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Optimal distance between olive trees and annual crops in rainfed intercropping system in northern Morocco

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ABSTRACT

In order to optimize the distance between annual crops and olive tree (*Olea europaea)* in rainfed intercropping system in northern Morocco, vegetative growth and yield in associations based on olive-wheat (*Triticum aestivum)*, olive-faba bean *(Vicia faba)* and olive-coriander (*Coriandrum sativum*) were evaluated at two sowing distances of crops: close to the olive trunk and from the limit of olive tree canopy. The results showed that vegetative growth and yield of olive tree were reduced by sowing wheat even from the canopy limit. In contrast, faba bean induced an improvement of olive production at the two tested sowing distances. However, coriander had no effect on olive tree whether sown below or outside the tree canopy. The annual crops were unproductive below the olive canopy and their production remained negatively affected outside the canopy until the limit of shading effect for faba bean and coriander and beyond this limit for wheat. We concluded that the sowing distance of crops associated with olive tree should be adjusted to minimize interspecific competition that concerns mainly light for crops cultivated during the olive dormancy period, such as faba bean and coriander. However, it concerns in addition the soil moisture and the nutrients for crops grown during the olive growing period, such as wheat.

KEYWORDS

Intercropping system;
Olive tree;
Annual crops;
Sowing distance;
Northern Morocco.

INTRODUCTION

Several studies carried out in North America and Europe demonstrated the benefits of intercropping systems (ICS), both in terms of productivity as for their environmental benefits[1, 2]. In this system, tree growth is improved as a result of the stimulation of soil microbial biomass and mineralization of organic nitrogen by intercropping and through the recovery of a significant proportion of fertilizer residues vested for the associated crops[3, 4]. In some situations, depressive effects on tree growth were observed that reside mainly in competition for water during the active periods of tree growth[5]. Regarding the associated crops, usually they are subjected to the competition exerted by trees for light, water and soil minerals, especially in the areas surrounding trees canopy[6]. However, these negative interactions are avoided when the associated crops and planting distances are well chosen[7].

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Trees shading does not every time cause a reduction in yield of the associated crops. Indeed, Lin *et al*.[8] observed that fescue plant produces more biomass with higher protein content under luminance intensity of 50%. Also, Clinch *et al*.[9] observed an improvement in vegetative growth and yield of willow plant under moderate shading of various tree species. However, for the majority of associated plants, the effect of shading depends on the spacing between trees and associated crops. Studies carried out in France has shown that the best compromise between the trees and the associated crops is often obtained with a spacing of 25 to 35 m for trees with a height of 15 to 20 m[2].

In Morocco, the ICS based on olive tree and annual crops dates back to antiquity, both in rainfed and irrigated areas[10]. Diagnostic studies carried in Moroccan revealed that about 75% of olive orchards are associated with annual crops, especially wheat and barley, food legumes such as faba bean, chickpea, pea and lentil, aromatic and medicinal plants such as coriander and fenugreek, and vegetable crops in irrigated orchards, especially potatoes and onion[11]. In this system, annual crops and olive trees share the same plot for 15 to 20 years until the trees shading inhibits growth of the annual crops. In some cases, where the distances between the rows of olive tree are high, trees shading is not a limiting factor; the intercropping then generally maintained throughout the life of the olive orchard.

Although this system is ancient in Morocco, there are no extensive studies under local conditions that could evaluate current practices and identify the best management options for annual crops, as well as their potential benefits or disadvantages on tree stratum and vice versa, although the adoption by farmers of this system is a proof of its performance. This work is a contribution for development of this system that aimed to identify optimal distances between the adult olive trees and the associated annual crops under rainfed conditions in northern Morocco.

MATERIALS AND METHODS

Studied associations and experimental design

The trials were carried out in four rainfed olive orchards planted on slight slope (about 20%) located in northern Morocco. The orchards are planted at a density of 100 trees/ha (10x10 m) where the trees are old than 30 years with an average of height of 7 m and a diameter of 4 m. In each orchard were cultivated in inter-rows space the bread wheat (*Triticum aestivum*), faba bean (*Vicia faba*) and coriander (*Coriandrum sativum*) which represent the most annual crops cultivated in intercropping system with olive tree in the study area. The experimental design was established not only to optimize the spatial soil occupation for the association olive trees - annual crops but also to demonstrate the advantages of impluviums around the olive trees in intercropping system. Thus a completely randomized design with three replications was established in each experimental orchard with two variable factors: the distance between olive trees and annual crops and the presence or absence of the impluviums. The treatments compared were:

T1: Cultivation of the annual crops until below the olive trees canopy close to trunk, which constitutes the mainly intercropping system practiced by farmers.

T2: Cultivation of the annual crops from the limit of olive tree canopy.

T3: Cultivation of annual crops in the same way as for the treatment T2 with placement of the impluviums around the olive trees at their canopy limit.

Faba bean and coriander were sown and harvested during the dormancy period of olive tree (Figure 1). Wheat was sown also during the dormancy period of olive tree at the end of November, but it was harvested in mid-June after the growth departure of shoot and fruit of olive tree. The tested intercropping systems were conducted following the usual practices by farmers which concern exclusively the annual crops, while no cultural practice is applied for olive tree.

The tested intercropping systems were conducted following the usual practices of farmers which concern exclusively the annual crops, while no cultural practice is applied for olive tree. The monthly rainfall recorded in the experimental site is presented in Figure 2 where it is shown that rainfall deficit is more marked between April and August.

Measurements

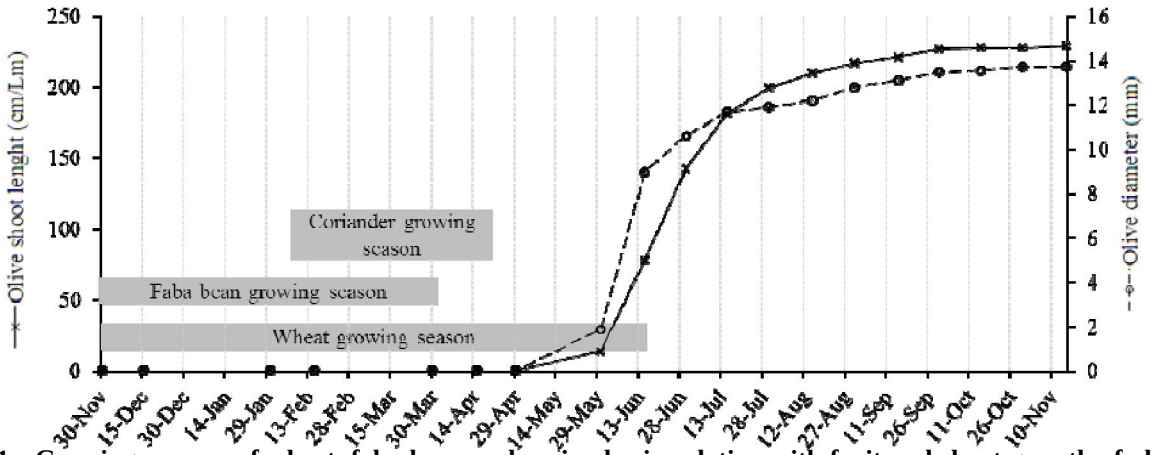

Figure 1 : Growing seasons of wheat, faba bean and coriander in relation with fruit and shoot growth of olive tree in intercropping system

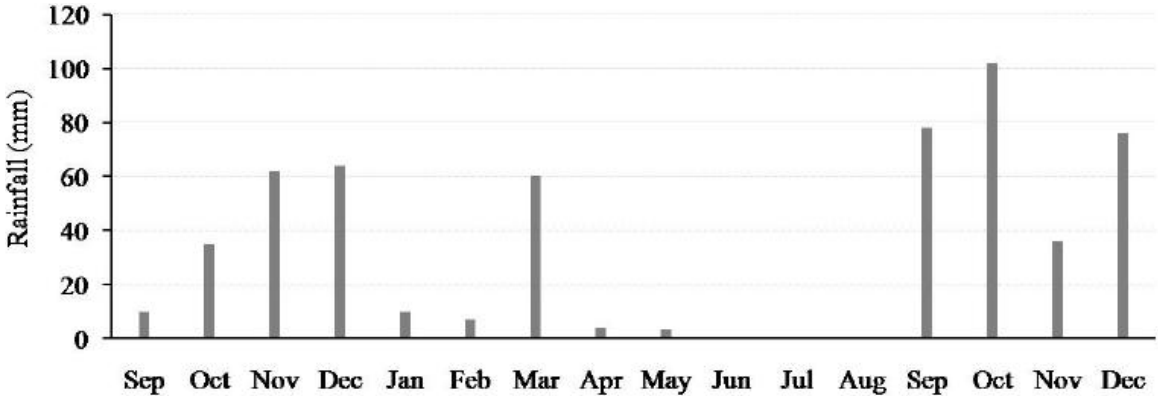

Figure 2 : Monthly rainfall recorded during the year of the experimentation in the study region

On olive tree, the measurements concerned the annual shoot elongation, leaf area, yield level and the physiological indicators of water and nutritional status of the trees: stomatal conductance, relative water content, leaf temperature and chlorophyll content. These indicators were measured during the fast growing of shoots at mid-June. The stomatal conductance was measured at midday on ten leaves per replication chosen from shoots extremity (4th and 5th leaf) using a leaf porometer. On the selected leaves for measuring stomatal conductance, was measured the leaf temperature by an infrared thermometer and the chlorophyll index using a SPAD chlorophyllmeter. At the same time, twenty developed leaves per replication were taken from shoots extremity to measure the relative water content (RWC). This parameter was determined following the formula of Turner[12]:

$$RWC = \frac{FW - DW}{SW - DW} \times 100$$

Where FW, DW and SW respectively designate fresh, dry and saturation weights of leaf sample. Leaves were saturated by placing their petioles in contact with water in boxes papered inside with wet filter paper for 24 hours in a refrigerator set at 5 °C and they were dried in an oven at 105 °C for 48 hours.

On the annual crops, bread wheat, coriander and faba bean, the measurements concerned plant height, biomass and yield below the canopy of olive tree and at different distances from the canopy limit: 0 m, 1.5 m and 3 m. The measurements were also performed on other olive orchards in the study region, other than the experimental orchards, to establish a relationship between the optimal distance for sowing annual crops and olive tree vigor.

Statistical analysis

Data were analyzed by variance analysis (ANOVA) using the SPSS software (version 17.0). Means were compared using student's test to evaluate the behavior of olive tree and annual crops under the tested treatments.

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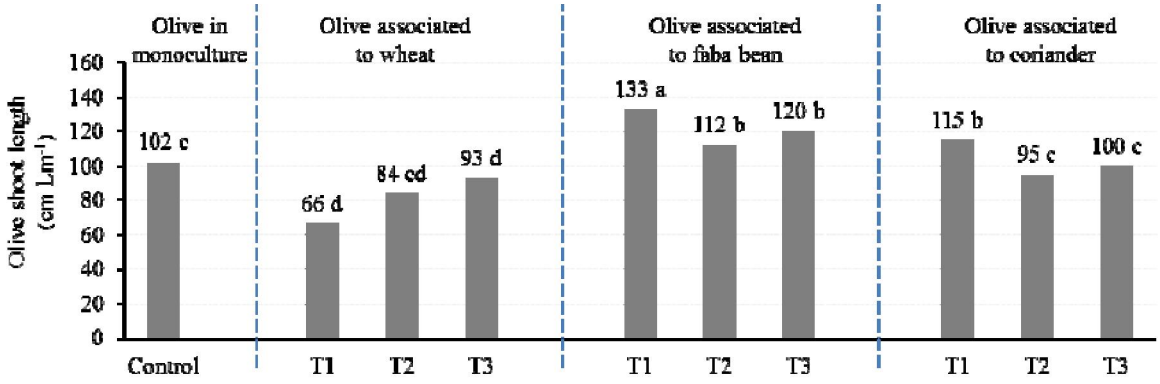
RESULTS AND DISCUSSION

Olive tree growth

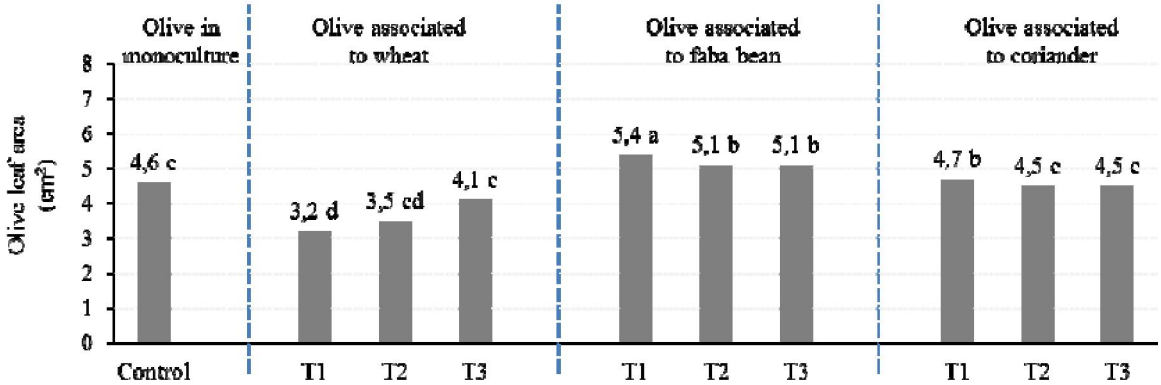
Vegetative growth of olive tree varied significantly according to the tested intercropping systems. In Association with bread wheat, olive tree developed a lesser number of shoots under the all tested treatments compared to trees cultivated in monoculture. Shoot length and leaf area of olive tree are also affected negatively when it was associated to wheat. When it was cultivated below tree canopy (treatment T1), wheat exert a severe competition which reduced shoot length and leaf area of olive tree respectively by 40% and 28% comparatively to olive tree growing in monoculture (Figures 3 and 4). The depressive effects induced by wheat on vegetative growth of olive tree are mainly due to the competition for soil moisture and nutrients during the critical period of olive shoots growth. In the study region, this period occurs during June[13] that overlaps with the final filling of wheat grains and their maturation[14]. Although the water and nutrient absorption of wheat is low during this period[15], this crop induced an accentuation of water and nutrient stress on olive tree which was considerable because it overlapped with a rapid shoots growth. In addition, the rainfall was low during the overlapping period between olive trees and wheat, thereby making the olive tree sensitive to a slight competition for water and nutrients. In fact, several studies indicated that water stress occurring during the rapid shoots growth of olive tree induce a significant reduction on shoots growth kinetic, thereby affecting their final length[16, 17].

This competition remained significant even when wheat was cultivated since the limit of the tree canopy (treatment T2), that reduced olive shoots length and leaf area by an average of 20%. This result indicates that the root system of olive tree cover



The values marked by the same letters are statistically equal, T1: annual crops sown below tree canopy; T2: annual crops sown from the limit of tree canopy; T3: annual crops sown from the limit of tree canopy with impluviums placed around trees

Figure 3 : Shoot elongation of olive tree grown in intercropping systems with different annual crops under rainfed conditions



The values marked by the same letters are statistically equal, T1: annual crops sown below tree canopy; T2: annual crops sown from the limit of tree canopy; T3: annual crops sown from the limit of tree canopy with impluviums placed around trees

Figure 4 : Leaf area of olive tree grown in intercropping systems with different annual crops under rainfed conditions

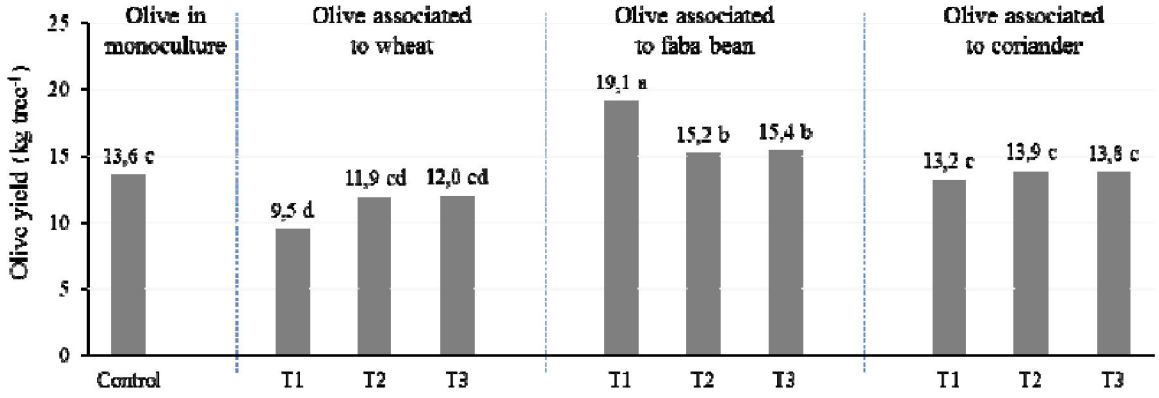
an area exceeding the limit of the tree canopy thereby making them partially submitted to the competition exerted by wheat for water and nutrient reserves. In fact, previous studies indicate that the root system of olive tree grows horizontally to beyond the canopy limit, especially under rainfed conditions where may cover an area of 20 m^2 for a young plants to 500 m^2 for an adult trees[18]. However, the placement of the impluviums around the olive tree at this limit (treatment T3) attenuated the competitive effect exerted by wheat by an average of 50%. The favorable effect of the impluviums is not related to an attenuation of the interaction between wheat and olive tree, but rather to an improvement in water and nutrient reserves of soil[19]. The depressive effect of wheat on the vegetative growth of the olive tree may be also linked to the liberation of ethylene from wheat grains, which is known for its inhibitory effect on stem elongation in most plant species[20].

Besides that, the association with coriander had neither depressive nor positive effects on vegetative growth of olive tree under the all treatments. This is could be explained by the fact that this crop has not overlapped with olive vegetative growth. The growth cycle of this crop was completed during the olive dormancy and it was harvested at the end of March, two months prior the vegetative departure of the olive tree. Also, faba bean completed its growth cycle during the olive dormancy and it was harvested at the end of April, one month prior the olive vegetative departure. But in contrast to the association with coriander, the association with faba bean improved vegetative growth of olive, particularly when it was cultivated below the tree canopy. At this sowing distance, faba bean induced an improvement of shoot length and leaf area of olive tree respectively by 30% and 22%. The positive effect of faba bean on vegetative growth of olive tree remained considerable even when it was cultivated since the limit of the tree canopy, improving olive shoot length by 14% without placement of the impluviums and by 20% when there are placed. The favorable effect of faba bean could be explained by the enrichment of soil by nitrogen biologically fixed by this legume. According to previous studies carried out in the study region, this crop may fix an important amount of nitrogen up to 300 kg/ha[21], that is largely sufficient to satisfy olive nitrogen requirements, particularly during the vegetative departure[22].

Olive yield

Wheat induced a significant reduction in olive yield, especially when it was cultivated below the tree canopy. At this sowing distance, wheat induced a reduction of olive yield by an average of 30% compared to olive tree in monoculture (Figure 5). Sowing wheat since the limit of the tree canopy has not been able to stabilize olive yield, even with placement of the impluviums around olive tree. However, at this sowing distance, the depressive effect exerted by wheat on olive yield was considerably mitigated by an average of 60% compared to treatment T1.

The depressive effect exerted by wheat on olive yield is related to the concurrence vis-a-vis water and nutrients during bud burst, flowering and early growth of olives, from April to early June, that overlap with the filling phase of wheat grains and their



The values marked by the same letters are statistically equal, T1: annual crops sown below tree canopy; T2: annual crops sown from the limit of tree canopy; T3: annual crops sown from the limit of tree canopy with impluviums placed around trees

Figure 5 : Olive yield in intercropping systems with different annual crops under rainfed conditions

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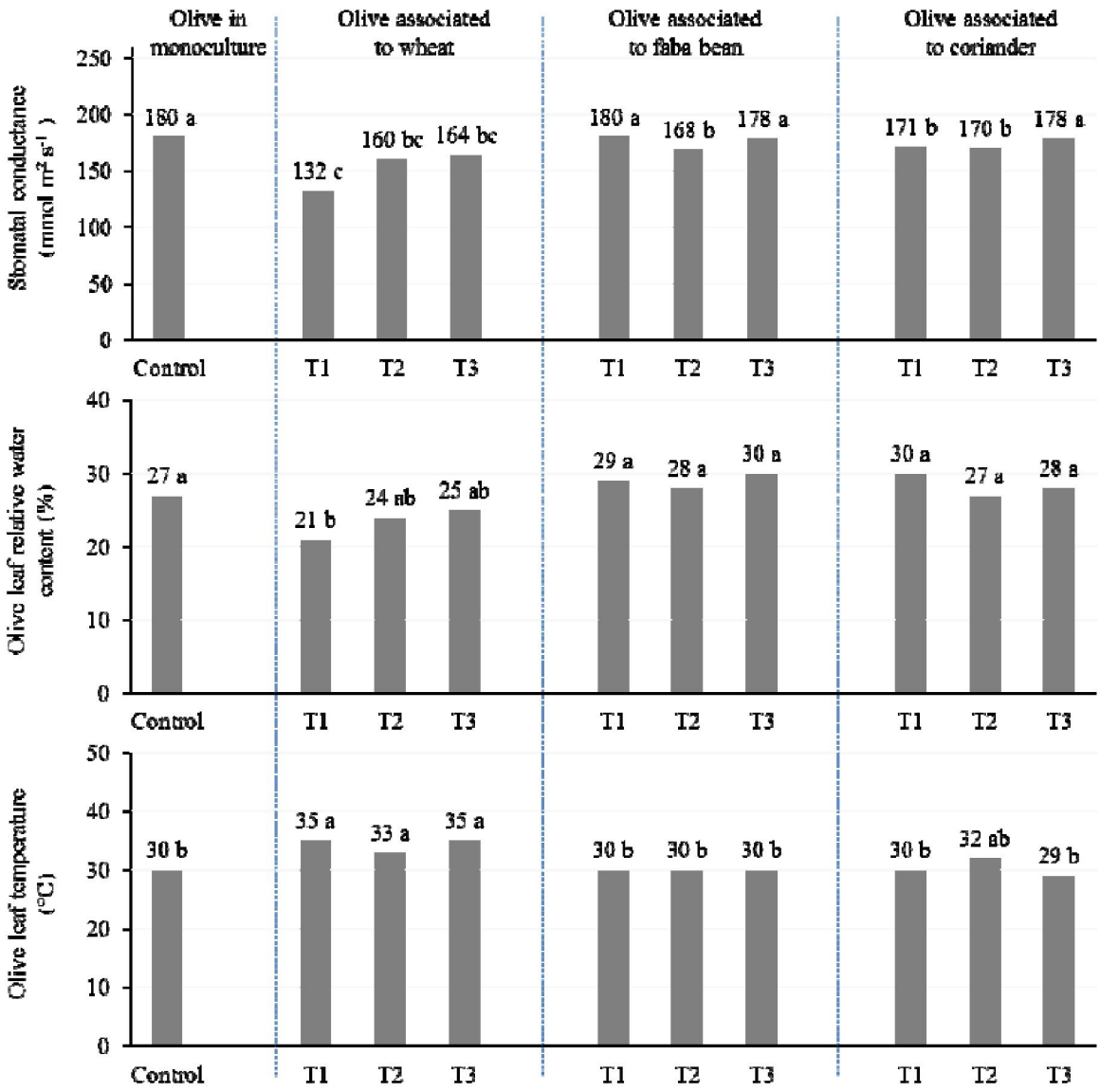

The values marked by the same letters are statistically equal, T1: annual crops sown below tree canopy; T2: annual crops sown from the limit of tree canopy; T3: annual crops sown from the limit of tree canopy with impluviums placed around trees

Figure 6 : Stomatal conductance, leaf relative water content and leaf temperature of olive tree in intercropping systems with different annual crops under rainfed conditions

maturation[13, 14]. Also, this depressive effect of wheat would be related to the liberation of ethylene from wheat grains during their maturation that is known to be an inhibitor of flowering for the most plants[23]. Indeed, the ethylene activates the enzymes responsible of the dissolution of cell walls in the abscission zones of flowers, thereby causing their fall[24].

As for the association with coriander, it had no effect on olive yield whether grown below or outside the tree canopy, with or without placement of the impluviums. This result is evident because coriander completed its growth cycle during the dormancy period of olive tree and it was harvested before the olive bud burst, thereby limiting the competition for water between the two crops. However, faba bean induced a significant improvement of olive yield, especially under the treatment T1 where it was cultivated until below the tree canopy. This treatment increased olive yield by an average of 40% compared to olive in monoculture. This effect of faba bean remained favorable when it was cultivated since the limit of the tree canopy, but with a mitigated manner. At this sowing distance, faba bean induced an increase of 12% for olive yield compared to olive in monoculture. This same increase of olive yield was observed under the treatment T3 where

The values marked by the same letters are statistically equal, T1: annual crops sown below tree canopy; T2: annual crops sown from the limit of tree canopy; T3: annual crops sown from the limit of tree canopy with impluviums placed around trees

Figure 7 : Chlorophyll index of olive tree in intercropping systems with different annual crops under rainfed conditions

TABLE 1 : Distances at which disappears the shading effect on annual crops biomass following the exposition of olive orchard

Olive orchard exposition	Distances at which disappears the shading effect on annual crops biomass
north / south	2.1 m from the olive canopy limit in east side From the limit of olive canopy in west side
east / west	2.1 m from the olive canopy limit in north side From the limit of olive canopy in south side
north-east / south-west	From the limit of olive canopy on both sides of the tree rows
north-west / south-east	3 m from the olive canopy limit on both sides of the tree rows

the impluviums were placed around the olive tree, showing that their effect was insignificant. The favorable effect of faba bean is due to the fact that this crop was harvested before the olive bud burst, thereby limiting the competition for water during the fructification period of olive tree. In addition, this legume enriches the soil by nitrogen through biological fixation which increases olive weight, thereby increasing olive yield[25].

Water status and chlorophyll index in olive tree

Olive water status was especially affected in the intercropping system based on the association with wheat. When this annual crop was sown below the tree canopy, it induced a decrease of stomatal conductance and leaf relative water content of olive tree respectively by 25% and 22% compared to olive tree conducted in monoculture (Figure 6). However, this depressive effect was attenuated by sowing wheat since the limit of the tree canopy, by an average of 45%. This result indicates that the olive tree grown under rainfed conditions extract water mainly from the soil area below the tree canopy. This is in agreement with works of Lhomme *et al*.[26] on water relations in the intercropping systems based on olive tree with the annual crops that demonstrated that olive roots grow mainly in the wet soil areas such as the area situated below the tree canopy where the evaporation of the rain-water is relatively limited by tree shading. The placement of the impluviums had no additional compensatory effect although they have proven their performance to collect the surface water demonstrated in several previous studies[27]. The non-signification of the impluviums effect is related to the severity of the rainfall deficit during the present experiment.

However, faba bean and coriander affected slightly the water status of olive tree under the all tested treatments. The effect of these two annual crops comes from the concurrence for water during the olive dormancy period since they were harvested before olive bud burst, especially during their active growth in February and March, thereby reducing the soil water reserves useful to maintain a satisfactory olive water status at vegetative departure in June[28].

As for leaf chlorophyll index that reflect the nutritional status of olive tree especially in nitrogen[29], it was significantly affected by the association with the annual crops only when they were sown below

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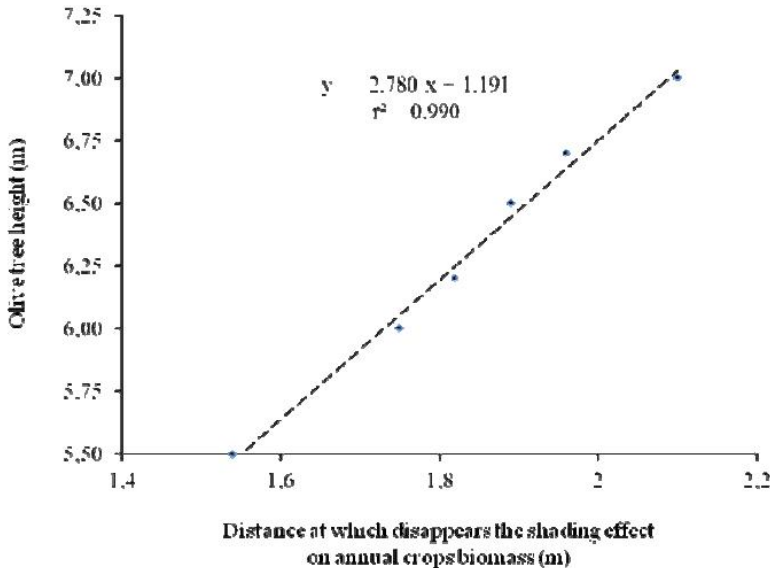

Figure 8 : Relationship between olive tree height and distance at which disappears the shading effect on annual crops biomass in the east side of the rows oriented north-south

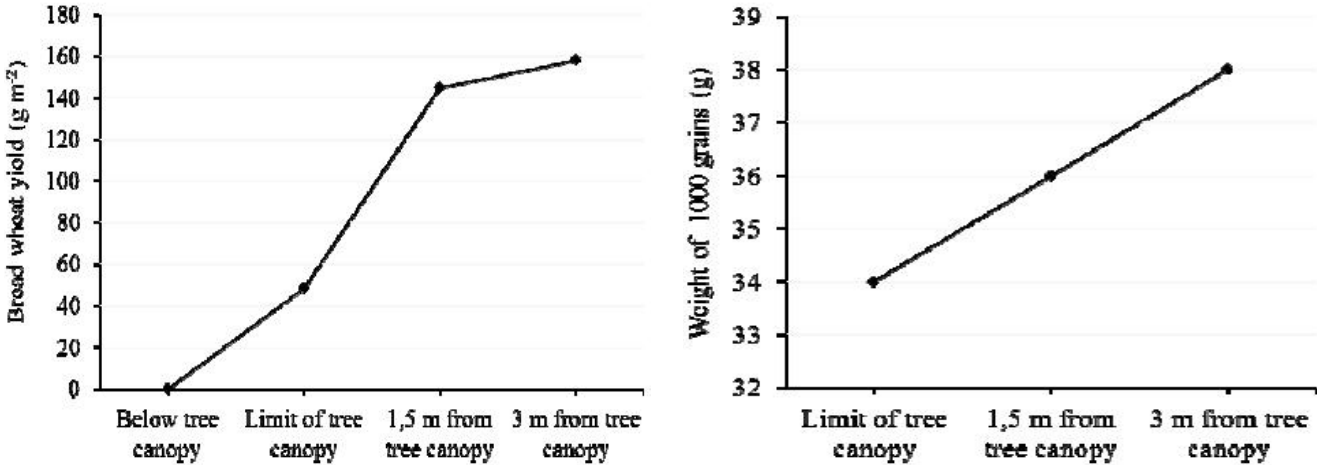

Figure 9 : Yield and grain weight of bread wheat at different distances from the olive tree in east side of rows on orchard oriented north-south

the tree canopy (Figure 7). The increase in chlorophyll index of olive tree was more pronounced in the intercropping system with faba bean by an average of 49% compared to olive grown in monoculture. However, wheat and coriander grown below the tree canopy induced an increase of this index respectively by 32% and 36%. Therefore, the olive tree extracts nitrogen mainly in the area under the canopy coming from a significant proportion of fertilizer residues vested for wheat and coriander and from the biological fixation for faba bean. This result is due to the fact that the horizontal transfers of nitrogen in intercropping systems based on olive tree and annual crop are limited under rainfed conditions[30].

Biomass and yield of the annual crops

The annual crops biomass was reduced around olive tree canopy in response to the shading effect. Particularly, the faba bean's response to tree shading was reflected by an etiolation of plants because of the indeterminate growth that characterizes this legume[31]. The reduction in annual crops biomass was marked over an aureole around the tree canopy having a maximum radius of 3 m in the northeast side of each olive tree. This result permitted to determine the optimal distance at which the annual crops should be sown to produce a satisfactory biomass in intercropping system with olive tree following the exposition of olive orchard (TABLE 1).

In fact, it is clear that the optimal distances in intercropping system are dependent on trees vigor defined mainly by their height. The measurements of

the annual crops biomass around olive trees with various heights in different orchards of the study region, other than the experimental orchards, permitted to establish a significant regression model to determine the optimal distance for sowing annual crops in the shady side of olive rows following tree height (Figure 8).

Yield of the annual crops was also greatly affected around olive trees. Below the tree canopy, the crops were practically unproductive. Crops start to produce since the limit of the tree canopy, but their yield level becomes normal and interesting since the distances indicated in TABLE 1. In olive orchard oriented north-south, wheat yield evolved following a polynomial curve from the east side to the west side of the trees rows (Figure 9). At the limit of olive tree canopy, shading induced a reduction of 70% in wheat yield and of 10% in grain weight. At 1.5 m from the olive canopy limit, wheat yield was considerable, but significantly lower than the yield level observed since 2.1 m from the olive tree canopy corresponding to the distance at which disappeared the effect of shading on crops biomass.

These depressive effects of olive tree on biomass and yield of the annual crops are in agreement with the results of several previous works such as of Daoui *et al.*,[11] about wheat and faba bean intercropped with olive tree in Morocco, Simpson *et al.*[32] and Reynolds *et al.*[33] about maize, soybean and corn intercropped with poplar and silver maple in Canada and Gao *et al.*[34] about soybean and peanut intercropped with apple tree in China. Since faba bean and coriander were sown and harvested during the dormancy period of olive tree, the reduction observed in their growth and yield in the area around the trees canopy is therefore related to the shading effect. However, the reduction of growth and yield of wheat is explained in addition by the competition exerted by olive tree for soil moisture and nutrients because its growth cycle overlapped with those of the olive tree.

CONCLUSION

As an effective method to improve land use efficiency and economic returns, the intercropping systems based on olive trees and annual crops are particularly important for the Moroccan smallholder farming. An efficient management of this system requires necessarily a judicious choice of the distance between trees and crops depending on intercropped species, exposition of the trees rows and trees vigor. The distances in intercropping systems are considered optimal when they ensure a satisfactory performance of the both associated crops. The experiments conducted in northern Morocco permitted to determine the optimal distances for sowing wheat, faba bean and coriander in intercropping system with olive tree under rainfed conditions. For sowing faba bean and coriander, the optimal distance correspond to the limit where the shading effect becomes insignificant which is correlated with the trees height following a linear regression model. Whereas the interactions regarding soil moisture and nutrient are negligible since these two annual crops are sown and harvested during the dormancy period of olive tree. In the shaded areas around the trees, faba bean and coriander do not affect growth and yield of olive tree, but their yields are low and produce small grains whose use may be limited to animal feed. For sowing wheat, the optimal distance depends not only on the trees shading, but also on the competition for soil moisture and nutrients because the growth cycle of wheat overlaps with growth departure of shoot and fruit of olive tree. The distance at which the interactions between wheat and olive tree becomes insignificant for light, water and nutrients depends mainly of the areas explored by olive roots which is often correlated to tree height. In association with olive trees having a height of 7 m, this distance is 2.1 m outside the tree canopy. Sowing wheat at a lower distance from the olive trees canopy induces considerable reduction in growth and yield for the both crops.

ACKNOWLEDGMENTS

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