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Study of a smart irrigation system for water managing for potatoes in Chlef region, Algeria

Mohammed Amoura[1)], Mustapha Douani[1)], Toufik Tahri[2)]

[1)] Hassiba Benbouali University of Chlef, Faculty of Technology, Laboratory of Vegetal Chemistry-Water-Energy, Algeria

[2)] Hassiba Benbouali University of Chlef, Faculty of Technology, Laboratory of Electrical Engineering and Renewable Energy LGEER, Route nationale No. 19, 2000, Chlef, Algeria

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Abstract: The configuration of the smart irrigation system was designed on the basis of data specific to the parameters concerning characteristics of the plant and the pedological properties of the local soil (permeability, pH, humidity, porosity, etc.), including the meteorological factors. In the Chlef area, the water availability is dependent on meteorological data. The objective of this work is to estimate irrigation water needs in crop gardening (potato) based on a smart irrigation system (SIS). Thus, to ensure an equilibrated growth of crops, we have developed a system with parameters, such as soil moisture and soil temperature, which are the input variables of this smart irrigation system. This system was applied for the irrigation of potatoes ('Bartina' variety), planted in the agricultural experimental station of Lard El Beida at Chlef. The results obtained in terms of production yield led to a conclusion that the smart irrigation system allows achieving production of 124.83% with lower water consumption (–19.31%), compared to that of a drip irrigation system. Moreover, the granulometric analysis of the potato tuber size showed that 80.83% of the production is within the size range between 30 mm and 55 mm. By comparison, we observed that 77.4% of products obtained from drip irrigation follow a uniform distribution. We conclude that this smart irrigation system is very economical in terms of water use for gardening crops. Given these encouraging results, it would be wiser to generalize its application and implement it to guarantee food self-sufficiency in the water-deficient regions.

Keywords: Chlef area, plot productivity, potato, smart irrigation system, water consumption

INTRODUCTION

In Algeria, the potato sector, in all its aspects related to seeds and consumption, occupies a strategic place because the colossal sums of money are annually mobilised for its production. Many works show that its cultivation is distinguished by production yields ranging between 20 and 30 Mg·ha^{-1} [Lahoual 2015; Djaafour 2019]. In particular, serious problems are encountered with potato seeds which are often imported but unsuited for local environmental conditions in both planting periods during the year. Thus, increasing the productivity remains a big challenge, but a promising alternative would be putting in place efficient water management systems on the one hand, and selecting appropriate fertilisers on the other hand, as well as soil preparation through correct plowing, etc. It is important to point out that imports (220 000 Mg·y^{-1}) hardly cover the national needs; this represents a cost that varies between 65 and 70 mln Eur, depending on the year [Lahoual 2015].

It should be noted that the Algerian agriculture is in a really delicate situation due to the reasons related to the inadequate management of various water resources. Indeed, the area occupied by crop gardening varies each year between 380 000 and 400 000 ha on average. So, 26% of this area is reserved for potato plantation [Lahoual 2015; Djaafour 2019]. It should also be noted that the five geographical areas meant for gardening crops are the Littoral, Sub-littoral, Tell Atlas, Algerian Desert and High Plains [FAO 2015]. The water deficit is due to the weak pluviometry and increased water consumption during the last four decades.

Despite the construction of new dams and the usage of desalination processes, Algeria will still record a water deficit of

1 bln m^3 by the year 2025 [REMINI 2010]. This deficit will be much greater in the hydrographic basins of Cheliff-Zahras (CZ) and Algiers-Soummam-Hodna (ASH).

To attenuate this deficit, which is likely to worsen according to many studies related to the topic, it was decided to focus on the development and application of a smart irrigation system (SIS) to save water for the crop gardening. In addition, the analysis conveys the comparison of the performance of the SIS with the drip irrigation system. In order to estimate the necessary volumes of water some simulation calculations proved to be indispensable. Indeed, the water balance makes it possible to evaluate the quantity of water depending on the growth stage of the crop, the plantation season and the soil properties. This approach provides a framework for reflection that, first of all, the following mistakes should be avoided:

– excessive supply of water leads to leaching, which results in the root asphyxia;
– weak supply of water has a negative impact on the vegetative development of the plant.

An irrigation system taking into account crops that have the same needs is essential in order to adapt the appropriate type of irrigation to control the water consumption strictly. In relation with this objective, a smart system based on a programming card facilitates the management and the control of irrigation. In general, the drip irrigation system is more efficient than a traditional irrigation system [ZELLA, SMADHI 2007].

In drip irrigation system, the problem of obstruction of drippers occurs frequently. Besides, this system should be equipped with a pressure regulator for a controlled and uniform distribution of the water flow through the irrigated parcel.

Numerous smart irrigation systems were available and were used to manage crop water needs based on climate data. Usually, smart irrigation is integrated with intelligent controllers; the main task of the irrigation controller is to control the electrovalves during the irrigation phase. Smart irrigation technologies are promising tools for achieving significant savings in water and also for reducing the diffuse pollution of water sources [NAUTIYAL *et al.* 2010].

SISs integrate many disciplines in order to improve crop production significantly and to manage the water resources efficiently [NORUM, ADHIKARI 2009]. There are various manufacturers of smart irrigation control systems already existing, and others are emerging. A recent study has been conducted in Cary, North Carolina (USA) to evaluate the efficiency of smart irrigation systems [NAUTIYAL *et al.* 2010]. The adoption of the SISs has solved most of the problems related to irrigation practices [CAPRARO *et al.* 2008]. This new method of water management uses various mathematical models basing on the measuring of the difference between the detected value and the expected value in a steady state [ISERMAN *et al.* 1992]. The latest technological advances have enabled the development of water sensors in soil to an automatic and efficient operating. These sensors are usually connected to an electrical circuit attached to the valve [MUÑOZ-CARPENA *et al.* 2003].

At the Dookie Experimental Farm in Egypt, a new smart irrigation system is still being evaluated and initial results indicate that this system achieves water savings of up to 43%, with an average of 38%, in comparison with conventional irrigation systems [DASSANAYAKE *et al.* 2009]. This smart irrigation system was compared with sprinkler and drip irrigation systems for irrigating wheat and tomato crops in arid regions. The results indicate that up to 25% of water was saved by this system compared to control method, while maintaining competing yield [AL-GHOBARI, MOHAMMAD 2011].

Indeed, many manufacturers have developed SISs that contribute to the considerable reduction of irrigation water consumption [MICHAEL, DUKES 2008]. Nowadays, smart irrigation systems have the ability to estimate the water needs of plants based on climatic conditions, such as temperature, humidity, evapotranspiration, rainfall, etc. [LOZANO, MATEOS 2007; MCCREADY *et al.* 2009]. These new systems are distinguished by their accuracy and reliability. PLAYÁN and MATEOS [2006] explained how modernising and optimising irrigation systems can help to increase crop productivity in a situation of scarcity of water resources. MUÑOZ-CARPENA and DUKES [2005] have shown that the smart irrigation systems are able to maintain soil moisture within the desired range, optimal or adequate, to ensure a smooth growth of good quality plants. The smart irrigation systems are based on modern electronic sensors, capable of collecting data, analysing and making decisions to start or stop irrigation. They are capable of transmitting the decisions taken to the electronic control devices which monitor the sprinkler or drip irrigation system. In parallel, some researchers used tensionmeter transducers in programming a drip irrigation system [MENDEZ-BARROSO *et al.* 2008].

Recent developments in agricultural technologies, such as wireless sensor networks which have sensing, data processing, communication and control capabilities [ZHANG *et al.* 2013], are improving real-time irrigation efficiency [SMARSLY 2013]. To be beneficial, these tools need to be accurate, complete and relatively reliable [MUN *et al.* 2015]. In the past years, irrigation controllers have been developed by a number of manufacturers and have been promoted by water purveyors in an attempt to reduce over-irrigation [DAVIS, DUKES 2016].

An experimental approach is carried out, the aim of which is to estimate the irrigation water needs in the crop gardening on the basis of a smart irrigation system. The objective is to ensure an equilibrated growth of crops. Therefore, we have developed a model with the parameters, such as the soil moisture and the soil temperature, which are the input variables of the smart irrigation system. This model was applied for the irrigation of potatoes ('Bartina' variety), planted in the experimental station of Lard El Beida at Chlef. The results obtained will be compared to the drip irrigation system.

Basing on water consumption results by SIS, the second part of our study will be devoted to the sizing of a fresh water production unit by humidification–dehumidification process, taking inspiration from the results of TAHRI *et al.* [2009a]. This fresh water is meant to satisfy the crop irrigation needs in coastal regions.

MATERIALS AND METHODS

STUDY SITE AND DATA COLLECTION

For experimentation, we have chosen the field situated in the experimental station of Lard El-Beida whose geographical coordinates are 36°09' N and 1°20' E. This site is at an altitude of 168 m above sea level (Fig. 1). All the experiments have been carried out during the first half of 2018. To monitor our experiments, we have used the principal equipment such as weather station, water meters, two water tanks, hydraulic pumps, polyethylene pipes, temperature and humidity probes. To ensure no loss of irrigation water, we used many accessories such as electrovalves, different fittings types, sizing reducers, and sprinklers (drippers).

Fig. 1. Location of Lard El-Beida site in the city of Chlef – Algeria; source: own elaboration

The experimental field was subdivided into two plots while adopting the irrigation scheme (Photo 1) to compare the results obtained by the traditional method of irrigation and those by our system. In order to collect the meteorological data relating to the air temperature, relative humidity, atmospheric pressure, global solar radiation, wind speed and its direction, we installed *in situ* a weather station "Vantage Pro 2". These data were recorded at 15-minute intervals on a removable data recorder at the weather station, which was placed approximately at the level of 2.5 m above the ground, as clearly shown in Photo 1. The weather station included a data recorder and a "Weather Link" operating system. The data recorder operated either in computer-connected mode or in a disconnected mode in which case the data would be collected in real time. As for the temperature and humidity of the soil, they were measured by probes placed at a depth of 0.10 m and then recorded on an Arduino SD card shield.

Photo 1. Weather station "Vantage Pro 2" at the University of Chlef – Lard El-Beida experimental station (phot.: *M. Amoura*)

OPERATING OF THE SMART IRRIGATION SYSTEM

For the best operating of a smart irrigation system, it is more interesting to access all variables in real time. Our system mainly consists of an Arduino SD card which controls the electrovalves operating. The Arduino SD card can be programmed *in situ* while fixing the favourable instructions such as the minimum soil moisture content settled at 50%. The sensors could detect the local variations of the temperature and humidity of soil. The opening and closing of the electrovalves depend on the difference between the measured value and the setpoint. These measured amounts are then used for the irrigation programming of the plots. The flowchart of this process is illustrated in Figure 2.

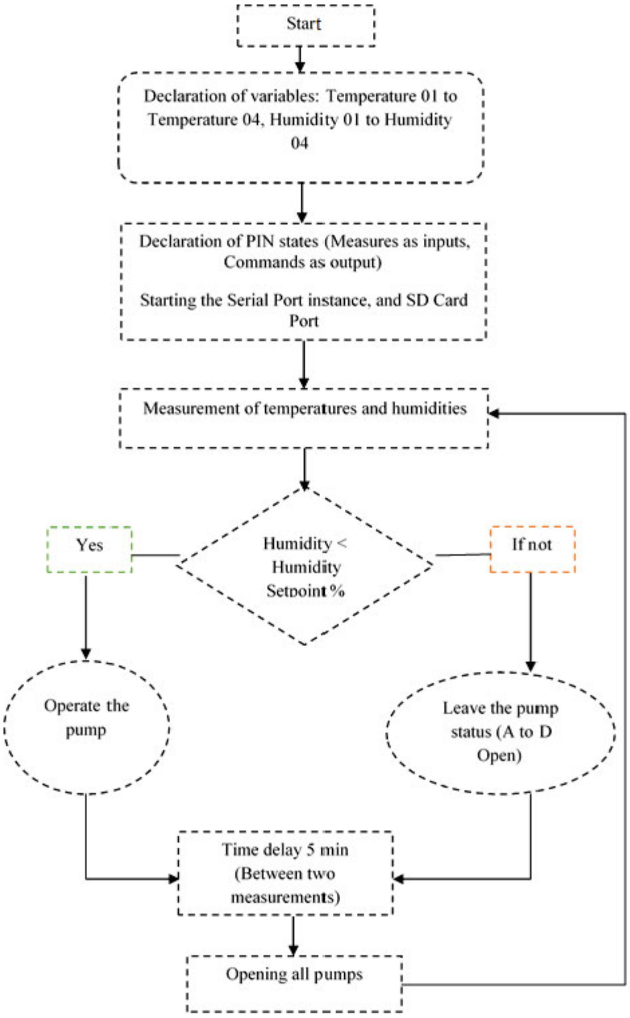

Fig. 2. Flowchart for temperature measurement and soil moisture control; source: own elaboration

INSTALLATION OF IRRIGATION SYSTEMS

Firstly, we mention that the drip irrigation systems were installed in both plots – A and B (Fig. 3) when we have planted potatoes with a difference in the distribution technique used. So, the potatoes in plot A were irrigated after the integration of a smart irrigation system. However, the crops in plot B were irrigated traditionally. These two irrigation systems were designed to manage the water consumption more efficiently during all its development period by a uniform water distribution during irrigation. We precise that the drip irrigation lines are spaced on an average of 1 m apart and the drippers of the same line are spaced 0.30 m.

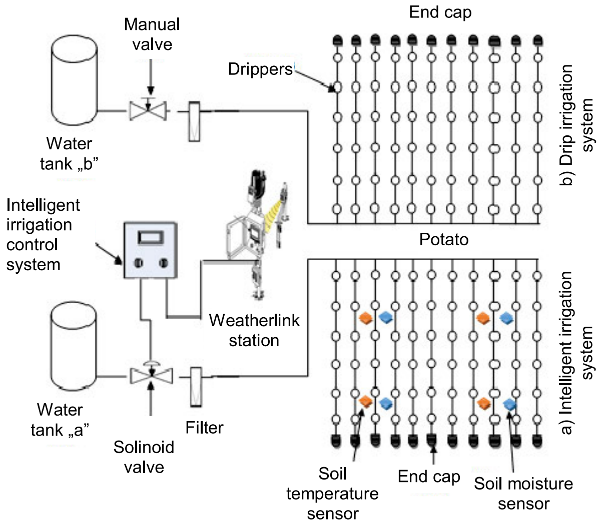

Fig. 3. Field planting scheme using irrigation systems; source: own elaboration

For each system, we installed a water meter in order to quantify its consumption during the irrigation operation. Moreover, in the event of water meter failure, these quantities are directly read on the graduated rules placed on tanks. This approach is based on the methodology developed by MERRIAM and KELLER [1978]. The assessment of performance tests was carried out through the verification of the good uniformity in water distribution, etc.

IDENTIFICATION OF PROPERTIES OF SOIL

The soil characterisation was done based on the physicochemical parameters. Thus, to identify it, a coring operation was carried out in the plots by agronomic laboratory FERTIAL (Algerian Fertilisers) and the analysis results are presented in Table 1. Besides its high fertility, we mention that the soil is very heavy and clayey, with very poor internal drainage and high retention capacity (water and fertiliser). According to the pH values, it emerges that the soil is alkaline, which can cause problems with the assimilation of microelements. In the case of potato cultivation, the most appropriate soil pH should be between 5 and 7.

During the regular development process, the crop needs in phosphorus and potassium are fulfilled with the help of fertilisers with a normal K:Mg ratio, there is no serious risk of being induced by Mg deficiency. However, the C:N ratio indicates that the soil is poor in organic substances. Consequently, there might be asphyxiation of plant roots.

Moreover, we noted that soil contains free nitrogen issued from the previous spreading of mineral fertilisers, but its carbonate content remains high. In order to solve this problem, it is possible to attenuate the C:N in soil content by compost addition after having incorporated 50 kg·ha^{-1} of urea or the equivalent of another nitrogen fertiliser.

Table 1. Physicochemical analysis of soil[1)]

Physical properties	Values	Characterisation of soil	Observations
Electrical conductivity	0.052 mS·cm^{-1}	unsalted	very low
pH water	8.8	alkaline	very high
C:N	6.83	–	low
Carbonates	20.95%	209500 ppm	high
Active limestone	–	–	–
Organic matter	1.41%	14100 ppm	low
Nitrogen	0.12%	1200.00 ppm	normal
Phosphorus (Olsen method)	0.07 meq·(100 g)$^{-1}$	20.8 ppm	low
Exchangeable potassium	0.4 meq·(100 g)$^{-1}$	172.0 ppm	low
Exchangeable magnesium	1.9 meq·(100 g)$^{-1}$	228.6 ppm	low
Exchangeable calcium	15.5 meq·(100 g)$^{-1}$	3106.2 ppm	normal
Exchangeable sodium	0.3 meq·(100 g)$^{-1}$	59.8 ppm	very low

[1)] Sand 40%, silt 28%, clay 32%, texture: clay.
Explanations: C:N = carbon to nitrogen ratio.
Source: own study.

SOIL PREPARATION

On January, we have plowed the plots. Taking into account the height of the plantation ranges and the development of the roots of the plant, we retained an average depth of plowing between 0.25–0.30 m. The disking operation was carried out two or more times to break the clods of soil. The field with dimensions of 46 m×30 m was subdivided into two plots:
1) plot A, intended to be controlled by SIS;
2) plot B, intended for drip irrigation.

Fertiliser spreading (type NPK 15.15.15) was done manually with a ratio of 350 kg·ha^{-1}. We have spread the fertilisers before the hoeing operation. This period corresponds to the start of the phase of growing tubers.

This operation has been carried out during two crop growth stages, namely sowing and weeding. To eliminate the weeds, two weeding techniques were used:
1) manual weeding in mid-March (the 4th week from the date of planting) as soon as the first weeds appeared;
2) selective chemical weeding with MITOZINE50 herbicide throughout the period preceding the wilting phase with a ratio of 1 kg·ha^{-1}.

As preventive measures against the proliferation of downy mildew (*Phytophthora infestans*) and *Rhizoctonia solani* in humid and warm weather conditions, it was decided to proceed with the chemical treatment. The phytosanitary treatments were carried out at the start of flowering (30 days) and after 90 days have elapsed when the appearance of mildew has been observed.

These operations contribute to preserving the objectives sought in this framework. After the last stage of crop defoliation, it is imperative to wait for two weeks before the tubers harvest in order to allow the skin to become sufficiently firm.

For a late harvest, there is a higher risk of damage to the tubers by wireworms, slugs, and drycore. The hand grubbing operation was done from June 24th at the full maturity of the potato. Then, the bad tubers were immediately eliminated.

QUALITY OF IRRIGATION WATER

The composition of irrigation water certainly contributes to modifying the chemical quality of soil, which affects the most crops. It is determined by its chemical analysis at the agronomic laboratory FERTIAL. The most important water parameters are the pH, the salinity, the sodium adsorption ratio (*SAR*), the carbonates, and the bicarbonates in their $CaCO_3$ and $MgCO_3$ forms. The results of these physicochemical analyses are presented in the Table 2.

Table 2. Physicochemical analysis of water used in the experimental station

Properties of irrigation water	Values
pH	7.96
EC (mS·cm^{-1})	1.130
Carbonate (mg·dm^{-3})	0.00
Bicarbonate (mg·dm^{-3})	21
NO_3^- (mg·dm^{-3})	0.960
Cl^- (mg·dm^{-3})	112.00
Na (mg·dm^{-3})	136.80
K (mg·dm^{-3})	4.050
Mg (mg·dm^{-3})	36.730
Ca (mg·dm^{-3})	105.500
SO_4^{2-} (mg·dm^{-3})	73.000
SAR (mg·dm^{-3})	2.913
Total salt (g·dm^{-3})	0.723

Explanations: *EC* = electrical conductivity, *SAR* = sodium absorption ratio.
Source: own study.

These results indicate that the exploited water from the experimental station is moderately saline. Its characteristics are an *EC* of 1.130 mS·cm^{-1} and a *SAR* of 2.913 mg·dm^{-3}. They represent a very high risk of salinisation. Its pH of 7.96 is due to the content of Na^+ and Cl^- ions in the soil.

RESULTS AND DISCUSSION

WEATHER CONDITIONS IN THE AREA

Air temperature

The variation in average weekly air temperature, during the whole growth period of the plant, is presented in Figure 4. The figure shows that the average temperature fluctuations are random, which affects the quantity of water the plant needs. To attenuate these fluctuations of temperature and to ensure regular and harmonious growth of crops, it seems that the integration of the smart irrigation system is the best solution. So, it was noted that the extreme values of average weekly temperatures have been 10.7°C in February and 27.4°C in June. The weather data indicated reasonable temperatures that were conducive to potato development.

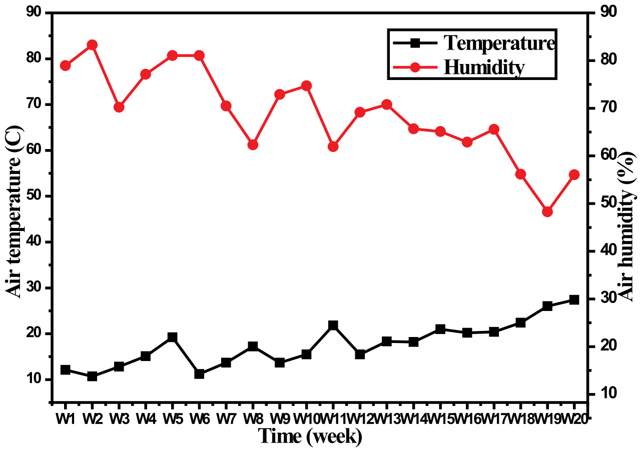

Fig. 4. Variation in the average weekly air temperature and air humidity during the growth period of the plant; source: own study

Air humidity

The relative humidity is the ratio of the amount of water actually contained in the air and its maximal absorption capacity at given temperature and pressure conditions. The weekly average relative humidity in the experimental station is shown in Figure 4. We can limit its variation between 46.6% and 83%. Therefore, it emerges that the monitoring of this parameter is of great importance. In addition, plant transpiration relates to the lowest relative humidity value. In this case, the smart irrigation system must intervene to meet the plant's need for water.

Rainfall

The evolution of rainfall between February 11, 2018, and June 21, 2018, is shown in Figure 5. It indicates that the rainfall is very irregular with a peak of 75 mm on May 17, 2018. We can find out that a major quantity of precipitations occurred during the months of February and March in the basin of the Chlef region.

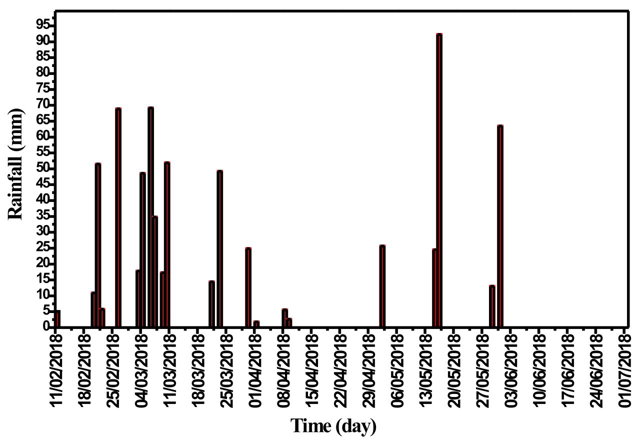

Fig. 5. Variation in rainfall recorded over time, during the growth period of the plant; source: own study

MONITORING OF SOIL PARAMETERS

Soil temperature

Figure 6 presents the temperature evolution of the soil, at the depth of 15 cm, in the experimental station. It is noted that the minimum and maximum soil temperatures are in the range of 11 and 26.6°C, respectively. In addition, it is important to mention that the soil temperature can be correlated with climatic factors and topographic characteristics of the region. According to DUCHAUFOU [1983], the weather has an important and direct influence on water in the soil, i.e. on its movements in the soil and its direct impact on vegetation. Water promotes the dissolution of organic matter to facilitate its absorption by plants to favourise the enzymatic reactions that are responsible for the development of tubers.

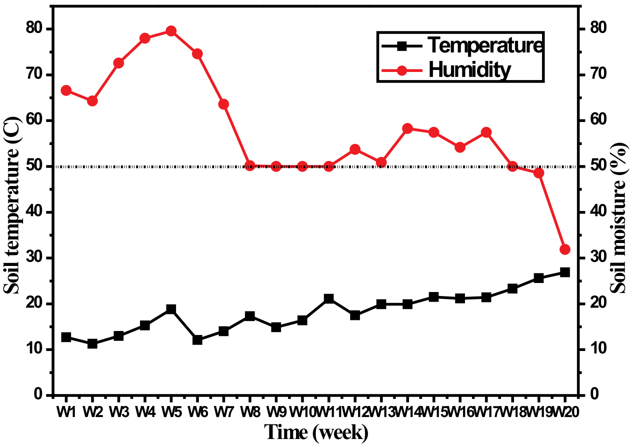

Fig. 6. Variation in the average weekly soil temperature and soil humidity, during the growth period of the plant (field capacity = 0.53, wilting point = 0.25); source: own study

Given the physicochemical properties of soil, DAJOZ [1971] indicated that under the effect of solar radiation, the soil layers accumulate more heat than the surrounding air. So, in Figure 6, the temperature difference recorded can be attributed principally to solar radiation.

Soil moisture

Figure 6 shows the average weekly soil humidity variations during the growth period of the plant. Indeed, water is an important factor that contributes to the physical, chemical, and biological phenomena that take place in soil. The soil moisture is a measure of the amount of water stored per unit of soil volume. Based on the physical properties of soil and those of liquid water, in Figure 6 we can note that the wet soil temperature is much weaker than that of the dry soil.

Beyond soil saturation, any additional water supply induces soil leaching, which results in the depletion of the organic matter in the soil, hence there is a need to amend the soil by adding more fertilisers for the purpose of having better crops. The presence of free water depends on the adsorption kinetic of the soil particles (adsorption isotherm). This observation allows distinguishing four different soil states [BRUAND *et al.* 1996; CHEIAKH 2018]:
1) water saturation state;
2) field capacity state;
3) wilting point (*WP*);
4) extra dry state.

It is worth noting that organic matter increases the water-holding capacity of soils. In times of drought, this would promote the trapping of a larger quantity of useful water in the soil. However, the high water retention capacity has a trend of slowing down the rate of soil drying and vice versa. In order to counteract the development of phytosanitary diseases (mildew, *Golovinomyces orontii*, etc.) during the rainfall period (March–June) when the weather is warm, it is highly recommended not to compromise the productivity yield by sprinkler irrigation.

However, we consider the drip irrigation as one of the best solutions to adopt.

COMPARATIVE RESULTS OF PLOTS

Evolution of vegetation

In each plot, the development of vegetation was monitored by taking into account the average size of stems throughout the crop cycle. We specify that the size of the plant is measured by means of a graduated ruler during its different phases of growth. Figure 7 shows the variation of average plant sizes every fifteen days.

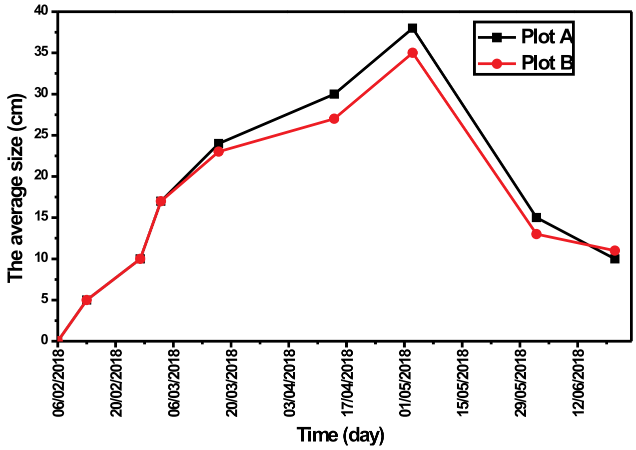

Fig. 7. Evolution of the average stem size of plants; source: own study

For each plot, the data were statistically processed to establish an own regression to variation of size versus the time without taking into account the wilting phase of the plant. Thus, an analysis of the variance table (Tab. 3, 4) is introduced to study the sensitivity of the model (cubic law) via the *P*-value which is very low compared to the significance level of 0.05. We found out that it was statistically identical for the two plots. Nevertheless, a slight difference in the two plots was observed after 45 days. Beyond this period, a stem size difference of 3 cm was observed in favour of plot A.

Table 3. Analysis of variance for the plot A

Source	*DF*	*SS*	*MSE*	*F*	*P*-value
Regression	3	1092.49	364.165	52.19	0.004
Error	3	20.93	6.978	–	–
Total	6	1113.43	–	–	–

Explanations: *DF* = degrees of freedom, *SS* = sum of squares, *MSE* = mean squared error, *F* = Fisher test statistic, *P*-value = probability value.
Source: own study.

Table 4. Analysis of variance for the plot B

Source	*DF*	*SS*	*MSE*	*F*	*P*-value
Regression	3	901.289	300.430	44.13	0.006
Error	3	20.425	6.808	–	–
Total	6	921.714	–	–	–

Explanations: *DF*, *SS*, *MSE*, *F*, *P*-value as in Tab. 3.
Source: own study.

With regard to irrigation, it is important to indicate that:
– plot A was irrigated using the SIS according to rainfall, hygrometric soil parameters, etc.;
– plot B was irrigated with the frequency of every five days.

Ten days after the cessation of irrigation, a test on the firmness of the tuber skin was performed. Taking into account the ripening state and plants wilting, the tubers were manually harvested on the 130th day.

Comparison of the productivity of the plots

The yields of the plots (drip irrigation and smart irrigation system) were compared. The results obtained are shown in Figure 8, which highlights that the productivity of plot A is greater than that of plot B. Indeed, relatively to seeds, the tuber yields were 535% for plot A and 428% for plot B. Therefore, we conclude that it is strongly recommended to use smart irrigation systems that have a positive impact on crop yields.

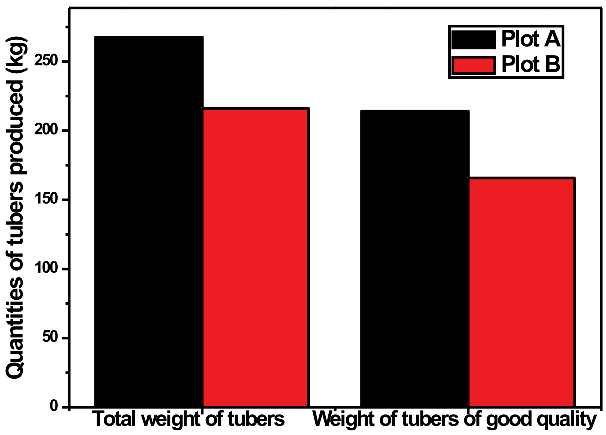

Fig. 8. Comparative analysis of the weight of tubers in the two land plots; source: own study

Comparison of water consumption

It is worth recalling that many varieties of potato, developed recently, are more sensitive to soil water deficit and need frequent and shallow irrigation. Figure 9 shows a comparison between the cumulative consumption of irrigation water in both plots. It is clearly noted that the smart irrigation system consumes less water for potato production, with a significant yield. The smart irrigation system, designed in this framework, is able to detect the daily needs of water for plants without being obliged to displace it to the site.

A comparative analysis between the plots, based on water consumption and yields, allowed stating that the smart irrigation system is more performant than the drip irrigation system.

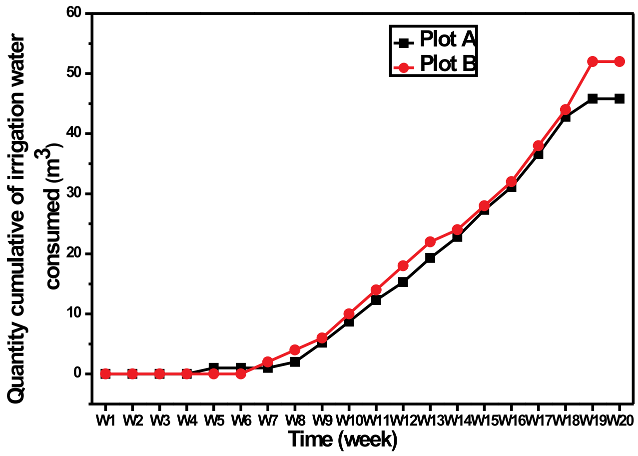

Fig. 9. Comparison of water consumption in the two plots during the plant growth period; source: own study

CONCLUSIONS

Agriculture's need for irrigation water continues to increase with the growth of the population. Taking into account the locality of the cultivation area, we focused on the analysis of the performance of drip irrigation systems. In this study, a smart irrigation system, coupled with the traditional drip system, was developed for the equilibrated growth of crops (potato) in the Chlef area. The configuration of the smart irrigation system was designed on the basis of data specific to the parameters in relation to the characteristics of the plant on the one hand and to the pedological properties of the local soil (permeability, pH, humidity, porosity, etc.) on the other hand, without neglecting the meteorological factors of the area.

The good control of the parameters has ensured a harmonious growth of the plant in its different stages. In this sense, the management of water needs is dependent on soil moisture as a setpoint varying over an interval between 50 and 60%.

During the vegetation of the potato, we ensure rigor and sufficient precision of the smart irrigation system in terms of water consumption resulting in a saving of 10 to 13% compared to the traditional drip irrigation system.

In terms of the quality of the produced tubers, we note that tubers' size follows an almost uniform distribution (average = 50 mm) with a yield of 124.83% compared to the traditional irrigation system. It is quite clear that the developed process is suitable for different regions characterised by a water deficiency and in arid coastal areas particularly.

In this last case, we intend to exploit the seawater humidification–dehumidification process developed in 2009 by Tahri *et al.* with a view to adapting the smart irrigation system for efficient management of the agricultural needs of these areas in order to ensure self-sufficiency in the water supply for irrigation.

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