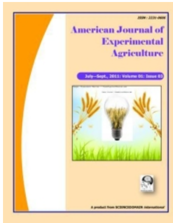

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Nitrogen Fertilization of Olive Orchards under Rainfed Mediterranean Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author K. Bouhafa designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors LM and KD supervised the study and managed the literature searches. Author KB managed the laboratory analyzes. Author AD performed the statistical analysis. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: This work has the objective of studying the effect of nitrogen fertilization on olive yield, oil content and quality.
Study Design: Randomized complete block design with four nitrogen fertilizer treatments and eight replications. Each individual plot consisted of four trees.
Place and Duration of Study: The experiment was conducted during 2011 in farmers' fields at three sites: Taza (S1), Taounate (S2) and Taoujdat (S3) in Morocco.
Methodology: Four nitrogen rates (0.00, 0.25, 0.50 and 1.00 kg N per tree) were applied to the varieties Moroccan Picholine (S1 and S2) and Arbequina (S3). Nitrogen was split into two contributions: half in March and half in May. Phosphorus (0.50 kg P_2O_5 per tree) and potassium (2.00 kg K_2O per tree) were applied in March.
Result and Discussion: At S2 (35 years old trees), nitrogen fertilizer improved yield, yield efficiency and olive oil content. At S1 (9 years old trees) and S3 (7 years old trees), nitrogen applications had no effect on the olive yield and negatively affected the olive oil

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quality in particular in S3.
Conclusion: The effect of nitrogen fertilization on olive yield was dependent of the olive orchard, some trees responded to applied N and others did not. It should be noted that these results are preliminary due to the short duration of the experiment.

Keywords: Olea europea; nitrogen fertilization; olive yield; oil content; oil quality; Morocco.

1. INTRODUCTION

Olive is one of the main crops in the Mediterranean basin with a cultivated area of about 8.2 M ha [1] Cited by [2]. In Morocco, olive orchard occupies an area of about 790 000 ha of which 60% grown under rainfed conditions [3]. It occupies a prominent place in the national arboreal sector. The diagnosis of the olive orchard management has focused the constraints of development of olive production to pruning and nitrogen nutrition [4]. A wrong pruning combined with low nitrogen application reduces the production of fruiting branches which affects fruiting trees. Fertilization of Moroccan olive orchards is, in most cases, random whether quantitative and qualitative point of views. The lack of standards for olive fertilization adapted to each agro-climatic region let Moroccan growers obliged to follow the traditional practices of fertilization.

Field trials are the most reliable for the determination of these standards means. However, few studies have been developed to determine the response of olive to nitrogen fertilization [5]. Fertilization, especially nitrogen, is a cultivation technique that greatly affects the olive tree productivity. Hartman [6] observed that trees grown on infertile soils in California responded to N inputs, showing a high level of nitrogen in leaves, fruit set and yield. Unlike grown on more fertile soils trees that showed no response to fruit set and yield to N inputs. In an experiment conducted with long-term rainfed olive orchards in several locations in Spain, Ferreira et al. [7] found that only trees with productivity lower than 35 kg tree^{-1} showed a positive response to the N application. Fernandez-Escobar et al. [5] found that nitrogen fertilization had no significant effect on yield, fruit characteristics and growth of trees in both typical orchards of the Mediterranean region for 13 years of testing period of while the leaf nitrogen concentration increased with the nitrogen fertilizer quantities. They also found that even when the N content of the leaves was below the threshold established deficiency of 1.4%, they did not notice any reduction in yield or growth. A survey across the Mediterranean basin, where about 98% of the 10 million ha of existing olive groves in the world are located [8] showed that nitrogen is present in most fertilizers, even when potassium is the element that can causes most severe nutritional disorders [9] Cited by [5]. Rodrigues et al. [10] reported a progressive and significant decrease in the olive yield when nitrogen was eliminated from the fertilization plan for four years, compared with treatments where nitrogen was brought annually. Jasrotia et al. [11] also found a significant increase in olive productivity with increasing nitrogen doses. In a study for five years in the olive orchards in southern Spain, Fernandez-Escobar et al. [12] found no significant differences in performance between the olive trees subjected to a fertilization regime program based on foliar diagnosis, and those receiving the current fertilization in the region [500 kg ha^{-1} of fertilizer NPK (15: 15: 15) and three foliar sprays of trace elements and amino acid].

Phosphorus deficiency limits the absorption of nitrogen, magnesium, calcium and boron and correspondingly reduced growth plant [13]. Oil content and quality are also influenced by the addition of fertilizers. Indeed, nitrogen promotes higher levels of oleic and stearic acid the drupe and its deficiency is associated of elevated levels of palmitic and linoleic acid [14]. Excess nitrogen can causes environmental degradation [15] and negatively affect olive oil [16]; Quoted by [5] and the flower quality [9]. Good nitrogen fertilization can, in fact, sustain soil fertility management, avoiding unnecessary waste of fertilizer and improves the level of crop yield.

The objectives of this work were to study the effect of nitrogen application on olive yield, on olive oil content and quality.

2. MATERIALS AND METHODS

The experiment was carried out during 2010/2011. Three trials were conducted in farmers fields at three sites: S1 (N: 34° 11.994 'W: 004° 17.613'), S2 (N: 34° 29.771 'W: 004° 40.482') and S3 (N: 33° 56,440 'W: 005° 14.035') belonging respectively to the following three areas: Taza, Taounate and Fez. The siting of experiments was done taking into the account the prominence of olive cultivation in these regions. Indeed, the region of Taza-Al Hoceima-Taounate and the region of Fez-Boulemane occupy, respectively, the second (318 500 ha) and third (120 000 ha) positions, in terms of area covered by olive trees in Morocco. Olive trees are planted at a distance of 10×10 m in S1, 9×9 m in S2 and 3×5 m in S3.

Soil physical and chemical characteristics are indicated in Table 1. Analysis were performed by the following methods: particle size by pipette method [17], the electrical conductivity of the saturated paste extract, organic matter by the Walkley and Black method [18], the total calcium by calcimeter Bernard [19], the active limestone by Drouineau method [20], nitrates by chromotropic acid [21], available phosphorus by Olsen method [22] and exchangeable potassium by ammonium acetate [23].

The soils where these studies were carried out present alkaline pH, low organic matter, non-saline for olives and moderately to strongly calcareous (Table 1).

Table 1. Physical and chemical characteristics of the experimentation soils sites

Site	**Oued Amlil (S1)**		**Taounate (S2)**		**Taoujdate (S3)**	
Depth (cm)	**0-30**	**30-60**	**0-30**	**30-60**	**0-30**	**30-60**
Texture	Loam	Loam	siltyclay	silty	silty	siltyclay
Organic matter (%)	1.5	2.2	2.3	1.8	2.3	1.4
Nitrates ($mg \cdot kg^{-1}$)	17.1	40.7	9.5	8.4	47.2	16.4
Available P ($mg \cdot kg^{-1}$)	5.7	5.2	6.7	1.5	33.6	29.1
Exchangeable K ($mg \cdot kg^{-1}$)	541.3	319.2	408.6	233.6	318.5	142.4
pH	7.9	7.6	7.6	7.8	7.5	7.9
Electrical Conductivity ($dS \cdot m^{-1}$)	0.7	2.9	0.2	0.2	1.7	1.4
Total limestone (%)	20.9	24.7	2.2	1.6	19.6	42.2
Active limestone (%)	10.3	9.9	-	-	9.8	16.7

During 2011 year, precipitations reached 580.1 mm in Site 1 with a maximum of 218.5 mm recorded during November (harvest period) (Fig. 1). In site 2 precipitations was about 499.6 mm with a maximum of 132.7 mm registered in November. At Site 3, precipitations this season reached 797.4 mm with a maximum of 194 mm in May. A lack of rain marked the period from June to September in the three sites.

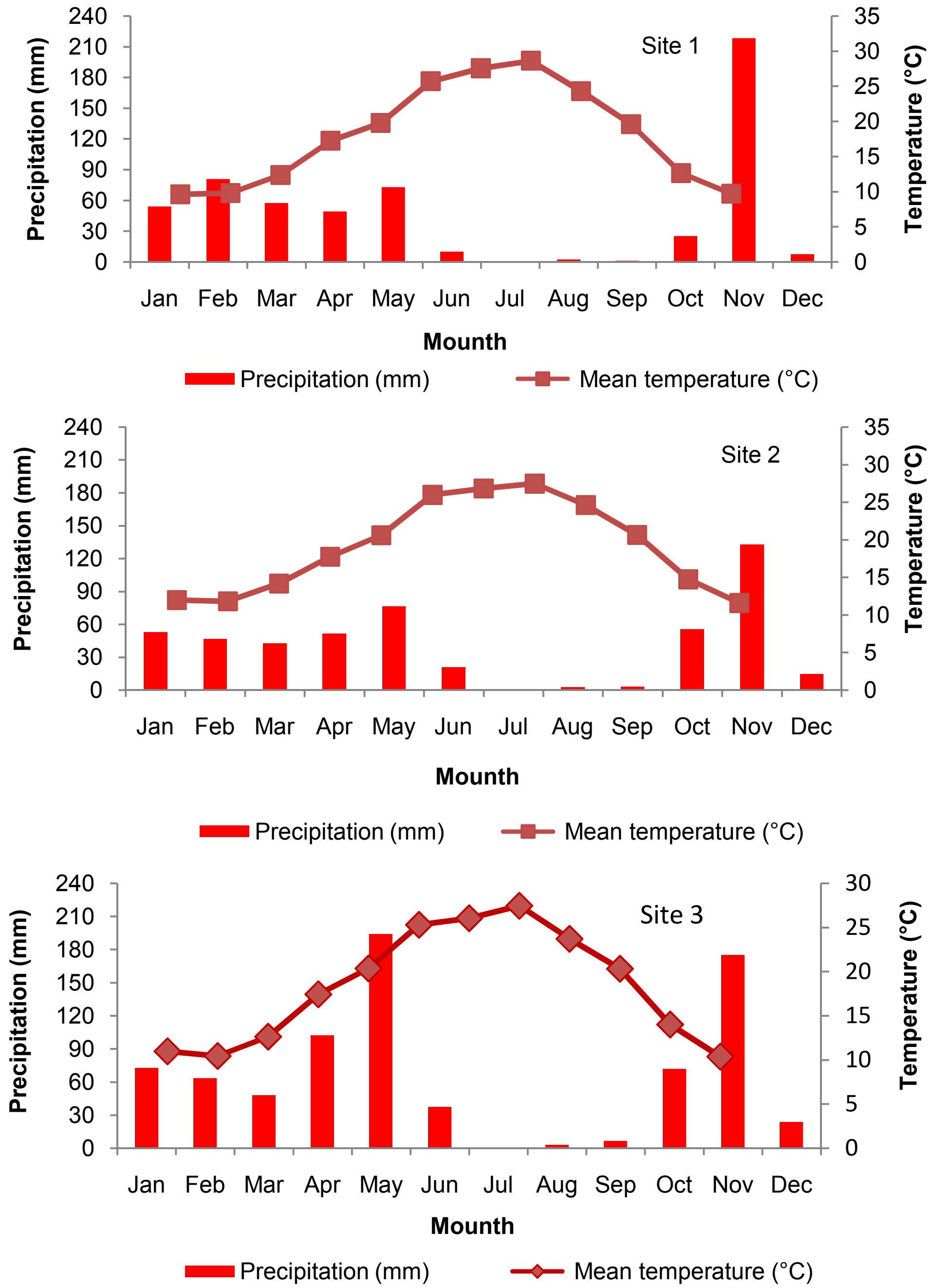

Fig. 1. Monthly precipitation and temperature recorded during the 2011 campaign in the three sites

The experimental design adopted for these experiments was a randomized complete block with eight replications. Four levels of nitrogen: 0.00, 0.25, 0.50 and 1.00 kg N per tree have been split into two contributions: half in March as ammonium sulfate and half in May as ammonium nitrate. Phosphorus (0.50 kg P_2O_5 per tree) as triple super phosphate and potassium (2.00 kg K_2O per tree) as potassium sulfate were applied in March. Each individual plot consisted of four trees. The leaves were collected (100 leaves per tree) during May to determine their nitrogen and total phosphorus concentration. The nitrogen concentration was determined by the Kjeldhal method and phosphorus by colorimetry after mineralization with concentrated sulfuric acid. The olive yield per tree was estimated at maturity in November in each of the three sites. Yield efficiency expressed as olive yield per the transversal section of the principal branches (TSPB) was also determined for every treatment.

Olive samples were also collected at harvest (about 2.0 kg of olives per tree) and were used to determine the oil olive content and quality (index of peroxide and acidity). The oil olive content was measured by nuclear magnetic resonance (NMR).

The statistical analysis was performed by SAS software (SAS Institute Inc. (2004). The error probability considered is 5%. Significance levels used are: Significant, highly significant and very highly significant, respectively, for an error probability of 5%, 1% and 0.1%.

3. RESULTS AND DISCUSSION

3.1 Yield and Yield Efficiency

The mean olive yields obtained were 60.6, 21.0, 57.5 $kg \cdot tree^{-1}$, respectively, at sites 1, 2 and 3 (Fig. 2). The difference appears between S2 and the other sites could be due to the age of the orchard which is older compared to orchards at S1 and S3. At the latters, yields were statistically equal even the varieties are different. Fernandez-Escobar et al. [5] in Spain reported mean yields achieved in thirteen years of trials, ranging from 28.0 to 30.5 $kg \cdot tree^{-1}$. While in Morocco, Razouk et al. [24] reported yields ranging from 30.0 to 55.3 $kg \cdot tree^{-1}$.

Nitrogen had no effect on the olive yield in sites 1 and 3. This could be due to the availability of mineral nitrogen in the soil of these orchards (Table 1). The same result was found in Portugal by Marcelo et al. [25] which, during two years of experiment, found no significant differences between the olive yields after the addition of nitrogen and magnesium in comparison with the control. A very highly significant difference was revealed between the different nitrogen treatments provided at the site 2. Indeed, it is the dose 0.50 kg N per tree which gave the maximum yield (53.8 $kg \cdot tree^{-1}$) in this site, followed by three additional doses 0.00, 0.25 and 1.00 kg N per tree; Control gave the lowest yield (Fig. 2). This says that nitrogen supply was needed at this site. However, the amount of nitrogen should not exceed the dose 0.50 kg N per tree, if it induces a fall in olive yield.

The crop response to nitrogen could be explained by the initial content of soil mineral nitrogen (nitrate) which is lower in comparison with the other sites (Table 1). In Spain, Garcia [26] recommended 0.5–1.0 kg N per tree, with a maximum of 150 $kg\ N \cdot ha^{-1}$, based mainly on exports of olive nutrients. Rodrigues et al. [27] suggested that more conservative N rates should be applied then those generally recommended by the analytical laboratories, since according to their study in Portugal, the annual exports of olive tree nutrients were relatively low. They recommended N rates not exceeding 20 $kg \cdot ha^{-1}$ for a young orchard (10 years) which main goal is 2500 $kg \cdot ha^{-1}$.

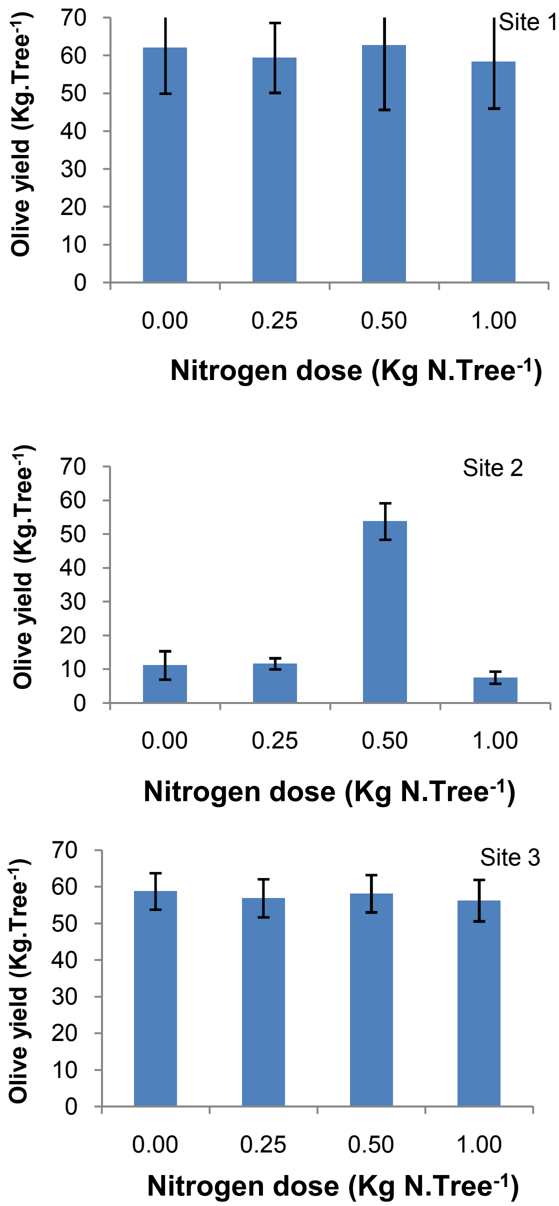

Fig. 2. Olive response to nitrogen fertilizer in the three sites

Yield per tree was influenced by variability of trees vigor in addition to nitrogen treatments variation. Consideration of the transversal section of the principal branches (TSPB) in evaluation of nitrogen treatments allowed eliminating vigor effect. Yield efficiency was on average 0.10, 0.01, 0.78 kg·cm^{-2}, respectively, at sites 1, 2 and 3 (Table 2). These differences between the three sites could be explained by the olive variety and age. Indeed, the best efficiency was obtained by the Arbequina variety, while for the two orchards Moroccan Picholine, the best efficiency was marked (0.10 kg·cm^{-2}) by the young orchard (S1). As for yield, the effect of nitrogen on the yield efficiency does not appear in sites 1 and

3. By cons, this effect was very highly significant in Site 2, where the N impact was the same as for the yield; it is the dose 0.50 kg N per tree which gave the best yield efficiency.

Table 2. Yield efficiency variation with nitrogen applications in the three sites

N dose (kg·tree^{-1})	Yield efficiency (kg·cm^{-2})		
	Site 1	**Site 2**	**Site 3**
0.00	0.09a(*)	0.01b	0.85a
0.25	0.10a	0.01b	0.74a
0.50	0.11a	0.03a	0.79a
1.00	0.09a	0.01b	0.76a

(*): for each column, number followed by the same letter are not significantly different at p=5%).

3.2 Leaf Nitrogen and Phosphorus Concentrations

The mean leaf nitrogen concentrations were 8.26, 6.44, 8.40 g·kg^{-1}, respectively, at sites 1, 2 and 3 (Fig. 3). They ranged from 7.03 g·kg^{-1} to 9.77 g·kg^{-1}, 6.17 g·kg^{-1} to 6.74 g·kg^{-1} and 7.43 g·kg^{-1} to 8.88 g·kg^{-1}, respectively, at sites 1, 2 and 3. These values are low compared to those found by Lopez-Granados et al. [2] in Spain and ranged from 12.6 g·kg^{-1} to 17.6 g·kg^{-1}.

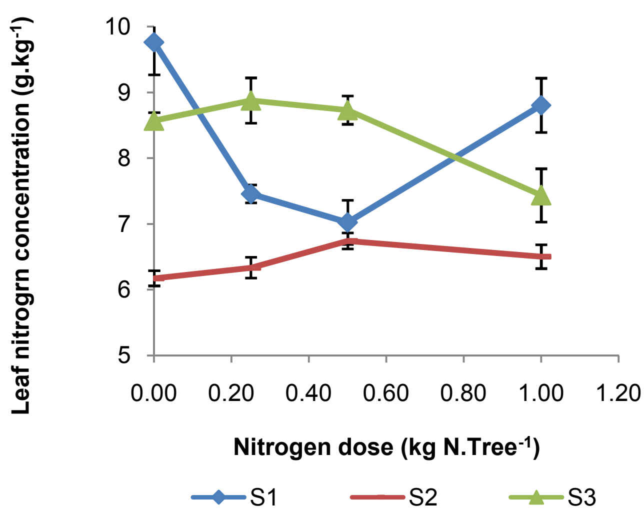

Fig. 3. Leaf nitrogen concentration as a function of N rate in the three sites

The nitrogen rate had no significant effect on leaf nitrogen concentration of olive trees in the three experimental sites. In other words, an increase in nitrogen supply did not induce an increase in its absorption by the leaves while the leaf nitrogen concentrations measured at all sites (Fig. 3) were lower than the critical value of N leaves (1.5%) defined by Marin and Fernandez-Escobar [28] and Fernandez-Escobar et al. [29]. Fernandez-Escobar et al. [30] reported an excess of nitrogen fertilization by annual applications of nitrogen to the soil, when the leaf nitrogen content equal to or greater than 1.5%. This not only negatively affects the oil olive quality due to a decrease in polyphenol content (quoted by Lopez-Granados et al. 2], but also affects the groundwater quality and agricultural economy.

The mean phosphorus concentration of the leaves were 0.56, 0.77, 0.91 g·kg^{-1}, respectively, at sites 1, 2 and 3 (Fig. 4). They ranged from 0.49 g·kg^{-1} to 0.69 g·kg^{-1}, 0.67 g·kg^{-1} to 0.93 g·kg^{-1} and 0.78 g·kg^{-1} to 1.08 g·kg^{-1}, respectively, at sites 1, 2 and 3. These values are similar to those found by Lopez-Granados et al. [2] and ranged from 0.60 g·kg^{-1} to 1.10 g·kg^{-1}. All these levels are below the threshold (0.1%) of the olive leaves concentration in phosphorus. The site 3 has recorded high levels of leaf P concentration (Fig. 4) may be due to the initial richness of the soil available phosphorus in comparison with other sites where it was low (Table 1).

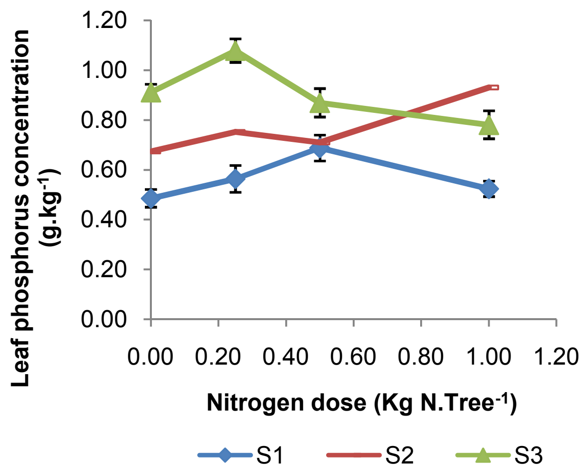

Fig. 4. Leaf phosphorus concentration as a function of nitrogen applications in the three sites

Nitrogen had a significant effect on the leaf phosphorus concentration only at site 3 (Fig. 4). This is the dose 0.25 kg N·tree^{-1} which gave the highest total phosphorus concentration leaves, followed by doses 0.00 and 0.50 kg N·tree^{-1}. The dose 1.00 kg N·tree^{-1} gave the lowest value of the measured variable. Therefore a nitrogen addition greater than 0.25 kg N·tree^{-1} resulted in a decrease in phosphorus absorption by the plant at this site.

3.3 Olive Oil Content and Quality

The mean levels of olive oil content were 28.24, 21.57, 39.39%, respectively, at sites 1, 2 and 3 (Table 3). This difference between sites could be explained by the variety and/or by the age of the orchard. Indeed, we see that it is the Arbequina variety (Site 3) which presented the high oil content. When for the other two orchards Moroccan Picholine, the site 1 (9 years old) which presented high content compared to Site 2 (35 years old). Nitrogen fertilizer effect on oil olive content was not significant in Site 1, very highly significant in site 2, and highly significant in the site 3. For site 2, we note that olive oil content increases with the addition of nitrogen while at the site 3 where the Arbequina variety is used, we see that the control had the maximum oil content.

The average index of peroxide was 9.96 and 13.07 meq O_2/kg respectively in sites 1 and 3. This is an important indicator of the olive oil quality since it expresses the degree of oil oxidation. Nitrogen had a significant effect on the peroxide at both sites 1 and 3. In fact, it increases with increasing the nitrogen supply. In Site 1 dose 0.50 kg N·tree^{-1} gave the maximum value of this index, addition of more N has reduced the peroxide. At the site 3 the dose 1.00 kg N·tree^{-1} gave the maximum value of the index. We note that an increase in this index implies a decrease in the olive oil quality. So, for the Arbequina variety (site 3), nitrogen negatively affected the olive oil quality. For Moroccan Picholine (site 1), application of more than 0.50 kg N·tree^{-1} did not increase the degree of olive oil oxidation.

Table 3. Nitrogen effect on olive oil content and quality in the three sites

Nitrogen dose	Site 1			Site 2			Site 3		
	Oil content	Acidity	Peroxide	Oil content	Acidity	Peroxide	Oil content	Acidity	Peroxide
(Kg.tree^{-1})	(%)	(%)	(Meq O_2/kg)	(%)	(%)	(Meq O_2/kg)	(%)	(%)	(Meq O_2/kg)
0.00	25,6a (*)	0.81a	3.54b	16c	ND	ND	41a	4.16a	7.78b
0.25	31.2a	0.74a	13.37ab	15,4c	ND	ND	37.6b	3.11ab	7.10b
0.50	28,7a	0.76a	17.33a	24,3b	ND	ND	39.1ab	2.51b	14.81ab
1.00	27.4a	1.68a	6.45ab	30,6a	ND	ND	39.9a	3.04ab	22.58a

ND.Analysis of olive oil has not been conducted for the site 2.
(*): for each column, number followed by the same letter are not significantly different at p=5%)

The average measured acidity was 1.0% and 3.2%, respectively, at sites 1 and 3. The measured acidity decreased with increased intake of nitrogen fertilizer. So nitrogen positively affects the olive oil quality in terms of acidity. The effect of N on the olive oil acidity was not significant in Site 1 and significant in the site 3. According to standards set by the International Olive Oil Council in 1994, oil in Site 1 (with the Moroccan Picholine variety) is classified as extra virgin virgin, while in the site 3 (with the Arbequina variety) it is classified as virgin common to lampante virgin.

4. CONCLUSION

Nitrogen had no significant effect on the olive yield or the yield efficiency in both sites 1 and 3. This could be explained by the soil initial nitrogen (nitrates) richness at these orchards which was available for cultivation (Table 1). In site 2, the nitrogen effect was very highly significant on yield and yield efficiency. The dose 0.50 kg N·tree^{-1} gave the best value for these two variables. This response to nitrogen could be explained by the low soil initial mineral nitrogen content in the orchard (Table 1), which has required the addition of nitrogen. The Arbequina variety (S3) recorded the best yield efficiency (0.78 kg·cm^{-2}). At both orchards Moroccan Picholine (S1 and S2), the young orchard (9 years old) scored higher efficiency (0.10 kg·cm^{-2}) compared to older (35 years old) orchard (0.01 kg·cm^{-2}). The Arbequina variety (Site 3) showed the highest olive oil content (39.39%). For the other two orchards Moroccan Picholine, the site 1 (9 years old) presented the high content (28.24%) compared to Site 2 (35 years old) (21.57%). The effect of nitrogen fertilizer on the olive oil content was not significant in Site 1, very highly significant in site 2, and highly significant in the site 3. Indeed, the olive oil content has increased with the nitrogen addition in the site 2 while in Site 3 the control presented the maximum olive oil content.

It can be concluded that in S1 (9 years old) and S3 (7 years old), nitrogen addition did not improve productivity parameters of olive orchards and has negatively affected the olive oil quality especially at site 3. At site 2 (35 years old), the nitrogen fertilizer contribution has been beneficial because it has improved the yield as well, the yield efficiency that the olive oil content. In this site, the olive tree nitrogen requirement is relatively high considering its age in comparison with the other two young orchards. This need for high nitrogen combined with low initial soil nitrogen available to the crop may explain this response to nitrogen in this site. So, nitrogen fertilization effect on the olive tree has been variable depending on the environment where it is grown (climate and soil at the site), the olive variety and age. These results are preliminary due to the short duration of the experiment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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