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Improved On-farm Irrigation Management for Olive Growing - A Case Study from Morocco

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Abstract: The key success factors of the olive oil market are the enhancement and stabilization of olive yields, improvement of olive oil quality and reduction of production costs. There is great potential for cost reduction in terms of water saving in olive production in Morocco. The main purpose of this four year (2010-2014) study was to enhance crop yields of smallholder olive farmers in Morocco, through the optimization of water management practices applied to olive cultivation. In Morocco's Marrakech region the low rainfall allows only irrigated olive cultivation and so the study investigated the effect of deficit irrigation in reducing water consumption without adversely affecting the olive yield. Results indicate that adding water at 70% of ET_c led to 63-77% saving in water compared to flood irrigation along with a 13-43% increase in yield. At the policy level, switching from flood to drip irrigation (100% ET_c) on 25% of the planted area can lead to additional olive fruit worth USD 213 million and switching to deficit drip irrigation (70% ET_c) can lead to an additional olive fruit worth USD 390 million from the same size area.

Key words: Drip irrigation, deficit irrigation, Morocco, supplemental irrigation, water productivity.

Olive has been cultivated since the beginning of historical times in its native Asia Minor. Its cultivation spread very early to most of the Mediterranean countries and this is still the prime area of production since this crop requires very warm average temperatures, dry climates and does not tolerate cold climatic conditions. The key success factors of the olive oil market are the enhancement and stabilization of olive yields, improvement of olive oil quality and reduction of production costs.

There are essentially three modern olive production systems at present that differ primarily in tree density. Traditional groves developed under rainfed conditions, often originally in areas of shallow soils and limited rainfall, were planted quite sparsely, with typical densities of 60 to 100 trees ha^{-1}. Pruning was customary to adjust canopy size to drought years thus avoiding catastrophic events. Yields were variable and low, oscillating between less than 1 up to 4 t ha^{-1} of olives. These groves can be transformed into irrigated plantations where water, capital, and knowledge are available.

Intensification of the traditional production system in the major producing countries came about in the 1970s and 80s via increased tree density, which has been raised from less than 100 to between 200 and 350 trees ha^{-1}. A typical spacing of 8 x 6 m or 7 x 5 m, and the training to a single trunk (contrary to many traditional systems where a tree was formed with three trunks) allowed for mechanical harvesting and the lowering of harvest costs. Additionally, the increased density meant a higher fraction of intercepted radiation, which led to increased productivity. In areas of abundant rainfall (more than 600 mm of annual rainfall), the water supply was sufficient to sustain production under rainfed conditions. However, irrigation became an essential part of olive intensification in the drier areas (annual rainfall 500 mm or less). Fruit yield of these systems can exceed 10-12 tons ha^{-1} and can be quite stable under irrigation.

Recently, there has been interest in further intensifying production in the developed countries by increasing tree density to much higher levels, up to 2000 trees ha^{-1}. One driving force behind this move is the possibility of using over-the-tree harvesters which would

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lower harvesting costs, below those achieved with the shakers and vibrators currently used. In this system, tree rows are spaced at 3.5 to 4 m, while the trees in the row are spaced at 1.5 m or less. There are several important issues still unresolved in this third system, and it should still be considered experimental, although there are many commercial plantations already in place, all of them less than 5-10 years old. Yields can be quite high in the first production years (5-15 t ha^{-1}) but there are questions about how to sustain them in the longer run. These plantations definitely require irrigation.

Demand for olive oil is steadily increasing worldwide and is expected to continue to increase, given the health benefits directly connected to the regular consumption of olive oil. Over the last 10 years world olive oil consumption has increased by 23%. During the last 3 years, average olive oil demand has been 2,900,000 t yr^{-1}, consistently above production. The EU is the main market with 70% of consumption in the year 2007. In 2007, the main exporters were the EU (52%) and Tunisia (22%), while importers were the USA (about 37%), and the EU (about 30%). Imports have been growing in Brazil, Canada and Australia.

Olive sector in Morocco provides almost 20 million workdays/year and permanent employment for 60,000 people. Additionally, it contributes to the livelihoods of two million people and covers 16% of Morocco's consumption requirements in edible vegetable oils. Morocco produced 75,000 t in the 2006-07 crop year, of which 15,000 t were exported.

The olive sector has been expanding very rapidly in recent years. In the last decade, Morocco experienced a similar growth rate in new olive plantings, bringing the total acreage to around 600,000 ha at present. In Morocco 220,000 ha (mainly in the southern areas) are irrigated, representing 35% of the total acreage. However, water supply limitations represent an important constraint to olive irrigation.

The main purpose of this four year (2010-2014) study was to enhance crop yields of smallholder olive farmers in Morocco through the optimization of water management practices applied to olive cultivation. Hypothesis was that improved and more stable olive yields were going to lead to improved earnings and livelihoods for the targeted smallholder farmers. The study objective was achieved through the testing, demonstration and dissemination of sustainable irrigation technologies, water management practices and effective irrigation techniques. Pilot experimental field was set up at Tessaout research stations near Marrakech.

Materials and Methods

The climate in this area is a typical Mediterranean semiarid characterized by hot and dry summer with an annual rainfall of 200 mm mostly received outside a 4-month summer drought period. Spring and summer seasons at the experimental site are normally characterized by severe drought stress associated with high temperatures (Table 1). The soil has a loamy clay texture and it is over 2 m deep.

Table 1. Mean climatic variables and reference evapotranspiration at the experimental sitr

Climatic variable	
Rainfall September-March (mm)	164.2
Rainfall April-June (mm)	22.2
Rainfall July-August (mm)	4.6
Mean daily min temp January-February (°C)	11.5
Mean daily max temp May-June (°C)	41.5
Mean daily max temp July-August (°C)	45.5
Total rainfall 12 months (mm)	191.0
Total 12 months ET_0 (mm)	1508.0

Two irrigation methods were applied, drip irrigation with two water regimes and flood irrigation or traditional system used by most of the farmers. The planting density of the orchard was 208 trees ha^{-1} in the case of flood treatment with a row spacing of 8 m x 6 m and 156 trees ha^{-1} for drip irrigation treatment with 8 m x 8 m row spacing. In both systems, olive trees had the same age.

Drip irrigation and traditional irrigation systems were used in two adjacent plots. A randomized complete block design (RCBD) was used with three replications per irrigation regime in the case of drip irrigation system (Fig. 1). The drip irrigated plot had an area of 1 ha and the traditional irrigation plot had an area of 0.5 ha. The drip irrigation experimental plot included 6 subplots (two irrigation regimes x three replicates). The two irrigation regimes under drip irrigation systems were: 100% of crop evapotranspiration (ET_c) and 70% of ET_c. Each replicate included 10 trees. Deep tillage

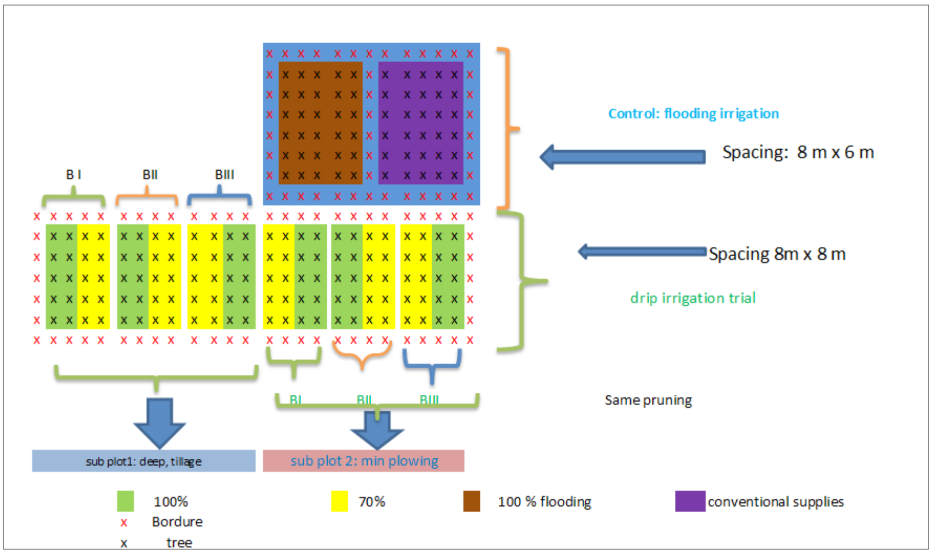

Fig. 1. Experimental design at Tessaout research stations near Marrakech, Morocco.

was conducted on 13 January at 60 cm depth and 1 meter from the trunk.

The ET_c was calculated following the equation:

$$ET_c = ET_o \times K_c \times K_e/N_e$$

where, ET_o is the reference evapotranspiration and K_c is the crop coefficient for olive tree, K_r is the corrector coefficient and N_e is the efficiency of irrigation network. ET_0 was estimated using Penman-Monteith (Allen *et al*., 1998) equation and daily meteorological data collected from an automatic weather station located 50 m away from the experiment plot. The Kc values used are the ones reported by Orgaz and Fereres (1997); while the value of Kr was estimated at 0.8 (Fereres and Goldhamer, 1990).

Results

In Morocco, the rainfall in olive growing regions is low (200-250 mm) and insufficient to grow olives using just the rainwater. So, farmers are compelled to practice irrigated olive plantations, mostly using the flood method. Our research compared traditional flood irrigation method with drip irrigation applied at full and regulated deficit level. Our results indicate that by adopting improved irrigation methods, there was a gain in yield of fruit and oil, and water productivity increased significantly, thus, saving water and increasing farmers' income. There was a declining trend with total water applied for all the four parameters. The linear trend was found significant ($P < 0.05$) for oil WP.

During 2011 growing season (a relatively wetter than normal year-303 mm), by switching from traditional flood irrigation to drip irrigation, there was a saving of 66% of water (600 mm vs. 203 mm), 27% increase in olive fruit yield, 76% increase in water productivity (0.19 kg m^{-3} vs. 0.78 kg m^{-3}) and 31% increase in oil yield (Table 1). Another 11% saving of water was possible by applying deficit drip irrigation at 70% of ET_c level - yield was 13% higher than traditional irrigation method, water productivity was 80% higher and oil yield was 25% higher.

Whereas, 2012 growing season received less than normal rainfall (140 mm) and so the water requirement of olive trees, in addition to the rainfall, was higher than the previous year. Traditional flood irrigation method consumed 1,061 mm of irrigation water and produced 4,530 kg ha^{-1} olive fruit yield at a WP of 0.43 kg m^{-3} water applied. Switching to regulated drip irrigation reduced the water usage by 412 mm (39%) for 100% ET_c treatment along with an increase of 3,040 kg ha^{-1} of yield (40%), and 70% ET_c treatment further saved 157 mm water (24%) and further increased yield by 190 kg ha^{-1} (2.5%).

Year 2013 was close to normal with total rainfall of 191 mm majority of which (86%) was received during September-March months.

Table 1. Summary of experimental results

Year	Treatment	Water applied (mm)	Olive yield (kg ha^{-1})	WP (kg m^{-3} water applied)
2011	100% ETc	203	1580	0.78
	70% ET_c	137	1320	0.96
	Traditional	600	1150	0.19
2012	100% ETc	649	7570	1.17
	70% ET_c	492	7760	1.58
	Traditional	1061	4530	0.43
2013	100% ETc	469	5900	1.26
	70% ET_c	339	5977	1.76
	Traditional	901	4527	0.50
2014	100% ETc	480	7722	1.61
	70% ET_c	340	6925	2.04
	Traditional	960	3800	0.40
Average	100% ETc	450	5693	1.21
	70% ET_c	327	5496	1.59
	Traditional	881	3502	0.38

Flood irrigation method produced 4527 kg ha^{-1} fruit yield consuming 901 mm of irrigation water at a WP on 0.50 kg m^{-3} water applied. The WP was 150% higher for the 100% ET_c drip irrigation treatment which produced 5,900 kg ha^{-1} fruit yield consuming only 469 mm of irrigation water. A further increase of 1.3% along with a saving of 28% of water was recorded for the 70% ET_c treatment.

Similar trend was witnessed during 2014 growing season but there was a much higher difference between flood and drip irrigation treatments. The 100% ET_c treatment produced 103% higher yields and 70% ET_c treatment produced 82% higher yields compared to the flood treatment.

Statistical Analyses

Our results indicated that by adopting improved irrigation methods, there was a gain in fruit yield (P <0.10) and water productivity increased significantly (P <0.01), thus, saving water.

Discussion

The olive tree is a thrifty water consumer well adapted to xeric conditions. Its mechanisms for drought tolerance (Fernández and Moreno, 1999; Connor, 2005; Connor and Fereres, 2005) make the species to be particularly suitable for deficit irrigation. Moriana *et al.* (2003) showed that the relation between olive ET and yield is curvilinear, and not linear as for other fruit tree species meaning that optimum irrigation application amount in olive could be less than that needed for a maximum ET_c, which agrees with results from Patumi *et al.* (2002) and Tognetti *et al.* (2005), among others. Patumi *et al.* (2002), for instance, report that irrigation application of 66% ET_c was sufficient to achieve good yields, while higher water volumes (100% of ET_c) gave little additional yield increases. Our results are also in line with those reached by Goldhamer (1999) in a four season study in San Joaquin Valley of California that 75% ET_c treatment saves water without sacrificing olive fruit yield.

Recommendations and Policy Implications

If 87,500 ha area (25% of 350,000 ha olive plantation area that is under flood irrigation in Morocco) switches from conventional flood irrigation to drip irrigation (100% ET_c), water consumption will reduce by 377 Mm^3. The water saved can be used for expanding drip irrigated olive plantation to additional 80,415 ha generating additional olive fruit worth USD 213 million (@ USD 0.45 kg^{-1}).

If same 87,500 ha area switches from conventional flood irrigation to deficit drip irrigation (70% of ET_c), water consumption will reduce 491 Mm^3. The water saved can be used for expanding deficit drip irrigated olive plantation to additional 144,745 ha generating additional olive fruit worth USD 390 million.

The Plan Maroc Vert targets to have 150,000 ha under drip-irrigated olive plantation across Morocco. Study-recommended deficit irrigation practice can help achieve this without any additional water allocation.

Conclusions

The objective of our research was to enhance crop yields of smallholder olive farmers in Morocco through the optimization of water management practices applied to olive cultivation. Four year research showed that switching from traditional flood irrigation to drip irrigation, on average, reduces water application by 49% and a further saving of 27% by switching to deficit irrigation at 70% ET_c level. There is a gain in olive fruit yield of 63% when the irrigation method is changed from flood to drip irrigation. At the policy level, switching from flood to drip irrigation in 25% of the planted area can lead to additional olive fruit worth USD 213 million and switching to deficit drip irrigation (70% ET_c) can lead to additional olive fruit worth USD 390 million from the same size area.

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