__Original Research Article__

Evaluation of the efficiency of irrigation in the Boghol valley, rural commune of Dabaga in the Aïr massif in Niger

ABSTACT

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 leads to the loss of crops or even the abandonment of vegetable gardens with a corollary 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 as well as those delivered to these crops. The objective of this work is to evaluate the efficiency of irrigation water use in the Boghol valley. The methodological approach consisted first of identifying irrigation systems in place, inventorying the crops grown and estimating the areas developed. Then, samples of the soils of the valley were taken for a granulometric analysis whose interpretation was made with the textural triangle. Finally, crop water requirements and valley-wide sampling were derived by extrapolation of the seasons and areas covered by crops. The results of the study show that irrigation is mainly carried out by gravity. The soils are 52% limono-sandy texture and onion is the main crop occupying 95 and 32.22% of areas sown respectively in winter season and hot dry season. In the cold dry season, potatoes are the main crop and account for 74.75% of the area planted. Water withdrawals from the groundwater table amount to 2,189,562.14 m3 compared with an estimated requirement of 1,698,132.74 m3, resulting in a loss of 28.93%. It is therefore necessary to improve efficiency by diagnosing irrigation practices.

Keywords: Irrigation efficiency, Cropwat, 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 extracted in recent years, contributing to the early drying out of the water table. Indeed, water withdrawals observed on irrigated agricultural land are 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 guarantee 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 (figure 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.

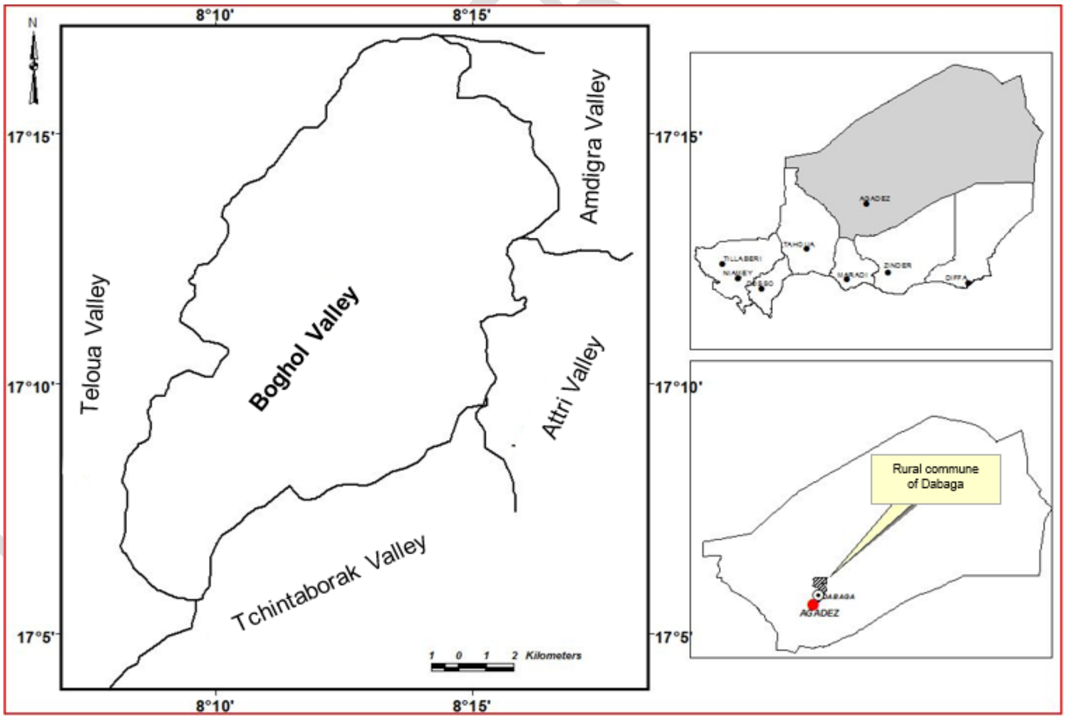

Fig. 1. Location of study area

2.2.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.

2.3.Determination of soil texture

To know 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 Agronomy of the University Abdou Moumouni of Niamey for particle size analysis. The latter was done by the Robinson pipette method described by [15]. After obtaining the particle sizes of the samples, the textural classes are determined using the texture triangle (Figure 2) according to the USDA nomenclature [16].

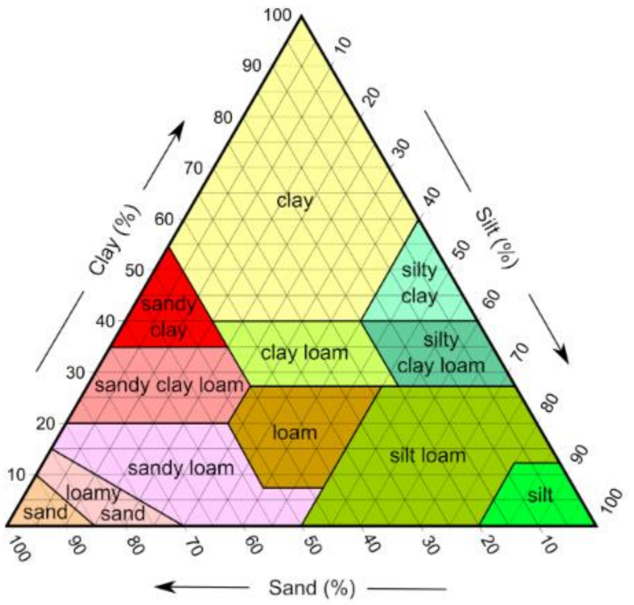

Fig. 2. Soil texture triangle diagram [16]

2.4.Calculation of crop water requirements

Water requirements were calculated using the FAO-developed Cropwat version 8.0 software based on Formula 1[17]. This software requires the introduction of parameters such as ET0, effective rain, data from the crop under consideration and soil type. 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:

$$ETC=PET *Kc$$

Where:

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

2.5.Quantification of samples

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 rotation plan, crop water requirement or energy consumed by the means of excavation [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.

2.6.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.

2.7.Evaluation of samples

The samples measured on the plots are reported on one (1) hectare for each crop. The volume of water taken for irrigation of a crop is calculated according to the following formula.

$$P_{cult} = \mathbf{V} \times \mathbf{S}$$

Where:

- Pcult: Crop irrigation sampling (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.

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

Where :

- Pt : total withdrawals (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. Spatial importance of crops

The estimated area under development shows that approximately 323.83 ha were exploited 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*).

3.1.2. Valley soil texture

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 Table 1. The dominant texture is sand-lime, representing about 52% of the valley's soils. Sand-silt texture is second, followed by sand and silt textures in equal proportions. The sandy clay texture remains the lowest in the valley (4 %).

Table 1. Proportion of textures in the valley

Texture	**Sand Limono**	**Silty Sablo**	Sandy	**Limoneuse**	**Sand clay**
Percentage (%)	52	28	8	8	4

3.1.3. Water requirements of crops in cold and hot dry season

Water requirements for the crops grown in the valley are shown in Table 2. The analysis of the latter that the need is proportional to the areas put into value. Thus, the potato has the highest need of 1 387 003.8 m^3 while the smallest need is 17 276.7 m^3 and concerns lettuce.

Table 2. Summary of crop water requirements by 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
Maize	399	9,9	39 501

3.1.4. Pump flow rates and irrigation times

Flow measurement operations give an average flow rate of 7.66 m^3/h in the cold dry season and 10.72 m^3/h in the hot dry season. One (1) hectare watering time is 31.86 and 36.72 hours during the cold and hot dry seasons, respectively.

3.1.5. Amount of water delivered to crops in cold dry season

- **Potato**

The quantities of water taken before the meter is installed amount to 39 m^3 per irrigation thus giving 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 cycle-based sample is 7 101.88 m^3/ha for irrigation. Figures 3 and 4 show the variation in sampling and irrigation operations respectively.

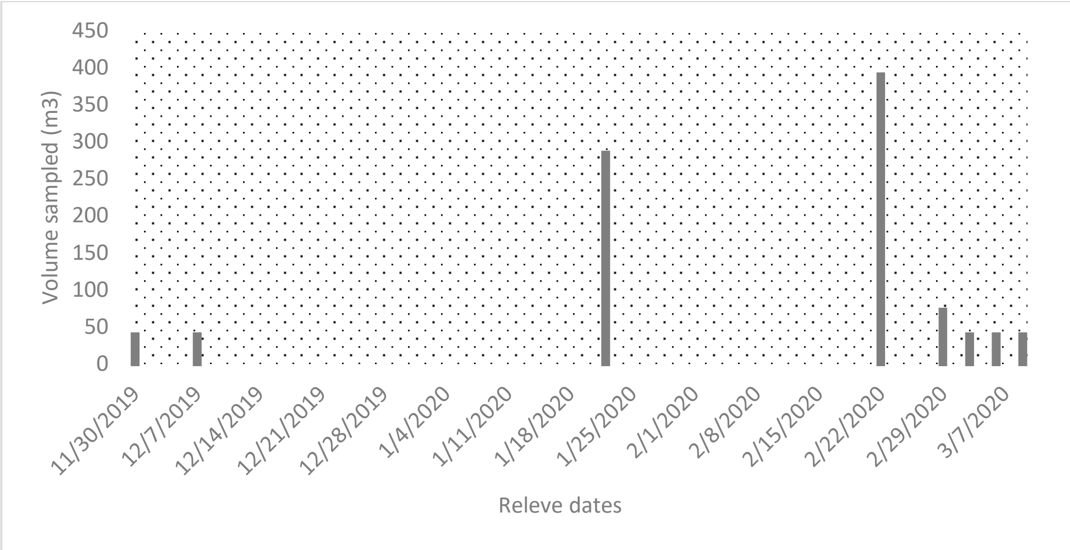

Fig.3. Irrigation frequency and amount of water delivered to the potato

Fig. 4. Potato irrigation in Tachagor

- **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.

- **Cold dry season summary**

The samples taken for crop irrigation are shown in table 3. It is noted that the amount of water taken depends on the type of crop being planted and the area being developed.

Table 3. Water Withdrawals by Crop and Area 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

3.1.6. Amount of water delivered to crops in hot dry season

- **Onion**

  The sum of the water volumes after each irrigation resulted in a cumulative water flow meter (Figure 5) 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. Figure 6 shows the variations in the quantities delivered during the onion cycle. This results in a sample of approximately 7455.58 m^3 for the irrigation of one hectare.

Fig. 5. Tachagor Onion Irrigation Tracker

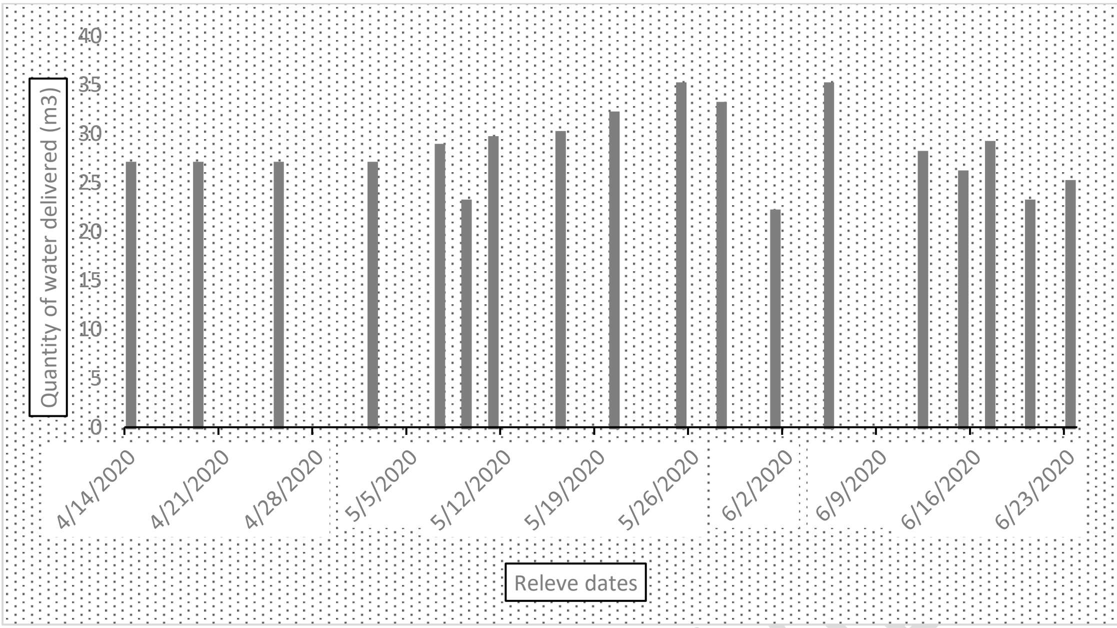

Fig. 6. Variation in the amount of water delivered to the onion

- **Lettuce and Cornet**

  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 samples in hot dry season**

  Water withdrawals for irrigation vary from crop to crop. They also depend on the area planted. The breakdown of these levies is shown in Table 4.

Table 4. Water Withdrawals by Crop and Area 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

3.1.7. Total Valley Samples

The results of the sum of samples delivered to crops show that the total volume is estimated at 2 189 562.14 m^3. Figure 7 shows the sampling for each crop according to the area developed in the valley. The main water-consuming crop in the Boghol Valley is potatoes, followed by tomatoes and maize.

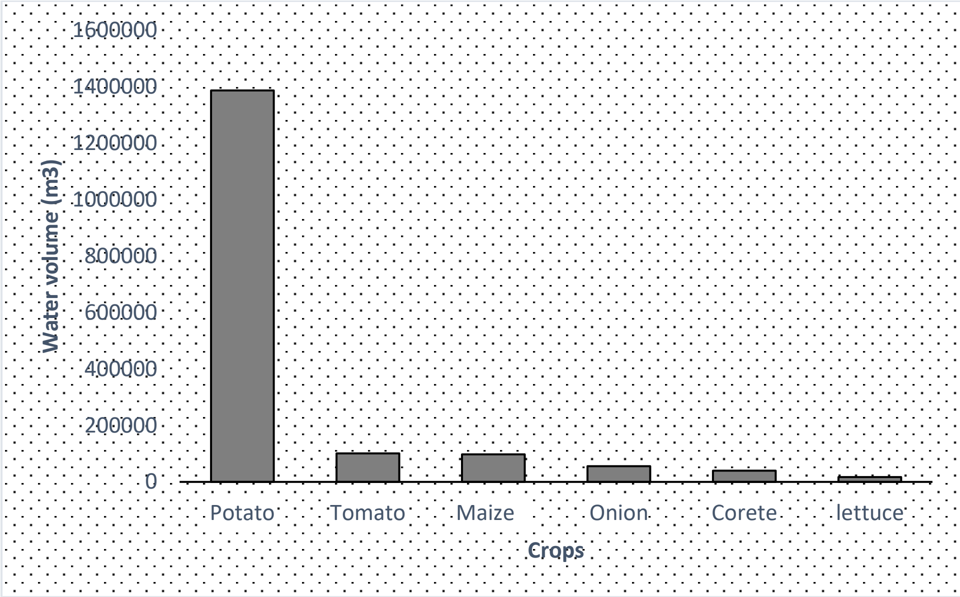

Fig. 7. Total volume delivered to crops

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3.1.8. Water requirements and withdrawals report

The overall amount collected is about 2 189 562.14 m^3 compared to a total crop need estimated at 1 698 132.74 m^3, representing a water waste of 491 429.4 m^3 corresponding to 28.93 %. The analysis in figure 8 shows that for all crops, the samples are higher than the crop needs. Also, for water needs and withdrawals, the quantities are larger in cold season than in dry season.

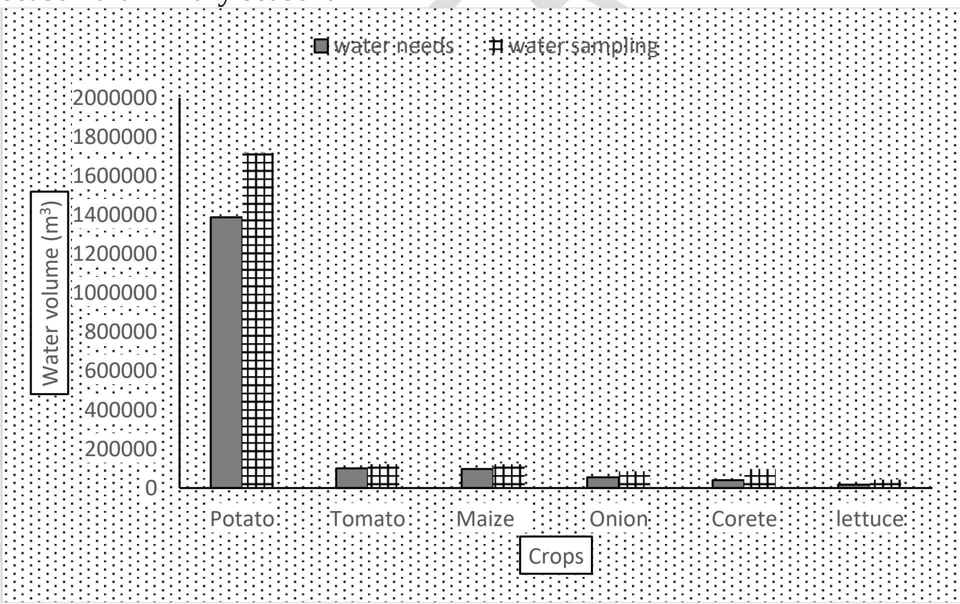

Fig. 8. Comparison of needs and sampling

3.2. Discussion

Water depletion in the catchment works can be equated with an increase in the area worked 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]. Thus, the more land is exploited, the more water needs increase and the groundwater will no longer be able to cover demand. In addition to this, there are the climatic effects, especially the strong evapotranspiration recorded by the Aïr. 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 [24]. 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 [25]. This means that, to meet the water needs of crops, the per hectare sampling in the hot dry season is higher than the sampling in the cold season. However, taking into account the overall situation in the valley, samples taken during the cold season are larger than those taken during the warm season. This difference is due to the large areas that are highlighted in the cold season. During this period the water table is shallow and the extraction is easier for all categories of producers, unlike in hot dry season where the level of the water table gradually decreases. Thus, the drying up of the water catchment structures is observed, pushing operators to dig more deeply into these structures [26]. This situation makes it difficult or impossible to transport water to serve the most remote gardens, especially since the irrigation system is gravity and earthen canals [27]. They generate a lot of losses, especially if we make the relationship with the soils of the valley [20,28]. Also, in the Boghol valley, the practice of controlling attacks on potato tubers is increasing sampling. Producers say a large amount of irrigation would prevent the development of crop pests such as worms. In the Boghol valley, irrigation efficiency is still insufficient and needs to be improved by diagnosing farmers' practices.

4. CONCLUSION

This study addressed the efficiency of irrigation in a context of early draining. The results show that irrigation is practiced all year round in the Boghol valley where the soil texture is predominantly limed-sandy. The areas developed and the crops cultivated are seasonal. The quantities of water delivered are for all crops exceeding their needs, with a deviation of 28.93%. With these losses of water in a very arid environment where the availability of water in the groundwater is dependent on rainfall, it is necessary to improve the efficiency of irrigation. This is possible by diagnosing irrigation practices in the valley.

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