Irrigation system performance in potato production in Northern Algeria

A case study of the portable sprinkler system

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This study was carried out by the Wageningen Research Foundation (WR), business unit Agrosystems Research under supervision of Dr.ir. Greet Blom-Zandstra (Agrosystems Research) and Prof. Dr.ir. Niels Anten (Centre for Crop Systems Analysis) and was commissioned and financed by Rijksdienst voor Ondernemend Nederland in the context of Policy Support. Project title: Baseline study El Oued (Mat16ALG01).

WR is part of Wageningen University & Research, the collaboration of Wageningen University and Wageningen

Wageningen, July 2017

Den Braber, H.J., 2017. *Irrigation system performance in potato production in Northern Algeria; a case study of the portable sprinkler system.* Wageningen Research, Report WPR-694, 26 pp; 18 fig.; 5 tab.; 34 ref.

Keywords: Algeria, irrigation, performance evaluation, potato production, soil moisture

Chamber of Commerce no. 09098104 at Arnhem
VAT NL no. 8065.11.618.B01

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Summary

This report presents a case study of the performance of the irrigation system commonly used in potato production in Northern Algeria, the portable sprinkler system. The aim is to determine water use, water losses and water distribution uniformity. Furthermore, it is evaluated whether the applied irrigation water can be stored in the root zone, and if irrigation applications match with crop water demand. Based on the findings, some recommendations will be given to improve the system. Algeria is among the countries with the lowest renewable water resources per capita in the world, but currently, data and information on irrigation system performance is lacking. In this study, the portable sprinkler system is evaluated by means of field measurements (catch can test, sprinkler discharge measurement, soil moisture measurements) and modelling (CROPWAT 8.0 model). It was found that water losses due to wind drift and evaporation are rather high (36%) compared to values found in literature, whereas the water distribution uniformity was low (DU 34.6% and CU 51.2%), from which it can be concluded that the system performs poorly. Furthermore, it was found that water applications are too high, especially in the beginning of the growing season. The most important recommendation to improve the performance of the irrigation system is an alternative irrigation schedule, adapting the timing and duration of irrigation events to crop water demand and the water storage capacity of the root zone.

To give an impression of the enthusiastic welcome and willingness to cooperate with us, Mr. Ammar Hettiri (potato farmer in El Oued) sent us after our internship the following message:

Video by Mr. Ammar Hettiri

1. Introduction

Potato (Solanum spp) is among the five most important staple food crops in the world, and it is cultivated along a wide range of climatic conditions (Kromann et al., 2014). It also has a low water footprint and a high nutritional value (Wolters et al., 2016). These features make it an interesting crop for Algeria, where potato production and consumption has expanded considerably the last three decades. Currently, large potato production areas (in total 90000 ha) are found in several regions in this large North African country, and the sector is still growing fast (Huizenga & te Maarn, 2013). An important characteristic of potato production in Algeria is the heavy reliance on irrigation. Although Algeria is among the countries with the lowest renewable water resources per capita in the world (Mohtar, Assi & Daher, 2017, WRI, 2005), water is still applied in a wasteful manner, and irrigation systems are not functioning optimal. Besides that, water demand is expected to increase drastically in the near future (Serbi, 2016). The coastal region of Algeria has already seen a decrease in annual precipitation of more than 50 mm per year since 1950, and climate models predict a temperature rise and a further precipitation decrease in the future. As a result, groundwater levels, as well as inputs to storage reservoirs are expected to decline (García-Ruiz et al., 2011). Currently, agriculture accounts for 70-80% of the total water use in Algeria, and as potato is the main irrigated crop in Algeria, (Huizenga & te Maarn, 2013) improving the potato production system and rationalizing the use of water is key to sustain the production in the future and to maintain and enhance food safety. It is therefore important that the performance of irrigation systems used for potato production is evaluated in order to reduce water losses and water use efficiency. This report presents a case study investigating the performance of a common irrigation system in Northern Algeria, the portable sprinkler system, in Boumerdes, one of the main production areas in Northern Algeria.

The main aim of irrigation is to apply the optimal amount of water to the crop. To optimize the water use efficiency of a system water loss should be minimized and the uniformity of the water distribution should be maximized (Siosemarde, Byzedi &Nodehi, 2012). Therefore, this report, has the following 5 aims:

- Evaluate the wind drift and evaporation loss (WDEL)
- Evaluate the water distribution uniformity
- Investigate whether applied irrigation depths can be stored in the soil
- Investigate whether irrigation matches crop water demand
- Give recommendations to improve the performance of the irrigation system

The structure of this report is as follows: chapter 2 describes the materials and methods and chapter 3 presents the results. In chapter 4, the results are discussed and the report ends with a conclusion in chapter 5. Annex 1 and 2 contain Excel sheets with the data of the field measurements and the calculations. Annex 3 contains the input values used for the CROPWAT model, and annex 4 contains a guideline for the field installation and software configuration of the Sentek Multi system used in this study.

2. Materials and methods

2.1 Water application rate

Water application rates can be measured with three different approaches in the field, namely by measuring with catch cans in the field (1), by measuring the flow rate at individual sprinklers (2) and by measuring the flow rate at the pump (3) (Smjastrla, et al., 1990). The first two methods have been applied for this research, unfortunately, we were not able to measure the flow rate at the pump, as the flow meter did not fit on the pipeline.

2.1.1 Catch cans

To measure directly how much of the water applied reaches the plants and to analyze the water distribution uniformity, catch can measurements were conducted. The guidelines for catch can measurements in portable sprinkler systems, as described by Meriam and Keller (1978) and Smjastrla et al., (1990) were used to design the catch can lay-out (fig. 1) and determine the field procedure.

30 catch cans were placed in a square grid in a space between three sprinklers on the sprinkler lateral. Each catch can was placed in the centre of a plot measuring 3.5*3.5 meter, thus representing 12.25 m2. It is assumed that each catch can collects an amount of water that is representative for the plot in which it was placed (Meriam and Keller, 1978). During the installation of the catch cans in the field, the sprinklers were locked in such a way that water could not enter the catch cans before the test started. After 1 hour of irrigation, the sprinklers were locked again, and the amount of water in each catch can was measured with a 250 ml graduated cylinder.

To check how much water evaporated from the catch cans during the test, 3 catch cans containing 80 ml of water (the average catch during a trial catch can measurement) were placed outside the field during the test and measured after the test. The difference in volume before and after the test is supposed to be due to evaporation from the catch cans during the test (Meriam and Keller 1978, Playan, 2005).

Water pressure in the system might differ at various places in the field, because elevation and distance from the pump influences the pressure. Following Smjastrla, et al., (1990) test locations were selected based on their distance from the pump, and their elevation. Four tests were conducted during four irrigation events. Tests 1 and 2 were conducted during two consecutive irrigation events, far away from the pump, where pressure is expected to be lower than average. Test 3 was conducted at medium distance from the pump (average pressure), whereas the test location for test 4 was close to the pump (high pressure). Catch cans were placed on sticks so that the opening of the catch cans was located just above the highest plants of the crop canopy. The catch can diameter was 119 mm, which matches with the recommendations by Playan et al., (2005) regarding catch can experiments under high wind conditions. See figure 1 and 2 for the catch can layout and a picture of the test, respectively.

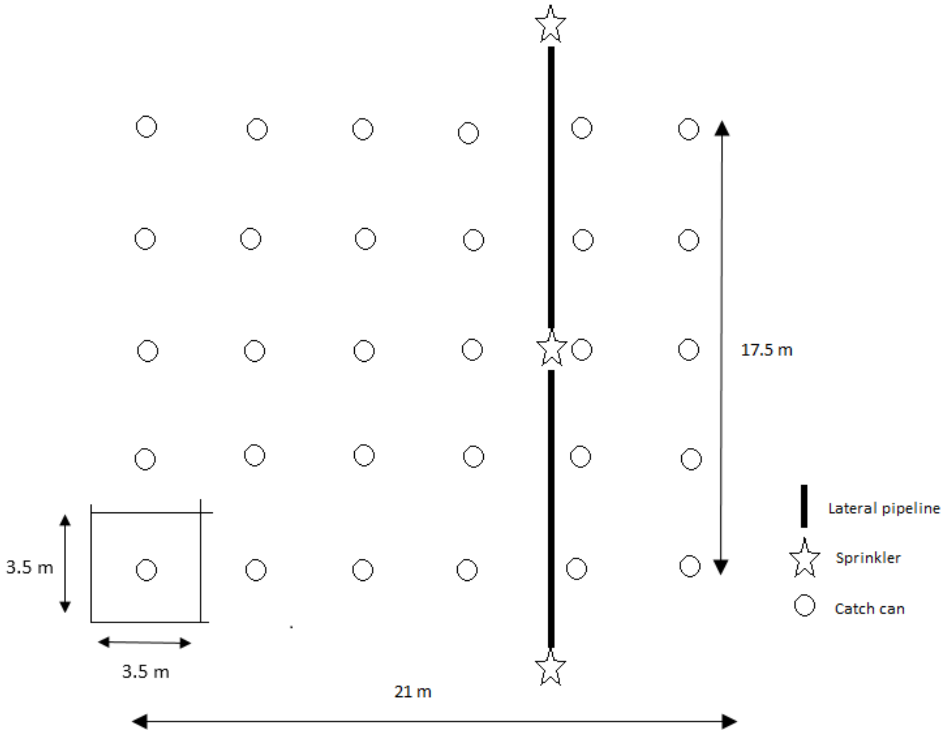


Figure 1 *Schematic representation of the catch can lay-out*

Figure 2 *Catch can measurements in the field*

2.1.2 Individual sprinkler discharge

Individual sprinkler discharge was measured by a method suggested by Meriam and Keller (1978) and Smjastrla, et al., (1990). A piece of hose was put over the nozzles of an individual sprinkler and the water flow was directed into a bucket of known volume. The time needed to fill the bucket was recorded and the flow rate (L/h) was calculated. During each catch can measurement, the discharge of the three sprinklers adjacent to the research plot was measured twice, as well as 3 other sprinklers the lateral line, in order to see if there were differences in discharge along the lateral line.

2.2 Calculations

The catch can measurements (in ml/h) were converted to observed irrigation depth (OD in mm/h):

$$OD = \frac{V}{A}$$

Where:
V = Volume (ml) in catch can
A = surface area of catch can (cm2)

From measurements of the sprinkler discharge the discharged depth per sprinkler (DD in mm/h) was calculated:

$$DD\ (mm/h) = \frac{Flow\ rate}{A}$$

Where:
Flow rate = Sprinkler flow rate (L/hour)
A = surface area covered by sprinkler (m3)

The difference between the average depth discharged on the catch research plot and the average observed depth allows to estimate how much water is lost through wind drift and evaporation (Demchi et al., 2005, Tarjuelo et al., 1999a)

$$WDEL = 1 - \left[\frac{OD}{DD}\right]$$

Where:
WDEL = % of water discharge lost through wind drift and evaporation
OD = average water depth observed (mm)
DD = average water depth discharged (mm)

To evaluate the water distribution uniformity two indicators are calculated, the distribution uniformity (DU) and Christiansen's coefficient for uniformity (CU) (Dechmi et al., 2005, Tarjuelo et al., 1999a)

$$DU = \frac{Average\ low\ quarter\ of\ water\ depths\ observed}{Average\ water\ depth\ observed} * 100$$

$$CU = \left[1 - \frac{average\ deviation\ from\ the\ average\ observed\ depth}{average\ observed\ depth}\right] * 100$$

2.3 Crop evapotranspiration

Crop evapotranspiration ETc was calculated by using the 'guidelines for computing crop water requirements' presented by Allen et al., (1998). The following formula was used:

$$ETc = Kc * ETo$$

Where:
ETc = crop evapotranspiration (mm/day)
Kc = crop coeffient
ET0 = reference crop evapotranspiration

The Kc value was adjusted according to the different growth stages of the potato crop, the local climate and the irrigation practices. Long term average ET0 values per day for Algiers (approx. 30 km from the study field) where obtained from the FAO CLIMWAT for CROPWAT database (CLIMWAT, 2017). See the attached Excel sheets in annex 2 for the calculation.

2.4 CROPWAT model

The CROPWAT model (CROPWAT, 2017) was used to combine data regarding climate, evapotranspiration and irrigation. It allows to calculate the daily crop water requirements, and simulates the soil water depletion of the root zone given the irrigation schedule, rainfall soil type and crop water demand. See annex 3 for the input data that have been used to simulate the conditions on the research field in Boumerdes.

2.5 Sentek MULTI system

Two soil probes (RS485 Drill&Drop Probe) were installed at the study field, measuring the soil moisture content, temperature and salinity at different depths in the soil profile (5,15,25,35,45,55 cm depth). The system also contained a thermometer and a rain gauge measuring the water application. See figure 3 for a picture of the thermometer, rain gauge and data transmission unit, and figure 4 for the installed soil probe. The measured data was processed into graphs using the IrriMAXlive software, a web based platform where one can access the output data measured by the Sentek Multi system.

Figure 3 *Rain gauge, thermometer and data transmission unit*

Figure 4 *Soil probe installed at the study field*

3. Results

The following subchapters describe the results regarding water use in the study field in Boumerdes. First, the irrigation system will be described in more detail (3.2.1), followed by a section describing the water distribution and the loss through wind drift and evaporation (3.2.2). Next, the soil characteristics are presented (3.2.3). Section 3.2.4 deals with crop evapotranspiration and combines the data gathered in the previous sections into a schedule showing the soil water depletion in the root zone in the growing season.

3.1 Portable sprinkler system

A portable irrigation system consists of a single lateral pipe on which sprinklers are placed at regular intervals, normally 12 meters. (Meriam and Keller, 1978, Smjastrla, et al., 1990). See figure 5 for the irrigation system at the study field. A well near the field is used to pump groundwater from 120 meter depth to a basin (fig. 6), from where it is distributed through a tube leading to the lateral pipe. If the water level in the basin is too low, irrigation is not possible. Consequently, after an irrigation event, farmers often have to wait several hours before the water level in the basin is high enough for a subsequent irrigation event. After four hours of irrigation, the water is turned off, the pipe is detached and moved manually to its new location, approx. 12-13 meter to the right, where a new plot is irrigated. Thus, the field is irrigated in multiple phases and it takes approximately one week before the whole field is irrigated. Consequently, a certain place in the field is irrigated once a week. Fields are irrigated continuously during the whole growing season, and regardless the weather conditions or crop growth stage, each irrigation event lasts four hours. The study field was located on a lightly sloping terrain and the ridges were oriented downhill.

Figure 5 *Portable sprinkler system*

Figure 6 *Basin for irrigation water*

Figure 7 *Sprinkler system manually moved*

During an irrigation event, the sprinkler lateral was placed in the furrow between two ridges, and often, this furrow, as well as the two adjacent furrows, was completely soaked and water flowed downhill through the furrows. This water stagnated at the field border and formed large puddles that were sometimes over 30 centimetres deep and several meters wide (fig 8). Furthermore, we have also observed leakage in the pipes leading to the sprinkler lateral (fig 9).

Figure 8 *Run-off, and stagnating water at the field border*

Figure 9 *Leakage in pipe*

Each year in the summer, the groundwater level dwindles, and the supply from the groundwater doesn’t match the demand for irrigation water. During this period, starting in May and ending at the end of the growing season, water is extracted from large storage reservoirs in higher regions. Water transport via underground pipelines from the storage reservoirs to farmer’s field is facilitated by the Algerian government.

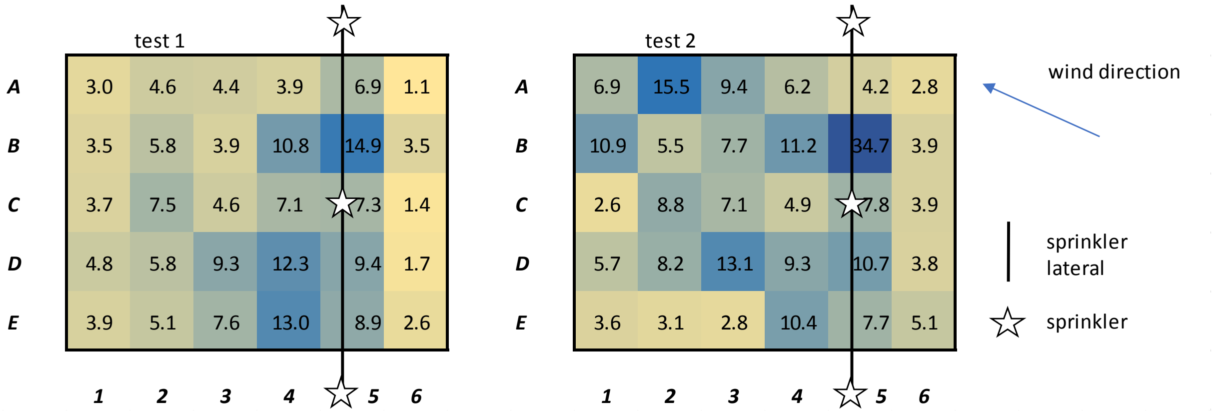
3.2 WDEL and water distribution

In this subchapter, the results from the catch can measurements will be presented. Table 1 shows the average observed depth (OD in mm/h) on the research plot, measured during the catch can tests. Based on that, the irrigation depth (mm) per event of 4 hours is calculated. The average irrigation depth (26.4 mm) gives an indication of the amount of water that reaches the soil surface per irrigation event. The average depth discharged (DD in mm/h) was calculated from the sprinkler discharge. From the difference between the discharged depth and the observed depth the water loss due to wind drift and evaporation (WDEL) was calculated. The average WDEL was 32.3%, which indicates that about one third of the water that is distributed by the sprinklers does not reach the soil surface in the research plot. The last two columns of the table present wo indicators for the uniformity of water distribution, namely the distribution uniformity (DU) and Christiansen’s coefficient of uniformity (CU). These indicators show how evenly the water is distributed over the surface area of the research plot.

Table 1 *Average observed irrigation depth in (OD in mm/h), irrigation depth per irrigation event of 4 hours (mm), calculated average depth discharged (DD in mm/h), discharged depth per irrigation event, distribution uniformity (DU %), Christiansen's coefficient of uniformity (CU%) and water loss through wind drift and evaporation as percentage of the water discharged (WDEL)*

Test	OD (mm/h)	OD (mm/4h)	DD (mm/h)	DD (mm/4h)	WDEL (%)	DU (%)	CU %
Test 1	6.1	24.3	8.8	35.2	31.0	42.2	53.8
Test 2	7.9	31.7	9.1	36.2	12.6	42.0	53.6
Test 3	6.2	24.8	10.3	41.2	39.7	29.5	57.1
test 4	6.2	24.6	13.0	52.1	52.7	22.8	40.3
Average	6.6	26.4	10.3	41.2	36.0	34.6	51.2

Figure 10 presents two maps that visualize how the water is distributed during two consecutive irrigation events. In both tests, the research plot was placed between the same sprinklers on the lateral line. Note that the sprinkler lateral is not in the center of the research plot, because the wind blew most of the water to the left. The time between the two tests was three hours. It can be observed that in both tests, variation in observed depths is large, and that the plots near the sprinkler often receive more water. Furthermore, it is striking that same locations receive large irrigation depths, whereas an adjacent plot receives only a fraction (Compare for instance test 2, B5 with the surrounding plots). In both tests, plot B5 receives most water, which might indicate that the central sprinkler has a distorted distribution pattern. It is striking how little water reaches column 6, especially in test 1, which shows how much the wind influences the distribution pattern of the sprinklers.



test 1

	1	2	3	4	5	6
A	3.0	4.6	4.4	3.9	6.9	1.1
B	3.5	5.8	3.9	10.8	14.9	3.5
C	3.7	7.5	4.6	7.1	7.3	1.4
D	4.8	5.8	9.3	12.3	9.4	1.7
E	3.9	5.1	7.6	13.0	8.9	2.6

test 2

	1	2	3	4	5	6
A	6.9	15.5	9.4	6.2	4.2	2.8
B	10.9	5.5	7.7	11.2	34.7	3.9
C	2.6	8.8	7.1	4.9	7.8	3.9
D	5.7	8.2	13.1	9.3	10.7	3.8
E	3.6	3.1	2.8	10.4	7.7	5.1

Figure 10 *Maps that show the observed irrigation depth (mm/h) for the catch cans in the research plot for two consecutive irrigation events. Yellow represents low irrigation depths, blue represents high values.*

3.3 Soil water holding capacity

This chapter presents the soil water holding capacity. Table 2 presents the soil texture of the research field, based on data of a soil analysis kindly made available by Etablissement HAOUCHINE. Note the very low organic matter content. With the data from the soil analysis, it can be determined that the soil texture is clay, as is shown in figure 11. Wolters et al., (2016) present the standard pF-curves from several soils common in arid zones, from which it was determined that the total soil available moisture in a clayey soil is 109 mm/m3. Thus, it is assumed that this is the soil available moisture of the soil at the study field.

***Table 2** Soil texture and OM content based on a soil analysis made available by 'Etablissement HAOUCHINE*

Texture	%
Clay	43.4
Fine silt	22.8
Coarse silt	10.3
Fine sand	18.1
Coarse sand	5.4
Total	**100.0**
Organic matter	1.7

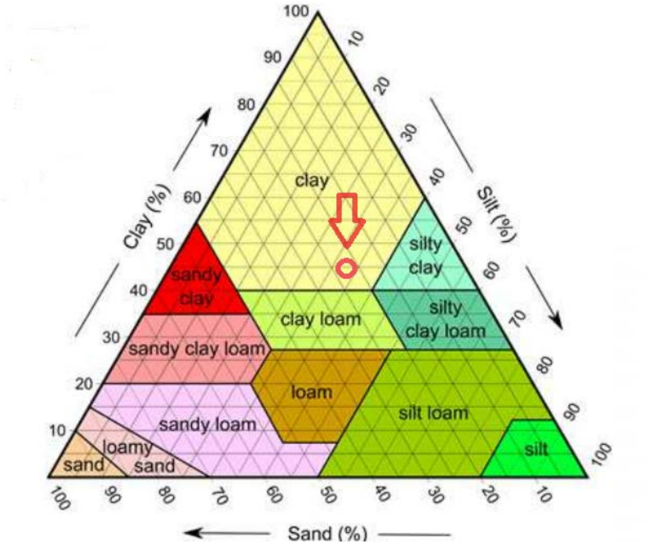


***Figure 11** Texture triangle. The arrow points at the texture of the soil at the research field. Source: Vos, Hoffland & Stomph, 2016*

3.4 Evapotranspiration and CROPWAT model

The potential crop evapotranspiration in a potato crop, calculated using the long-term climate data for Algiers, planted at 10 February at the study field, and harvested at 15 June, is shown in figure 12. The figure also shows the water supply, both precipitation and irrigation. The monthly irrigation is calculated based on the catch can tests, and corrected for WDEL. Note that the water supply is (much) higher than the evaporative demand, especially in the beginning of the season.

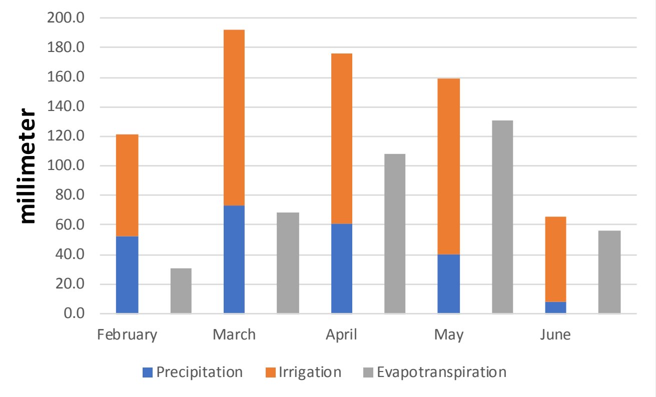


***Figure 12** Total precipitation, irrigation (corrected for WDEL) and potential crop evapotranspiration (ETc in mm) for the growing season in Boumerdes, assuming planting at 10 February and harvesting at 15 June.*

The data regarding irrigation, soil, climate and ETc are combined using the CROPWAT model. The output of the model regarding the water supply, total crop evapotranspiration and water losses in the growing season is summarized in figure 13. The difference between the irrigation depth discharged and the total net irrigation is due to the losses through wind drift and evaporation of water droplets in the air. The model also distinguishes between rainfall and so called effective rainfall, which refers to that part of the total rainfall that is available for plants. Not all rainfall is available for plants: if the rain intensity is high water is easily lost through run-off, whereas small amounts of precipitation are easily lost by evaporation (CROPWAT, 2017). The figure also shows the total evapotranspiration during the growing season, based on the local climatic conditions. Deducting the total evapotranspiration from the water available to plants and correcting this for the soil moisture depletion at harvest results in the irrigation surplus, which is 206 mm. This comes down to 2060m3/ha per growing season.

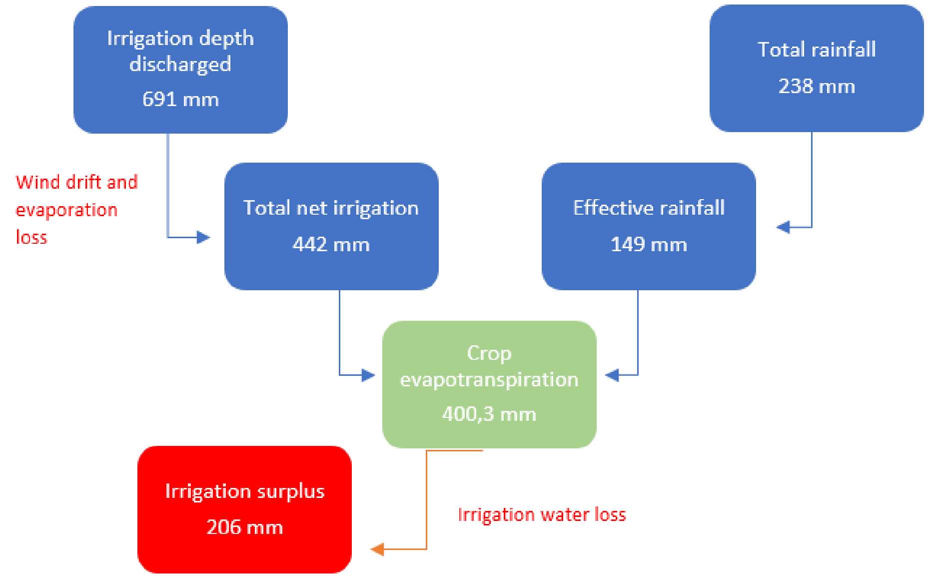


Figure 13 *Scheme showing the total water inputs, total crop evapotranspiration and the water losses during the growing season*

The quantities shown in figure 13 have been used to calculate the water productivity of the potato system in Boumerdes. The water productivity expresses how many kilograms of yield are produced from 1 cubic meter of water, or in other, words, 'how much crop is produced per drop' (Bouman, 2007, Descheemaker, 2016). Table 3 shows several measures for water productivity, with respect to evapotranspiration, irrigation input and total water input, assuming an average yield of 42 tons (Mr. Messaoudi, agronomist, June 6, 2017, personal interview).

Table 3 *Several indicators for water productivity*

	mm/growing season	Water productivity
Evapotranspiration	400	10.5
Irrigation	691	6.1
Total water input	929	4.5

The second output of the model is a scheme (Figure 14) showing the depletion of the root zone and the surplus of water applied throughout the growing season, given the local conditions. This allows to evaluate how much of the water input (precipitation and net irrigation) is stored in the soil, and if water stress occurs. The red line represents the amount of water stored in the soil (mm). The peaks in the red line indicate irrigation events. Figure 14 shows that the water applied during irrigation events fills the soil above field capacity, because the red line crosses the straight black line indicating the field capacity. As this water cannot be permanently stored in the soil, it is assumed to be lost. In the beginning of the season the soil remains very close to field capacity, while from half April onwards the soil water depletion is higher. However, the soil water depletion never exceeds the critical threshold (green line) at which yield reduction starts to occur. Therefore, no yield reduction due to lack of water is expected under the current irrigation schedule. On the contrary, the amount of water applied is too high, especially in the beginning of the season.

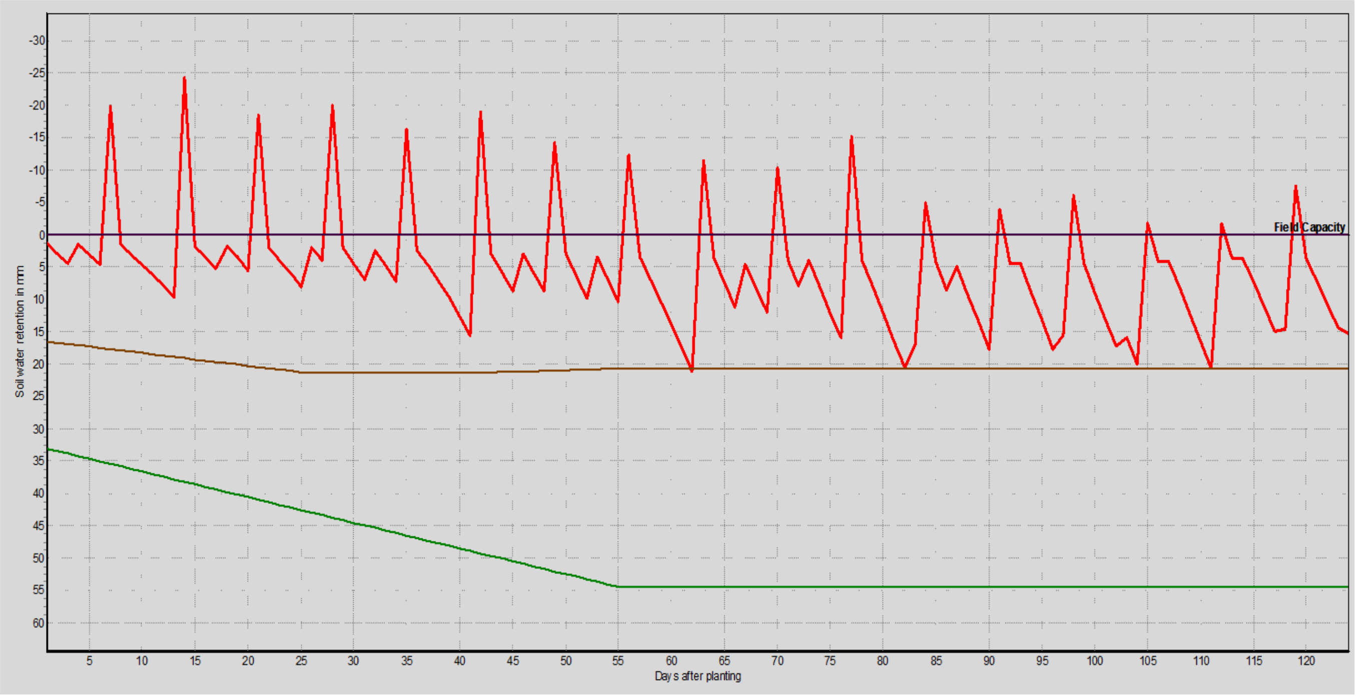


Figure 14 *Soil water depletion of the root zone (mm) in the growing season under the current irrigation scheme in Boumerdes. The black horizontal line represents field capacity, the lower green line the wilting point and the middle brown line the readily available water. The fluctuating red line represents the soil water depletion.*

3.5 Sentek drill and drop results

Some results of the Sentek drill and drop system are presented in figures 15-17. Figure 15 shows the amount of water applied (both precipitation and irrigation), fig. 16 shows the moisture content in the soil at different depths. After each water application, the soil moisture content increases. The graphs also show how deep the water infiltrates and if it is stored in the root zone or lost through deep percolation (Alpha Group consulting, 2016a). For example, after the water application on the 25th of May, the soil moisture content in the upper 10 centimeters of the soil first increases sharply, followed by a steep decrease. This indicates that part of the water is drained below that zone to deeper layers. This can be seen from the sharp increase in the soil moisture content at the 10-20 centimeters depth. The absence of a steep decrease indicates that water is stored in that zone. Soil moisture content at 20-30 centimeters depth increases a bit, but the deeper layers are unaffected by the water application at May 25th, which indicates that there is no drainage below the root zone.

The high water application on May 30th affects the soil water content throughout the profile, and after this event water is also stored in the deeper layers at 30-60 centimeters depth. However, in this case, it cannot safely be assumed that no water is lost by percolation below the root zone, because the flat line of the deepest layer (55cm) can mean two things: 1) water is stored permanently in this zone and no percolation below this zone occurs, or 2) the deepest layer has reached field capacity, and water drains though below this zone.

Figure 17 shows the total amount of water (mm) present in the soil (0-60 cm). Note that after the last water application at June 5th, there is a stepwise reduction in the soil moisture content. This is due to the fact that during day time there is high crop water use, and as a result the soil moisture content decreases fast. During night time, crop water use is low, and the soil moisture hardly decreases. Thus, those sections were the line is more or less flat represent night time, whereas the decreasing sections represent day time (Alpha Group Consulting, 2016b).

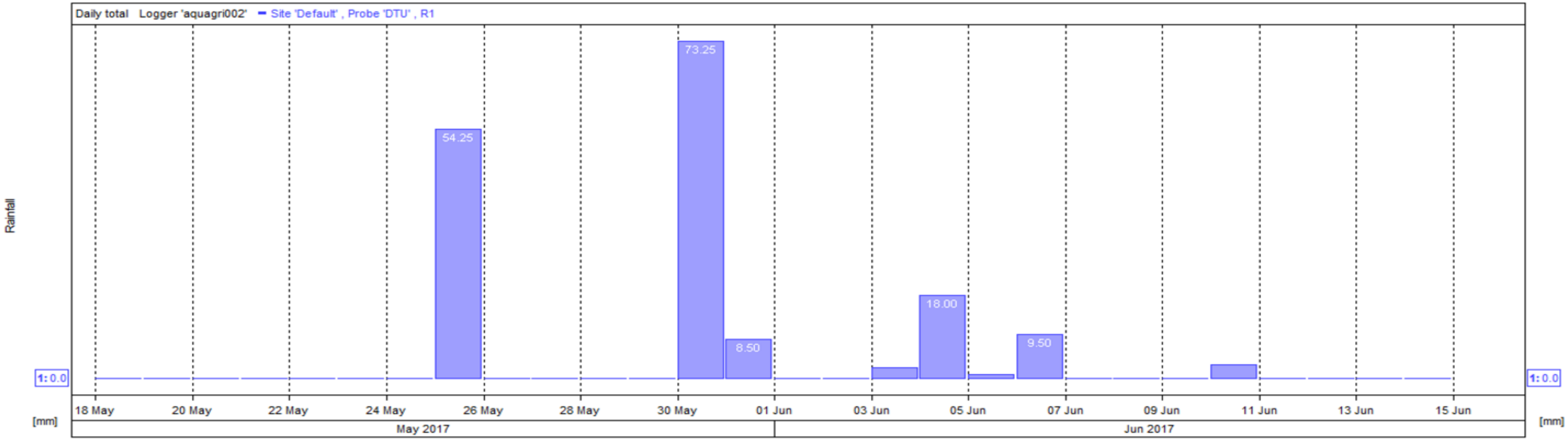


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Figure 15 *Water application in mm, note that the system does not distinguish between irrigation and precipitation*

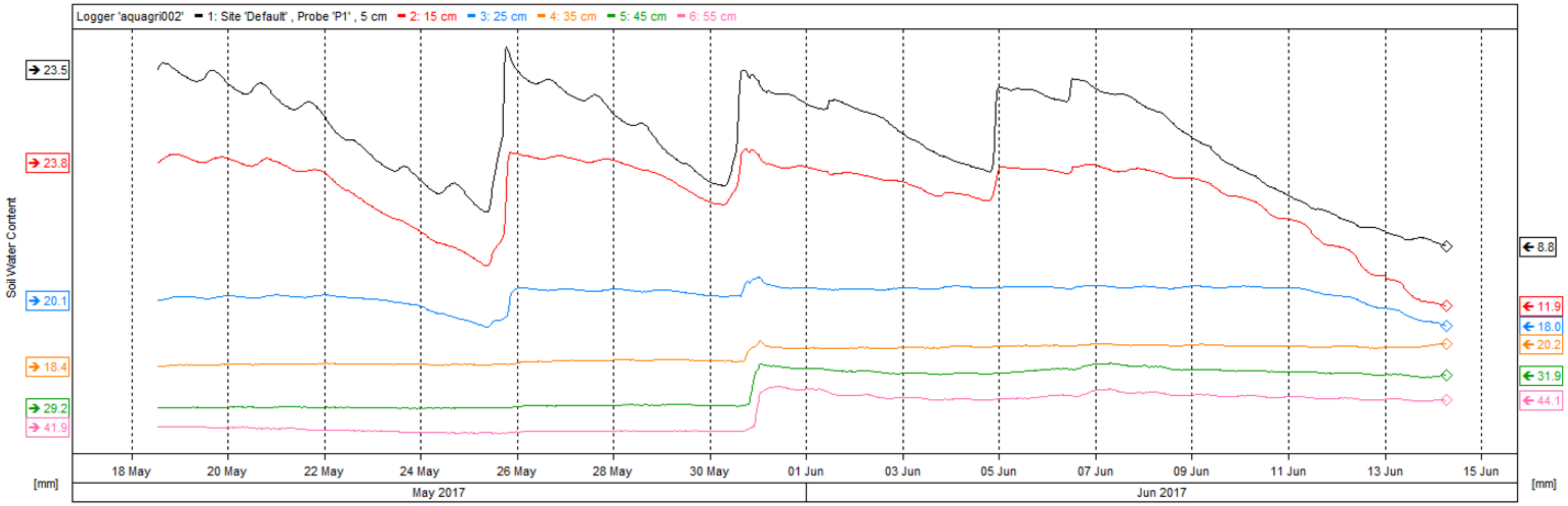

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Figure 16 *Soil moisture content (mm) at different depths in the soil profile. The upper (black) line represents the layer at 0-10 cm depth, the next (red) line represents the layer at 10-20 cm depth etc.*

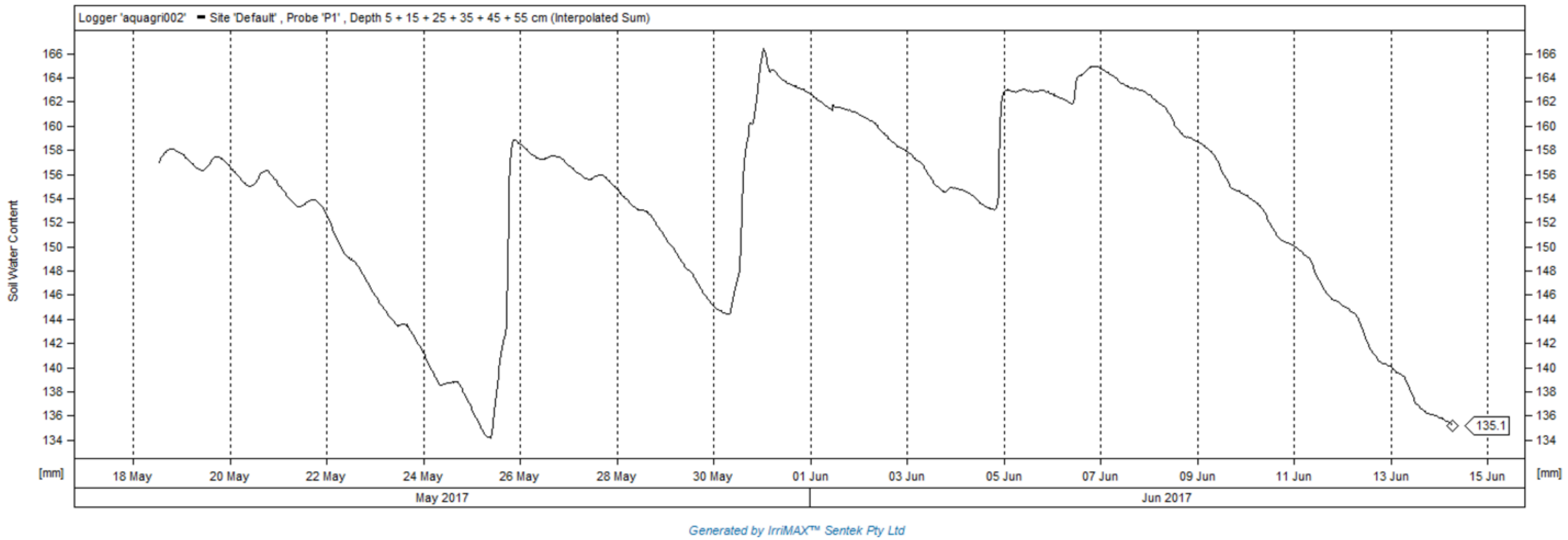

Fig. 17 *Interpolated sum of the soil moisture contents at the different depths measured, the line represents the total soil moisture (mm) present in the 0-60 cm layer.*

4. Discussion water use

4.1 WDEL and water distribution

The main aim of irrigation is to apply the optimal amount of water to the crop. To optimize the water use efficiency of a system water loss should be minimized whereas the uniformity of the water distribution should be maximized (Siosemarde, Byzedi &Nodehi, 2012). This section will therefore evaluate the results of the WDEL and water distribution uniformity of the studied irrigation system in Boumerdes. Note that though catch can tests are a widely used evaluation method to evaluate both the water loss (Tarjuelo 1999b), and the water distribution uniformity (Dukes, Haley &Hanks, 2006), they might be subject to significant measurement errors (Playan et al., 2005, Uddin et al., 2010). The size of a plot represented by one catch can influences the accuracy of the measurements; the larger the plot, the lower the accuracy (Tarjuelo et al., 1999b). The catch can plot size in this study (3.5m*3.5m) was chosen for practical reasons, but the large size might have influenced the accuracy of our measurements.

4.1.1 WDEL

When a sprinkler system is used to irrigate crops, a significant part of the discharged water does not reach the crop because the droplets evaporate in the air or because wind drift occur. This loss of water is referred to as WDEL (wind drift and evaporation loss) (Playan et al., 2005). WDEL in portable sprinkler systems doesn't seem to receive much scientific attention as literature is almost absent, probably due to the fact that it is an older system (Meriam and Keller, 1978). However, for WDEL, portable sprinkler systems can be treated the same as solid set sprinkler systems, because the only difference is the number of pipelines used during an irrigation event (Smjastrla, et al., 1990).
Reported WDELs in solid set sprinkler systems range from 2-28% (Playan et al., 2005) and 2-25% (Tarjuelo et al., 1999a). See table 4 for an overview of several parameters for irrigation system performance found in other studies, compared to the findings in this report. Note that our findings regarding WDEL (12.6-52.7%) are considerably higher, which indicates that the studied irrigation system doesn't perform well in comparison with other systems. However, several older studies conducted in the 80's and 90's also report losses of 30 to 50% (Playan et al., 2005). As the irrigation systems used by farmers in Algeria are locally produced, it is likely that the performance is less than the modern sprinkler systems evaluated in recent reports.

Table 4 *Values for WDEL and uniformity indicators found in this study, compared to some values found in the literature*

Indicator	values	Source
Wind drift and evaporation loss	12.6-52.7%	This report
	2-28%	Playan et al., 2005
	2-25%	Tarjuelo et al., 1999a
	30-50%	Older literature, as cited in Playan et al., 2005)
Distribution uniformity	22.8-42.2	This report
	40-80%	Maroufpoor et al., 2010
	50.4-91.4	Tarjuelo et al., 1999a
Christiansen's coefficient of uniformity	40.3-57.1	This report
	50-80%	Maroufpoor et al., 2010
	51.6-94.2%	Demchi et al., 2003
	61.6-94.7	Tarjuelo et al., 1999a

4.1.2 Factors influencing WDEL

Yazar (1983) reports that the wind drift component is mostly determined by the wind speed; wind drift losses increase exponentially with increasing average wind velocity. Note that a fraction of the droplets drifted away by the wind will still be used by the crop downwind of the irrigation system. The evaporation loss component is mostly determined by wind speed and vapor pressure deficit. A major factor influencing WDEL is the size of the droplets, because droplets of larger size are less prone to evaporation and wind drift (Tarjuelo, et al., 1999b). Droplets smaller than 1 mm are most prone to evaporation in the air (Molle et al., 2011). Droplet size is influenced by nozzle size and operating pressure: small nozzle diameter and high operating pressure result in small droplets (Uddin et al., 2010, Playan, et al., 2005).

4.1.3 Water distribution uniformity

Water distribution uniformity measures (CU and DU) express the uniformity of the observed depths in the catch cans in the research plot. The higher the value for these indicator, the higher the homogeneity of the water application. Table 4 shows the values for the two uniformity indicators calculated in this report, as well as some values reported by other studies. Striking is that the values found in this study are (much) lower than the values found in the literature. Partly, this might be due to the inaccuracy of our measurements, but it is undoubtedly also a warning that the performance of the irrigation system in Boumerdes is very poor. There are two main negative consequences of a low distribution uniformity. Firstly, a lower distribution uniformity results in more water loss through deep percolation and run-off, because some places in the field receive too much water (Siosemarde, Byzedi &Nodehi, 2012, Louie& Selker, 2000, Burt et al., 1997).

The second consequence of low distribution uniformity is that it can incur plant stress and eventually also yield reduction. Both drought stress, as well as water logging can be the result of a low distribution uniformity (Darko et al., 2017). This is also the case in this study because the system applies varying amounts of water to plants at different places in the field (Figure 10), so some plants receive too little water, whereas other plants get an excessive amount of water.

4.1.4 Factors influencing water distribution uniformity

Burt et al., (1997) report that three major factors causing low distribution uniformities are worn-out nozzles, the mixed size of nozzles and differences in operating pressure. Demchi et al., (2005) mention that wind speed is another principal factor because the wind distorts the distribution pattern of sprinklers, resulting in decreasing uniformity with increasing wind speeds. At least three of these factors apply to the irrigation system in Boumerdes. First, it is quite likely that many of the nozzles are worn-out: the agronomist working at the study field stated that nozzles are only replaced if it is noticeable that they don't work. However, for an irrigation system to perform well, it is of crucial importance to routinely check the nozzles, since many nozzles that appear to function don't function very well in practice, or are worn-out (Louie& Selker, 2000). Second, we have measured differences in discharge of sprinklers that were located next to each other (Annex 1) which indicates that either the nozzles of these sprinklers were of different size, and/or that the operating pressure of these sprinklers was different. In both cases, distribution uniformity is negatively affected. Thirdly, wind speeds during the tests were high (unfortunately not measured), which also contributed to a low distribution uniformity.

4.1.5 Recommendations to avoid high WDEL and low distribution uniformity

Firstly, it is recommended to do more maintenance on the irrigation system, especially the nozzles, as the nozzle influences both the WDEL (Playan et al., 2005), as well as the distribution uniformity (Burt et al., 1997). Each beginning of the season, nozzles diameters should be checked, and worn out and damaged nozzles should be replaced. Second, it is advised to operate the irrigation system on a low pressure, but within the range specified by the manufacturer, in order to reduce the losses by wind drift and evaporation (Tarjuelo et al., 1999a). Third, irrigating during high wind and high temperatures should be avoided as much as possible (Demchi et al., 2003). In practice, this means that preferably, irrigation around midday should be avoided. Playan et al., (2005) report a decrease in WDEL of almost 50% when irrigating during night time, thus leading to the recommendation to irrigate at night. However, it is questionable if this is feasible in Boumerdes, as it implies that farm workers have to work in night shifts.

4.2 Water productivity

Water loss reduces the water productivity (WP), which refers to the amount of yield (kg) that is produced per m3 of water (Descheemaker, 2016). By some authors, it is also referred to as water use efficiency (WUE) (Howell, 2001). Table 3 presents several indicators for water productivity. In an experiment conducted in Lebanon, with crop evapotranspiration similar to the study field in Boumerdes, Darwish et al., (2006) found that water productivity with respect to irrigation water applied (WPIr) was in the range of 4.8-8.8 kg yield/ m3 irrigation water applied, which is similar to the finding in this report (WPIR =6.1). From figures 12, 13 and 14, it can be concluded that the combined water application (rainfall and irrigation) is higher than the crop evapotranspiration, especially in the beginning of the growing season, when the root system is not yet well developed. Later in the season, the amounts of water applied to the crop match the water use by the potato crop better. Figure 14 shows that before day 80 (May 1st), each irrigation event applies more water than can be stored in the root zone, whereas after May 1st, field capacity is hardly exceeded. This indicates that water loss from May onwards is less severe than in the beginning of the growing season. Excess of water is lost through mainly through deep percolation and run-off (Burt et al., 1997). Each of these water loss components will be discussed separately.

4.2.1 Deep percolation

Water that percolates below the root zone is not available for the crop, and should be avoided. Furthermore, deep percolation can result in nutrient leaching (Louie & Selker, 2000), thus resulting in less efficient use of fertilizer. As most deep percolation is expected to occur in the beginning of the growing season, this might lead to nutrient deficiencies and plant stress during the initial growth stage. However, not all water percolating below the root zone should be considered as a loss per se. Deep percolation contributes to regulating soil salinity in the root zone since salts are leached below the root zone, which might have a positive effect on crop growth (Howell, 2001, Burt et al., 1997). It is unknown if this is the case in Boumerdes, but as Mg2+ and Ca2+ levels at the study field are known to be high it is not unlikely that some deep percolation is beneficial.

4.2.2 Run-off

The CROPWAT model assumes all the surplus water is lost through deep percolation but we have also observed severe run-off during irrigation events. This indicates that the water application rate exceeds the soil infiltration rate (Darko et al., 2017). This is most likely the case, as the average observed depth (6.6 mm/h, table 1), exceeds the standard values for infiltration rates of clayey soils, which range from 1 to 5 mm/h (Brouwer, Goffeau, Heibloem, no date). Figure 10 shows that catch cans located close to the sprinkler lateral received irrigation depths that are often double the expected infiltration rate.

4.2.3 Recommendations to improve water productivity

From the above sections, it can be concluded that the two key issues influencing the water productivity in Boumerdes are run-off during irrigation events and overirrigation, especially in the beginning of the growing season.

In the current situation, the ridges are oriented downhill, so that the furrows between the ridges form canals that can easily transport the irrigation water downwards, thus increasing run-off. Therefore, it is recommended to change the orientation of the field 90 degrees, so that the ridges are oriented in perpendicular position to the slope of the hill.

Changing the irrigation schedule will contribute to decreasing water loss caused by over-irrigation. Irrigation scheduling comes down to two issues; 1) the interval between two irrigation events (when to irrigate) and 2) the water application per irrigation event (how much to irrigate) (George, Shende, & Raghuwanshi, 2000). Under the current situation, throughout the growing season, the interval between two irrigation events on the same place in the field is seven days, and the irrigation duration is four hours. This comes down to a 26.4 mm irrigation depth every week, regardless of the crop water demand and the weather conditions, which often results in water applications that exceed the crop water demand (fig. 12) and the storage capacity of the soil (fig. 14). A change in the irrigation schedule, taking into account the crop's water demand and the weather conditions could result in significant water saving. In the CROPWAT model, we tried several options in order to adapt the irrigation timing and irrigation depth to the local conditions in Boumerdes. The best option, with optimal use of irrigation water, seemed to change the irrigation interval in the first two growth stages of the potato crop to ten days instead of seven days. This means that till 55 days after planting (beginning of April) each place in the field receives an irrigation each 10th day, and from April onwards, the irrigation interval stays seven days. Furthermore, rather than applying fixed amounts of water, it is recommended to irrigate till the soil is filled to field capacity, which means that the irrigation depths per irrigation event should be adjusted. Table 5 shows a proposed new irrigation schedule aiming to increase water productivity by decreasing the irrigation interval in the first

Table 5 *Proposed irrigation calendar. Irrigation depths needed to refill the soil to soil capacity and the corresponding duration (minutes) of irrigation needed, given an average application of 6.6 mm/h (table 1).*

Date	Irrigation depth (mm)	Duration (min)
19-feb	4.7	43
1-mrt	5.6	51
11-mrt	10.5	95
21-mrt	12.7	115
31-mrt	14.9	135
7-apr	6.2	56
14-apr	14.9	135
21-apr	18.9	172
28-apr	14.9	135
5-mei	21.5	195
12-mei	25.6	233
19-mei	24.3	221
26-mei	23.8	216
2-jun	27.4	249
9-jun	22.2	202

two growth stages, and adjusting the duration of each event so that the field capacity of the soil is not exceeded. Figure 18 contains a graph with the soil water depletion under the proposed irrigation schedule, showing that field capacity is not exceeded, and minimum plant water stress occurs.

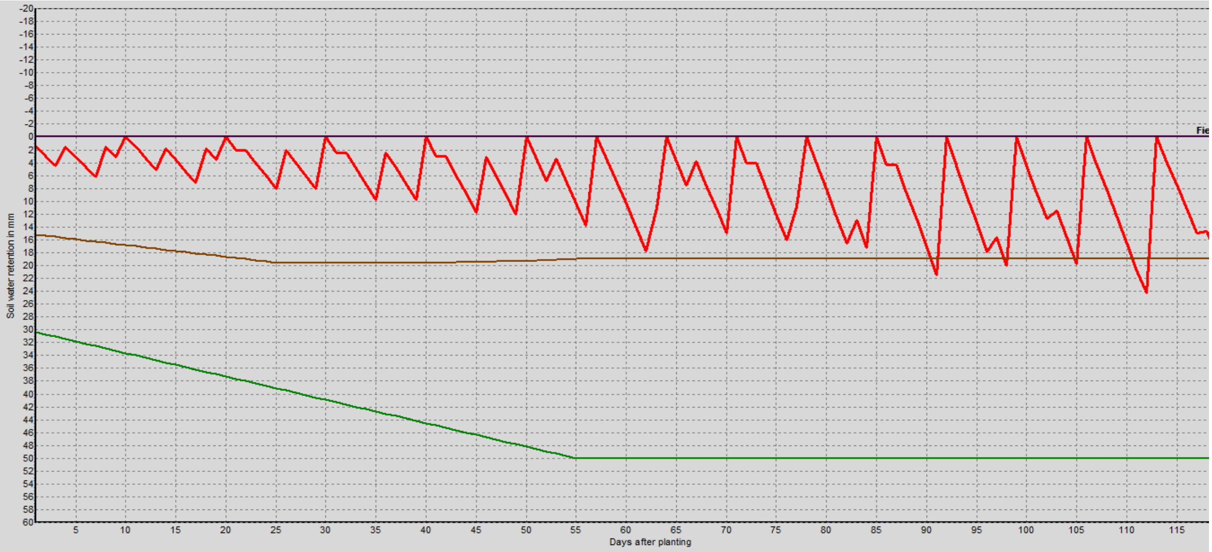

Figure 18 *Soil water depletion of the root zone (mm) in the growing season under the proposed irrigation schedule presented in table 1. The black horizontal line represents field capacity, the lower green line the wilting point and the middle brown line the readily available water.*

5. Conclusions

- The irrigation system performs rather poor with regards to wind drift and evaporation loss, as well as water distribution uniformity, probably due to high wind speeds during irrigation events and poor maintenance of the irrigation system, especially the nozzles.

- In the beginning of the growing season, water application exceeds the storage capacity of the root zone, and water is lost through deep percolation.

- Water applications exceed the infiltration rate of the soil, resulting in run-off.

- Routinely checking and replacing of the nozzles, and irrigating in the early morning, late evening, and night is recommended to reduce WDEL and to improve the water distribution uniformity.

- Run-off could be reduced by changing the field orientation.

- The timing and duration of irrigation events should be adapted to the crop water demand and the storage capacity of the root zone in order to reduce water loss through over-irrigation.

Acknowledgements

It was already stated that Algerian farmers are very cooperative and willing to share information. Therefore, and for their additional assistance and great hospitality we would like to thank all the farmers we have interviewed. Special thanks goes out to mr. Haouchine, who gave us the opportunity to do field measurements at his fields and provide us with extended information.

While we could visit El Oued only at a very late state of our internship and for a short period, even so special thanks goes out to mr. Khalifa Debbar, Ammar Hettiri and mr Moumen Messoud Djemal, who not only showed us their farms and the CASAB cooperative, but also guided us during working and spare time. We couldn’t have gathered that amount of information in such a short period without them. Therefore we also thank mr. Hadj Tidjani of the Guemar cooperative for his great tour. In contradiction with the governmental concerns about our safety, our hosts in El Oued made us feel extremely safe and invited. Thanks to them we could visit El Oued a second time to do the interviews.

With that, we come to another very important person, our wonderful host and advisor in Algeria, mr. Khaled Benchaalal who not only supplied us with his extended knowledge of Algerian history, agriculture and potato production but also always helped us out when there was no way to improvise anymore. The same goes for mrs. Greet Blom, our supervisor at the research institute, for her thoughts, involvement and persistence. Also we would like to thank mr. Tahar Maza, for his extended fertilizer knowledge, help and being a great colleague.

Zohir, Yaya and their friends were of great support during our field work, sustaining a great ambiance and giving site information.

Since going to Algeria already required quite some effort in The Netherlands, we send our special thanks to mr. Cor Langeveld, our study advisor who supported us in getting the University’s approval to go to Algeria. Last but not least we thank mr. Niels Anten for his supervision of our internship and supporting us to go to Algeria.

Furthermore we thank everyone who supported us during our preparations, stay and work in Algeria.

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