TAS Trends in Agricultural Sciences

OPEN ACCESS

Interplanting Lentils Within Olive and Orange Trees Under Different Sources of Nitrogen Fertilizer in North Sinai

[1]Yaser Ahmed Abd El-Haleem Hefny, [2]Eman Ibrahim Abdel-Wahab and [2]Marwa Khalil Ali Mohamed

[1]Department of Crop Intensification Research, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt

[2]Department of Food Legume Research, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt

ABSTRACT

Background and Objective: Interplanting legumes with orchards is a popular practice on newly reclaimed soils. A field trial was conducted over two consecutive seasons in 2021/2022 and 2022/2023 at the newly reclaimed soils of East of Suez Canal Horticulture Research Station, Agricultural Research Center (ARC), North Sinai Governorate, Egypt. This study aimed to determine the optimal source of nitrogen (N) fertilizer for interplanting lentils within olive and orange trees to achieve high crop yields, efficient land use and financial benefits in sandy soil conditions. **Materials and Methods:** The treatments were two interplanting systems (interplanting lentils within olive trees and interplanting lentil within orange trees) and four sources of N fertilizer (mineral N fertilizer, bio+mineral N fertilizer, organic manure fertilizer and bio-N fertilizer). A strip design with three replicates was used for this experiment; the two interplanting systems were assigned in the vertical strips and the four sources of N fertilizer were distributed in the horizontal strips. **Results:** Compared to interplanting lentil within olive trees, interplanting lentil within orange trees increased number of branches/plant, seed yield/plant and seed yield/fad. Full dose of mineral N fertilizer had the highest number of branches/plant, seed yield/plant, 100-seed weight and seed yield/fad. The interaction has a dependent effect on plant height, number of pods/plant, seed yield/plant, seed yield/fad in both seasons and 100-seed weight in the second season. Once different sources of N were supplied, the significance between treatments for either olive or orange fruit production or trend disappeared. **Conclusion:** In sandy soil, high land usage and profitability were attained by growing two rows of lentil in six ridges with a full dose of mineral N fertilizer within the olive trees and two rows of lentil in six ridges with rhizobia and a starter dose of mineral N fertilizer within the orange trees.

KEYWORDS

Interplanting, sandy soils, olive trees, orange trees, lentil, N fertilizer sources, land usage

INTRODUCTION

The productivity efficiency of smallholder farms significantly impacts the development strategies of most developing countries[1]. Lentil (*Lens culinaris* Medik), a staple crop in Mediterranean, play a crucial role in the diets of low-income communities in developing nations due to their ability to substitute animal proteins[2]. Lentil offer a cost-effective crop diversification option, as they can be grown in marginal soils

ISSN: 2957-9449 (Online)
ISSN: 2957-9430 (Print)
https://doi.org/10.17311/tas.2024.136.148

Received: 18 Apr. 2024
Accepted: 29 Jun. 2024
Published: 30 Jun. 2024

unsuitable for other crop. Additionally, lentils are nutritionally rich, containing high levels of protein, fiber, vitamins and minerals, making them valuable in combating malnutrition and food insecurity in vulnerable populations. Lentil are a rich source of iron, calcium, phosphorus, magnesium, vitamin A and vitamin B, providing essential nutrients such as proteins (23%), carbohydrates (59%), oils (1.8%) and ash (0.2%)[3]. Additionally, lentil aid in soil phytoremediation by removing pesticides from the soil[4]. Despite global lentil production increasing annually, the cultivated area of lentils in some regions remains limited, the local production falls short of meeting the country's demand. This gap between supply and demand necessitates importing lentils to fulfill the country's needs. To address this issue, promoting sustainable practices to boost domestic lentil production could help reduce reliance on imports in the future. One potential solution to address the issue of high population growth is to enhance the use of sandy soils by implementing interplanting techniques to boost productivity per unit area of newly reclaimed soils.

It is crucial to prioritize the reclamation of sandy soils to enhance crop productivity and reduce the use of chemical nitrogen (N) fertilizers. Introducing intra-specific diversity in cropping systems can boost productivity and ecosystem services without significant technological limitations[5]. Lentils play a key role in farming systems[6]. The reclaimed soils currently lack essential mineral nutrients and have poor biological and chemical qualities[7]. To address this issue, integrating leguminous crops like lentils can enhance soil fertility through N fixation. Diversifying crops in sandy soils not only increases productivity but also reduces dependence on chemical fertilizers, promoting sustainable agricultural practices.

Farming on recently reclaimed soils is challenging and often results in low crop productivity[8,9]. Citrus (*Citrus sinensis*) is one of the most important fruit crops globally and a major agricultural product exported by Egypt, serving as a significant source of foreign currency. International statistics reported that Egypt ranks as the sixth-largest orange producer in the world, following Brazil, China, the US, the EU and Mexico. Moreover, in the semi-arid Mediterranean basin, olive (*Olea europaea* L.) trees play a vital role in maintaining soil nutrients[10]. According to Moghazy and Kaluarachchi[11], olives are a key industrial crop in the region, impacting the economy and agriculture significantly. Olive orchards in the Mediterranean are commonly established in low-fertility soils that have been recently reclaimed[12]. It was mentioned how effectively water is used in orchards with drip irrigation[13]. It was observed that the sprinkler irrigation system had the least impact on all the characteristics studied, while the drip irrigation system significantly improved all lentil traits[14]. Introducing intra-specific diversity into cropping systems can enhance productivity and ecosystem services without any major negative technical effects[15]. A common strategy on newly reclaimed soils is to interplant legumes with orchards, which not only enhances soil fertility but also boosts the overall sustainability of the agricultural system. By planting different species together in the same field, farmers can optimize land use efficiency and promote biodiversity.

Research by Phoomthaisong *et al.*[16], Selim *et al.*[17] and Amassaghrou *et al.*[18] suggests that the benefits of legumes are comparable to applying 50-100 kg of N/ha as fertilizer. However, pollutants can transfer from plants to animals and humans, leading to serious health issues. Rao *et al.*[19] have documented environmental contamination resulting from the excessive use of chemical N fertilizers. The depletion of organic matter in the soil, caused by the prevalent use of chemical fertilizers over organic nutrients, has significantly reduced the soil's nutrient pool[20]. Legumes can fix atmospheric N by forming nodules through symbiosis with rhizobia, which is advantageous for growth in low N content soils[21]. Even in high N soils, using an inoculant is recommended based on Bremmer *et al.*[22] findings.

Lentil infected with rhizobia performed better than non-infected ones. Organic manure application significantly influenced various growth parameters and yields in lentils, as reported by Sonkarlay *et al.*[23]. These results emphasize the importance of considering multiple factors to optimize lentils production. In another study, Zakeri *et al.*[24] found that all studied traits increased as mineral N fertilizer rates increased from 0 to 60 kg/ha. Additionally, in two out of three years, lentil yields were higher when N fertilizer was added. However, in one year, there was no significant response to the N treatment, suggesting that additional N did not impact yields. However, Fatima *et al.*[25] reported that combining NPK and FYM resulted in a significantly higher biological yield of lentils compared to using NPK alone. Therefore, this study aimed to determine the optimal source of N fertilizer for interplanting lentils within olive and orange trees to achieve high crop yields, efficient land use and financial benefits in sandy soil conditions.

MATERIALS AND METHODS

The study was conducted at the East of Suez Canal Horticulture Research Station, ARC, North Sinai Governorate, Egypt (30°53 09"N, 32°05 04"E). Three-year-old Valencia oranges and Koroneiki olive trees were planted at a spacing of 4×6 m under drip irrigation during the 2021/2022 and 2022/2023 seasons. A strip design with three replicates was used for this experiment; the two interplanting systems were assigned in the vertical strips and the four sources of N fertilizer were distributed in the horizontal strips. For the olive and orange crops, a randomized complete blocks design with three replicates was used. Each plot was 96 m^2 (12 m in length and 8 m in width). Lentils cv. Giza 4 were sown on November 30th and December 5th in 2021 and 2022 winter seasons, respectively. Mechanical and chemical analyses of the soil (20-70) were done by Water, Soil and Environment Research Institute, ARC. Mechanical and chemical properties of the soil were determined using the methods described by Bradford *et al.*[26]. The soil was sandy (81.40% sand, 12.35% silt and 6.25% clay). With respect to chemical properties, EC (0.60 dSm^{-1}), pH (8.38), Na^+ (4.43 meq/L), K^+ (0.06 meq/L), Ca^{++} (0.87 meq/L), HCO_3^- (1.36 meq/L), SO_4^- (1.68 meq/L), N (37.33 ppm), P (2.60 ppm), K (32.00 ppm) and O.M. (0.18%).

Phosphorus was supplied to olive trees under solid plantings and interplanting at a rate of 200 kg/fad in the form of calcium superphosphate (15.5% P_2O_5) at the start of each season. Furthermore, from February to July, equal monthly dosages of ammonium nitrate (33.5% N), applied under interplanting or solid plantings, were given at a rate of 60 kg N/fad of N fertilizer. Potassium sulfate (K) fertilizer was administered to lentils under interplanting and solid plantings at a rate of 50 kg K/fad. Lentil was treated with 50 kg K/fad of calcium nitrate in both solid and interplanted plantings. Olive trees were treated with microelements in both solid and interplanting plantings between March and May.

At the beginning of each season for orange trees, the experimental trees which subjected to interplanting or solid plantings received 0.5 kg calcium super phosphate (15.5% P_2O_5) per tree mixed with 10 kg/tree organic manure applied in rounded trenches close to the root system around the tree canopy. In addition, N fertilizer was applied at a rate of 125 kg N/fad as ammonium nitrate (33.5% N) divided by equal monthly doses from March to October under interplanting or solid plantings, respectively. Potassium (K) fertilizer was applied at a rate of 1.5 kg K/week under interplanting or solid plantings. Moreover, phosphoric acid was applied at a rate of 1 L/15 days under interplanting or solid plantings.

At the beginning of each season for lentil, calcium super phosphate (15.5% P_2O_5) was applied for lentil at a rate of 150 and 200 kg/fad under interplanting and solid plantings, respectively, during soil preparation in the two winter seasons. The K fertilizer was applied for lentils at a rate of 37.5 and 50 kg K/fad under interplanting and solid plantings, respectively, as potassium sulfate.

The treatments were two interplanting systems (interplanting lentils within olive trees and interplanting lentil within orange trees) and four sources of N fertilizer (mineral N fertilizer, bio+mineral N fertilizer, organic manure fertilizer and bio-N fertilizer).

Interplanting systems were as follows:

Interplanting lentil within olive trees: Two rows of lentil were seeded at the rate of 45 kg/fad in six ridges (4.0 m in length and 0.75 m in width). There is a 0.75 m space between the olive trees and the lentil ridge next to the trees.

Interplanting lentil within orange trees: Two rows of lentils were seeded at a rate of 45 kg/fad in six ridges (4.0 m in length and 0.75 m in width). There is a 0.75 m space between the orange trees and the lentil ridge next to the trees.

In addition to:

Solid planting of lentil: Eight ridges, each 0.75 m wide, were sown with two rows of lentil at a rate of 60 kg/fad and the soil was treated with 60 kg N/fad of ammonium nitrate (33.5% N).

Solid planting of olive trees: Owing to the alternating bearing in orange trees, three-year-old Koroneiki trees (on-year bearing) were selected in the second year and placed in groups of two, with the same bearing status, at a distance of 4×6 m (175 trees/fad), for trials in the first season.

Solid planting of orange trees: Three-year-old Valencia Orange trees (on-year bearing) were growing at a distance of 4×6 m (175 trees/fad) and were subjected to experiments in the first season. Other groups of trees (with the same bearing status) were chosen in the second year due to the existence of alternate bearings in orange trees. To estimate LER and LEC, solid plantings of every species were utilized.

Four sources of N fertilizer for lentils were as follows:

Mineral N fertilizer: It was applied for lentil at a rate of 60 kg N/fad as ammonium nitrate (33.5% N) in three equal doses.

Inoculated seeds+starter dose of mineral N fertilizer: Lentil seeds were inoculated with *Rhizobium* sp. and Arabic gum was used as a sticking agent. Mineral N fertilizer was added for lentil at a rate of 20 kg N/fad as ammonium nitrate (33.5% N) before the first irrigation.

Organic manure fertilizer: It was added at 7.5 m^3/fad. This treatment was applied before sowing.

Bio-N fertilizer: Soil that was cerialin-treated at a rate of 400 g/fad. The Biofertilizer Unit, ARC, Giza, Egypt, was the company that developed cerialin for the commercial market. It contained free-living microorganisms that could fix atmospheric N in the soil's rhizosphere. This treatment was used as a side-dress close to hills before the initial watering.

Drip irrigation system was used in all tested treatments by separated nets for each crop to control the amounts. Date of supply of the N fertilizer in the experimental soil for each treatment was done according to a source of N fertilizer. The other prescribed cultural procedures for orange and olive trees, as well as lentil, were followed. Lentil was harvested on 4th May, 2022 and 27th April, 2023 after the growth departure of the shoot and fruit of the olive tree and before harvesting of orange fruits. Orange fruits were harvested on 8th and 11th May, 2022 and 2023, respectively. Olive fruits were harvested on 21st and 14th November, 2022 and 2023, respectively.

The studied traits were as follows:

- **Seed yield and yield components of lentils:** At harvest, five lentil plants were randomly taken to estimate the following traits: Plant height (cm), number of branches and pods/plant, seed yield/plant (g) and 100-seed weight (g). Seed yield/fad was recorded based on the experimental plot (kg) and then converted to kg/fad [2.38 fad is equal to one ha]
- **Orchards fruit yield/fad (ton):**
  - **Olive fruit yield/fad (ton):** It was recorded based on the experimental plot (kg) and then converted to ton/fad
  - **Orange fruit yield/fad (ton):** It was recorded based on the experimental plot (kg) and then converted to ton/fad
- **Competitive relationships:**
- **LER:** It is the ratio of area needed under sole cropping to one of interplanting at the same management level to produce an equivalent yield[27].
- LER is calculated as follows:

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

where, Y_{aa} represents the pure stand yield of crop a (olive or orange), Y_{bb} represents the pure stand yield of crop b (lentils), Y_{ab} represents the interplant yield of crop a (olive or orange) and Y_{ba} represents the interplant yield of crop b (lentils). The Relative Yield (RY) is calculated as follows:

$$\text{RY of olive or orange} = Y_{ab}/Y_{aa} \text{ and RY of lentils} = Y_{ba}/Y_{bb}$$

- **LEC:** It is a measure of interaction concerned with the strength of relationship[28]. It is calculated as follows:

$$LEC = RY_a \times RY_b$$

where, $_{Rya}$ is relative yield of crop a (olive or orange) and $_{Ryb}$ is relative yield of crop b (lentils)

- **Economic evaluation:**
  - **Total return/fad:** It was calculated by plus income of olive or orange fruits/fad (Egyptian pounds) with income of lentil seeds/fad (Egyptian pounds). Olive and orange fruits, as well as lentil seeds prices presented by market price (2023), were used. Market prices (2023) of crops are 35000 Egyptian pounds/ton for olive fruits and 8000 Egyptian pounds/ton for orange fruits, as well as 40000 Egyptian pounds/ton for lentil seeds [One euro is equivalent to 33.41 Egyptian pounds]
  - **MAI:** It is recommended to conduct an economic evaluation based on the value of the conserved land, which can be estimated using the land's rental value as a reference point. Tripathi *et al.*[29] suggested a formula was utilized to calculate the MAI, which is calculated as [value of combined intercrops multiplied by (LER-1)] divided by LER

Statistical analysis: Analysis of variance of the obtained results of each season was performed. The measured variables were analyzed by ANOVA using MSTAT-C statistical package. Mean comparisons were performed using the least significant differences (LSD) test with a significance level of 5%[30].

RESULTS

Seed yield and yield components of lentils

Interplanting systems: Interplanting systems had a significant impact on plant height, seed yield/plant and seed yield/fad in both seasons and number of branches/plant in the second season (Table 1).

In comparison to interplanting lentils within orange trees, interplanting lentils within olive trees produced taller plants during both growing seasons. Compared to interplanting lentils within olive trees, interplanting lentils within orange trees led to an increase in the number of branches/plant, seed yield/plant and seed yield/fad.

Different sources of N fertilizer: Different sources of N fertilizer showed significant differences in seed yield/plant and seed yield/fad in both seasons and numbers of branches/plant and 100-seed weight in the second season (Table 1). Full dose of mineral N fertilizer had the highest numbers of branches/plant, seed yield/plant, 100-seed weight and seed yield/fad. In contrast, there were fewer branches/plant, lower seed yield/plant, 100-seed weight and seed yield/fad with bio-N fertilizer.

Table 1: Effect of cropping systems, N fertilizer sources and the interaction between them on seed yield and yield components in both seasons

Traits	Plant height (cm)	Number of branches/plant	Number of pods/plant	Seed yield/plant (g)	100-seed weight (g)	Seed yield/fad (kg)
First season						
Lentils+olive						
F_1	46.26	2.69	36.67	1.03	2.26	436.13
F_2	44.59	2.55	35.25	0.97	2.18	419.32
F_3	43.65	2.35	34.65	0.90	2.05	394.11
F_4	41.75	2.28	32.83	0.83	1.98	377.96
Mean	44.06	2.46	34.85	0.93	2.12	406.88
Lentils+orange						
F_1	42.47	3.16	40.41	1.25	2.53	499.18
F_2	41.92	3.02	39.60	1.17	2.42	479.33
F_3	40.70	2.88	37.55	1.05	2.21	448.50
F_4	39.53	2.79	35.59	0.99	2.10	434.78
Mean	41.15	2.96	38.29	1.11	2.31	465.45
Average of N fertilizer sources						
F_1	44.36	2.92	38.54	1.14	2.39	467.65
F_2	43.25	2.78	37.42	1.07	2.30	449.32
F_3	42.17	2.62	36.10	0.97	2.13	421.31
F_4	40.64	2.53	34.21	0.91	2.04	406.37
F test 0.05 cropping systems	**	ns	ns	**	ns	*
LSD 0.05 N fertilizer	ns	ns	ns	0.15	ns	60.56
LSD 0.05 Interaction	10.12	ns	11.91	0.21	ns	82.20
Solid lentils	29.36	3.96	54.54	1.39	3.01	673.99
Second season						
Lentils+olive						
F_1	37.57	2.92	42.51	1.22	2.65	481.41
F_2	38.01	2.73	41.83	1.17	2.54	464.48
F_3	35.84	2.48	39.83	1.08	2.38	443.73
F_4	35.16	2.40	36.26	1.02	2.30	433.80
Mean	36.64	2.63	40.11	1.12	2.46	455.85
Lentils+orange						
F_1	36.69	3.51	46.53	1.52	2.98	590.47
F_2	34.95	3.43	44.55	1.46	2.91	576.41
F_3	33.61	3.31	42.49	1.37	2.77	539.79
F_4	33.33	3.24	39.77	1.31	2.63	519.42
Mean	34.64	3.37	43.33	1.41	2.82	556.52
Average of N fertilizer sources						
F_1	37.13	3.21	44.52	1.37	2.81	535.94
F_2	36.48	3.08	43.19	1.32	2.72	520.44
F_3	34.72	2.89	41.16	1.22	2.57	491.76
F_4	34.24	2.82	38.02	1.16	2.46	476.61
F test 0.05 cropping systems	**	*	ns	**	ns	**
LSD 0.05 N fertilizer	ns	0.20	ns	0.17	0.26	39.09
LSD 0.05 interaction	11.39	ns	11.45	0.19	0.36	73.11
Solid lentils	25.43	4.26	57.69	1.66	3.43	731.93

F_1: Full dose of mineral N fertilizer, F_2: Inoculated seeds+starter dose of mineral N fertilizer, F_3: Organic manure, F_4: Bio-N fertilizer, Ns: Non-significant and **,*Significant results at 0.05

Table 2: Effect of different sources of N fertilizer on olive and orange fruit/fad under interplanting in both seasons

Traits	Olive fruit yield/fad (ton)	Orange fruit yield/fad (ton)
First season		
Full dose of mineral N fertilizer	2.80	2.12
Inoculated seeds+starter dose of mineral N fertilizer	2.66	2.22
Organic manure	2.51	2.01
Bio-N fertilizer	2.73	2.08
LSD 0.05	ns	ns
Second season		
Full dose of mineral N fertilizer	3.45	2.36
Inoculated seeds+starter dose of mineral N fertilizer	3.42	2.55
Organic manure	3.27	2.43
Bio-N fertilizer	3.20	2.24
LSD 0.05	ns	ns

Recommended solid olive yield: 2.71 ton/fad in 1st season and 3.12 ton/fad in 2nd season, Recommended solid orange yield: 1.88 ton/fad in 1st season and 2.29 ton/fad in 2nd season and ns: not significant

Interaction between interplanting systems and different sources of N fertilizer: Plant height, the number of pods/plant, the seed yield/plant, the seed yield/fad in both seasons and 100-seed weight in the second season were all strongly impacted by the interaction between interplanting systems and different sources of N fertilizer, as Table 1 illustrates.

Olive and orange fruit yields/fad: Different sources of N fertilizers did not significantly affect olive and orange fruit yields/fad in both seasons (Table 2).

Competitive relationships

LER: Based on information on the recommended solid plantings of both crops, the values of LER were estimated. A yield advantage is indicated by an LER of more than 1.00; a yield loss is shown by an LER of less than 1.00; and no gain or loss is indicated by an LER equal to 1.00. It can be applied in an additive or replacement series of interplanting. Strong agreement was found between the acquired results and the definition of LER. By interplanting olive and orange trees in both seasons, LER values were larger than one for lentils with applied different sources of N fertilizer (Table 3). The LER varied from 1.47 when interplanting lentils, which received organic manure, within olive trees to 1.64 when interplanting lentils, which received a full dose of mineral N fertilizer, within olive trees in the first season. Meanwhile, the LER varied from 1.58 when interplanting lentils, that received bio-N fertilizer, within olive trees to 1.72 when interplanting lentils, that received a full dose of mineral N fertilizer, within olive trees in the second season. The LER varied from 1.69 when interplanting lentils, that received organic manure, within orange trees to 1.87 when interplanting lentils, that received inoculated seeds with rhizobia+starter dose of mineral N fertilizer, within orange trees in the first season.

Meanwhile, the LER varied from 1.64 when interplanting lentils, that received bio-N fertilizer, within orange trees to 1.85 when interplanting lentils, that inoculated seeds with rhizobia+starter dose of mineral N fertilizer, within orange trees in the second season.

LEC: The LEC is an interaction metric that looks at a relationship's strength. The minimum predicted productivity coefficient (PC) for a two-crop mixture using LEC is 25%; a yield advantage is realized if the LEC value is higher than 0.25. The LEC values were higher than 0.25 (Table 3). The LEC varied from 0.50 when interplanting lentils, that received organic manure, within olive trees to 0.62 when interplanting lentil, that received a full dose of mineral N fertilizer, within olive trees in the first season. Meanwhile, the LEC varied from 0.57 when interplanting lentil, that received bio-N fertilizer, within olive trees to 0.68 when interplanting lentils, that received a full dose of mineral N fertilizer, within olive trees in the second season.

Table 3: Relative yield of both crops, LER and economic evaluation of interplanting lentil within olive and orange trees under different sources of N fertilizer in both seasons

Traits	RY of orchards	RY of lentils	LER	LEC	Total return (Egyptian pounds/fad)	MAI
First season						
Lentil+olive						
Full dose of mineral N fertilizer	1.03	0.61	1.64	0.62	115445	45051
Inoculated seeds+starter dose of mineral N fertilizer	0.98	0.58	1.56	0.57	109872	39441
Organic manure	0.92	0.55	1.47	0.50	103614	33128
Bio-N fertilizer	1.00	0.53	1.53	0.53	110668	38336
Mean	0.98	0.56	1.55	0.55	109900	38996
Recommended solid planting of olive trees	---	---	1.00	1.00	94850	---
Lentils+orange						
Full dose of mineral N fertilizer	1.13	0.69	1.82	0.78	16960	19967
Inoculated seeds+starter dose of mineral N fertilizer	1.18	0.66	1.84	0.78	17760	19173
Organic manure	1.07	0.62	1.69	0.66	16080	17940
Bio-N fertilizer	1.11	0.60	1.71	0.67	16640	17391
Mean	1.12	0.64	1.76	0.72	35477	15320
Recommended solid planting of orange trees	---	---	1.00	1.00	15040	---
Second season						
Lentil+olive						
Full dose of mineral N fertilizer	1.10	0.62	1.72	0.68	140006	58607
Inoculated seeds+starter dose of mineral N fertilizer	1.09	0.60	1.69	0.65	138279	56457
Organic manure	1.05	0.57	1.62	0.59	132199	50594
Bio-N fertilizer	1.02	0.56	1.58	0.57	129352	47483
Mean	1.06	0.58	1.65	0.62	134959	53165
Recommended solid planting of olive trees			1.00	1.00	109200	---
Lentil+orange						
Full dose of mineral N fertilizer	1.03	0.76	1.79	0.78	42498	18756
Inoculated seeds+starter dose of mineral N fertilizer	1.11	0.74	1.85	0.82	43456	19966
Organic manure	1.06	0.69	1.75	0.73	41031	17584
Bio-N fertilizer	0.97	0.67	1.64	0.65	38696	15101
Mean	1.04	0.71	1.75	0.74	41420	17751
Recommended solid planting of orange trees			1.00	1.00	18320	---

Recommended solid olive yield: 2.71 ton/fad in 1st season and 3.12 ton/fad in 2nd season, market price (2023) was 35000 Egyptian pounds/ton. Recommended solid orange yield: 1.88 ton/fad in 1st season and 2.29 ton/fad in 2nd season, market price (2023) was 8000 Egyptian pounds/ton. Recommended solid lentil: 717.62 kg/fad in 1st season and 775.62 kg/fad in 2nd season, market price (2023) was 40000 Egyptian pounds/ton, LER: Land equivalent ratio, LEC: Land equivalent coefficient and MAI: Monetary advantage index

The LEC varied from 0.66 when interplanting lentil, that received organic manure, within orange trees to 0.82 when interplanting lentil, that received inoculated seeds with rhizobia+starter dose of mineral N fertilizer, within orange trees in the first season. Meanwhile, the LEC varied from 0.65 when interplanting lentil, that received bio-N fertilizer, within orange trees to 0.82 when interplanting lentil, that inoculated seeds with rhizobia+starter dose of mineral N fertilizer, within orange trees in the second season.

Economic evaluation

Total return/fad: The economic return of interplanting lentil within olive and orange trees compared with recommended solid plantings of olive and orange trees, respectively, is shown in Table 3. The total return of interplanting lentils within olive trees varied between treatments from 103614 Egyptian pounds/fad with applied organic manure to 115445 Egyptian pounds/fad with applied full dose of mineral N fertilizer compared with recommended solid planting of olive trees (94850 Egyptian pounds/fad) in the first season. Meanwhile, these treatments ranged from 129352 Egyptian pounds/fad with applied bio-N fertilizer to 140006 Egyptian pounds/fad with applied full dose of mineral N fertilizer compared to recommended solid planting of olive trees (109200 Egyptian pounds/fad) in the second season.

With regard to interplanting lentils within orange trees, the total return of interplanting lentils within orange trees varied between treatments from 34020 Egyptian pounds/fad with applied organic manure to 36933 Egyptian pounds/fad through inoculated seeds with rhizobia+starter dose of mineral N fertilizer compared with recommended solid planting of orange trees (15040 Egyptian pounds/fad) in the first season. Meanwhile, these treatments ranged from 38696 Egyptian pounds/fad with applied bio-N fertilizer to 43456 Egyptian pounds/fad through inoculated seeds with rhizobia+starter dose of mineral N fertilizer compared to recommended solid planting of orange trees (18320 Egyptian pounds/fad) in the second season.

MAI: The economic performance of the interplanting was evaluated to determine if lentil and olive or lentil and orange combined yields were high enough for the farmers to adopt this system (Table 3). The MAI of interplanting lentil within olive trees varied between treatments from 33128 Egyptian pounds/fad with applied organic manure to 45051 Egyptian pounds/fad with applied full dose of mineral N fertilizer in the first season. Meanwhile, these treatments ranged from 47483 Egyptian pounds/fad with applied bio-N fertilizer to 58607 Egyptian pounds/fad with applied full dose of mineral N fertilizer in the second season. On the other hand, MAI of interplanting lentil within orange trees varied between treatments from 13889 Egyptian pounds/fad with applied organic manure to 16860 Egyptian pounds/fad through inoculated seeds with rhizobia+starter dose of mineral N fertilizer in the first season. Meanwhile, these treatments ranged from 15101 Egyptian pounds/fad with applied bio-N fertilizer to 19966 Egyptian pounds/fad through inoculated seeds with rhizobia+starter dose of mineral N fertilizer in the second season.

DISCUSSION

The shade from olive trees, rather than orange trees, may have influenced plant height. Olive trees may have boosted gibberellin production, leading to increased plant height compared to orange trees. Given that the olive trees provide shade, it is possible that interplanting lentil within them could increase plant height. These results were consistent with the findings of Selim *et al.*[17], who reported increased plant height when interplanting soybeans within mandarin trees. Similarly, Amassaghrou *et al.*[18] observed taller plants when interplanting lentil within olive trees compared to solid planting of lentil. It is important to highlight that olive trees had a more pronounced negative impact on the number of branches/plants in the second season, as well as seed yield/plant and seed yield/fad in both seasons compared to orange trees. The higher number of branches and leaves in the aerial portion of olive trees' forms more shade on lentils, potentially explaining the greater negative effect on yield compared to orange trees. Further research could explore strategies to mitigate this impact and optimize interplanting practices for increased seed yield of lentils. The shading effect of olive trees during winter negatively affects crop branching, resulting in fewer branches and pods[31].

It is important to mention that there were no significant differences between full dose of mineral N fertilizer and inoculated seeds+starter dose of mineral N fertilizer in terms of the mentioned traits. It is noteworthy to add that there were no appreciable variations found in these traits between organic manure and bio-N fertilizer. Mineral fertilizers are easy to use, provide precise application and have proven effectiveness[32]. Organic manures have nutrients distributed sparsely, are heavy, expensive to transport and have unpredictable nutrient release rates, especially for N. In contrast, mineral fertilizers offer a reliable and consistent nutrient source for crops, making them a popular choice among farmers. The controlled application of mineral fertilizers allows for efficient resource use and helps prevent nutrient leaching into the environment. However, symbiotic N fixation, which raises N availability in the soil and encourages better crop growth rates in lentils, may be the cause of these results[33]. Rhizobium may have this effect because it makes N more available to plants, which will be crucial for raising crop yields. Growth hormones produced by Rhizobium encourage the shape of roots. By increasing the quantity of these bacteria, the microbial process is accelerated, increasing the amount of nutrients available in a form that the plant can readily absorb[34,35].

Plant growth is enhanced by enriching the soil with nutrients through N fixation[36]. Rhizobial inoculation alone is insufficient for achieving high yields of legumes[37]. As a result, rhizobial inoculation combined with mineral N supplementation is required to maximize seed yield of lentils. For the highest crop production, it is important to take into account both biological N fixation and additional N sources. As a result, it may be more affordable to inoculate seeds with a starter dose of mineral N fertilizer rather than apply mineral N fertilizer directly, all while maintaining crop productivity. These findings imply that conventional chemical fertilizers may be more successful in stimulating plant growth and output than both organic manure and bio-N fertilizers.

Concerning the interaction between interplanting systems and different sources of N fertilizer, the data demonstrate that plant height, the number of pods/plant, the seed yield/plant and the seed yield/fad in both seasons and 100-seed weight in the second season are all influenced by the two factors in a dependent manner. These findings suggest that the growth of lentils enhances rhizobial symbiosis in the topsoil, providing orange trees with more readily available fixed N compared to olive trees. Additionally, the fibrous roots of orange trees may face challenges in accessing water and mineral N fertilizer, unlike olive trees with deeper roots that can efficiently absorb mineral N in sandy soil. This symbiotic interaction between crops could potentially enhance agricultural productivity in similar environments. It is important for farmers to carefully consider the interaction between interplanting systems and N fertilizer sources to optimize seed yield.

With regard to olive crops, the significance between treatments for olive and orange fruit yields/fad vanished when different sources of N were introduced. Given that the olive fruits will be harvested in November, it is possible that the availability of N during the winter months encouraged vegetative growth[38], or the aerial portion of the fruit and as a result, increased fruit yield. Incorporating biological N fixation into the treatment comparisons could provide a more comprehensive understanding of the impact on olive fruit yield. Additionally, further research could investigate the specific mechanisms by which different N sources affect vegetative growth and fruit production in olive trees.

With respect to orange crop, the citrus tree's huge fruit yield is likely attributed to its high N requirements[39]. This highlights how important it is to consider the sources and requirements of nutrients when attempting to optimize crop output. Further research may be necessary to fully understand the relationship between orange tree fruit yield and N sources.

The different root systems can explain the results of competitive relationships. Olive trees have deeper, branched roots, while orange trees usually have a fibrous root system. Every tree has a taproot; however, an olive tree's taproot goes farther into the ground than an orange tree’s. This difference in root systems allows olive trees to access mineral N fertilizer and water from deeper soil layers, making them more resilient in sandy soil conditions. The growth of lentil in this area indicates that rhizobial symbiosis is enhanced in the topsoil, providing orange trees with more readily available fixed N than olive trees. This implies that cultivating lentil alongside orange trees could be a more sustainable and profitable option for farmers in sandy soil conditions. Conducting additional research on the symbiotic interaction between lentils and orange trees could offer valuable knowledge for agricultural practices in similar environments. On the other hand, orange trees with fibrous roots may struggle to reach mineral N fertilizer and water in the same environment. These results were in accordance with Selim *et al.*[17].

With respect to economic evaluation, the results reveal that interplanting lentil that a received full dose of mineral N fertilizer within olive trees is more profitable than solid plantings of olive and orange trees for Egyptian farmers. Under interplanting with orange trees, the application of rhizobia with a starter dose of mineral N fertilizer for lentil appears to be a successful strategy for maximizing land utilization and profitability in sandy soil conditions. These results were in the same context with Selim *et al.*[17].

CONCLUSION

Lentil grown with a full dose of mineral N fertilizer alongside olive trees, as well as lentil that received rhizobia with a starter dose of mineral N fertilizer within orange trees, demonstrated the highest land utilization and profitability in sandy soil conditions. These results indicate that integrating lentil with different tree types and fertilizer combinations can enhance land productivity in specific soil conditions. This study underscores the significance of considering multiple factors when developing agricultural systems for optimal efficiency and profitability.

SIGNIFICANCE STATEMENT

These findings suggest that planting lentil alongside specific tree species and utilizing appropriate fertilizer techniques is the most effective method to boost agricultural production in challenging soil conditions. Further research is needed to determine these practices' long-term sustainability and environmental implications. Additionally, assessing the financial feasibility of implementing these integrated agricultural methods would provide valuable insights for farmers and governments. Adopting a comprehensive approach in resource-constrained areas could offer a sustainable solution to improve livelihoods and food security in the long run.

REFERENCES

1. Ogundari, K., S.O. Ojo and I.A. Ajibefun, 2006. Economies of scale and cost efficiency in small scale maize production: Empirical evidence from Nigeria. J. Social Sci., 13: 131-136.
2. Zhang, B., H. Peng, Z. Deng and R. Tsao, 2018. Phytochemicals of lentil (*Lens culinaris*) and their antioxidant and anti-inflammatory effects. J. Food Bioactives, 1: 93-103.
3. Zafar, M., M. Maqsood, M.R. Anser and Z. Ali, 2003. Growth and yield of lentil as affected by phosphorus. Int. J. Agric. Biol., 5: 98-100.
4. Montejano-Ramírez, V. and E. Valencia-Cantero, 2024. The importance of lentils: An overview. Agriculture, Vol. 14. 10.3390/agriculture14010103.
5. Meng, L., W. Ding and Z. Cai, 2005. Long-term application of organic manure and nitrogen fertilizer on N_2O emissions, soil quality and crop production in a sandy loam soil. Soil Biol. Biochem., 37: 2037-2045.
6. Ghimire, B., S.C. Dhakal, S. Marahatta and R.C. Bastakoti, 2023. Technical efficiency and its determinants on lentil (*Lens culunaris*) production in Nepal. Farming Syst., Vol. 1. 10.1016/j.farsys.2023.100045.
7. Mansour, E., A.M.A. Merwad, M.A.T. Yasin, M.I.E. Abdul-Hamid, E.E.A. El-Sobky and H.F. Oraby, 2017. Nitrogen use efficiency in spring wheat: Genotypic variation and grain yield response under sandy soil conditions. J. Agric. Sci., 155: 1407-1423.
8. Omar, M., H.A. Rabie, S.A. Mowafi, H.T. Othman and D.A. El-Moneim *et al*., 2022. Multivariate analysis of agronomic traits in newly developed maize hybrids grown under different agro-environments. Plants, Vol. 11. 10.3390/plants11091187.
9. Abd El-hady, M.A., Y.M. Abd-Elkrem, M.O.A. Rady, E. Mansour, K.A. El-Tarabily, S.F. AbuQamar and M.E. El-temsah, 2022. Impact on plant productivity under low-fertility sandy soil in arid environment by revitalization of lentil roots. Front. Plant Sci., Vol. 13. 10.3389/fpls.2022.937073.
10. Kavvadias, V., M. Papadopoulou, E. Vavoulidou, S. Theocharopoulos and G. Koubouris *et al*., 2018. Effect of sustainable management of olive tree residues on soil fertility in irrigated and rain-fed olive orchards. J. Water Clim. Change, 9: 764-774.
11. Moghazy, N.H. and J.J. Kaluarachchi, 2020. Sustainable agriculture development in the western desert of Egypt: A case study on crop production, profit, and uncertainty in the Siwa Region. Sustainability, Vol. 12. 10.3390/su12166568.
12. Karydas, C.G., T. Sekuloska and G.N. Silleos, 2009. Quantification and site-specification of the support practice factor when mapping soil erosion risk associated with olive plantations in the Mediterranean island of Crete. Environ. Monit. Assess., 149: 19-28.

13. Zeleke, K.T., 2014. Water use and root zone water dynamics of drip-irrigated olive (*Olea europaea L.*) under different soil water regimes. New Zealand J. Crop Hortic. Sci., 42: 217-232.
14. Khattab, E.A. and E.A. El-Housini, 2019. Evaluation of some lentil varieties under sprinkler and dripping irrigation systems in newly reclaimed sandy soil. Iraqi J. Agric. Sci., 50: 753-758.
15. Wuest, S.E., R. Peter and P.A. Niklaus, 2021. Ecological and evolutionary approaches to improving crop variety mixtures. Nat. Ecol. Evol., 5: 1068-1077.
16. Phoomthaisong, J., B. Toomsan, V. Limpinuntana, G. Cadisch and A. Patanothai, 2003. Attributes affecting residual benefits of N_2-fixing mungbean and groundnut cultivars. Biol. Fert. Soils, 39: 16-24.
17. Selim, M.A.F., Y.A.A. Hefny, E.I. Abdel-Wahab and M.K.A. Mohamed, 2020. Interplanting some soybean cultivars with mandarin trees in sandy soil. Agric. Sci., 11: 88-110.
18. Amassaghrou, A., K. Barkaoui, A. Bouaziz, S.B. Alaoui, Z.E.A. Fatemi and K. Daoui, 2023. Yield and related traits of three legume crops grown in olive-based agroforestry under an intense drought in the South Mediterranean. Saudi J. Biol. Sci., Vol. 30. 10.1016/j.sjbs.2023.103597.
19. Rao, D.M.R., J. Kodandaramaiah, M.P. Reddy, R.S. Katiyar and V.K. Rahmathulla, 2007. Effect of VAM fungi and bacterial biofertilizers on mulberry leaf quality and silkworm cocoon characters under semiarid conditions. Caspian J. Environ. Sci., 5: 111-117.
20. Bajiya, R., H. Lakhran, S. Kumar and Seema, 2017. Biochar for enhancing agricultural sustainability under climate change. Int. J. Curr. Microbiol. Appl. Sci., 6: 1876-1883.
21. Andrews, M., J.A. Raven and P.J. Lea, 2013. Do plants need nitrate? The mechanisms by which nitrogen form affects plants. Ann. Appl. Biol., 163: 174-199.
22. Bremer, E., C. van Kessel and R. Karamanos, 1989. Inoculant, phosphorus and nitrogen responses of lentil. Can. J. Plant Sci., 69: 691-701.
23. Sonkarlay, E., E. Luikham and H.S. Athokpam, 2020. Effect of chemical fertilizer, organic manure and biofertilizer on nodulation, yield and economics of lentil (*Lens culinaris* L. Medik.). Int. J. Curr. Microbiol. Appl. Sci., 9: 2653-2662.
24. Zakeri, H., R.A. Bueckert, J.J. Schoenau, A. Vandenberg and G.P. Lafond, 2012. Controlling indeterminacy in short season lentil by cultivar choice and nitrogen management. Field Crops Res., 131: 1-8.
25. Fatima, K., S.A. Ganie, Y. Kumar, T.H. Masoodi and A. Shah, 2018. Effect of organic and inorganic fertilizer doses on growth and yield of lentil under cold arid conditions of Ladakh. Int. J. Curr. Microbiol. Appl. Sci., 7: 1449-1455.
26. Bradford, G.R., H.D. Chapman, P.F. Pratt and A.P. Vanselow, 1961. Methods of Analysis for Soils, Plants and Waters. University of California, Oakland, California, Pages: 309.
27. Mead, R. and R.W. Willey, 1980. The concept of a 'Land Equivalent Ratio' and advantages in yields from intercropping. Exp. Agric., 16: 217-228.
28. Adetiloye, P.O., F.O.C. Ezedinma and B.N. Okigbo, 1983. A Land Equivalent Coefficient (LEC) concept for the evaluation of competitive and productive interactions in simple to complex crop mixtures. Ecol. Modell., 19: 27-39.
29. Tripathi, S.C., K. Venkatesh, R.P. Meena, S. Chander and G.P. Singh, 2021. Sustainable intensification of maize and wheat cropping system through pulse intercropping. Sci. Rep., Vol. 11. 10.1038/s41598-021-98179-2.
30. Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons, Hoboken, New Jersey, ISBN: 9780471870920, Pages: 704.
31. Rivest, D., A. Cogliastro and A. Olivier, 2009. Tree-based intercropping systems increase growth and nutrient status of hybrid poplar: A case study from two Northeastern American experiments. J. Environ. Manage., 91: 432-440.
32. Johnston, A.E., 1999. Organic Manures and Mineral Fertilizers. In: Improved Crop Quality by Nutrient Management, Anac, D. and P. Martin-PrÉvel (Eds.), Springer, Dordrecht, Netherlands, ISBN: 978-0-585-37449-9, pp: 7-11.

33. Ladha, J.K., M.B. Peoples, P.M. Reddy, J.C. Biswas, A. Bennett, M.L. Jat and T.J. Krupnik, 2022. Biological nitrogen fixation and prospects for ecological intensification in cereal-based cropping systems. Field Crops Res., Vol. 283. 10.1016/j.fcr.2022.108541.
34. Mounika, S., B. Mehera, D. Sathvik and N. Chandan, 2022. Influence of bio fertilizers and zinc on growth and yield of lentil (*Lens culinaris* L.). Int. J. Environ. Clim. Change, 12: 788-793.
35. Naik, M.V. and V. Debbarma, 2022. Influence of nitrogen and boron on growth and yield of lentil (*Lens culinaris* Medikus.). Int. J. Plant Soil Sci., 34: 882-887.
36. Gopalakrishnan, S., A. Sathya, R. Vijayabharathi, R.K. Varshney, C.L.L. Gowda and L. Krishnamurthy, 2015. Plant growth promoting rhizobia: Challenges and opportunities. 3 Biotech, 5: 355-377.
37. Mendes, I.C., M. Hungria and M.A.T. Vargas, 2003. Soybean response to starter nitrogen and *Bradyrhizobium inoculation* on a Cerrado oxisol under no-tillage and conventional tillage systems. Rev. Bras. Ciênc. Solo, 27: 81-87.
38. Haberman, A., A. Dag, N. Shtern, I. Zipori, R. Erel, A. Ben-Gal and U. Yermiyahu, 2019. Significance of proper nitrogen fertilization for olive productivity in intensive cultivation. Sci. Hortic., 246: 710-717.
39. Ennab, H.A., M.A. El Shemy and M.H.A. El Aziz, 2019. Impact of organic and inorganic nitrogen fertilizers on Washington navel orange trees. II. Fruit quality during cold storage. Menoufia J. Plant Prod., 4: 415-427.