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Impacts of the *Meskat* water-harvesting system on soil horizon thickness, organic matter, and canopy volume of olive tree in Tunisia

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ABSTRACT

The *Meskat* system is the main traditional water-harvesting practice widely used in the region of Tunisian Sahel. This study aims to assess the impact of this system on several soil characteristics and on olive tree vigor. For this purpose, a strip experimental design was selected in the Sousse region. This study was focused on soil horizon thickness, its saturated hydraulic conductivity, and its organic matter content; olive tree canopy volume; and length of fruiting shoots of olive trees. The results showed that thickness of soil horizon A and B increased in the area close to the water-harvesting system. However, the soil-saturated hydraulic conductivity decreased in the structures close to the *Meskat* and organic matter content of the soil increased, especially in the root zone. These soil parameters could be considered as key indicators of soil fertility, affecting the agronomic performance of olive trees. Data indicate that canopy volume increased for the trees in the *Mankaa*, a small plot delimited by embankment that collecting run-off, close to the *Meskat*. Because olive tree is biennial bearing when rain-fed, this water-harvesting system seems to have no significant effect on the length of its fruiting shoots. The investigated parameters for soil are affected by *Mannkaa–Meskat* distance, indicating the beneficial effect of this water-harvesting system.

Keywords: Meskat system; Run-off; Soil fertility; Olive tree; Tunisian Sahel

1. Introduction

Located in the southern bank of the Mediterranean Sea and affected by the maritime influences and the desert, Tunisian territories are characterized by the arid and semi-arid climate. Consequently, water resources' availability is the most limiting factor for agricultural land productivity and farmer livelihood. Precipitation intensity, slope roughness, soil erodobility, vegetation abundance, and farming practices are considered as the main factors of erosion intensity [1].

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In Tunisia as in most Mediterranean countries, soil erosion is largely considered as one of the main phenomena that reduces farming production. More than three-million hectares are severely affected by erosion in the central and northern part of the country, where most economic activities are located [2]. Soil and water conservation practices are mainly designed to increase agricultural yield, control erosion, and silting of hydraulic structures; to improve water management in rivers and reservoirs; and to increase availability of groundwater. In dry areas, water availability affects ecosystem productivity, agriculture yield, food security, and outward and inward migration. Populations in these regions, constrained to cope with water scarcity, have developed and constructed several forms of water conservation practices to collect run-off for cropping [3]. These practices are implemented, in addition to collect run-off, to control erosion and to rehabilitate degraded lands [4], to improve crops' yield, to preserve soil fertility, and to cope with water scarcity in dryland areas severely affected by erosion limitations [5–8].

The Tunisian Sahel, located in the east from Hammamet Gulf in the north to Sfax region in the south, provides a typical territory where intensive water-harvesting practices were made by peasants to manage aridity and to improve crops' yield. The rainfall is erratic and insufficient for rain-fed crops, thus run-off-harvesting practices are designed to collect supplementary water. In this region, inhabitants constructed sequences of small earthen dikes in the foothills, in the gently sloped areas, and across watershed in order to intercept the surface run-off from the surrounding hilly slopes in the upstream sides, generally used as rangeland (Fig. 1). This traditional system is commonly known as olive grove *Majrouf* or *Meskat* system. The earthen dike, traditionally called *Isser* or *Tabia*, is managed by spillway routing the remaining run-off to the downstream structures and is extended by embankments in the lateral sides. The plots equipped with these embankments, known as *Mankaa*, are used for cropping fruit species, especially olive trees. The hilly bared upstream area, with moderate to steep slope commonly called *Meskat*, produces surface run-off needed to ensure olive oil production in this dry region. The *Meskat* is arranged with channels along the slope that diverts flow to cropped trees in the *Mankaa*. This system contributes to crop olive trees through improvement of water availability and soil fertility [9]. The increasing rates of erosion have led the introduction in the farming system build on the use of erosion control practices.

Studies evaluating the effects of soil and water conservation practices have focused on the impact of soil and water conservation practices such as contour ridge benches [10–14] and small hill dams [15–18] and water supply infrastructures. The impacts of traditional water-harvesting practices in Tunisia such as *Jessour* system on run-off [19] and on erosion control [8] have been previously reported. Even though the antiquity of the *Meskat* system and its unequivocal benefits on fruit tree farming, little is known about its effect on soil fertility and tree yield. It might be pertinent to consider the effect of this system in order to understand its effectiveness on olive rain-fed orchard. The objective of this study is to assess the impact of this system, one of the main soil and water conservation practices, on some characteristics of soil and vigor of olive trees (*Olea europaea* L. cv *chamlali*, *Oleaceae*) in dry land environments.

2. Materials and methods

2.1. Study area

Agriculture in Sousse region is dominated by fruit trees, cropped in more than 47% of the arable land; the olive tree cropping is an ancient orchard often related to water-harvesting practices, especially *Meskat* system (Fig. 1). The *Meskat* system, as water conservation practice, is mainly located in the inland of Sousse, Monastir, and Mahdia regions. Around 300,000 ha are managed with this system in the Tunisian Sahel. The *Meskat* system is prevailing in Sousse region, with

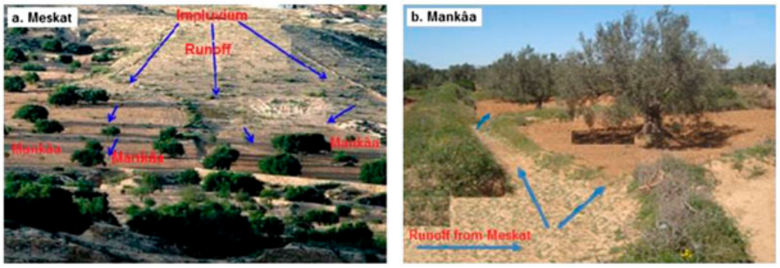

Fig. 1. Some illustrations of *Meskat* components.

around 44,000 ha [20,21]. In order to study the effect of this system, an olive tree orchard managed with *Meskat* system was chosen in the zone of Kroussia located in M'saken (Sousse region, Tunisian Sahel). The geographic coordinates of the site are 35°43′ 58.62′′ North and 10°29′59.95′′ East, with elevation ranging from 50 to 80 m above sea level. The *Meskat* area (Fig. 1(a)) is used as rangeland with moderate slope, ranging from 5 to 8%, and the *Mankaa* (Fig. 1 (b)) is located in its foot slope in a large valley with slope less than 2%. The olive orchard is rain-fed farmed and its soil is relatively shallow. According to the IUSS classification, the soils belong to *regosols* and *calcisols* in the *Meskat* and *Mankaa*, respectively, which are common in calcareous parent materials and widespread in arid and semi-arid environments [22].

The study area is in the Mediterranean semi-arid bioclimate, marked by intense summer drought from May to September, that is characterized by irregular and often torrential rainfall, with an average annual precipitation of 327 mm extending from September to May, as measured at Sousse rain gauge, located about 20 km to the north east of the study area. The average annual temperature is 18.5 °C. The warmest month is August (mean maximum daily temperature is 33 °C) and the coldest month is January (mean minimum daily temperature is 8 °C). The potential evapotranspiration, measured at Nfidha meteorological station which is located 50 km to the north of the study area, is 1,621 mm/year indicating an annual water deficit of nearly 1,300 mm. The olive tree production, probably being in cultivation longer than any species in the Tunisian Sahel, is the main source of income for farmers in the Sahel region. The olive groves are exclusively rain-fed, with tree inter-rows ranging from 8 m × 8 m to more than 12 m × 12 m.

2.2. Experimental design and sampling method

This experiment was carried out in an old olive grove, planted since more than two centuries ago, using a strip-plot design (experimental design in bands). The area of the *Meskat* is 20 ha where the *Mankaas* occupy 15 ha. The strips are considered as replications. Three strips have been selected: left strip, mid strip, and right strip. Four treatments, as subplots cutting across each stripe, are investigated as follows, in regard to the distance to *Meskat* system (Fig. 2):

- Upstream *Mankaa*: located in the upstream of the studied olive grove at only 10 m, it is the closest to the catchment of the system, the *Meskat*; therefore, these *Mankaas* might harvest the maximum of surface run-off as several overflows.
- Medium *Mankaa*: located at 47 m from the *Meskat*, the surface run-off from the system reaches this *Mankaa* one or two times each year.
- Downstream *Mankaa*: located at 85 m from the *Meskat*, the surface run-off reaches this *Mankaa*, not more than once a year.
- Control plot: located at 125 m from the *Meskat*, this plot could receive run-off only during the exceptional precipitation events.

Two reconstituted pedologic profiles, for soil parameters characterization, were considered for each *Mankaa*, which are two replications for each plot and six for the whole experiment, as well as for vigor indicators of the olive tree. Three horizons related to the degree of soil profile development and/or root penetration were considered in each soil profile based on visual analysis [23]. As farmers refuse digging soil profiles in the *Mankaa*, the sampling were performed using an auger, each 20 cm. Then, soil profiles have been restored in laboratory to establish horizon depth and to make a random composite sample from all layers of the same horizon. Two producing trees were selected, among those in the studied *Mankaas*, to assess vigor growth indicators.

2.3. Data collection

The present trial was carried out during the spring of 2010 for vigor parameters of olive tree and early 2010 for soil investigation. Soil horizons' depth was determined through the reconstitution of its profile. Saturated hydraulic conductivity of soil was determined in the field; measurements were made with a double ring infiltrometer [24]. Organic carbon was determined by the Walkley and Black method, based on the principle of soil carbon oxidation by potassium dichromate, and total organic matter was calculated by multiplying the organic carbon content by a factor of 1.72 [25]. The impact of the *Meskat* system on olive trees was assessed through fruiting shoots length and tree vigor. Five shoots per tree, one on each of the four orientations and one in the middle of the tree, had been randomly selected to estimate fruiting shoot length [26]. Canopy volume, which was used in this work as an indicator of tree vigor, was measured on randomly selected trees. It was calculated from canopy height and spread, considering canopy as an oblate spheroid and applying the following formula [27]:

$$CV = \frac{\pi}{8} \times (D_{\text{canopy}})^3 \tag{1}$$

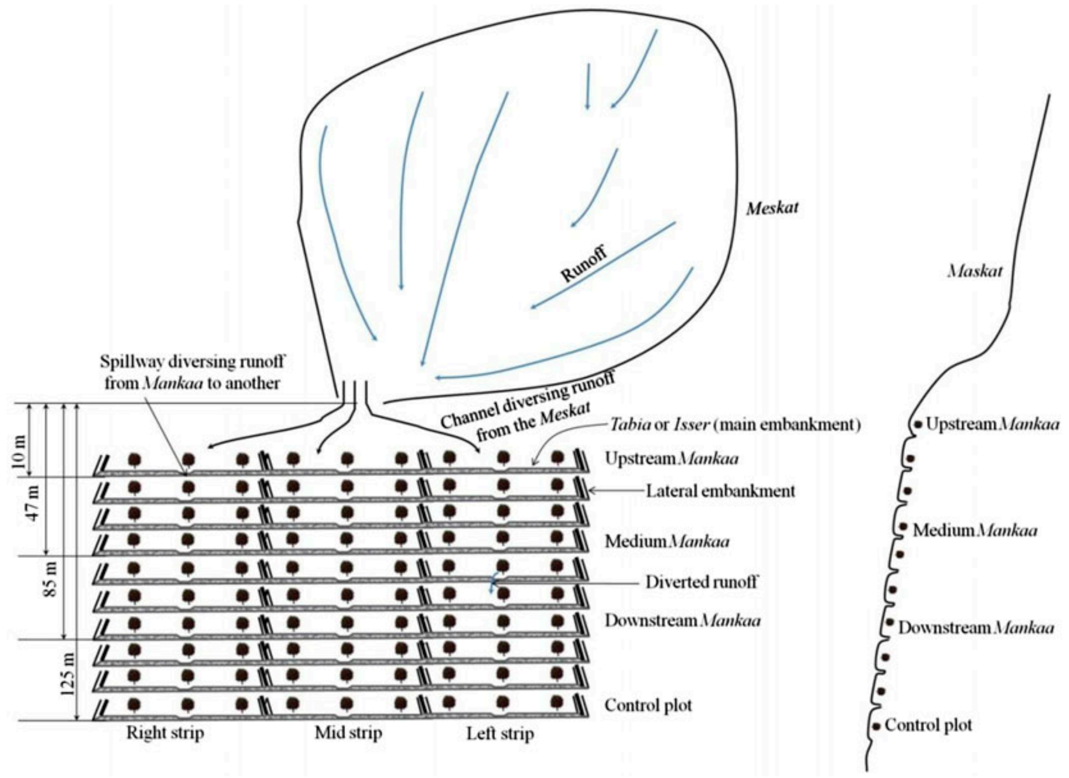

Fig. 2. Schematic representation of the *Meskat* system and location of the experiment sampling plot.

where CV: olive tree canopy volume; and D_{canopy}: average diameter of the canopy, measured *in situ*.

2.4. Data analysis

ANOVAs were used to determine whether soil horizon thickness, saturated hydraulic conductivity of soil, organic matter content of soil, canopy volume of olive trees, and their length of fruiting shoots differ significantly among *Mankaas*. Also, *F*-test was performed for organic matter in regard to soil depth. Furthermore, the ANOVAs were performed for the strips, considering the same parameters. Standard deviation and coefficient of variation were estimated. An analysis of correlation, through Pearson correlation coefficient, was applied in order to try to understand the relationship between the studied parameters.

3. Results and discussion

3.1. Effects of Meskat *system on soil horizon thickness*

Horizon A, the upper layers of the soil, contains most of the roots and horizon B is transitional while horizon C is the layer where very few olive tree roots were present [28]. The statistical analysis showed significant differences among horizon thickness of the soil according to *Mankaa* location (Table 1). For the horizon A, significant differences are observed among stripes whereas not for horizons B and C. When the coefficient of variation in the experiment does not exceed 15%, data homogeneity is assumed. The thickness of the horizons A and B is 90 and 84 cm, respectively, for the soil located in the upstream *Mankaa* and medium *Mankaa* and 50 cm for each A and B horizons of soils located in the downstream *Mankaa* (Table 2). The thickness of the horizon C ranges from 70 to 130 cm for soil located in upstream *Mankaa* and in control plot, respectively. These observations indicate that *Meskat* system improves root zone thickness which might be explained by the sedimentation of the eroded material from the upstream side and is inversely related to the *Mankaa*–*Meskat* distance, as reported for others soil and water conservation practices [10,14,29]. Increasing thickness of horizons A and B might have a beneficial effect on water retention capacity, nutrient content, and root growth, especially relevant for the semi-arid Mediterranean region.

Table 1
Analysis of variance of soil horizon depth, saturated hydraulic conductivity, organic matter, canopy volume, and fruiting shoots length according to the *Meskat* distance

Variable	Horizon thickness			Saturated hydraulic conductivity	Organic matter	Canopy volume	Fruiting shoots length
	A	B	C				
Mankaa	28.06***	7.0*	29.1***	5.4*	10.0***	81.2***	0.57 ns
Strip	6.5*	3.2 ns	0.8 ns	1.3 ns	2.074 ns	15.6***	0.17 ns
Soil thickness	–	–	–	–	15.5***	–	–
Mankaa × soil thickness	–	–	–	–	0.382 ns	–	–
R^2	0.896	0.659	0.749	0.515	0.585	0.961	0.014
CV (%)	7.4	14.4	8.0	30.1	50.1	6.5	27.1

Notes: ns: *F* test not significantly different at $p<5\%$. $^{*}F$ test significant at $p<5\%$. $^{***}F$ test significant at $p<0.1\%$. R^2: coefficient of determination. CV: coefficient of variation.

Table 2
Variation of horizon thickness and saturated hydraulic conductivity according to the *Meskat—Mankaa* distance

Mankaa location	Horizon thickness (cm)			Saturated hydraulic conductivity ($\times 10^{-6}$ m/s)
	A	B	C	
Upstream	91.7 (7.2)	84.2 (16.6)	70.0 (13.2)	10.00 (1.00)
Medium	84.2 (7.2)	66.6 (8.0)	95.0 (5.0)	*14.20 (7.38)
Downstream	71.7 (13.8)	64.2 (5.8)	100.0 (2.5)	19.50 (2.88)
Control	52.5 (2.5)	49.2 (13.8)	130.2 (4.7)	25.20 (0.27)

Note: Each value is the average of six observations. Between parentheses are standard deviations.
*The saturated hydraulic conductivity of the medium *Mankaa* of the right strip was not included, which is 30.0×10^{-6} m/s.

3.2. *Effects of* Meskat *system on saturated hydraulic conductivity*

The saturated hydraulic conductivity of the soil was significantly different between *Mankaas* while there is no significant difference among stripes (Table 1). With 30% as coefficient of variation, the data seem to be heterogeneous. It is one of the often used soil properties for evaluating land cropping suitability and one of the main parameters for its erodibility. Field saturated hydraulic conductivity ranged from 10.0×10^{-6} to 29.9×10^{-6} m/s (Table 2), mainly due to sandy soil texture. Except for the soil in the medium *Mankaa* of the right strip, it can be said that the saturated hydraulic conductivity increases when the *Meskat–Mankaa* distance increases, indicating that *Meskat* system contributes to its decrease. This could be explained by the sediment deposition behind the *Mankaa* close to the *Meskat*, as run-off brings substantial amount of fine eroded material. It is known that erosion control practices collect eroded materiel from the upstream and they are considered as sediment plugs [12,16,19,29]. The eroded material might be loam or clay and thus could explain the lower saturated hydraulic conductivity in the upstream *Mankaas*, close to the *Meskat*.

3.3. *Effects of* Meskat *system on soil organic matter*

Organic matter content is significantly different among *Mankaa* locations and horizon thicknesses (Table 1). The highest organic matter content was less than 1%, as it is known for Mediterranean poor soils (Table 3). The maximum organic matter content in the soil (0.83%) was observed in the top horizon of the upstream *Mankaa*, close to *Meskat*, and the minimum organic matter content (less than 0.4%) was measured in the horizon closest to the parent material located in the control *Mankaa*, far from the *Meskat*. The highest organic matter contents were observed in the top horizons whereas the lowest were found in the deepest horizons. Despite its low level, the decrease in

Table 3
Variation of organic matter content in the soil according to the *Meskat—Mankaa* distance and soil horizon (%)

Mankaa location	Horizon A	Horizon B	Horizon C
Upstream	1.04 (0.27)	0.88 (0.30)	0.56 (0.29)
Medium	0.83 (0.44)	0.53 (0.13)	0.30 (0.19)
Downstream	0.69 (0.37)	0.40 (0.26)	0.29 (0.20)
Control	0.53 (0.27)	0.42 (0.24)	0.30 (0.28)

Note: Each value is the average of six observations. Between parentheses are standard deviations.

topsoil organic matter content can be considered one of the main effects of the *Meskat* system on soil fertility preservation. It was reported that several erosion control practices enhance organic matter such as no-till cropping [30,31], contour ridge benches [14], and stone bunds [29]. Organic matter at relatively high content is advantageous to soil ability to retain water and improve its cation exchange capacity.

3.4. Effects of Meskat *system on olive tree canopy volume*

One of the main characteristics of olive tree vigor is canopy volume. Data showed significant differences between olive trees grown on different *Mankaas* (Table 1). The coefficient of variation is 6.5% indicating the homogeneity among this olive grove. The average canopy volume of the trees in the upstream *Mankaas* was 216.3 m^3, followed by 179.3 m^3 in the medium *Mankaas*, while the downstream ones and the control plots had the lowest values with 115.9 and 106.7 m^3, respectively. These results indicate that *Meskat* system has a beneficial effect on olive tree vigor (Fig. 3). These differences might be due to the fact that surface run-off is more substantial for the *Mankaas* close to the *Meskat*; water availability is considered the most limiting factor for plant growth in Mediterranean environment [32]. The canopy volume in the right strip seems to be lower than in the other strips, which can be explained by pruning fructification and maintenance practiced by the landowner as well as soil tillage. These findings confirm that olive tree vigor, investigated through canopy volume, is related to thickness of the root zone, considered here as horizons A and B. Our results are similar to those of olive tree in Spain as reported by Galvez et al. [28]. These authors showed a significant correlation between tree vigor parameters and soil properties such as organic matter, cation exchange capacity, clay content, and saturated hydraulic conductivity. Water availability seems to be related to the amount of the surface run-off that might be collected from the *Meskat*. Melgar et al. [33] pointed out the effects of different irrigation regimes and rain-fed system on vegetative growth of olive tree. The positive significant correlation between canopy volume of olive tree and horizon A thickness ($r = 0.71$) and that of horizon B ($r = 0.80$) in one hand and the negative significant correlation between canopy volume and horizon C thickness ($r = -0.75$) in the other hand (Table 4) indicate that olive tree vigor might be influenced by the thickness of the root zone. It should be also emphasized the positive significant correlation between the canopy volume of olive tree and the organic matter content of the soil horizons ($r = 0.59$ and $r = 0.63$ for horizons A and B, respectively). It is known that these soil parameters are related to olive tree vigor, as reported in Southern Spain [28]. The survival, growth, and yield of olive trees depend on soil characteristics, climatic conditions, and farming practices. Our results revealed the positive impact of the *Meskat* system on olive tree vegetative development under rain-fed conditions, prevailing in the Tunisian Sahel.

3.5. Effects of Meskat *system on fruiting shoots' length of olive tree*

The fruiting shoots' length is always an indicator of olive production during the coming season since olive trees are biennial bearing species especially when rain-fed. Data showed no significant differences between

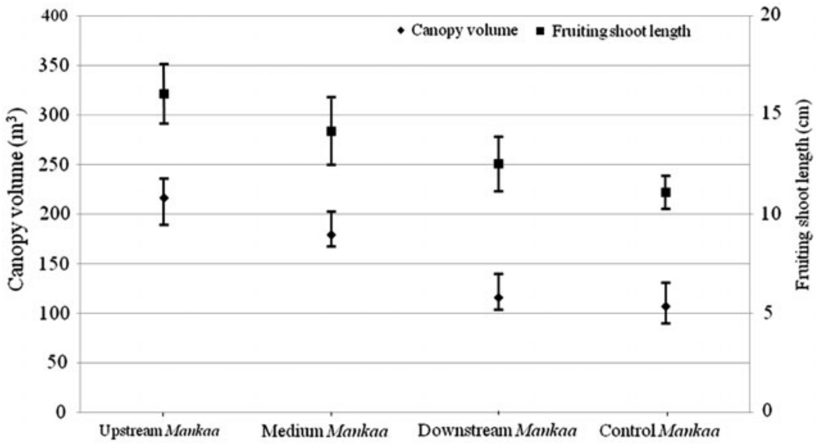

Fig. 3. Variation of canopy volume and fruiting shoots length according to *Mankaa—Meskat* distance (vertical bars indicate the observed minimum–maximum value; each value is the average of six observations).

Table 4
Pearson correlation coefficients between olive tree agronomic parameters and selected soil properties

Variable		Thickness			Saturated hydraulic conductivity	Organic matter content			Canopy volume	Fruiting shoots length
		Horizon A	Horizon B	Horizon C		Horizon A	Horizon B	Horizon C		
Thickness	Horizon A	1.000								
	Horizon B	*0.513	1.000							
	Horizon C	***−0.783	***−0.825	1.000						
Saturated hydraulic conductivity		**−0.701	−0.477	**0.665	1.000					
Organic matter content	Horizon A	**0.634	*0.586	**−0.698	−0.333	1.000				
	Horizon B	**0.662	0.499	**−0.618	−0.494	***0.895	1.000			
	Horizon C	0.494	0.247	−0.449	*−0.582	**0.687	***0.880	1.000		
Canopy volume		**0.713	**0.804	**−0.752	*−0.529	*0.596	**0.627	0.359	1.000	
Fruiting shoots length		0.208	0.231	−0.467	0.067	0.415	0.229	0.116	0.216	1.000

*Correlation significant at $p < 5\%$. **Correlation significant at $p < 1\%$. ***Correlation significant at $p < 0.1\%$.

olive trees grown on different *Mankaas* (Table 1). It is 16.1 cm in the upstream *Mankaa* and 11.1 cm in the control *Mankaa*, indicating a non-significant decrease with the *Mankaa–Meskat* distance (Fig. 3). It should be noted that the development of new shoots is essential for the reproductive process, as they support the new buds and consequently are determinant of the yield in the following years [34,35]. Considering our results, we can say that *Meskat* system does not affect the fruiting shoots' length. This could be attributed to the seasonal growth character of the rain-fed farming system in arid and semi-arid Mediterranean environments.

4. Conclusion

By analyzing relevant soil properties and tree vigor, beneficial effects of the *Meskat* system have been investigated in Tunisian Sahel. This water-harvesting practice has increased thickness of horizons A and B of soil in *Mankaas* close to the *Meskat*. Also, the organic matter content was found to be higher close to the *Meskat* than further away. However, this system decreases the saturated hydraulic conductivity which might be explained by the accumulation of the fine eroded material from the *Meskat* in the upstream *Mankaas*. The clear beneficial effect is certainly the increase of canopy volume of the olive tree farmed in the structures close to the *Meskat*, as consequence of the improvement of the soil characteristics and the substantial surface run-off. The canopy volume of the olive tree and the investigated soil parameters have been found to be correlated. The ambiguous effect on fruiting shoots' length was mitigated by alternate bearing of the olive tree as well as the landowner farming practices.

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