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Determination of Nitrogen Rates in Olive (*Olea europaea* cv Memecik)

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The objective of the present study is to examine the effect of increasing nitrogen rates on yield and nitrogen nutrition of olive trees (cv Memecik). A 5 year nitrogen fertilization experiment was conducted in an olive orchard. Trees were consecutively fertilized at 6 different rates of nitrogen (control-400-800-1200-1600-2000 g N $tree^{-1}$) in the form of $(NH_4)_2SO_4$. Yield, leaf total N, NO_3-N and NH_4-N were measured regularly. Results showed that the trees received 800 g N responded with the highest yield, however, higher rates (1600-2000 g N $tree^{-1}$) resulted in significant yield depressions. Leaf total N, NO_3-N and NH_4-N concentrations increased parallel to increasing N rates. Long-term higher rates nitrogen fertilization in the form of ammonium may be the cause of phytotoxicity in olive. Results revealed that for a yield 60-65 kg $tree^{-1}$ and for optimum nitrogen nutrition, up to 800 g N $tree^{-1}$ can be applied taken into account the results of initial leaf and soil analysis.

Key Words: Olive, Nitrogen, Yield, Rate, Ammonium, Fertilization, Memecik.

INTRODUCTION

Olive (*Olea europaea* L.) is an evergreen, drought and moderately salt-tolerant tree that has been cultivated since ancient times. Currently, 9 million hectares of land on the world is covered by olive and 95 % is located in the Mediterranean Basin[1]. Nitrogen is perhaps the most important plant nutrient for olive production in most of the olive growing regions[2,3]. It is claimed that nitrogen nutrition directly affect shoot growth, flowering, fruit set and yield[4]. Deficiency and excess of nitrogen causes a decrease in ovule viability[5]. It also has an affect on quality parameters *e.g.*, oil content and composition[6,7]. Lack of information is available about the optimum rate of nitrogen. Therefore, in olive orchards nitrogen is commonly practiced in different rates without any scientific basis, in most cases the rate changes according to the individual experience and economic situation of the growers which usually results in excess use[2,8].

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A worldwide ecological concern exists as a result of over fertilization with nitrogen which may cause groundwater and air pollution. Therefore, finding an optimum rate of nitrogen is extremely important in the management of nitrogen fertilization. Numerous factors such as climate, cultivar, soil characteristics and fertilization (rate, time and form) are significant in this regard. In addition, quality, alternate bearing and remobilization of nitrogen is very important with relation to the optimization of nitrogen for evergreen trees like olive[7,9]. Thus, optimization is not a easy task in coping and investigating optimum nitrogen fertilization rates in olives, it needs special emphasis.

Until the late 1980s, there has been limited number of publications related to the effect of nitrogen fertilization on yield and quality of olives[10-14]. After that the number of relevant researches have increased[2,3,7,15-17]. However, insufficient amount of long-term experimentation exists to analyze the present data on nitrogen fertilizer rates. In some of the Mediterranean countries like Turkey, research into olives still largely focuses on surveying the nutrient status of the orchards in different regions[18-20]. For the best management of nitrogen, site specific fertilizer recommendations are required[21].

The objective of this research is to investigate the optimum nitrogen rate for Memecik olive trees which is a common variety in Ege region of Turkey.

EXPERIMENTAL

The experiment was carried out between the years 1993 and 1998 in a Memecik olive plantation in Kemalpasa-Izmir-Turkey under rainfed conditions. The experimental area is typically Mediterranean, with dry, hot summers and mild, rainy winters and the annual rainfalls of the region were 673-636-790-803-711 and 1083 mm from 1993 to 1998. The orchard soil is classified as Vertic Xerefluvent (Alluvial). Further data related to the soil characteristics and plant material (Memecik cv) is given in Tables 1 and 2.

TABLE-1
BACKGROUND INFORMATION RELATED TO THE EXPERIMENTAL ORCHARD

Variety	Alternate Bearing	Age	Plantation (m)	Consumption	Irrigation	Fertilization
Memecik	Severe	25	9 × 9	Oil and Table	In drought years	Seldom

TABLE-2
SOIL CHARACTERISTICS OF EXPERIMENTAL ORCHARD

Depth (cm)	pH	(%)			(cmol kg^{-1})	(mg kg^{-1})				Texture
		Total N	$CaCO_3$	O.M	CEC	NO_3-N	NH_4-N	P	K	
0-18	7.60	0.07	7.20	0.70	28.2	10.9	6.0	1.20	200	Clay loam
18-59	7.65	0.05	7.17	0.62	28.2	8.5	4.5	1.00	150	Clay loam

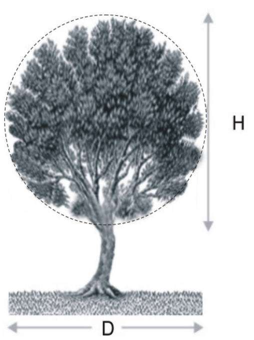
P: Water Extractable P (Bingham) ; K: 1 N NH_4OAc (pH = 7); O.M: Organic matter

Layout of the experiment: The experiment was designed as randomized blocks with 5 replications, each replicate possessing 2 trees. Trees with similar vigours were chosen and the average canopy diameter was 4.51 m. Olive trees were fertilized at 6 different nitrogen rates (0-400-800-1200-1600- 2000 g N $tree^{-1}$)

In the experiment, $(NH_4)_2SO_4$ (21 % N) was used as the nitrogen source and all the trees received a constant amount of P and K (400 g P_2O_5 $tree^{-1}$ and 500 g K_2O $tree^{-1}$) in the forms of triple super phosphate (45 % P_2O_5) and K_2SO_4 (50 % K_2O). Each year, at the end-February to mid March, fertilizers were incorporated in a band of 20 cm × 20 cm width and depth on 4 sides of the canopy.

Data collection and analysis

Yield: Yield was determined in the fruit bearing-on years of 1994-1996 and 1998 and non-bearing years were omitted from the study. Yield was also determined as per unit volume (kg m^{-3}) according to Pastor[22] (Fig. 1).



Crown $= \frac{D}{H} = \frac{4}{3} = 1.33 \Rightarrow H = \frac{3}{4}D$

Crown Volume (m^3) $= \frac{\pi}{6}D^2H$

Fruit Setting Area (m^2) $= \pi DH$

D= Diameter (m)

H= Crown Height (m)

$$V(m^3) = \frac{\pi}{8}D^3$$

$$S(m^2) = \frac{3}{4}\pi D^2$$

Fig. 1. Calculation of crown volume (V) and fruit setting area (S) [Ref. 22]

Leaf sampling and analysis: Leaf samples were taken prior to the fertilization of the experiment (1993) to ascertain the initial nitrogen nutrition of the orchard. From the beginning of the study (1994) to the end of the experiment (1998), leaves were regularly sampled from the mid of one year old shoots in December, the specific recommended time[23] for Memecik olive cv. leaf samples were cleaned, dried (65-70 ºC) and ground. Total N was determined according to the Kjeldahl procedure[24]. Spectrophotometric methods were used for water extracted nitrate[25] and ammonium[26]. After wet digestion (HNO_3:$HClO_4$; 4:1), phosphorous and potassium content of leaves were quantified spectrophotometrically and flame photometrically[24].

Statistical analysis: Variance (ANOVA) and covariance analysis were used for statistical evaluation of the obtained data and means were compared by LSD test ($p < 0.05$) using the SPSS package programme (Version 13.0, Chicago, USA).

RESULTS AND DISCUSSION

Yield: Yields varied from 35.0 to 63.3 kg tree^{-1} in 3 consecutive on-years. Each year, the tested treatments resulted in significant differences and indicated that the highest yields were obtained from N_2 (800 g N tree^{-1}) rate. On the other hand, the lowest yields changed by year. In the first year, the lowest yield was received from the control. In the last two years, yield depressions were measured in the N_4 and N_5 treatments compared to the control (Fig. 2).

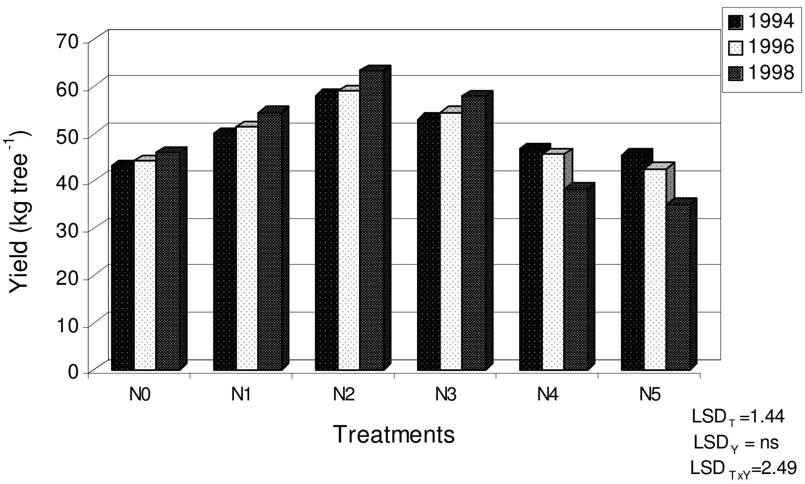


Fig. 2. Effect of treatments on yield (kg tree^{-1})

The average relative yield increase was 35 % in the N_2 rate compared to that of the control. Results revealed that the Memecik variety of olive trees responds best to nitrogen fertilization up to 800 g N tree^{-1} and higher rates would cause yield losses.

The yield per unit volume (kg m^{-3}) changes were found to be similar to yields (kg) per tree. The lowest yields were obtained from the control parcel (2.35 kg m^{-3}) in the first year and from N_5 (2.20 and 1.81 kg m^{-3}) in the last 2 years. The highest yield values were from the N_2 treatments (3.04-3.08 and 3.29 kg m^{-3}) (Table-3).

Yield change trends per volume unit (kg m^{-3}) were found similar to the findings of yield per tree. According to these results, nitrogen rates might be accepted as one of the most important factors in determining the yield. Dikmelik *et al.*[27] reported that yield per unit volume, varied with fertilizer treatments between 1.51 and 2.47 kg m^{-3} in the Memecik olive variety.

It is well known that the response of fruit trees to nitrogen depend highly on soil fertility *i.e.*, the capacity of sufficient available soil nitrogen supply[21]. Hartmann[10] reported that trees did not respond to nitrogen fertilization in fertile soils. In contrast, positive results are putforth in foothill soils of low-fertility. The fertility level of the orchard soil under experimentation indicated that response to nitrogen applications

TABLE-3
EFFECT OF TREATMENTS ON YIELD PER UNIT VOLUME (kg m^{-3})

Treatments	Crown Volume (m^3)	Yield (kg m^{-3})			
		1994	1996	1998	$Mean_{(treat)}$
Control	18.40	2.35 b	2.40b	2.50b	2.42
N_1	18.20	2.75a	2.83a	2.98a	2.85
N_2	19.10	3.04a	3.08a	3.29a	3.14
N_3	18.94	2.80a	2.87a	3.05a	2.91
N_4	19.37	2.41b	2.36b	1.97c	2.25
N_5	19.32	2.38b	2.20b	1.81c	2.13
$Mean_{(year)}$	18.89	2.62	2.63	2.60	
	LSD_T: 0.19	LSD_Y = ns		LSD_{TxY}: 0.33	

can be possible (Table-2). Olive responses to nitrogen fertilization are reported by many other researchers as well[11-13]. Llamas[13] stated that 90 % of the experiments resulted in positive responses to nitrogen fertilization. He also reported that the effect of nitrogen fertilization could start by the 1st year of application and result in up to 72 % yield increases in further years.

In the orchard, starting from the study year 1996 and onwards 'dieback' symptoms of shoots were observed in the N_4 and N_5 treatments. In the last 2 years of the experiment (1997 and 1998), incidence and severity of the reported symptoms increased with the intensity being highest in the N_5 treatments. It could possibly due to high and consecutive (5 years) N/NH_4 applications. Since one-year old shoots are main and current season shoots are potential locations for flowering and fruit setting, dieback can be a cause of decrease in yield. It is well known that ammonium is one of the major nitrogen forms and has some advantages like energy saving in the assimilation of nitrogen. However, when concentrations exceed the assimilation rate, free NH_4^+ accumulate in tissues and can be toxic for plants. Plants do not tolerate to excess ammonium as much as they do to nitrate[28-31]. To the best of our knowledge, no relevant ammonium threshold value is cited for olive in literature to compare the measurements. There is not a general consensus in method and interpretation of ammonium analysis, as well[30,32,33]. Findings (Table-6) of this study showed that leaf ammonium concentraions increased along with increasing N rates, the highest being in the N_5 treatments. The following observations and measurements can be supportive in the ammonium toxicity assessment of the current study.

(1) In a further study conducted in the same orchard, Irget *et al.*[34] found that there were high amounts of NH_4-N accumulation in the soil profiles of the N_4 and N_5 treatments in the year 1997. A possible explanation may be that high and unnitrified NH_4-N in the root zone resulted in accelerated uptakes which in turn increased the toxicity.

(2) For the observation of visual ammonium toxicity symptoms, accumulation should take place and the levels must exceed the critical concentration. Since the toxicity symptoms appeared in the 3rd year of the study, ammonium toxicity must be linked to time and N rate.

(3) Banned application of ammonium fertilizers in huge amounts might be another cause of the toxicity[35]. In this regard, the fertilizer application method used in the experiment seems to trigger the toxicity.

(4) Ionic imbalances in the plants induced by excess ammonium include decreases in cation while increases in anion concentrations in the tissues[31]. Results related to leaf potassium contents confirm similar findings of the experiment. Leaf potassium contents decreased parallel to the increases in nitrogen rates in all of the study years especially in the on-years (Table-8). Fruits are accepted as the main sink for potassium. The analyzed low leaf potassium levels in the on-years might then be natural phenomena. However, in the off-years the decreasing leaf K levels in accordance with the N rates reflect a probable ionic imbalance/NH_4 antagonism. All of these arguments show that the toxicity might be caused by ammonium rather than nitrate. Overall evaluations highlight that over fertilization (N_4 and N_5) may be a cause for yield depressions.

Nitrogen nutrition: The nitrogen content of the leaves ranged from 1.20 to 2.00 % during 1993 and 1998. The tested treatments had marked effects on leaf total N and results varied from year to year. The lowest leaf total N (1.20-1.30 %) contents were always measured in the control treatments throughout all the experimental years. In general, leaf total N increased parallel to increasing nitrogen rates in both of the on/off years (Table-4).

TABLE-4
EFFECT OF TREATMENTS ON LEAF TOTAL N (%) CONTENTS

Treatments	1993	1994	1995	1996	1997	1998	$Mean_{(treat.)}$
Control	1.30	1.20d	1.30e	1.22d	1.30e	1.29e	1.26
N_1	1.20	1.35c	1.47d	1.74c	1.80d	1.66d	1.60
N_2	1.26	1.42b	1.73c	1.84b	1.86c	1.76c	1.72
N_3	1.30	1.45ab	1.81b	1.85b	1.93b	1.80b	1.77
N_4	1.28	1.46ab	1.87a	1.89b	1.95b	1.82b	1.80
N_5	1.29	1.49a	1.90a	1.96a	2.00a	1.90a	1.85
$Mean_{(year)}$	1.27	1.40	1.68	1.75	1.81	1.71	
	LSD_T=0.021	LSD_Y =0.019		LSD_{TxY}=0.046			

Leaf total N concentrations were analyzed[36] below the sufficiency range (1.5 to 2.0 %) at the beginning of the experimentation (Table-4). In the first year, the total N concentrations of the leaves increased slightly in all the treatments, however, were still to be found below the above cited threshold value. This result for nitrogen in the on-year might be related to the sink effect of fruits as reported earlier in this paper for potassium. In the following year, total N contents of all the treated trees increased over the sufficiency level excluding the N_1 treatment rate. Total N contents in the same rate exceeded the sufficiency by the third year. The situation explains the cycle of nitrogenous compounds including storage-translocation in ever-green trees such as olive. Recalde and Chavez[37] claimed that the olive trees with 1.3 to 1.7 %

total leaf N responded to N fertilization. However, no response was found in those above 1.8 %. Freeman *et al.*[4] suggested that the goal of using nitrogen fertilizer is to maintain leaf nitrogen levels of 1.5 to 1.8 % which results in adequate shoot growth of 20-51 cm per year with optimal bloom and fruit set. According to these authors, it is a common practice to apply 450 to 900 g N tree^{-1} year^{-1} for olive in USA.

Leaf nitrate-N concentrations varied from 313 to 1165 mg kg^{-1} with respect to treatments and years. The lowest nitrate-N contents were analyzed in the controls which was similar to the findings of total N. It was also found that nitrate-N increased parallel to nitrogen rates, the highest being in the N_5 rate in all of the experimental years (Table-5).

TABLE-5
EFFECT OF TREATMENTS ON LEAF NO_3-N (mg kg $^{-1}$) CONTENTS

Treatments	1993	1994	1995	1996	1997	1998	Mean
Control	320	313c	352d	315d	345e	328f	331
N_1	313	334bc	423cd	494c	540d	528e	464
N_2	325	405abc	526bc	620b	680c	697d	586
N_3	330	415abc	593ab	648ab	835b	900c	678
N_4	320	435ab	625ab	686ab	1020a	1069b	767
N_5	315	450a	673a	734a	1100a	1165a	824
$Mean_{(year)}$	320	393	532	583	753b	781	
LSD_T=49.06		LSD_Y = 16.61		LSD_{TxY} =40.69			

The changes in leaf nitrate-N concentrations with respect to N rates were found similar to that of the leaf total N, however, the change was more pronounced. Thus, in the last on-year (1998), the leaf nitrate-N of the N_4 and N_5 treatments were nearly 4 fold of the control, however, 1.5 fold in the case of leaf total N. In general, deficiency and sufficiency ranges of leaf total N contents are very close in fruit trees, therefore, the interpretation is somewhat troublesome. In the current study total N measurements reflected the nitrogen fertilization, however, nitrate-N reflections were found to be more pronounced.

Ammonium-N concentrations of the leaves varied from 30.3 to 149.2 mg kg^{-1} and increased parallel to increasing nitrogen rates. The highest ammonium-N was measured in the N_5 treatment in 1996. In the last two years, however, decreases were determined compared to the ammonium results of N_5 of the year 1996 (Table-6).

Phosphorous and potassium nutrition: Leaf P concentrations changed between 0.068 and 0.131 % from 1993 to 1998. Highest leaf P concentrations were obtained from N_5 and the lowest from control. In general, leaf P concentrations increased parallel to increases in nitrogen rates (Table-7).

Leaf K concentrations varied from 0.40 to 0.98 % during the study years (1993-1998). The variation indicated that the highest average value (0.84 %) was in the control and decreased as the nitrogen rates increase, the lowest being (0.54 %) in the N_5 treatment (Table-8).

TABLE-6
EFFECT OF TREATMENTS ON LEAF NH_4-N (mg kg $^{-1}$) CONTENTS

Treatments	1993	1994	1995	1996	1997	1998	$Mean_{(treat.)}$
Control	37.5	30.3f	40.0d	35.1e	38.5f	36.5f	36.1
N_1	37.2	40.6e	45.0cd	47.1d	48.5e	49.5e	46.1
N_2	36.9	45.2d	48.9cd	53.8cd	56.2d	58.0d	52.4
N_3	39.0	50.8c	53.2c	60.5c	64.5c	67.3c	59.3
N_4	38.0	54.1b	67.0b	98.4b	85.3b	76.3b	76.3
N_5	37.0	62.1a	83.9a	149.2a	99.5a	88.8a	96.7
$Mean_{(year)}$	37.6	47.2	56.4	74.0	65.4	62.8	
LSD_T=4.15		LSD_Y =3.79		LSD_{TxY} =1.76			

TABLE-7
EFFECT OF TREATMENTS ON LEAF P (%) CONTENTS

Treatments	1993	1994	1995	1996	1997	1998	Mean
Control	0.079	0.084c	0.090d	0.089c	0.098d	0.090c	0.088
N_1	0.069	0.090ab	0.096c	0.102a	0.104c	0.096b	0.093
N_2	0.079	0.086c	0.116b	0.106a	0.107bc	0.098ab	0.099
N_3	0.073	0.085c	0.120b	0.095b	0.108abc	0.100a	0.097
N_4	0.068	0.087bc	0.128a	0.093b	0.110ab	0.102a	0.098
N_5	0.078	0.091a	0.131a	0.096b	0.112a	0.102a	0.102
Mean	0.074e	0.087	0.113	0.097	0.106b	0.098	
LSD_T : 0.02		LSD_Y:0.02		LSD $_{TxY}$: 0.004			

TABLE-8
EFFECT OF TREATMENTS ON LEAF K (%) CONTENTS

Treatments	1993	1994	1995	1996	1997	1998	$Mean_{(treat.)}$
Control	0.84	0.80a	0.90a	0.79a	0.98a	0.75a	0.84a
N_1	0.76	0.70b	0.80b	0.67b	0.76b	0.60b	0.71b
N_2	0.83	0.60c	0.78bc	0.51c	0.73b	0.52c	0.63c
N_3	0.89	0.60c	0.75c	0.49c	0.63cd	0.45d	0.58d
N_4	0.78	0.55d	0.75c	0.45d	0.66c	0.42de	0.57e
N_5	0.86	0.52e	0.70d	0.44d	0.61d	0.40e	0.54f
Mean $_{(year)}$	0.83	0.63c	0.78a	0.56d	0.73b	0.52e	
LSD_T=0.016		LSD_Y= 0.014		LSD_{TxY} =0.035			

Conclusion

It is concluded that the Memecik olive cv responds to N fertilization up to 800 g N tree^{-1}. Higher nitrogen rates (1600 and 2000 g N tree^{-1}) may cause yield decreases. A previous study[7] in the same orchard and with the same cv also confirms this specified rate as optimum for the quality of the fruit.

In general, fertilizer recommendations for fruit trees are made in accordance with the target yield. For a yield of 60-65 kg tree^{-1} and for optimum nitrogen nutrition, up to 800 g N tree^{-1} can be applied taken into account the results of initial leaf and soil analysis.

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