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Impact of Irrigation Intervals on the Yield and Quality of Lupine (*Lupinus termis* L.) Grown in Sandy Soil Amended by an Organic Amendment

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Authors' contributions

This work was carried out in collaboration between all authors. Authors FHAEA and SMAA designed the study, wrote the protocol, followed up the field work and managed the laboratory analyses of the study. Author RTR managed the literature searches, performed the statistical analysis and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Two field experiments have been carried out to study the effect of different irrigation periods in the presence of compost as an organic amendment on the yield and quality of lupine (*Lupinus termis L.*) under the sandy soil conditions.
Study Design: Split-plot design.
Place and Duration of Study: The successive winter seasons of 2016/2017 and 2017/2018 at the Ismailia Agricultural Research Station, (30°35'30" N 32°14'50" E elevation 3 m), Agricultural Research Center (ARC), Egypt.
Methodology: Compost has been applied at the rates of 11.90, 23.81 and 35.71 ton/ha before planting. Three irrigation intervals were assigned after planting by 3, 6, and 9 days; the applied water volume for each was 4761.91 m^3/ha.
Results: After harvesting, some parameters were estimated. As the compost rates increased, the soil EC significantly decreased while the available N, P, K, and Fe were significantly increased by

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9.51, 12.79, 5.17, and 5.8%, respectively. For same compost rate, the irrigation intervals (3, 6, and 9 days) significantly decreased the available N relatively by 2.88, 5.16, and 6.96%, respectively and the available K by 3.45, 5.06, and 4.37%, respectively. The 6 days interval showed that most significant increase in the seeds' content of nutrients at different compost rates and the seed yield has increased by 19.59, 22.31, and 21.88% for the compost rates of 11.90, 23.81, and 35.71 ton/ha, respectively. The relative increase was by 20.48, 7.63, 4.49, 10.89, and 14.92% for the crude protein, crude lipids, total ash, TSS and the amino acids, respectively. The effect of treatments on the relative shoot moisture (%) and the field water use efficiency (F.W.U.E.) (kg/m^3) was discussed.
Conclusion: The 6 days irrigation interval along with a compost application rate of 23.81 ton/ha can be recommended for lupine grown in sandy soil as they showed the most significant increase in the nutrients content of seeds by 22.31%.

Keywords: Irrigation intervals; compost; lupine; sandy soil; water use.

1. INTRODUCTION

Sandy soil is often deficient in the major soil nutrients leading to a decreased yield. Essential nutrients required for optimum plant growth are easily leached with the water depletion. Continuous and suitable fertilisation improve the productivity of such soil.

Compost is typically used as a sandy soil organic amendment to enhance the chemical, physical, biological properties, and water-holding capacity of the soil. It is not a fertiliser, although when used at normal rates it can reduce the required amount of the fertilisers. Compost has a medium to high carbon content good to build carbon in the soil. It contributes to the soil organic matter for enhanced soil fertility because it is a slow source of available nutrients – such as N and P. About one-third to half of the nutrients applied can be available within 1 to 2 months. Compost is a relatively stable and complete nutrient source for crops. Applying compost months before a crop planted is the best strategy. Decomposition occurs well before young plants are present and such application poses minimal risk to food safety [1].

Climate change predictions including temperature increases and drought in the semiarid regions and improving water use efficiency (WUE) is mandatory for global food production [2]. The efficient use of available irrigation water needs to be a priority due to the globe decrease in the water resources that resulted in a steep decline in the irrigation water availability. Deciding the critical time, frequency and amount of irrigation are necessary to achieve higher crop outputs. Several scientists have studied maximising the WUE by scheduling the irrigation and decreasing the supplemental irrigation during the initial growth stages of different crops such as wheat [3].

Moisture stress is one of the major factors that restrict the legumes yield which is widely used as a pre crop to improve soil fertility. Irrigation generally improves the yield of legumes but can also reduce the quality of the harvested seeds. The soil and climatic requirements of lupines vary considerably between cultivars, but in general, they will grow adequately where many other crops are limited due to low fertility of the soil. The moisture requirement of lupines is not high. Lupines prefer a moist, well-drained soil as well as a neutral to the slightly acidic soil, sandy to sand over clay soils and well-structured loam soils. They are tolerant of most other soils even those poor in nutrients but will not grow successfully in chalky soils [4].

There are two types of lupine: the narrow leaf species (*Lupinus angustifolius*) of higher protein better used as stock feed and the larger seeded and broader leaf *Lupinus albus* that is generally produced for the human consumption [5].

Water-use efficiency in lupine crops is lower than in cereal crops. The process of fixing nitrogen requires more energy and uses more water. Lupine has high protein content in its seed. Plants need more energy to produce 1 g of protein than to produce 1 g of carbohydrate. Protein production also requires more nutrients and water. Lupine has some adaptations to make it more water-use efficient [6].

The response of sweet lupine to different moisture levels had been investigated. There was a large response to irrigation during the dry season, and the yield increased significantly with increasing water applied up to the highest moisture level tested (five irrigations). The irrigation response was less in the wet season, and the highest moisture regime required three irrigations. The yield increased with moisture level but not significantly. Increasing the moisture stress decreased the seed yield [7].

Some studies indicated that there was no benefit from irrigation during the vegetative stage even when the soil moisture fell to wilting point. Irrigation during flowering and pod fill significantly increased the yield, and the optimum levels during such growth stages need to be determined. The seed yield of lupine is highly dependent on moisture conditions especially during flowering and pod filling [8].

Flowering in annual legumes is the most moisture sensitive growth stage. It was found that irrigation prior to flowering had no benefit but irrigation during flowering and pod swelling increased the yield greatly. This was mainly resulted from an increased number of lateral branches, bearing pods although the number of seed in each pod was also greater with irrigation. The 1000 seed weight showed variable trends. Irrigation during the vegetative phase caused earlier flowering; irrigation from the start of flowering prolonged flowering and delayed harvest [4,9].

Narrow-leaved lupine is one of the lupine species sometimes used as feed for animals. The influence of the tillage and irrigation factors on the quality of the harvested seeds was studied. Irrigation of the parent plant decreased germination of the harvested seeds and increased percentage of mouldy seeds. Reduced and no-tillage systems decreased the germination of seeds produced under irrigation conditions. There was no significant effect of soil tillage systems in the non-irrigated variant. However, higher moisture for the plants and seeds might increase infestation by fungi and moulds especially with minimum tillage [5].

The present study aims to study the impact of different irrigation intervals on the yield, and quality of lupine grown in the sandy soil amended by compost as an organic amendment. Compost has been applied at the rates of 11.90, 23.81 and 35.71 kg/ha 20 days before planting. Three irrigation intervals were assigned after 3, 6, and 9 days.

2. MATERIALS AND METHODS

Two field experiments have been carried out during the two successive winter seasons of 2016/2017 and 2017/2018 at the Ismailia Agricultural Research Station (30°35' 41.9" N latitude 32°16' 45.8" E longitude elevation 3 m), Agricultural Research Center (ARC) - Egypt. The aim was to study the effect of the different irrigation periods in the presence of compost at different rates on the yield and quality of lupine grown in the sandy soil (TypicTorripsamment; Entisol [Arenosol AR] [10]). Soil samples before planting were air dried, finely ground then sieved by a 2 mm sieve and kept for analysis. Some of the physical and chemical properties of the experiment soil were estimated [11,12] and presented in Table 1.

Table 1. Some characteristics of the experiment soil before cultivation

Particle size distribution (%)						
Coarse sand	**Fine sand**		**Silt**		**Clay**	
10.85	72.00		5.17		11.98	
Texture class					Loamy sand	
$CaCO_3$ (%)					2.65	
Organic Matter (OM, %)					0.63	
pH (1:2.5 soil : water suspension)					7.89	
Electrical Conductivity (EC, dS/m) (1:5 soil : water extract)					1.45	
SAR					4.23	
Anions (meq/l)			**Cations (meq/l)**			
HCO_3^-	**Cl^-**	**SO_4^{--}**	**Ca^{++}**	**Mg^{++}**	**Na^+**	**K^+**
1.40	6.94	6.16	3.85	1.64	8.22	0.79
Available nutrients (mg/kg)						
Macronutrients				**Micronutrients**		
N	P	K		Fe	Mn	Zn
39.52	4.23	165		2.85	1.20	0.61

2.1 Planting

Treatments were organized in a split plot design. The plot area was 5 m × 10 m divided into rows 50 cm apart with three replicates. Compost as an organic amendment has been applied at the rates of 11.90, 23.81 and 35.71 ton/ha 20 days before planting. Some characteristics of the applied compost are presented in Table 2.

The soil was fertilized by the superphosphate (15.5% P_2O_5, 476.19 kg/ha application rate) during the soil tillage.

Sowing of lupine (*Lupinus termis* L., cv. Giza 2) was performed on the 15th of November 2016 and 25th of November 2017. The seeds had been hand sown 2-3 seeds/hill of 5 cm depth and 20 cm apart. The plants were thinned to one plant after 15 days of planting. Three irrigation intervals were assigned after 3, 6 and 9 days; the applied water volume for each is 4761.91 m^3/ha (≈ 2000 m^3/fed. The quantity of the irrigation water was controlled by a water meter fixed on the irrigation pipe. The irrigation water used in the study was from the Ismailia canal, and Table (3) shows its chemical composition. Samples from the irrigation water have been taken and analysed during December, February, March, and April for both seasons [11].

Urea (46% N) was applied at the rate of 95.24 kg N/ha in three equal doses after 21, 49, and 60 days of planting. Potassium sulphate (48% K_2O) was applied at the rate of 119.05 kg/ha in two equal doses after 21 and 45 days of planting according to the Ministry of Agriculture recommendation.

After harvesting, a random sample of 10 plants from each plot was collected and air-dried. Some of the growth parameters such as plant height (cm), number of branches/plant and the number of pods/plant were recorded. Yield components such as the weight of the fresh and dry shoot (g/plant), the weight of 100 seeds (g) and the seed yield (ton/ha) have been calculated according to the total seed yield per plot area and the mean of the two seasons was recorded.

2.2 Analysis of Plant and Soil Samples

Lupine seeds were dried at 70 ºC for 72 h and ground. A half gram of ground seeds was wet digested using the acid mixture (1:1 $H_2SO_4/HClO_4$) [13]. After harvesting, the soil pH and EC were measured. The soil available N, P, K were extracted by 1% K_2SO_4, 0.5 N $NaHCO_3$, and 1 N NH_4OAc (pH 7.0), respectively. The total percentage of N, P and K in the digested plant samples and the available in the soil extracts were estimated by distillation using Kjeldahl apparatus, colorimetrically by UV-Vis. Spectrophotometer using SnCl2 indicator and by a flame photometer, respectively [14,15]. The soil available and seed's total content of Fe, Mn and Zn were measured for both by Inductively Coupled Plasma Spectrometry (ICP-*Ultima 2 JY Plasma*).

Crude protein (%) was calculated as the (N, %) × 6.25 [16]. The total lipid content (%) was estimated as follows: 1-2 g of the dried samples were accurately weighed, and extracted by petroleum ether for 15 h in a Soxhlet apparatus (60-80°C). Then, the solvent was evaporated under reduced pressure, and the total lipids content was weighed [17]. The TSS content (%) was determined using the phenol sulphuric acid method according to Dubois et al. [18]. The total amino acid (g/100 g dry weight) content was estimated according to the methods described by Rosen [19].

Table 2. Chemical composition of the compost used in the study

pH	EC	O.C.	(%)			C/N	(mg/kg)		
(1:10)	(dS m^{-1})	(%)	N	P	K	(%)	Fe	Mn	Zn
7.65	3.16	32.31	1.50	0.21	2.14	21.54	75.96	145.25	68.25

Table 3. Chemical composition of the irrigation water used in the study

pH (1:2:5)	EC	Anions (meq/l)			Cations (meq/l)			
	(dS/m)	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
7.75	0.85	1.69	1.85	4.96	2.40	1.89	3.49	0.75

Macronutrients (mg/kg)				Micronutrients (mg/kg)		
N(as NO_3^-)	N(as NH_4^+)	P	K	Fe	Mn	Zn
15.66	8.75	3.50	6.90	1.65	1.20	0.083

2.3 Relative Moisture and Field Water Use Efficiency (F.W.U.E.)

The relative moisture content (%) of the lupine shoots for the different treatments was calculated as follows:

$$Relative\ moisture\ content\ (\%) = \frac{Fresh\ wt.\ (g) - Dry\ wt.\ (g)}{Fresh\ wt.\ (g)} \times 100 \quad (1)$$

Field water use efficiency sometimes termed as Irrigation water use efficiency (IWUE) Singh et al. [20] is the crop yield produced (kg/ha) per the applied volume of the irrigation water (m^3/ha). It was calculated by the following equation [21,22]:

$$F.W.U.E.\ (kg/m^3) = \frac{Yield\ (kg/ha)}{Water\ applied\ (m^3/ha)} \quad (2)$$

2.4 Statistical Analysis

The statistical significance of the treatment effects at a significance level of $P = .05$ has been obtained using the one-way analysis of variance (ANOVA) carried out using the Co-State software (Ver. 6.311) [23].

3. RESULTS AND DISCUSSION

3.1 Impact of the Irrigation Intervals on Some Properties of the Studied Soil

The variation in the soil pH, EC, available macro- and micro-nutrients under the effect of the different treatments are presented in Table 4. Neither compost rates nor irrigation intervals significantly changed soil pH, available Mn or Zn. Both factors; compost rates and irrigation significantly affected available N and K. Compost rates significantly affected soil EC, available N, P, K, and Fe. The relative increase or decrease was calculated by the difference percentage between the minimum and maximum compost rate or irrigation interval relative to the minimum. As the compost rates increased, the soil EC significantly decreased (relatively by 11.54%) while the available N, P, K, and Fe were significantly increased by 9.51, 12.79, 5.17, and 5.8%, respectively. The increase in the available Mn and Zn was non-significant. Compost has been stated previously as a promising sandy soil amendment that improves soil nutritional status [24].

Irrigation intervals significantly decreased available N and K only. For the compost rates 11.90, 23.81, and 35.71 ton/ha the available N have relatively decreased due to the irrigation intervals by 2.88, 5.16, and 6.96%, respectively while the available K has significantly decreased by 3.45, 5.06, and 4.37%, respectively. The effect of the interaction between the compost rates and the irrigation intervals was non-significant for soil pH, EC, available NPK and Fe, Mn, and Zn. Both studied factors were independent with respect to the soil.

3.2 The Macro- and Micro-nutrients Content in the Lupine Seeds

Table 5 shows the total content of the NPK, Fe, Mn, and Zn for the lupine seeds affected by the studied factors. The increased compost rates significantly increased the concentration of NPK and Fe, Mn, and Zn in the lupine seeds. Phosphorus and K were less affected than N, Fe, Mn, and Zn. Also, the studied irrigation intervals significantly affected the estimated nutrients except for P. The relative increase resulting from the compost rate 35.71 ton/ha was by 25.77, 23.08, 31.29, 9.52, 5.31, and 12.27% for the NPK and Fe, Mn, and Zn, respectively.

The irrigation at 6 days interval resulted in the most significant increase in the seeds' content of nutrients that were decreased when the irrigation interval increased to 9 days. The interaction between the compost rates and the irrigation intervals showed no significant effect on the seeds' content of nutrient except for the total N and Mn. A global meta-analysis shows that in dry climates, crop yields sometimes declined in irrigated conditions because irrigated crops have a higher energy demand than others [25].

3.3 Growth Parameters and Yield Components of Lupine Plant

Some of the growth parameters and yield components for the lupine were estimated, and the results are included in Table 6. For the studied compost rates, plant height (cm) and number of pods/plant were the most significantly affected followed in Table 5.

By the seed yield (kg/ha) then the number of branches/plant, shoot fresh weight (g), and the 100-seed weight. The variation in the shoot dry weight (g) was non-significant. The 35.71 ton/ha rate of compost resulted in the highest relative increase in the number of pods/plant by 20.1%, shoot dry weight (g) by 26.5%, the 100-seed weight (g) by 10.7%, and seed yield (kg/ha) by 16.11%. The compost application has been highly effective in increasing the lupine yield [26].

The variation due to the irrigation intervals was highly significant for the plant height, a number of pods/plant, shoot fresh weight (g) and the seed yield (kg/ha). Lower significance was observed for the number of branches/plant and the shoot dry weight (g) followed by the 100-seed weight (g). As mentioned above, the 6-days irrigation interval showed the maximum value for the estimated growth and yield parameters. At an irrigation interval of 6 days, the seed yield has increased by 19.59, 22.31, and 21.88% for the compost rates 11.90, 23.81, and 35.71 ton/ha, respectively. The interaction between the compost rates and the irrigation intervals was non-significant for the estimated growth parameters (except for the plant height, cm) and yield components.

It has been stated previously that irrigation increased lupine yields mainly through the production of a greater number of pod bearing lateral branches with an additional small increase in the number of seed in each pod [7].

Table 4. Soil pH, EC and available macronutrient in soil after harvest

Compost rates (ton/ha)	Irrigation intervals (days)	pH (1:2.5)	EC (dSm^{-1})	Macronutrients (mg/kg)			Macronutrients (mg/kg)		
				N	P	K	Fe	Mn	Zn
11.90	**3**	7.85	1.30	41.32	4.69	174	2.93	1.36	0.69
	6	7.86	1.35	40.56	4.48	169	2.90	1.30	0.65
	9	7.88	1.39	40.13	4.45	168	2.88	1.27	0.63
L.S.D. $_{5\%}$		**0.09**	**0.08**	**1.03**	**0.19**	**3.87**	**0.08**	**0.1**	**0.12**
23.81	**3**	7.80	1.22	43.18	5.14	178	2.98	1.42	0.74
	6	7.82	1.25	41.63	5.08	170	2.96	1.39	0.69
	9	7.84	1.27	40.95	4.98	169	2.94	1.34	0.66
L.S.D. $_{5\%}$		**0.09**	**0.12**	**1.38**	**0.29**	**6.98**	**0.06**	**0.15**	**0.09**
35.71	**3**	7.79	1.15	45.25	5.29	183	3.10	1.53	0.79
	6	7.81	1.17	43.62	5.18	180	3.00	1.48	0.75
	9	7.82	1.19	42.10	5.10	175	2.99	1.43	0.72
L.S.D. $_{5\%}$		**0.09**	**0.12**	**1.38**	**0.29**	**6.98**	**0.06**	**0.15**	**0.09**
Significance of factors									
Compost rates		ns	*	**	*	*	*	ns	ns
Irrigation intervals		ns	ns	**	ns	**	ns	ns	ns
Compost rates*Irri. Int.		ns	ns	ns	ns	ns	ns	ns	ns

Table 5. Macro- and micro-nutrients concentration in the lupine seeds

Compost rate (ton/ha)	Irrigation intervals (days)	Macronutrients (g/kg)			Micronutrients (mg/kg)		
		N	P	K	Fe	Mn	Zn
11.90	**3**	38.8	5.2	15.5	69.93	92.49	52.89
	6	42.5	5.5	19.5	72.48	96.54	55.90
	9	35.5	4.9	14.5	64.90	89.40	50.29
L.S.D. $_{5\%}$		**1.19**	**1.19**	**0.97**	**0.68**	**0.68**	**1.19**
23.81	**3**	43.0	5.9	16.9	72.58	95.29	53.82
	6	49.7	6.4	19.9	75.20	98.50	58.99
	9	41.0	5.3	16.0	68.40	93.88	54.30
L.S.D. $_{5\%}$		**2.57**	**0.87**	**1.51**	**0.87**	**0.87**	**0.87**
35.71	**3**	48.8	6.4	18.8	76.59	97.40	56.40
	6	51.2	7.3	21.4	79.99	99.85	60.37
	9	47.7	6.0	17.5	74.20	96.10	55.12
L.S.D. $_{5\%}$		**2.57**	**0.87**	**1.51**	**0.87**	**0.87**	**0.87**
Significance of factors							
Compost rates		***	*	*	***	***	***
Irrigation intervals		***	ns	***	***	***	***
Compost rates*Irri. Int.		*	ns	ns	ns	*	ns

Table 6. Growth parameters and yield components of lupine plant

Compost rate (ton/ha)	Irrigation intervals (days)	Plant height (cm)	No of branches /plant	No of pods/ plant	shoot wt. (g/plant) Fresh	shoot wt. (g/plant) Dry	100 seed wt. (g)	Seed yield (kg/ha)
11.90	**3**	65.84	4.85	18.62	25.89	6.15	25.61	1640.5
	6	74.39	5.12	22.38	27.63	8.38	28.34	1961.9
	9	52.47	4.34	19.85	22.14	5.85	23.16	1881.0
L.S.D. $_{5\%}$		**0.97**	**0.68**	**1.19**	**0.68**	**1.19**	**0.68**	**285.7**
23.81	**3**	70.35	5.69	21.52	27.34	6.59	27.85	1750.0
	6	79.52	6.47	25.47	30.48	8.98	30.14	2140.5
	9	67.32	4.95	20.34	24.52	6.18	24.63	1928.6
L.S.D. $_{5\%}$		**1.51**	**1.15**	**0.87**	**2.3**	**0.87**	**0.87**	**214.3**
35.71	**3**	79.34	6.25	22.36	28.50	7.78	28.35	1904.8
	6	89.52	7.35	27.41	32.64	9.08	32.66	2321.4
	9	72.30	5.45	22.38	25.96	6.40	26.48	2207.1
L.S.D. $_{5\%}$		**1.51**	**1.15**	**0.87**	**2.3**	**0.87**	**0.68**	**214.3**
Significance of factors								
Compost rates		***	*	***	*	ns	*	**
Irrigation intervals		***	**	***	***	**	*	***
Compost rates*Irri. Int.		***	ns	ns	ns	ns	ns	ns

Additionally, Stoker had stated that no benefit was obtained from irrigation prior to flowering but irrigation during flowering and pod swelling increased yield greatly. Increase in yield was mainly the result of an increase in the number of lateral branches bearing pods although the number of seed in each pod was also significantly greater with irrigation [4]. Early flowering and pod formation were significantly correlated with seed yield. Fast rates of seed growth were highly and significantly correlated with high yields [9].

Previous studies revealed that irrigation of the parent plant decreased the germination of harvested seeds and increased the mouldy seeds. The dry weight of seedlings from seeds produced under the irrigation treatments was significantly lower [5].

Water quality (Table 2) significantly affected both the yield and water use efficiency (WUE). Using good irrigation water show quite valuable effects in storing irrigation water and then enhance the root growth and the yield [27].

3.4 Effect of the Compost Rates and Irrigation Intervals on Some Quality Parameters of the Lupine Seeds

The content of the lupine seeds from the crude protein (%), crude lipids (%), total ash (%), TSS (%) and the amino acids (mg/g f.wt) was estimated under the effect of the compost rates and irrigation intervals (Table 7). The maximum significant values obtained for the estimated quality parameters belonged to the maximum applied rate of compost; 35.71 ton/ha, at the 6-days irrigation interval. The relative increase was by 20.48, 7.63, 4.49, 10.89, and 14.92% for the crude protein, crude lipids, total ash, TSS and the amino acids, respectively. Increasing the irrigation interval to 9 days resulted in a decrease in the estimated quality parameters. High significance was observed for the effect of the studied factors on the crude protein and the amino acids followed by the TSS (%) in the lupine seeds [28].

The effect of the compost rates and irrigation intervals, as well as the effect of their interaction on the seeds' crude lipids and the total ash, was non-significant.

3.5 Relative Moisture and Field Water Use Efficiency (F.W.U.E)

3.5.1 Relative moisture

The relative moisture (%) values calculated for the lupine shoots were shown in Fig. 1. Increasing the irrigation intervals from 3 to 9 days decreased the relative moisture of the lupine shoots from 76 to 74% and from 76 to 75% but increased it from 73 to 75% for compost applied at rates of 11.90, 23.81 and 35.71 ton/ha, respectively. In other words, increasing the compost application rate from 11.90 to 35.71

ton/ha with same irrigation interval decreased the relative moisture (%) from 76 to 73% for the 3-days but increased it from 70 to 72% and from 74 to 75%, for the 6 and 9-days intervals, respectively.

Such behaviour has been explained earlier by Carminati [29]. He stated that when the plant roots absorb water, the soil dries and water depletion is expected to occur in the *rhizosphere*. Studies showed that the lupine rhizosphere was wetter than the bulk soil during the drying status. Surprisingly, the rhizosphere remained temporarily dry after irrigation. A water dynamics in the rhizosphere may include the drying/wetting dynamics of mucilage exuded by roots. Such mucilage may possess a capacity to hold large volumes of water at negative water potential enhancing water uptake by the root. The mucilage hydrophobicity after drying may temporarily limit the local water uptake after irrigation. The rhizosphere dynamics vary along roots and as a function of the soil water content. The root systems of lupines during drying/wetting cycles of different duration have been studied. A fast and almost immediate rewetting of the rhizosphere of the distal root segments was suggested. The rewetting rate of the rhizosphere was a function of time (decreases with time) not a function of the water content before irrigation. The rhizosphere variability may be an adaptation strategy to increase the water uptake of young root segments [29].

3.5.2 <u>Field water use efficiency (F.W.U.E)</u>

Fig. 2 indicates the estimated F.W.U.E (kg/m^3) for the different treatments in the present study. It was found that at same irrigation interval, the F.W.U.E (kg/m^3) has increased as the compost rate increased from 11.90 to 35.71 ton/ha. The increase ranges were 0.34-0.40, 0.41-0.49, and 0.40-0.46 kg/m^3 for the 3, 6, and 9 days irrigation intervals, respectively.

The 6 days interval showed the maximum F.W.U.E (kg/m^3) for the compost rates 11.90, 23.81, and 35.71 ton/ha. This is in agreement with the optimum results obtained in the present study for the lupine yield (kg/ha) and its estimated quality parameters. This can be explained on the basis of the earlier statement that water use efficiency (WUE) decreases under severe water deficit [30]. Water stress affects the physiological mechanisms in the plant. A range of toxic reactive oxygen species (ROS) may be produced during photosynthesis, photorespiration and dark respiration, resulting in cell damage. They may combine with the vital molecules, such as fats, proteins, nucleic acids, leading to lipid peroxidation, and DNA mutation. Cellular membranes and organelles such as mitochondria and chloroplasts are affected causing the leakage of the cellular content outside the cell. This, in turn, inhibits the crop yield and quality [31-33].

Table 7. Effect of the compost rates and irrigation intervals on some quality parameters of the lupine seeds

Compost rate (ton/ha)	Irrigation intervals (days)	Crude protein (%)	Crude lipids (%)	Total ash (%)	TSS (%)	Amino acids (mg/g f.wt)
11.90	**3**	24.25	12.78	3.50	19.40	35.98
	6	26.56	13.90	3.79	22.41	37.60
	9	22.19	11.40	3.41	18.80	32.90
L.S.D. $_{5\%}$		**1.19**	**19.19**	**0.78**	**0.97**	**0.98**
23.81	**3**	26.88	12.89	3.59	20.53	38.99
	6	31.06	14.00	3.86	23.89	41.20
	9	25.63	12.77	3.50	19.85	37.40
L.S.D. $_{5\%}$		**0.87**	**24.82**	**1.97**	**1.57**	**1.55**
35.71	**3**	30.50	13.20	3.66	22.98	40.33
	6	32.00	14.96	3.96	24.85	43.21
	9	29.81	13.10	3.60	20.51	38.50
L.S.D. $_{5\%}$		**0.87**	**24.82**	**1.97**	**1.57**	**1.55**
Significance of factors						
Compost rates		***	ns	ns	*	**
Irrigation intervals		***	ns	ns	***	***
Compost rates*Irri. Int.		ns	ns	ns	ns	ns

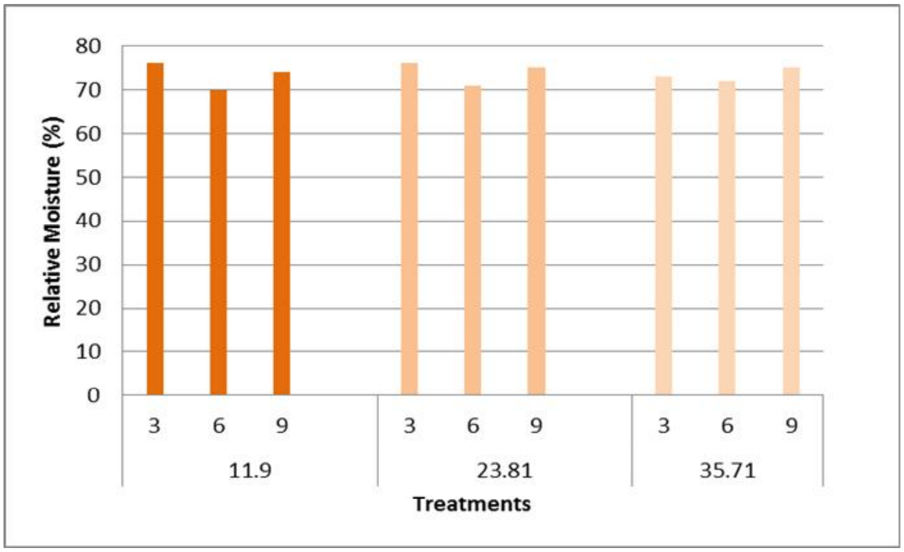

Fig. 1. Effect of the compost rates and irrigation intervals on the relative moisture of the lupine shoots

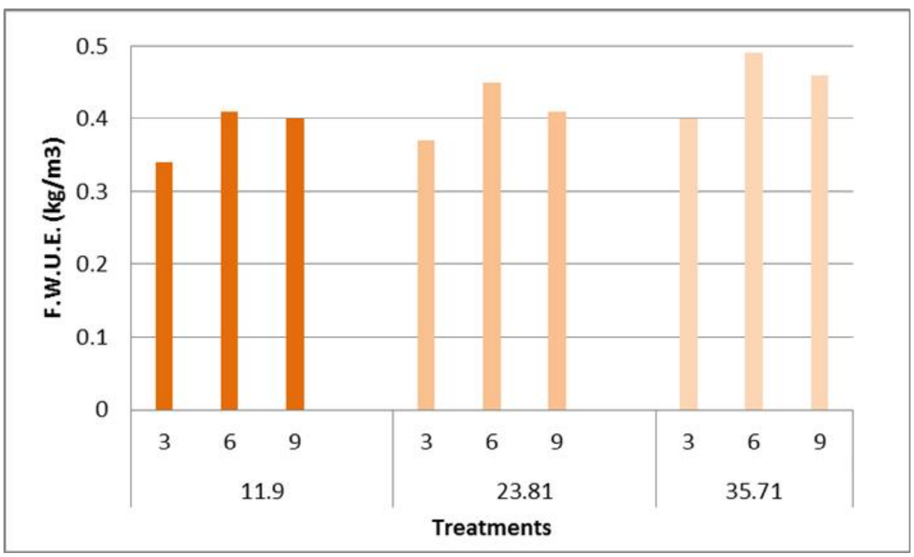

Fig. 2. Effect of the compost rates and irrigation intervals on the field water use efficiency F.W.U.E. (kg/m^3)

4. CONCLUSION

Lupine seeds were grown under the sandy soil conditions using compost rates (11.90, 23.81 and 35.71 ton/ha) with irrigation intervals (3, 6 and 9 days). The applied compost at a rate of 35.71 ton/ha, with the 6-days irrigation interval showed the most significant values estimated for the seeds' percentage of the crude protein, crude lipids, total ash, TSS and the amino acids (mg/g f.wt). Increasing the irrigation intervals from 3 to 9 days decreased the relative moisture for the lupine shoots from 76 to 74% and from 76 to 75% but increased it from 73 to 75% for compost applied at rates of 11.90, 23.81 and 35.71 ton/ha, respectively. The 6 days interval showed the maximum F.W.U.E (kg/m^3) for the compost rates 11.90, 23.81, and 35.71 ton/ha. This is in agreement with the optimum results obtained in the present study for the lupine yield (kg/ha) and its estimated quality parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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