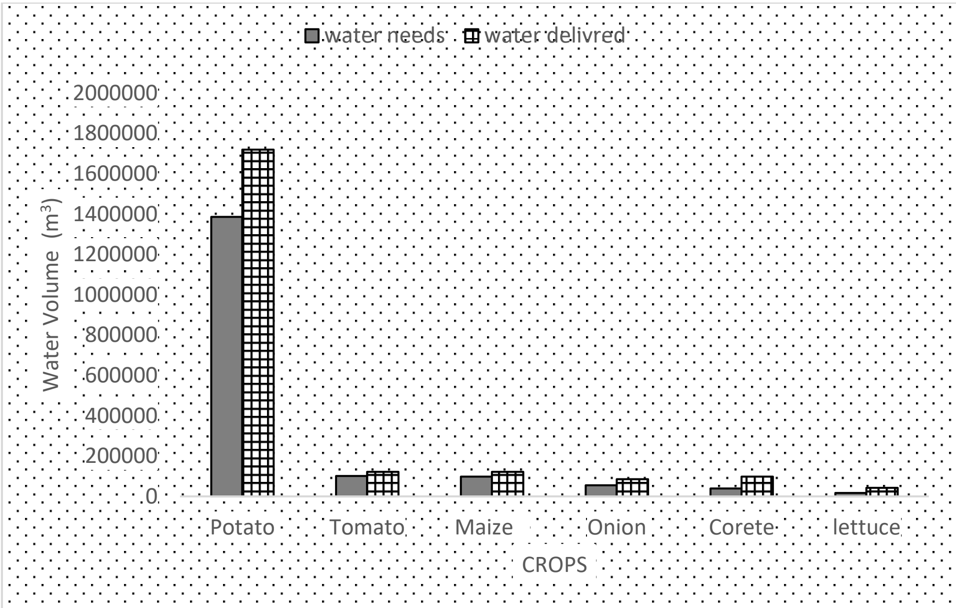

Fig. 9. Need and quantity of water delivered to crops at valley level

cold season. It is to be remembered that during this period the water table is shallow and the excavation is easier for all categories of producers, unlike in hot dry season where the level of the water table gradually decreases. Then, the drying up of the water catchment structures is observed, pushing operators to dig more deeply into these structures [28]. This makes it difficult or impossible to transport water to serve the most remote gardens, especially as the irrigation system is gravity-based and the channels are in earthen soil as evidenced by the texture of the soils [29]. They generate a lot of losses, especially if we make the relationship with the soils of the valley [20,30]. As a result, overall irrigation efficiency in Boghol is estimated at 71.07% despite the observed inter-seasonal disparities. This is in harmony with the one found by [31], which is of the order of 71.02% in the arid Moroccan Gharb. In the hot dry season, efficiency is slightly lower than that found by [32] who estimated it at 52%. [33] as well as [34] they also showed that the quantities of water delivered to crops exceed their needs, which is a similarity to this study. This shows that in the Boghol valley, irrigation efficiency is still insufficient and needs improvement.

4. CONCLUSION

This study addressed the efficiency of irrigation in a context of early draining of the water table in arid environments. The results show that irrigation is carried out throughout the year, with the extent of development depending on the seasons. The quantities of water delivered are for all crops exceeding their needs. Irrigation efficiency of 71.07% was recorded. However, it showed disparities with values of 80.75% and 49.70% in the cold dry season and hot dry season respectively. Given these water losses in an arid environment, especially during the hot dry season, it is necessary to improve irrigation efficiency by diagnosing irrigation practices in the valley.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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