Sustainable water use in potato production in Algeria

Introduction of a subsurface fertigation system in the desert

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This study was carried out by the Wageningen Research Foundation (WR) and subsidised by the Ministry of Agriculture, Nature and Food Quality in the context of the Policy Support 'Sustainable agricultural development in a food system approach' (BO-43-003.02-007).

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

Wageningen, September 2020

Report WPR-1017

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Greet Blom-Zandstra & Jean-Marie Michielsen, 2020. *Sustainable water use in potato production in Algeria; Introduction of a subsurface fertigation system in the desert.* Wageningen Research, Report WPR-1017. 34 pp.

This report can be downloaded for free at: https://doi.org/10.18174/530075

Keywords: potato, subsurface fertigation, demo

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

Report WPR-1017

Photo cover: Greet Blom

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Preface

The region around El Oued city in Algeria is an important population area with 750,000 inhabitants using water from an approximately 60 m deep aquifer. The region of El Oued has been growing potatoes for about 15 years, and with 33.000 hectares potato cultivation, the region has turned into the largest potato production area of Algeria with two harvests per 12 months. However, the commonly used irrigation system is not sustainable due to high water waste. Therefore, a subsurface Decision Support System (DSS) fertigation method was introduced in this project to explore the opportunities for innovation towards more sustainability in potato production in a desert area.

The smallholder potato producers of El Oued (in total around 2000) did not have the financial means to fully sponsor the project, but were willing to make land available for setting up, testing and demonstrating this innovative technique. This project, financed by the Dutch Ministry of Agriculture, Nature and Food Quality, via the Policy Support program has been carried out within the framework of the current and highly relevant theme “Sustainable agricultural development in a food system approach”.

In 2017, Wageningen UR Plant Research signed a collaboration agreement with the Algerian universities of El Oued, Biskra and Ouargla to work together on the innovation and sustainability of water use in potato cultivation in the Sahara. For the introduction of this DSS fertigation system Wageningen and the University of El Oued successfully cooperated and paved the way for future research cooperation.

September 2020

Summary

Along the Mediterranean coast of Algeria, agriculture depends on rainfall, whilst in the rest of the country, agriculture depends on scarce, or at least hard to reach, underground water. However, in the El Oued region of Algeria, an enormous sub-Saharan Aquifer comes close to the surface. Here, agriculture has developed on a sandy soil, of which the potato cultivation is the most important agricultural activity. Generally, farmers in El Oued continuously irrigate the potatoes, which are planted *between* the ridges in 1 ha *circular* fields. Irrigation is done with a locally developed pivot system with overhead sprinklers. The current practices are unsustainable and much can be gained by improving water use, fertilizer and pesticides use, varieties choice, quality of the starting material and prevention of post-harvest losses.

In this project, more sustainable potato growing practices were piloted in a real life situation. In close cooperation with staff members and students from the Hamma Lakdar Univerity in El Oued, a 5 ha demonstration farm was set up and managed over an autumn and a spring growing season to test and illustrate the innovative technique of subsurface fertigation (combination of irrigation and liquid fertilization) and how it can contribute to more sustainable water use practices. The pipes used for the fertigation system were integrated in the potato ridges by a tractor drawn machine, which in one operation makes the ridge and plants the seed potatoes in the ridges under the fertigation drip. New (climate smart) varieties were tested. During the growing seasons, water consumption with subsurface irrigation system was measured and compared to water use per pivot circle. Apart from measuring the amounts of water being applied to the field, also soil and air temperature, the dynamics of the soil moisture and evapotranspiration, plant development and tuber production were measured during the growing seasons.

The introduction of the subsurface irrigation method and different potato varieties resulted in a clear improvement of the potato production in terms of land use and labor efficiency, sustainable water use and yield: 1) Planting and installation of driplines could be done at the same time, 2) Water saving was about 50% and 3) Tuber yields slightly increased (mainly in Autumn), while the new potato varieties Arizona, Manitou and Rudolph yielded better than the traditionally used Spunta.

During various field visits and workshops, the new technique and the comparison in water use and productivity between pivot and subsurface irrigation were shared with local farmers, representatives of the (local) government, business people, representatives from other organizations and the local and national TV press. From the start of the project, there had been great interest in the field activities.

As a demonstration pilot, the project was successful. The data collected on water waste when using a pivot convinced everyone that improvement of the pivot methodology is urgently needed. However, the adoption rate of the new technique was low, probably due to a knowledge gap on technology and lack of skills to get it running. But given the great interest and enormous publicity the pilot received, it is expected that with financial incentives and political and societal support the adoption rate will increase.

For the Netherlands, which is increasingly confronted with recurring periods of long-term precipitation shortfall, the project also yielded several intriguing insights for practical use, such as:

1. Mechanical planting of potatoes easily combines with the unwinding and installation of subsurface hoses.
2. With well-drained soils, multiple and short irrigation doses are more effective and yield greater water savings than prolonged irrigation at greater intervals.
3. The technology offers possibilities to guide the irrigation based on tuber setting and tuber size, thereby offering added value for seed potato companies.
4. Insight into crop propagation and the water, nutrient, pesticides and energy savings make it possible to calculate the economic feasibility of the technology for each company.

1 Introduction

1.1 General

Algeria is 2,381,741 km^2 total land, divided in 48 administrative districts (Wilaya's), in which the desert covers more than four-fifths of the country (Figure 1). Total population of Algeria comprises about 42 million people, three quarters of whom live in the major cities in the North and has been doubled in the last 25 years (Figure 2).

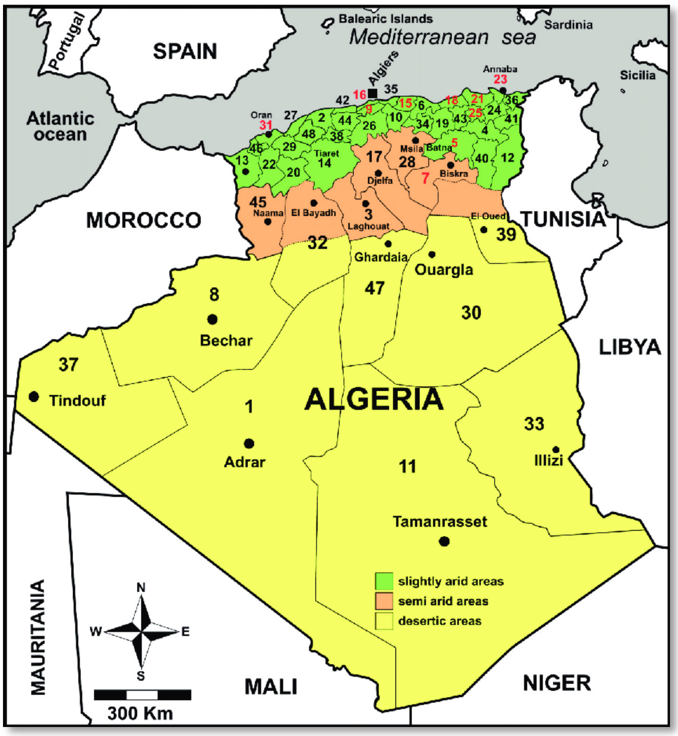

Figure 1. Algeria with its 48 current administrative districts and their degree of aridity (Source: Amrani et al., 2015)

The agriculture sector contributes on average about 12 percent of Algeria's GDP (2016 estimates) and employs at least 20 percent of the population in rural areas. Algeria has about 8.4 million hectares of arable land. About 51 percent of the total arable land is dedicated to field crops, mostly cereals and pulses, 6 percent to arboriculture, and 3 percent to industrial crops. Algeria's imports of agricultural commodities and food represented about 17.6 percent of the total imports (around 40 billion euro's) in 2016. Algeria is one of the world's largest importers of wheat and dairy products (USDA Foreign Agricultural Service, 2018). Main crops grown in Algeria are vegetables (Figure 3). Potato is third in the ranking of the main commodities (Figure 3) and the main irrigated crop in Algeria (Huizenga & te Maarn, 2013).

Water is available in an underground water reservoir (the Albian aquifer), which together with the Nubian is an important water source for North Africa (Figure 4). Despite no clear data on the withdrawal is present, it is expected that the groundwater resources of the high and middle Cheliff Basin in Algeria will decrease substantially in the long run (Figure 5). Currently, agriculture accounts

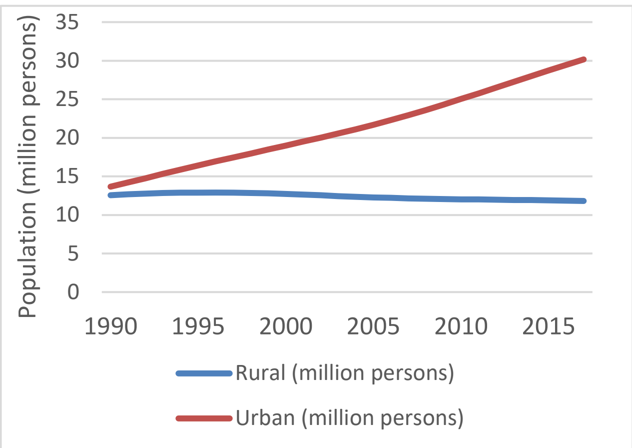

Figure 2. Growth of rural and urban population since 1990 (Source, FAOSTAT, 2017)

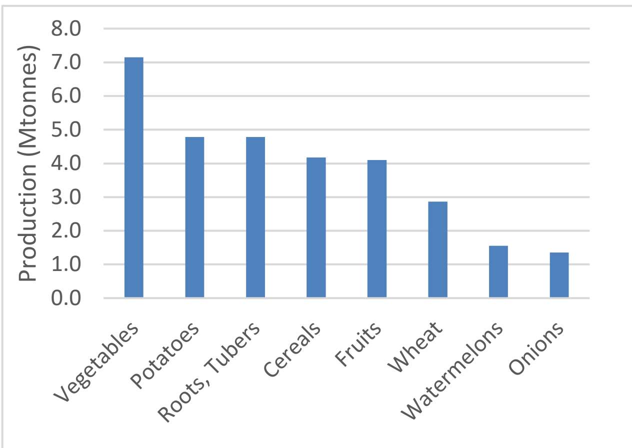

Figure 3. Yearly production (Mtonnes) of main commodities in Algeria (Source FAOSTAT, 2017)

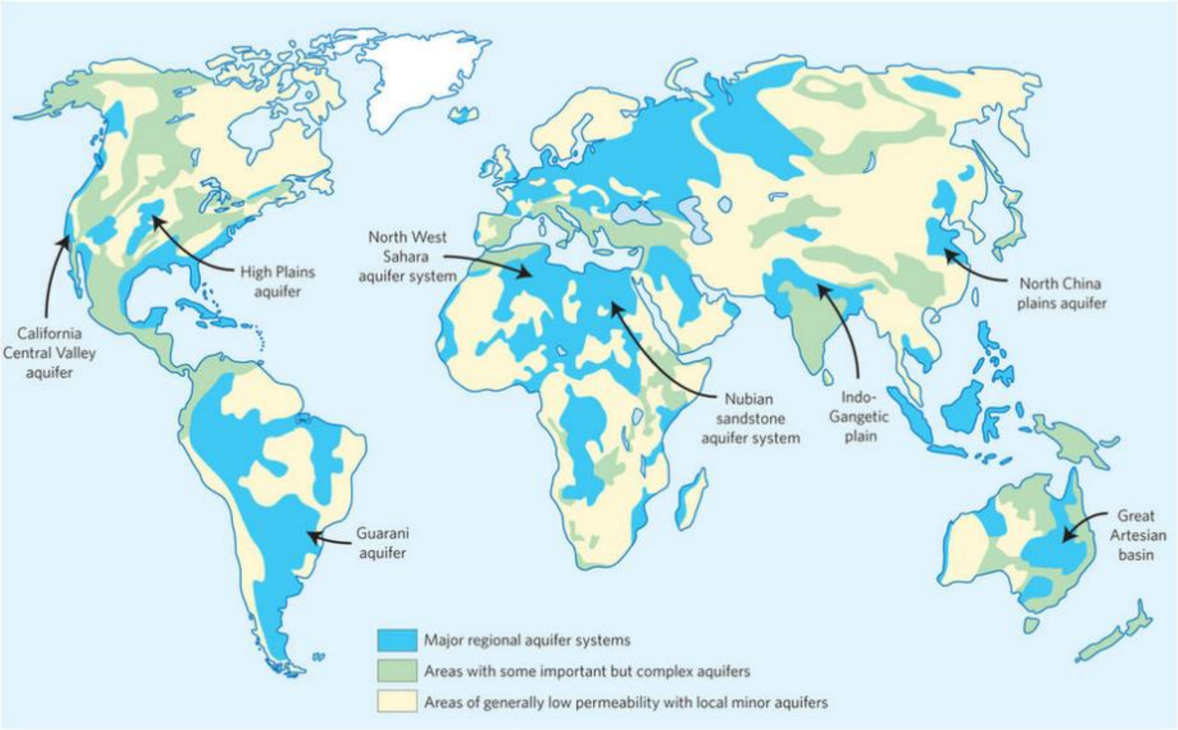

Figure 4. Global underground water resources (Source: Taylor et al., 2013)

for 70-80% of the total water use in Algeria. 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. In general, no measurements are being carried out to monitor the effects of groundwater offtake on the underground water levels. Permits are given to drill a well, not for the offtake of certain volumes over certain time. Water demand is expected to increase drastically in the near future (Sebri, 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).

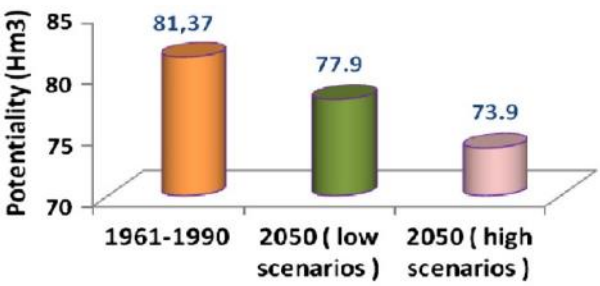

Figure 5. Expected decrease in groundwater resources in the High and Middle Cheliff Basin calculated by two different scenarios (Source: Elmeddahi et al., 2014)

1.2 Potato production

Potato (*Solanum tuberosum* L.) 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 has a low water footprint and a high nutritional value (Blom-Zandstra et al., 2014), features making it an interesting crop for Algeria, where potato production and consumption has expanded considerably over the last three decades. Formerly, potatoes used to be grown in the coastal zone only. However, some 20 years ago potato growing has started in the region of El Oued (Rebai et al., 2017). This region with 750,000 inhabitants is situated on the northern borders of the Sahara desert in the eastern part of Algeria and is currently developing into an important population centre in the south eastern part of the country. The presence of the superficially lying Albian aquifer (40 – 60 meters deep) in combination with a mild and sunny winter climate leads to a promising winter potato yield, harvested a few weeks earlier than in the coastal region

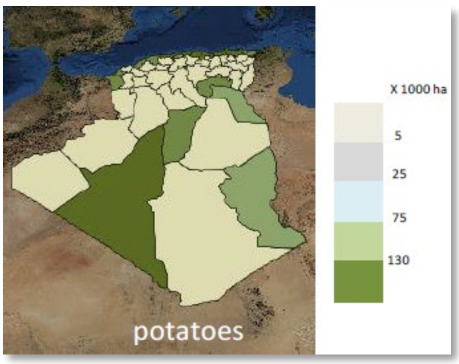

Figure 6. Potato growing regions in Algeria (Source: FAO Agromaps, 2010)

and thus offering a commercial advantage on the market.

Currently, large potato production areas (in total 90,000 ha) are found in several regions in this large North African country including regions in the Saharan desert (Figure 6), and the sector is still growing fast (Huizenga & te Maarn, 2013; Kempenaar et al., 2017). With its 33.000 hectares the region of El Oued has turned into the largest potato production area of Algeria with two harvests per 12 months.

An important characteristic of potato production in Algeria is the heavy reliance on irrigation. El Oued has a desert climate with many sun hours and temperature varying from below zero in the coldest winter nights to the highest summer day temperatures of around 48°C. Figure 7 shows the great changes in maximum day temperatures throughout the year.

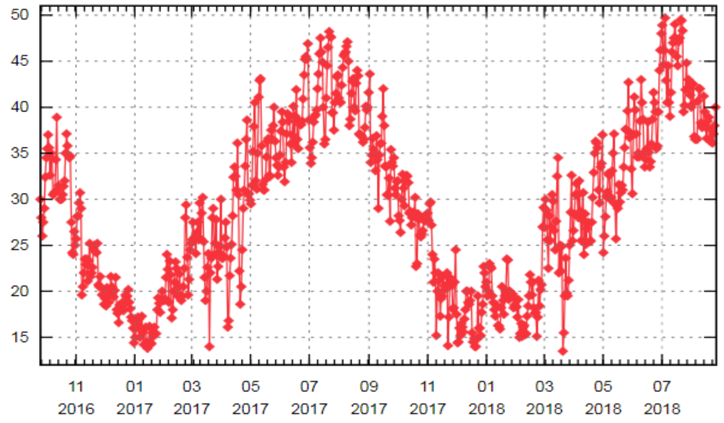

Figure 7. Maximum day temperatures (°C) in the period between Oct 2016 and Aug 2018 in El Oued (Source: weatheronline.co.uk)

Annual rainfall is limited (Figure 8) and in total around 55 mm, the area totally depends on sub terrain water as source of life. The potatoes are irrigated by centre pivots, grown in one hectare circular fields (Rebai et al., 2017). Water is supplied to the potato plants through overhead nozzles mounted on 56 meter long pivot arms during a four hour turning cycle. The amount of water that is given to the plants is not controlled. The method of overhead irrigation is wasteful for: 1. the high evaporation before the water reaches the roots, 2. the drift of water due to the wind and 3. at least half of the irrigation water is applied between the plants and does not reach the roots and is thus lost in the soil. Thus, improving the potato production system and rationalizing the use of water is therefore important in order to sustain the production in the future and to maintain and enhance food safety through reducing water losses and increasing water use efficiency as much as possible (Den Braber, 2017; Houben 2017; Rebai et al., 2017)).

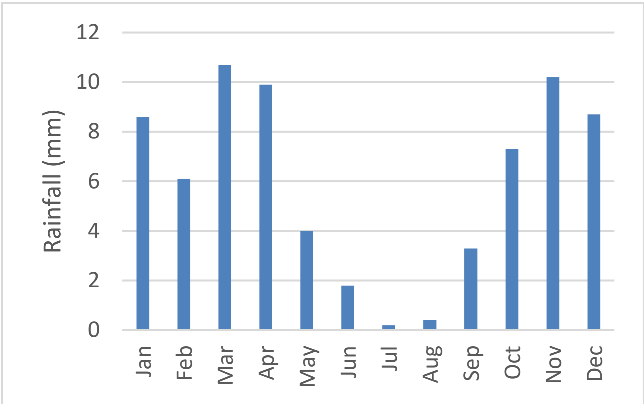

Figure 8. Monthly average rainfall (mm) in El Oued over a year (Source: 2020, World-climates.com)

El Oued has two planting seasons: the winter season starting in September and harvest in December and the summer spring season starting in February and harvest in May. The actual and potential yield was estimated with the LINTUL-POTATO-DSS model for the two growing seasons in El Oued and is shown in Table 1 (Kempenaar et al. 2017). With planting dates September 15 and February 1 and assuming a 105 days growing season, the model uses temperature, solar radiation, precipitation and evapotranspiration to calculate potential yields and water use. Actual and potential yields are greater in spring than in autumn since solar radiation is higher in spring. The amount of irrigation water per season (also per ton of potato produced) is higher in spring as well. So the spring season has a higher land use efficiency but a lower water use efficiency.

The seed potatoes used for potato production are of different origin and mixed quality, resulting in uneven field patterns and mixed production per plant. The most popular variety is Spunta (*ca*. 40% of the production). Spunta seed is produced in Algeria for the winter season. Other varieties are Désirée, Fabula, Ultra (Houben, 2017). For the spring season seed is imported from abroad (mainly from the Netherlands).

Table 1. Comparison of some selected autumn and spring crop data in El Oued

Production season	Average radiation ($MJ/m^2/day$)	Growing season (days)	Potential yield (t/ha)	Actual yield t/ha)	Actual/ potential	Irrigation need (mm)
Spring (Feb – May)	17.3	105	43	30	0.70	688
Autumn (Sep – Dec)	13.3	105	35	25	0.71	455

Harvesting is done by windrowing and picking up manually. Potato growers have great difficulty in finding enough workers during the harvesting season, which is the reason for the growers to be interested in mechanising the harvesting (Houben, 2017).

Cold/controlled storage has not been well developed in the El Oued area. Storage is not a common practice amongst potato growers in El Oued. The winter harvest from the El Oued region has an advantage with respect to the harvests in the northern part of the country as it comes to the market at a time that no other potato producing areas are harvesting. As a result, the harvested potatoes are directly supplied to the market in the north of the country without being stored. Part of the potatoes harvested in spring are temporarily stored (Houben, 2017).

1.3 Reasons for change

There are several reasons to aim for a transition in the potato production in the El Oued region towards a sustainable approach.

1.3.1 Lower the Water Footprint

Since water extraction and consumption used for potato irrigation is basically not regulated, enormous amounts of water are being depleted from the non-renewable fossil water reserves under the North Sahara for the production of potatoes in the El Oued region (Abdelkader et al., 2015; Jacobs and Van ‘t Klooster, 2012; Rebai et al., 2017). Subsurface drip irrigation in ridges consumes much less water by irrigating the water and fertilizer straight to and only on the roots of the potato plant (Hansen, 2015). By applying water in the immediate root zone of the crop, the uptake and use of the water is more efficient. The abilities to use precision nutrient management are further advantages for drip irrigation systems. In a U.S. Great Plains study, irrigation requirements were reduced by 25% using subsurface drip irrigation compared with sprinkler irrigation without any loss in crop productivity (Lamm and Trooien, 2003).

1.3.2 Efficient fertilizer application

Fertilizers are often being applied without structural knowledge of the plants’ needs for certain minerals and additives. No soil analysis is done, nor any water analysis. In traditional potato production, fertilisation is applied on the basis of a standard 15x15x15 NPK mix product (see also Annex 1) that is hand spread over the whole field twice per growing season, once at the start of the season and once in the second half of the growing season. In addition, large quantities of chicken manure are fed to the soil, partly as fertilizer partly to raise the organic-matter in the soil. Subsurface drip irrigation in combination with subsurface fertilisation (*fertigation*) allows for a much more precise application of the missing fertilizing elements directly to the roots of the potato plants (Hansen, 2015).

1.3.3 Climate smart agriculture and the choice for the potato

In 2003, the Algerian government adopted a National Plan of Action and Adaptation to Climate Change Change (PNA-ACC), which was updated in 2013[1]. Herein, chronic drought and insufficient water resources were highlighted. Thus, investments in climate change adaptation, like water system innovation, and mitigation measures were considered to be urgent. Potatoes are ideally suited for a demonstration pilot on sustainability as they require less water than other staple foods like wheat and rice (Mekkonen et al., 2011; Lovarelli et al., 2016). Moreover, root and tuber crops like potato benefit more than any other crops from the fertilizing effect of increased atmospheric CO_2 (Haverkort et al.,

[1] https://www.lse.ac.uk/granthaminstitute/publication/climate-change-legislation-in-2015/

2014). Thus, potato consequently is a relatively high ranking climate smart crop. Notwithstanding, potatoes are sensitive to salinity, heat stress, drought and postharvest losses by low quality starting material. So, if these factors can be controlled properly, growing potatoes in El Oued can be supported from a climate smart perspective.

1.3.4 Prevention of post-harvest losses

A large percentage of the potatoes is being lost in the post-harvest phase (Hanafi, 1999; Houben, 2017), but no clear figures are available for El Oued. Part of the loss occurs during (manual) harvest, further losses occur during transportation due to inadequate packaging and transportation as well as infrastructure problems. To limit losses, harvesting practices should be improved by the introduction of harvest machines and storage of tubers in air conditioned rooms.

1.4 Aim of the project

The first initiative for this project dates from December 2015, when the Netherlands Embassy in Algiers organized a workshop in El Oued on sustainable potato production with field visits to the El Oued potato farmers. This initiative resulted in the formulation of the actual project, which is developed in close collaboration with private, public and scientific partners on a national level and in El Oued.

The goal of the project is to make potato production systems in El Oued more sustainable through the introduction of a water saving subsurface irrigation method. For successful implementation of this new technique by farmers, setting up a pilot in which data are collected and the advantages of using this new technique are demonstrated might be the most attractive approach. A demonstration pilot may prove to potato farmers in the El Oued region, to the Algerian agricultural and water authorities, that the innovative subsurface drip fertigation method gives a good potato harvest, whilst using substantially less water than in the original potato growth with pivot irrigation (Arous et al., 2013).

Therefore, this project is primarily a demonstration project in which water consumption with subsurface irrigation system is measured and compared to water use per pivot circle. Apart from measuring the amounts of water that are being applied to the field, also the dynamics of the soil moisture, plant development and tuber production will be measured during the growing seasons. All data will be intensely communicated with the farmers. Based on the good results, the farmers of the El Oued region might be encouraged to decide to leave their current practices and to switch to the "new‟ method of potato farming.

The project is executed in close cooperation with the Hamma Lakhdar University in El Oued, with whom an MoU was signed.

2 Material and methods

To provide a practical, tangible answer to the current unsustainable potato production practices, 10 demonstration fields (each 0.5 hectares) were set up in which different stress resistant potato varieties were grown. Herein, new introduced techniques were tested in a real live situation and compared with data (plant growth, water use, tuber yield) collected from the traditional potato production with pivot irrigation. The demonstration pilot included an autumn and spring production cycle, each performed at a different location.

2.1 Potato growth and water use under pivot irrigation

For evaluation of the water use by the traditionally used pivot irrigation, 5 cultivars of potatoes were grown in 3 different circular 1 ha plots. The 5 cultivars were planted in 4 replicates and were within each plot randomized per block (planting design: Figure 9). The plots were during ~ 4 hours irrigated by pivot irrigation with 3 different watering strategies, respectively: 1) High speed, 2) Water supply according to crop demand, calculated by CROPWAT and 3) Farmers’ practice based on experience (estimation of water demand through watching plant development).

Water supply along the pivot boom was measured by the catch can method in which spraying water is collected while the boom passes by (see Figure 10). Water use by each pivot was measured with water meters connected to the water supply hoses of the pivot systems.

At the end of the potato growing cycle, 133 days after sowing, tubers were harvested and tuber weights were determined for each field.

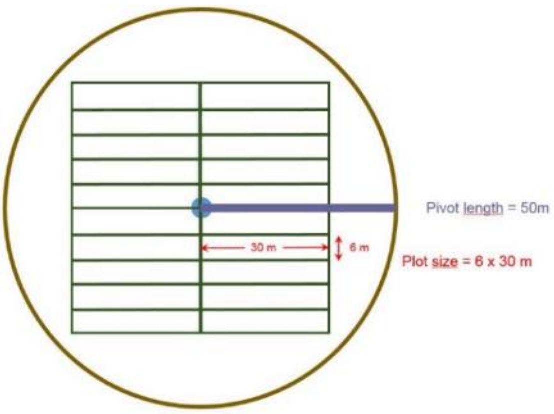

Figure 9. Potato planting design in the pivot field, five cultivars were randomized per block

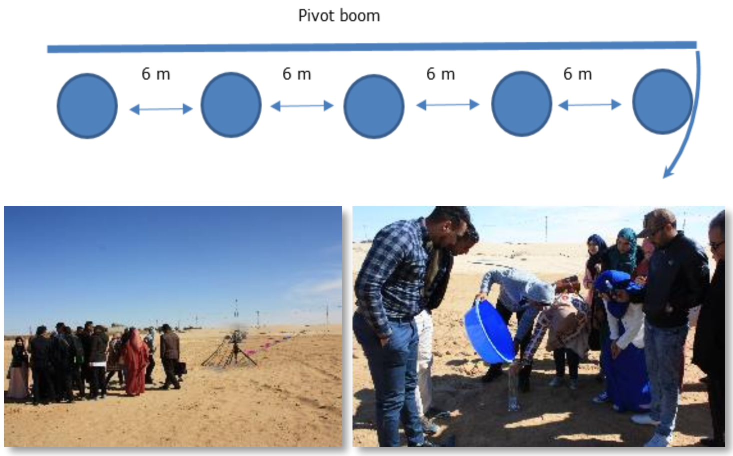

Figure 10. Measurements of water supply along the pivot boom

2.2 Potato growth and water use with a subsurface fertigation system

Over a period of 2 production cycles 5 hectares demonstration plots were installed at two different locations:

1) At Farm I (N 33°15’51” E 6°53’36”) from September 27^{th} 2018 until January 20^{th} 2019 (Autumn), and
2) At Farm II (N 33°36’27” E 6°78’64”) from February 5^{th} 2019 until June 18^{th} 2019 (Spring).

2.2.1 Introducing subsurface *fertigation*

For the demonstration of the subsurface fertigation system, 10 plots of *ca*. 100 X 50 m^2 were used, designed as shown in Figure 11. A combination tractor that thus combines a. ridging, b. seed potato planting c. *fertigation* pipe laying (Figure 12) was bought from Holland Agri Machinery B.V., Bant, the Netherlands. This just-under-the-surface irrigation combined with fertilization (hence *fertigation*)

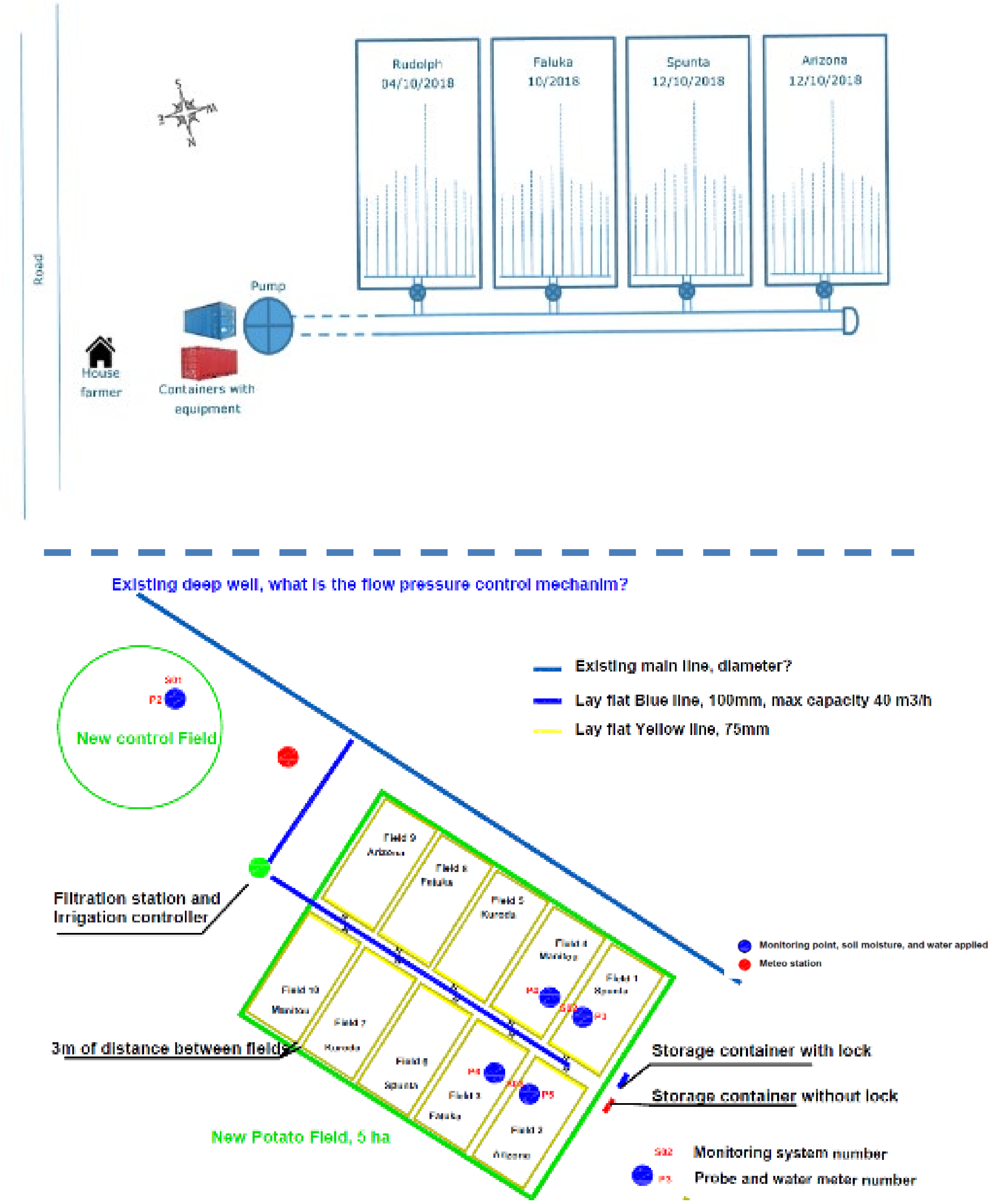

Figure 11. Field design at first location (left) and second location (right)

system *in* the ridges was installed during ridging and planting by one and the same tractor drawn contraption. The drip lines were installed ca 5 cm below the soil surface, the potatoes ca 15 cm below soil surface (Figure 13).

2.2.2 Soil moisture monitoring and irrigation practice

Instruments used for data collection and control were bought from Aquagri International Irrigation Management, LDA, Oeiras, Portugal (see: https://www.aquagri.com/site/index.php/en/). Measurements on soil water characteristics were done by the Sentek Multi logging and data transmission system (Figure 14) with following instruments:

- Communication Unit,
- Sentek (Drill & drop) probe for measuring soil moisture,
- Salinity and soil temperature at 5, 15, 25, 35, 45, 55 cm,

– Rain gauge and flow meter.

Soil moisture content, soil temperature and salinity (EC) were followed on-line on computer, laptop or smartphone (software package 'MyIrrigation', provided and patented by Aquagri). A meteorological station measured: Air Temperature, Relative Humidity, Wind speed, Solar Radiation and Leaf Wetness. The measurements were used to calculate evapotranspiration of a reference crop ET0 (Penman-Monteith).

The actual crop water use of potato is calculated by using this ET0 and the potato growth coefficient Kc ($0.5 < Kc < 1.15$): $ET_{potato} = Kc * ET0$. The value for ET_{potato} was used for calculating the advised amount of irrigation water (mm).

The amount of water supplied (both by irrigation and rainfall) was also measured and on-line displayed by the software package 'MyIrrigation'.

Weekly, fertilizer was added to the irrigation water. The amounts of nutrients that were supplied are summarized in Annex I

Figure 12. Planting and installation of drip lines

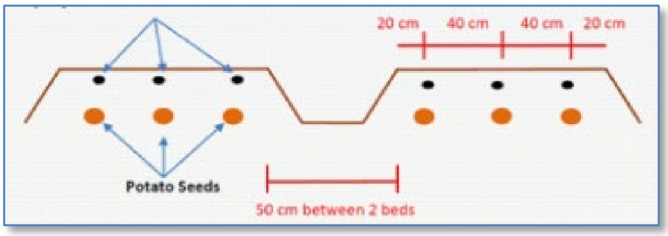

Figure 13. Cross section seed bed ridges

Figure 14. Sentek multi logging and transmission system (© Aquagri IIM)

2.2.3 Potato varieties

Next to the traditionally grown variety Spunta, 4 other potato varieties were bought from Agrico, Emmeloord, the Netherlands. All varieties were used for comparison in both the pivot evaluation growth cycle and the two potato growth cycles with subsurface irrigation. The variety choice was based on main characteristics being high yield and resistance to heat and drought stress: the yellow varieties Faluka and Arizona and the red varieties Kuroda and Rudolph (evaluation pivot, autumn demo pilot), respectively Manitou (spring demo pilot).

2.2.4 Analyses and growth measurements

At the start of the growing cycles two water samples of water and six soil samples were collected for analyses. During potato growth following data were collected: water application, salinity root zone, air and soil temperature. At the end of the potato growing cycle, tubers were (pre)harvested in representative areas of 5 x 0.6 m^2 in each plot and tuber weights were determined for each plot.

2.3 Implementation of the new technology

To demonstrate to farmers that this innovative technique saves water while also resulting in higher production and better quality of the produced potatoes, field days and workshops were organised every few months for which all farmers from the El Oued region were invited to look at the results of the measurements and in the fields and to discuss possibilities and opportunities for implementation of the innovative techniques into their own farm management. The farmer field visits, workshops and trainings were co-organized and supported by the El Oued Potato Growers Cooperative.

Guidelines and manuals for Good Agricultural Practice were written to support the farmers in their new farm management.

3 Results

3.1 Water use of traditional pivot irrigation system

The water use of the pivot irrigation system at the 3 plots with different watering strategies (High speed, water supply according to crop demand and farmers' practice) were measured with water meters at two different periods in the spring production cycle.

Table 2. Pivot water use (l/day/m^2 ~ mm) at 3 different watering strategies in 2 periods in March 2018

Watering strategy	**6/3 - 21/3**	**21/3 - 28/3**
High speed	10	7
Crop demand	37	26
Farmers' practice	17	36

Table 2 shows big differences between the watering strategies and periods. It can also be seen that farmers' practice and crop demand did not match. However, it is not appropriate to draw clear conclusions from these measurements, as – unfortunately - we did not receive enough details from the staff members in El Oued (i.e. start time, duration, weather conditions) to be able to interpret the numbers properly.

The water distribution by a pivot installation is shown in Figure 15 for 4 different measuring dates.

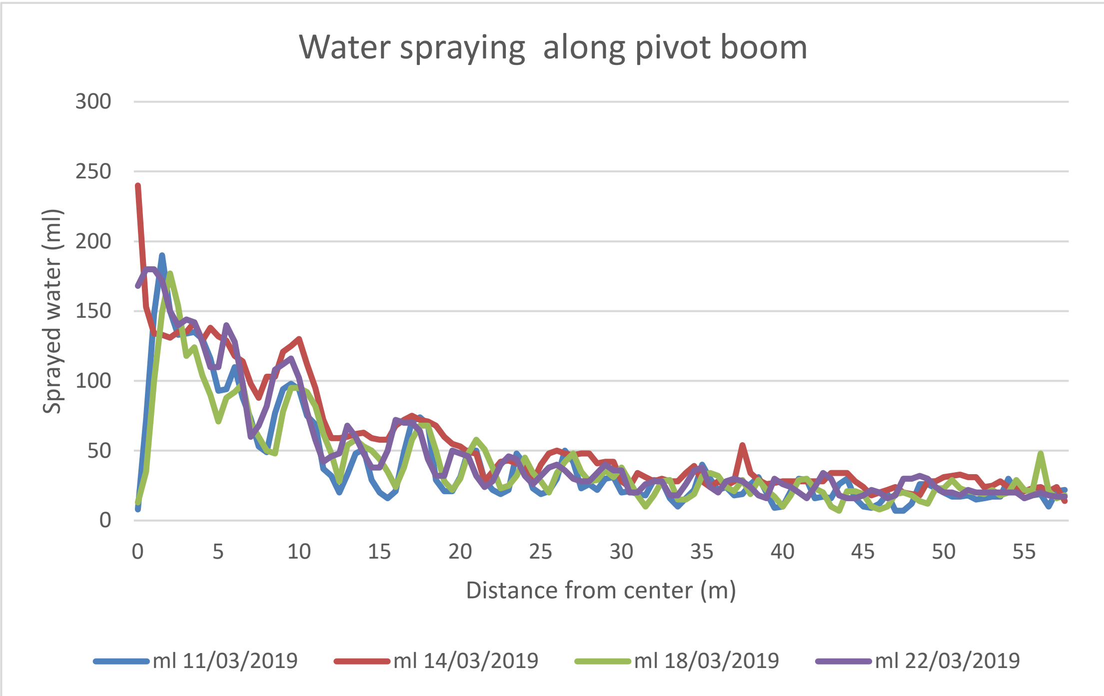

Figure 15. Water spraying along the pivot boom collected while dropping by once

It can be seen that the spraying significantly decreased along the boom.

Average yields (tons/ha) are shown in Table 3. Differences can be seen between both watering strategies and between the varieties. Although the high-speed-watering-strategy used the least amount of water, tuber yields were the highest at this watering strategy (except for the variety Rudolph), while tuber yield was lowest when water was supplied according to a calculated crop demand. Lower yields (crop demand and farmers' practice) may indicate an excess of water supply, while Rudolph appears to be insensitive.

Table 3. Yields (tons/ha) of different potato varieties, grown at different watering strategies during 133 days

	Watering strategy			
Variety	High speed	Crop demand	Farmers' practice	**Average**
Arizona	60.9	35.6	40.3	42.6
Faluka	60.7	35.1	43.9	43.7
Kuroda	62.6	36.0	44.3	44.6
Rudolph	49.2	50.9	54.9	52.2
Spunta	52.2	37.2	45.7	43.6
Average	**57.1**	**39.0**	**45.8**	**45.3**

The amount of plants and number of stems (per m^2) are shown in Table 4. Although Faluka and Rudolph look quite good in terms of number of stems and plants, Arizona and Kuroda show to be most productive per plant, better than the traditionally grown variety Spunta.

Table 4. Amount of plants and number of stems (per m^2) of 5 potato varieties, grown at different watering strategies during 133 days

	Watering strategy					**Average**	
	High speed	Crop demand		Farmers' practice		plants	stems
Variety		plants	stems	plants	stems		
Arizona	**No data**	3.0	6.3	3.2	7.2	3.1	6.8
Faluka		3.5	9.6	3.1	10.1	3.3	9.8
Kuroda		3.4	5.1	2.8	5.1	3.1	5.1
Rudolph		3.4	8.7	3.8	10.7	3.6	9.7
Spunta		3.9	8.2	3.1	5.6	3.5	6.9
Average		**3.4**	**7.6**	**3.2**	**7.7**	**3.3**	**7.7**

3.2 Rolling out the demo

3.2.1 Soil and water characteristics

Soil characteristics are shown in Figure 16.

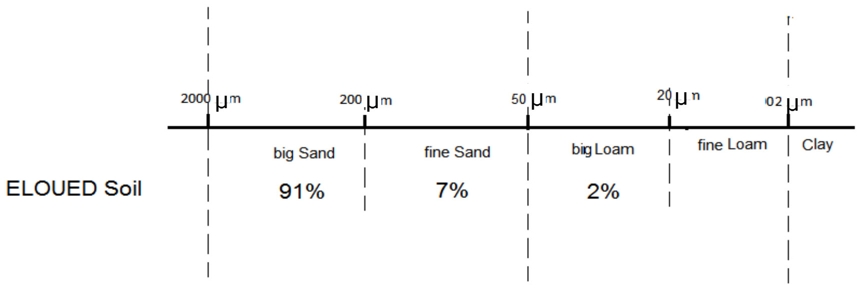

Figure 16. Soil composition (µm) in El Oued

The soil mainly contains big (i.e. coarse-grained) sand, while no organic matter could be detected . With respect to the water holding capacity: 1 gram of El Oued soil holds 0.048 cm^3 of water.

Further composition (nutrients, pH, etc) of the soil is shown in Table 5 for the two test locations and in Table 6 for the water of the well at Farm I. At both locations a small amount of nutrients are present, organic matter is indeed very low, while pH and carbonic lime % are high. In the water of the well nutrient composition is also low, pH is relatively high and EC is rather high.

Table 5. Average soil composition (± standard deviations) of nutrients and other components at the two test locations

	Farm I	**Farm II**
Dry matter (g/kg)	973 (± 20.5)	
Crude ash (g/kg dm)	1000 (± 0.7)	
Organic matter (%)	0.02 (± 0.04)	<0.5
N (g/kg dm)	0.32 (± 0.04)	<0.2
P (g/kg dm)	0.21 (± 0.01)	0.0003 (± 0.0002)
P_2O_5 g/kg dm)	0.48 (± 0.03)	0.2 (± 0.02)
K (g/kg dm)	0.63 (± 0.04)	0.03 (± 0)
K_2O (g/kg dm)	0.76 (± 0.05)	
S (g/kg dm)	0.42 (± 0.07)	0.75 (± 0.05)
Mg (g/kg dm)	1.08 (± 0.07)	0.03 (± 0)
MgO (g/kg dm)	1.80 (± 0.10)	
Na (g/kg dm)		0.025 (± 0.005)
Cl (g/kg dm)		
pH	8.82 (± 0.09)	7.85 (± 0.15)
C-anorganic (%)	1.47 (± 0.11)	3.75 (± 0.19)
Carbonic lime (%)	11.22 (± 0.87)	29.45 (± 1.45)
Conductivity (mS/cm, 25°C)	0.46 (± 0.10)	

Table 6. Average water composition (± standard deviations) in the well at Farm I

	Average (± sdev)
NH_4 (ppm)	< 1.9
K (ppm)	23 (0)
Na (ppm)	255 (0)
Ca (ppm)	617 (0)
Mg (ppm)	83 (0)
NO_3 (ppm)	87 (0)
Cl (ppm)	333.5 (3.5)
S (ppm)	601 (5)
HCO_3 (ppm)	24 (0)
P (ppm)	< 1.0
Fe (ppb)	11 (0)
Mn (ppb	13.5 (2.5)
Zn (ppb)	13 (0)
B (ppb)	443 (0)
Cu (ppb)	< 6.4
Mo (ppb)	29 (0)
Si (ppm)	9.15 (0.15)
Fe (ppb)	190 (17)
pH	7.4 (0)
EC (mS/cm 25°C)	3.75 (0.05)

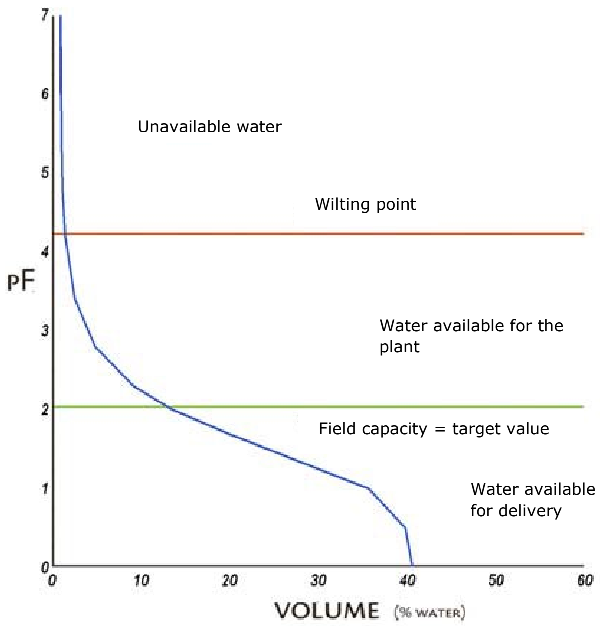

Figure 17. pF-curve of the soil at Farm I

The pF curve of the soil is shown in Figure 17. Approximately ca 36 mm water is available for the plant.

3.2.2 On-line monitoring

Online soil moisture content (at 5 different depths and summed) and water supply is shown in Figure 18. The colors in the middle panel indicate: blue is too wet; green is field capacity and red is too dry. The data clearly show, that Measuring and Control was very difficult for the farmer and his coworkers:

- Soil moisture content varied considerably, but this was muffled with depth. From this flattening it can be concluded that the roots were up to about 30 cm deep.
- The frequency of irrigation supply was very irregular and not always adequate: From time to time, too much water (blue zone, middle panel) was supplied. At other times, not enough water was supplied causing the root zone to become too dry (red zone, middle panel).

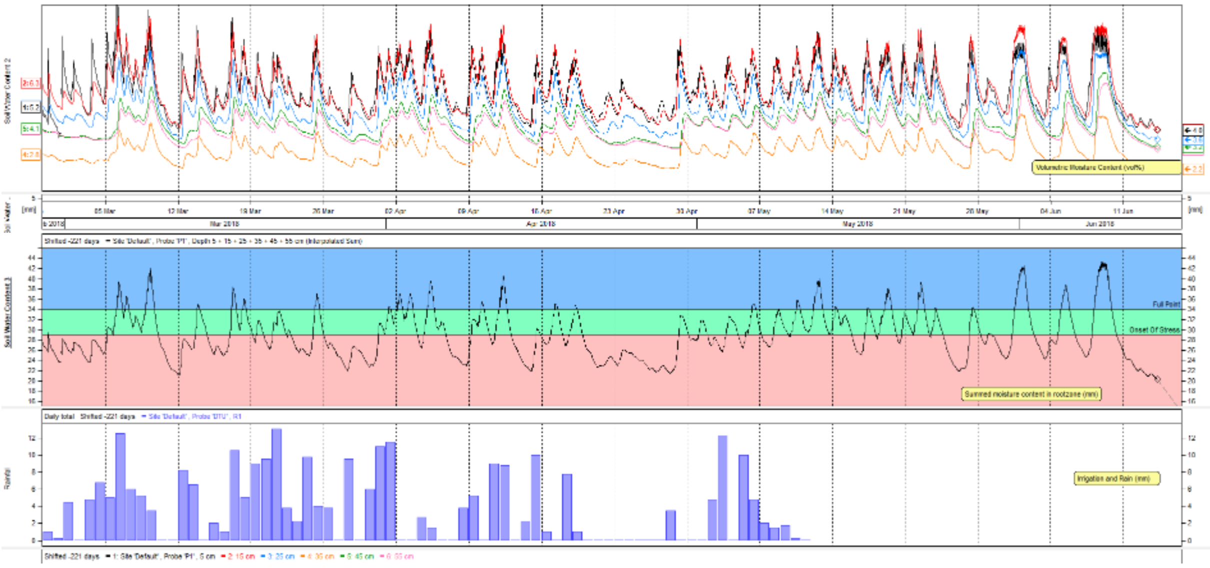

Figure 18. Online (Feb - June, 2018) measurement data with respectively (from top to bottom):soil moisture content at 5 different depths (upper panel), total moisture content in the root zone (blue: too wet, green: field capacity, pink: too dry), Water supply (mm) by rainfall or irrigation (lower panel). © Aquagri

- After water supply, soil moisture content decreased rapidly due to a large runoff in the sandy soil. Both soil salinity and soil moisture considerably varied with time and with depth (Figure 20), while showing an inverse relationship.

Online monitoring of the air and soil temperatures for a situation in June is shown in Figure 19. Air temperature varied more than 20 degrees within a day, while the variation of the soil temperatures quickly decreased with depth. So, roots and tubers are generally not exposed to big differences in temperature, provided that they are at a reasonable depth, like around 15 – 20 cm.

3.2.3 Water supply

At both farms, water availability was very irregular. At Farm I, the well was actually not deep enough to maintain proper pressure on the pipes all the time. At Farm II, high priority was given to the production of olives, with the result that in the potato fields the pressure dropped from the pipes from time to time.

The amount of irrigation water, daily needed, was determined as described in chapter 2.2.2. For the Autumn potato production cycle in 2018, monthly water supply (by subsurface fertigation (SF) and pivot irrigation), the reference transpiration ETO (Penman-Monteith), amount of rain (mm), needed irrigation (ET0-RAIN, mm) and irrigated fraction are shown in Table 9. In the pivot field water supply

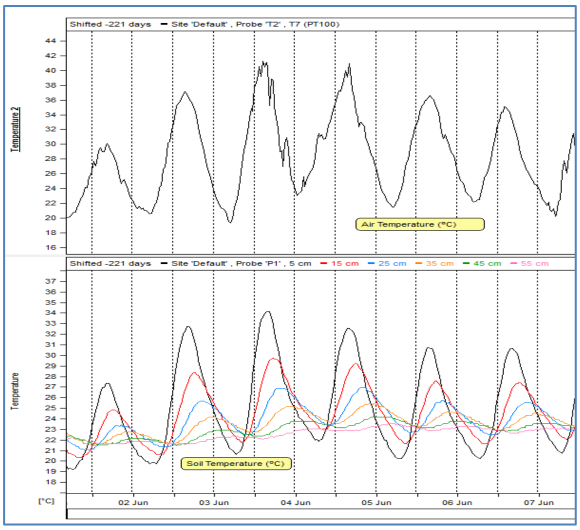

Figure 19. Daily variation of the air temperature (upper panel) and soil temperature at 5 different depths (lower panel). © Aquagri

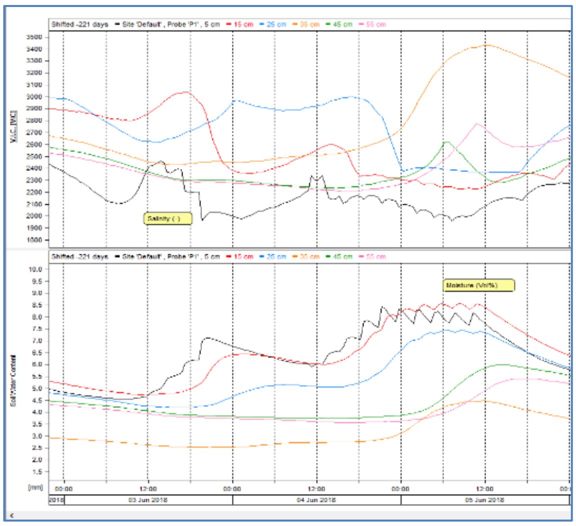

Figure 20. Daily variation in soil salinity (upper panel) and soil moisture (lower panel) at 5 different depths.© Aquagri

by pivot was about as twice as much as by SF. Water saving by SF was considerable (53%). In both water strategies water supply exceeded water demand as Irrigated Fraction was much greater than 1 (except for the water supply by SF in January.

Table 9. Water supply (mm) and water saving SF/pivot (%), transpiration reference ET0 (mm), amount rain (mm), needed irrigation (mm) and irrigated Fraction in Autumn potato growth of 2018 at growth periods

	Water supply					Irrigated Fraction*	
Growth period	SF	Pivot	ET0	RAIN	ET0-RAIN	SF	Pivot
1 - 30 November	193	333	73	0.4	72	2.7	4.6
1 - 31 December	105	286	51	0.0	51	2.1	5.6
1 - 7 January	8	31	10	0.0	10	0.8	3.2
Total	**306**	**650**	**133**	**0.4**	**133**	**2.3**	**4.9**
Water saving	**53%**						

**Irrigated Fraction = Irrigated amount (mm) / (ET0-RAIN) (mm)*

For the Spring potato production cycle in 2019, monthly water supply (by subsurface fertigation (SF) and pivot irrigation), the reference transpiration ETO (Penman-Monteith), amount of rain (mm), needed irrigation (ET0-RAIN, mm) and irrigated fraction are shown in Table 10. In this potato growth, water supply by pivot corresponded to that by SF in February and March. However, from April water supply by pivot exceeded that by SF to such extent that total water saving by SF appeared to be considerable again (49%). In this growth cycle water supply fitted rather well to water demand, calculated as potential transpiration. However, in order to minimize runoff in the big sand it was often necessary to shorten irrigation time while increasing the frequency, causing a lot of effort.

Table 10. Water supply (mm) and water saving SF/pivot (%), transpiration reference ET0 (mm), amount rain (mm), needed irrigation (mm) and irrigated Fraction in Autumn potato growth of 2018 at growth periods

	Water supply					Irrigated Fraction*	
Growth period	SF	Pivot	ET0	RAIN	ET0-RAIN	SF	Pivot
Feb 2019	18	18	41	0.0	41	0.4	0.4
March 2019	85	65	117	9.2	108	0.8	0.6
April 2019	132	249	171	27.4	144	0.9	1.7
May 2019	106	339	142	0.4	141	0.7	2.4
Total	**342**	**671**	**471**	**37.0**	**434**	**0.8**	**1.5**
Water saving	**49%**						

**Irrigated Fraction = Irrigated amount (mm) / (ET0-RAIN) (mm)*

3.2.4 Yields

Both in Autumn and in Spring, tubers were harvested (picture in Figure 21) and yields were measured for all fields (subsurface drip irrigation and pivot irrigation; Tables 7 and 8). Estimated yields at different possible harvest dates for the Spring potato growth are determined by on trial harvesting, as yield data from the final harvest (executed by the staff of the university) were not measured properly. Yields in fields with subsurface drip irrigation were significantly higher than the yield in the pivot field.

Figure 21. Different potato varieties are harvested in all fields

Table 7. Tuber yields (tons/ha) of different potato varieties grown in Autumn 2018 during 115 days under subsurface drip irrigation (SF) or pivot irrigation (Farm I)

Variety	Watering strategy	Tuber Weight
Rudolph	SF	15.6
Faluka		13.7
Arizona		14.8
Spunta		11.5
Spunta	Pivot	9.2

Table 8. Estimated tuber yields (tons/ha) of different potato varieties grown in Spring 2019 during 128 days under subsurface drip irrigation (SF) or pivot irrigation determined by trial harvests (2019, Daioua Farm).

Variety	Watering strategy	1/5/2019	9/5/2019	17/5/2019	26/5/2019	2/6/2019	11/6/2019
Spunta	SF	5.6	-	6.4	12.4	6.3	14.3
Kuroda		5.1	5.9	7.2	11.0	5.9	15.6
Faluka		8.0	6.0	8.7	10.5	8.7	10.1
Arizona		-	11.9	12.2	18.0	16.2	21.8
Manitou		8.0	-	10.4	10.4	11.4	20.6
Spunta	Pivot		7.8	4.1	11.2	11.2	15.4

Both in the Autumn and Spring potato production, the varieties differed in tuber yields substantially. In Autumn the variety Rudolph showed the highest yield. The varieties Arizona and Manitou achieved best in Spring. In Autumn, Spunta grown under subsurface irrigation showed higher yields, however not in Spring.

3.3 Dissemination of knowledge and capacity building

The results very well illustrate the importance of optimal irrigation and are very useful for the discussions with farmers and other stakeholders during various workshops at the University of El Oued and field visits, attracting many visitors and much publicity on both the local and national radio and television. In total, 12 presentations were held. The sustainability theme was considered to be a topical issue.

3.3.1 Official kick-off and closure

At Farm I, the project was officially opened by the Dutch Ambassador and the rector of the University at November 28th 2018 (Figure 22). The project was officially ended by an International Seminar on 'Sustainability of Saharan agriculture and water use' at the University of El Oued from 2-4 March 2020 (Figure 23).

Figure 22. Official opening of the project at November 28th 2018 at Farm I. The Dutch ambassador cuts a ribbon (left) and the rector of the University of El Oued gives an opening speech (right)

Figure 23. International seminar at the University of El Oued to conclude the project

3.3.2 Field visits and knowledge exchange

From the start of the project, there has been great interest in the field activities from local farmers, representatives of the (local) government, business people or representatives from other organizations (picture in Figure 24). They regularly stood at the edge of the field in large numbers, looking at our activities. With the visitors, the results were shown and sustainable cultivation strategies were discussed on the basis of posters.

Figure 24. Visitors at the edge of the field (left) and posters used for presentation and explanation of the project (right).

Once the fieldwork began, we provided different guidelines, staff and students from the University of El Oued assisted in planting, measuring and harvesting and were educated in workshops at the university (Figure 25). Students were very eager to learn the innovative technology, but it was not always easy to make good appointments with them about the planning and division of roles, as:

- A large proportion of the students (> 80%) were women, who had to be accompanied by men and had to return home before 4 p.m.,
- During Ramadan it was hard for staff and students to exert themselves,
- Repeated strikes by the students caused much delay,
- The hierarchy between the employees of the university played a role.

Figure 25. Workshop at the university (left) and field work by students (right)

The staff of university was heavily involved in the fieldwork. They visited the field almost every day and felt very meticulous when cleaning the filters. However, there existed a serious knowledge gap on plant physiology, crop production and computer technology. The staff had difficulty understanding potato growth and were not familiar with the use of software. Thus, they were difficult to persuade to adhere to some water supply strategies, to use our guidelines and to tune their water supply to the online measurements with the MyIrrigation software from Aquagri. They preferred to be guided by what they saw above ground (a dry topsoil) and tended to supply too much water resulting in an inhibited root growth of the potato plants. Moreover, they were not used to a participatory approach and thus the communication with the farmer was not optimal.
Fortunately, the staff of the university involved in the field work were able to visit the Netherlands and to meet several people from potato production and breeding companies at the end of the project.

3.3.3 Implementation

Although many stakeholders and staff and students of the university visited the project and showed much interest in the project, we had the impression that the innovative technique was too complicated for all stakeholders being not familiar with computer-controlled systems. Yet, in the Autumn of 2019, Debouia Farm introduced a drip irrigation system for growing potatoes (at 1,5 ha) and testing the new potato variety Loane (Figure 26). Unfortunately, the system was not computer-controlled, but it was anyway an improvement compared to the pivot irrigation system.

Figure 26. Potato production with drip irrigation

3.3.4 Publicity

Both the local and national TV press filmed and interviewed us several times in the field (Figure 27). This has resulted in a YouTube recording and video film of 22 minutes, in which also drone recordings are processed. A potato farmer in El Oued, Mr. Ammar Hettiri, sent us after an enthusiastic message to express his willingness to cooperate with us.

The YouTube recording can be seen < Here >.
The video film can be seen at: < Video film (22 min) >.
The message of a local farmer can be seen at: < Video by local farmer >.

Results and lessons learnt for the Dutch situation are published (Blom-Zandstra, 2019; Blom, 2019). At the International Seminar the results from the project and their lessons learnt are presented and officially published (Blom, 2020).

Figure 27. Recordings for television during the official opening of the project

4 Discussion

The introduction of a computer controlled subsurface irrigation method and different potato varieties in a potato production in El Oued have clearly resulted in an improvement of the potato production, both in terms of efficiency, sustainability and yield:

1. Planting and installation of driplines can be done at the same time,
2. Water saving is about 50%,
3. Tuber yields slightly increase (mainly in Autumn), while there are better yielding potato varieties, that are more suitable for a desert environment than Spunta.

Notwithstanding the bad quality of the water (high pH, high EC) potatoes grow well and looked healthy (Figure 26). The success of substituting pivot irrigation by subsurface fertigation in increasing water use efficiency and yields has already been reported in literature by several authors (Al-Ghobari et al., 2018, Hashem et al., 2018, O'Neill et al., 2008, Valentin et al., 2020) and also holds for the arid El Oued region. So, introduction of a subsurface system does have potential for increasing sustainability of potato growth. Although the use of water from the sub-Saharan aquifer in the El Oued region is not well accounted for, nor is the actual volume, the predicted lifespan of the reserves and impact of the use (Richey et al., 2015), for an area of 33.000 hectares a water saving of 50% is substantial. Also the introduction of more resilient and better yielding varieties as Arizona, Manitou and Rudolph will increase income and enhance opportunities for investing in innovations.

4.1 Success of the demo project

As a demonstration pilot, the project was partly successful. The staff of the university, who was leading the field work, was very dedicated to fulfill this work. The data collected on water use clearly showed the irregular pattern in time and along the boom of the pivot irrigation (table 2, Figure 15) and were very convincing for the staff, students and visitors of the workshops and fields. Also appealing were: differences in yield between varieties, a better appearance of the crop (see f.e. Figure 26) and relative low disease and weed pressure compared to potatoes grown with pivot irrigation (visual observation; no quantitative data collected).

The collected data convinced everyone that points of improvement of the pivot methodology were urgent and challenging for innovation. However, the introduction of the innovative equipment and the use of online measurements as tool for irrigation strategies was not handled properly. It is undeniable that many practical difficulties had to be overcome, like the irregular pressure on the pipes, the sand coming from the well and clogging the filters, the need for minimizing runoff from in the root zone because of the big size of the grains of sand. But it was difficult for the staff of the university to adopt the new technology and to get it running. The knowledge gap on plant physiology, crop production and computer technology, the lack of skills and absence of good laboratory facilities appeared to be too large to bridge and to trust computer data well enough to start steering on these data. Therefore, the amount of water needed by the crop was more tuned to the visual dryness of the topsoil than to measurement data (f.e. Figure 18) and to maintaining field capacity in the root zone. Moreover, we experienced that the university (like all scientific organizations in Algeria) is not familiar with a participatory approach, resulting in an unfortunate cooperation with the farmers. On top of that, political developments caused students to strike for long periods, hampering the field measurements and complexing the making of appointments.

Several papers have been published on the development of Algerian agriculture in the last decade, in which various reasons were mentioned for poor development, like:
- Lack of knowledge transfer (Arous et al., 2013),
- Lack of a clear framework for evaluation and exchange that provide tools to foster the capitalization and enhancement of scientific output (Bernaoui and Hassoun (2011),
- Political restrictions for proper development of agriculture (Laoubi & Yamao 2012),
- Insufficient technology transfer (Ayad et al., 2020).

As we experienced in this demo project, technology transfer is indeed a big problem in Algeria. Ayad et al. (2020) blame this on its complexity as one of the chief barriers to enter into the high technology industry, leaving Algeria to have not progressed beyond assembly (screwdriver) operations. The authors consider the existence of well working networks to be an absolute constraint: 'The effectiveness of knowledge transfer is reflected in the local value created, stemming in particular from a well-established supply chain and several producers working together, but the density and continuity of interactions often prove insufficient. Weak interactions are a major handicap, mostly because of institutional barriers, lack of flexibility and cumbersome procedures'. They mention that 'the limited number of Algerian engineers added to the constraint duration of the projects, prevented them from engaging in work rotation that could have given them multicomponent vision experience, facilitating the acquisition of more integrative knowledge'.

During the course of the project, upscaling did not happen. But due to the huge publicity by local and national press and the fact that many representatives from governmental and private organizations and farmers visited the workshops and fields, the attention for the innovative technique strongly increased. Also the fact that Debouia introduced a drip irrigation system for growing potatoes after the end of the project and started testing the new potato variety Loane, are hopeful developments. If the sense of urgency, the financial incentives and a political and societal support increase, the introduction of new technology in El Oued can get a chance.

4.2 Lessons learnt for the Netherlands

The long-term precipitation shortfall due to drought becomes an increasing problem in the Netherlands too and places ever higher demands on Dutch water management. Currently, mainly measures are taken to prevent the depletion of water reserves during the summer, but the steadily falling groundwater level is a growing bottleneck (Jeuken et al., 2015). The agricultural sector is experiencing a heightened risk of loss of earnings (Tolk and Veldstra, 2016). However, precision farming can significantly improve the efficiency of crop water use and may even become crucial for the Netherlands to become water-robust in the future and to protect the economy against the negative consequences of climate change. The introduction of online sensor technology for open-ground cultivation in the Netherlands has hardly gotten off the ground. Subsurface fertigation is commonly applied for multi-year cultivation, such as fruit farming and arboriculture, albeit rarely utilized for annual crops.

The demo project in El Oued has provided valuable data on the distribution of water and nutrients in the soil, water uptake characteristics in relation to crop growth and root depth, the course of electrical conductivity (EC) over time and the relationship between soil and air temperature. This allowed researchers to calibrate the software for potato cultivation in relation to environmental factors (air and soil temperature, irradiation and soil characteristics).

Next to the generation of parameters, the demo project has yielded several intriguing insights for practical use in the Netherlands, such as:

6. Mechanical planting of potatoes at a depth of around ten centimeters easily combines with the unwinding and installation of subsurface hoses. During the harvest, a single machine can roll up the hoses and dig the potatoes. Therefore, both the installation and removal of drip hoses is not an issue with annual crops.
7. With well-drained soils, multiple and short irrigation doses are more effective and yield greater water savings than prolonged irrigation at greater intervals. In addition, short and frequent irrigation intervals lead to less salinization within the root zone than longer and less frequent irrigation.
8. The technology offers possibilities to guide the irrigation based on tuber setting and tuber size, thereby offering added value for seed potato companies.
9. Insight into crop propagation and the water, nutrient, pesticides and energy savings make it possible to calculate the economic feasibility of the technology for each company.
10. Farmers in the Netherlands often begin irrigating crops too late. Computer-controlled fertigation offers possibilities to guide the water and nutrient dosing on the basis of the plants themselves.

5 Recommendations

As outlined and discussed in chapter 4, the demo project was successful in improving potato production in terms of efficiency, environmental sustainability and yield. From the data collection the sense of urgency to innovate was felt by all stakeholders involved. But the adoption and operationalizing of the new technology was less successful, due to many bottlenecks in the cultural, societal and political landscape. However, given the great interest for change, a transition in Algeria towards a more technology driven sustainable potato production may be promising by following incentives and support:

- Improve and stimulate the knowledge-exchange and exchange of practical experiences between researches – extension officers - farmers – private sector (breeders, technology suppliers) (Laoubi & Yamao, 2011)
- Develop an information system and enhance monitoring activities to improve scientific and industry knowledge and the suitability for a practical approach
- Stimulate cooperation between universities specialized in different disciplines (physiology, physics, agriculture) to enable implementation of an integrated practical approach
- Stimulate the investment in good equipped and certified laboratory facilities
- Stir up the interest of young people in IT and robotics and motivate them to use it for practical applications in agriculture.

Figure 28. Water wasting pivot installation

6 Acknowledgements

The authors like to thank Dr Khaled Laïche and Dr Ahmed Allali for their commitment and dedication to make the project a success. Thanks to their contribution, new insights were gained into how water use can be further optimized under long lasting and intense drought.

The authors like to thank also Mr. Khalifa Debar and Mr. Djebali Belkhir for making their plots available for the pilot. Due to their support and investment in this project the opportunities for innovation and chances for future development of potato cultivation could be studied.

Finally, the authors like to thank the rector Prof. Omar Ferhati, the deputy rector Prof. El Habib Guedda, the dean Dr. Ali Boutlelis Djahra and the deputy dean Dr. Abdelmalek Zaater of the Hamma Lakdar University in El Oued for their interest and support during the course of the project. This project was a basis for the close cooperation between the University in El Oued and Wageningen University & Research in the Netherlands. It contributed to the setup of a framework for scientific knowledge exchange and offers perspectives for further cooperation in the near future.

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Annex 1 Fertilizer supply subsurface irrigation

Table

		Unit/Ha	Unit	Total required quantity (5 ha)	
Pre Planting (Broadcasted on soil)	DAP	400	Kg	2.00	Tons
	Potassium Sulfate	350	Kg	1.75	Tons
Before ridging (Broadcasted on soil)	DAP	0	Kg	0.0	Tons
	Potassium Sulfate	0	Kg	0.0	Tons
From ridging until harvest (Fertigation-applied with Irrigation)	Urea	275	Kg	1.38	Tons
	Phosphoric Acid (Pioneer 56.5% P2O5)	94	Kg	470	Kg
	Magnum 18-44-0	20	Kg	0.10	Tons
	Soluble Potassium 0-0-50	120	Kg	0.60	Tons
	Magnesol (MgSO4)	40	Kg	0.20	Tons
	8-6-40	10	Liters	50.0	liters
	Trace elements (Librel BMX)	1.5	Kg	7.5	Kg
	Zinc (EDTA)	2	Kg	10.0	Kg
	4 - 4 - 4	4	Kg	20.0	Kg
	Amino Acid	1	Liters	5.0	Kg

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Report WPR-1017