Journal of Agricultural Science and Engineering
Vol. 1, No. 3, 2015, pp. 108-113
http://www.aiscience.org/journal/jase

The Effects of Deficit Irrigation Regimes on Yield and Growth Components of Linseed (*Linum Usitatissimum* L.)

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Abstract

A field study was carried out in order to determine the effect of deficit irrigation regime on grain and oil yield, seasonal evapotranspiration, yield response to water, water use efficiency and linseed (*Linum usitatissimum* L.) growth in Trakya region, Turkey. The field trials were conducted on a clay loam Entisol soil with Raulin, regionally most popular variety. The trials experimental design was randomized complete blocks with three replications. Three well-known growth stages of the plant were considered and total of 8 irrigation treatments (including rain). The effect of irrigation and water stress at any stage of development was studied on the following variables: grain yield per hectare, tgrain weight, oil yield and plant growth. For the non-stressed treatment, the seasonal irrigation water use and evapotranspiration were 270 and 730 mm, respectively, and linseed grain yield was 2.85 t/ha. The seasonal yield response factor value was 1.32. The total water use efficiency was in the range 3.0 to 4.1 kg/ha/mm depending on the deficit irrigation regime. Results showed that linseed was significantly affected by water stress during the sensitive flowering stage (include statistic results), with the highest yield obtained from non-stressed treatment during the flowering, yield formation and ripening stages.

Keywords

Evapotranspiration, Deficit Irrigation, Linseed, Grain Yield, Yield Response to Water, Plant Growth Components

Received: April 10, 2015 / Accepted: May 3, 2015 / Published online: June 23, 2015

1. Introduction

Linseed is one of the ancient cultural plants in the earth and basically is used in two forms: oil and fibber. It was first grown for fibber but then its usage area expanded in time and although linseed is still considered as a fibber plant, the oil production is nowadays more important, covering an area of about 1.5 million ha and 5.0 million ha, respectively (Ugur and Arslan, 1997; Tuncturk, 2007).

Linseed seeds contain 30-40% olive. The oil has a high commercial value with outstanding features and is used for dye industry. The remaining pulp after the extraction of oil is a valuable animal food (Gencer, 1993). Linseed oil, also rich in Omega-3, is consumed as cooking oil especially when the linolenic acid content is reduced below the threshold value of 3% (Schuster, 1992).

Linseed cultivation has been increasing recently in Mediterranean Region, as well as in Turkey. Linseed production in the crop rotation is subsidized by the Turkish government for a sustainable farming. Limited water resources in the area inevitably lead to deficit of irrigation. Deficit irrigation can be defined as an agricultural water management system in which less than 100% of the potential evapotranspiration can be provided by a combination of stored soil water, rainfall and irrigation, during the growing season. As water supplies decline and the cost of water increases, it is clear that producers are being driven toward deficit irrigation management, and some level of plant water stress is unavoidable. The challenge is to define a

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management system that will minimize the negative impact of the expected stress. Irrigation management requires choosing the timing and amount of water to be applied, optimizing the timing and degree of plant stress, within the restriction of available water. (Pereira et al., 2002; Fereres and Soriano, 2007; Geerts and Raes, 2009).

Linseed growth under full irrigation conditions is sufficiently investigated locally and globally. Because each field crop shows different sensitivity to water stress at different phenological stages (Kirda, 2002), it is necessary to know the response of linseed to water deficit.

The purpose of the present study is to investigate the seasonal evapotranspiration, irrigation water requirement, water use-production functions, water use efficiency, growth components, oil content and the response of linseed yield to water deficit during flowering, yield formation and ripening stages, with a view to reducing irrigation applied with a minimum of yield loss.

2. Materials and Method

2.1. Site Description

Field experiments were conducted at the Agricultural Faculty of Tekirdag Province located at Thrace Region in Turkey (40°59' N latitude, 27°35' E longitude) during the years 2013 and 2014. The experimental area was 500 m from Marmara Sea with an altitude of 30 m.

The climate of Tekirdag is Mediterranean type with mild and rainy winters and hot and dry summers at the coast while continental type prevails inland. The long-term (1975-2014) averages of annual temperature, relative humidity, wind speed, sunshine duration and total annual precipitation are 13.8 °C, 75%, 2.8 m/s, 5.83 h and 579.7 mm, respectively (Anonymous, 2015). Daily climatic parameters measured at a weather station located adjacent to the experimental site were: monthly temperature, relative humidity, wind speed, precipitation and sunshine duration, during the experimental years are given in Table 1.

Table 1. Some climate parameters during the 2013-2014 in the experimental area.

Months	Climatic parameters									
	Temperature (°C)		Humidity (%)		Wind speed (m/s)		Precipitation (mm)		Sunshine (h)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
January	8.2	3.6	90.7	78.5	2.9	3.0	18.4	20.2	4.9	4.2
February	7.2	4.9	92.9	77.3	2.8	2.5	33.2	18.5	2.9	4.5
March	9.1	10.9	92.1	74.0	2.6	2.8	42.8	56.2	4.4	5.8
April	11.5	14.0	85.0	74.2	2.2	2.3	17.4	20.1	8.3	5.4
May	18.4	17.3	88.3	69.4	2.0	2.2	45.9	18.9	8.1	9.6
June	24.2	22.4	78.4	68.8	2.5	2.4	9.1	9.8	10.0	9.8
July	26.0	24.4	68.1	62.1	2.6	2.9	-	12.0	10.9	10.1
August	25.5	25.3	76.4	64.6	2.6	2.6	3.1	1.2	8.1	8.9
September	19.1	20.1	84.5	70.5	3.1	2.7	33.1	29.5	6.7	7.1
October	17.0	16.2	90.5	75.7	2.7	2.7	41.3	55.1	4.5	6.1
November	10.2	12.4	84.4	80.2	2.7	3.1	242.0	39.5	3.2	3.9
December	5.8	7.9	77.9	79.9	1.4	2.7	60.2	23.2	3.5	-
Annual	15.2	15.0	84.1	72.9	2.5	2.7	546.5	304.2	6.3	6.3

2.2. Experimental Design

Soils of the experimental field are textured clay–loam (46.0% sand, 22.0% silt and 32.0% clay) on the top of Entisol ordo, prevalent in the region (Anonymous, 2010). Soil moisture characteristics such as field capacity, permanent wilting point, bulk density and available water holding capacity were determined at the experimental site. The areas do not have boron, salt, sodium or drainage problems. Irrigation water quality is C_2S_1 (electrical conductivity is 0.5 dS/m and sodium adsorption ratio is 7.0).

Raulin, the most popular linseed variety in the Region (OCP, 2007), was sown in the plots on 01 November 2012 and 20 October 2013. Each experimental plot was 3.0 m wide x 5.0 m long (twenty rows per plot) at sowing and plant spacing on the row was 15 cm, adjusted to provide 550 plants per square meter for the use of a pneumatic sow machine (Kurt et al., 2006). Nitrogen and phosphorus fertilizer at 100 kg N/ha and 100 kg P_2O_5/ha were applied before sowing each year. Since the soil analysis results pointed out for the sufficient level of the potassium in the soil, no additional fertilization was applied. Winter wheat had been growing in the experimental site before the experiment.

2.3. Irrigation Treatments and Water Use

In the selection of irrigation treatments, three different growth stages of linseed were considered: flowering (F, approximately 50% level, on the 172–185th days from sowing), yield formation (Y, seed filling, on the 197–216th days from sowing) and ripening (R, on the 213–230th days from sowing/before 22-24 days from harvest). Water application stages were determined according to Doorenbos and Kassam (2008). The treatments were as follows: rain fed (non-irrigation), irrigation at flowering stage (F), irrigation at yield formation stage (Y), irrigation at ripening stage (R), irrigations at flowering and yield formation (FY), irrigations at flowering and ripening (FR), irrigations at yield formation and ripening (YR), irrigations at flowering, yield formation and ripening (FYR). The treatment of FYR was the control. Field trials design was the randomised complete block design, with three replications.

All the experimental treatments were irrigated at the same time as the FYR treatment, being watered at each growth period with the amount of irrigation water required to fill the 0–90 cm soil depth to field capacity. Individual treatments were treated similarly expect for omitting the irrigation application at a specific growth stage. Weekly soil moisture content of the plots was determined gravimetrically in the soil layers 0–30, 30–60 and 60–90 cm during the whole growing season (from sowing to harvest). Water applied to each experimental plot was measured using a flowmeter connected to an irrigation pipe. The plots were irrigated by furrow. Irrigation water amounts applied to each experimental treatment as well as data concerning the application date are presented in Table 2.

Table 2. Irrigation water quantities applied to linseed at different stages of the experimental years.

Experimental years	Water application	Stage of development			Total stage
		Flowering (F)	Yield formation (Y)	Ripening (R)	
2013	Application date[a]	172	197	213	237
	Irrigation water (mm)	64	97	114	
2014	Application date[a]	185	216	230	252
	Irrigation water (mm)	76	92	96	
Average	Application date[a]	178,5	206,5	221,5	244,5
	Irrigation water (mm)	70	94,5	105	

[a], Days after sowing

Evapotranspiration (ET) from each plot was determined using the soil water balance equation: ET = P + I + R + SD + D, where P is the precipitation (mm), I is the irrigation water amount (mm), R is the runoff/runon (mm), SD is the soil water depletion (mm) and D is the drainage (mm) below the root zone. Runoff/runon was considered zero because the experimental plots were surrounded with dikes. Soil water depletion was calculated as the difference between soil water content values at the beginning and end of each period for a soil depth of 90 cm. Drainage below the root zone was assumed to be zero, since water applied with each irrigation was equal to water deficit in the 0–90 cm soil profile of the fully irrigated treatment (FYR).

All the experimental treatments were harvested at the same time as the FYR treatment, on 26 June 2013 and 30 June 2014. The grains of approximately 0.25 kg per plot were oven-dried to constant weight at 65 °C and re-weighed to determine the water content. The grain yields were converted to a standard grain water content of 10%. Total grain yield and 1000–grain weight were measured. Plant growth components of linseed were measured at the harvest time.

Data was subjected to an ANOVA and regression analysis using the procedure given by Yurtsever (1984) and Duncan mean separation test procedure was applied. First ANOVA and application of Duncan tests were done on the data for the treatments of each year separately. Then, the same procedure was performed for both trial years together after the homogeneity test showing that there was no statistically significant difference between them. Regression was used to evaluate water use–yield relationships using seasonal evapotranspiration and grain yield data obtained from the experiment. Seasonal values of the yield response factor (k_y) for each experimental year was determined using the Stewart model (Stewart et al., 1977).

$$1-\left(\frac{Y_a}{Y_m}\right)=k_y\left[1-\left(\frac{ET_a}{ET_m}\right)\right] \quad (1)$$

where Y_a is the actual harvested yield (obtained from all the treatments), Y_m is the maximum harvested yield (obtained from fully irrigated control), k_y is the yield response factor, ET_a is the actual evapotranspiration and ET_m is the maximum evapotranspiration. In this study, ET of fully irrigated control treatment (FYR) was taken as ET_m whereas ET from the other treatments was defined as ET_a. While total water use efficiency (TWUE) was calculated from ratio of grain yield and total water use. Irrigation water use efficiency (IWUE) was calculated from ratio of grain yield and irrigation water use (Unger et al., 2006; Fereres and Soriano, 2007).

3. Results and Discussion

3.1. The Effect of Water Stress on Grain and Oil Yield

Average of yearly yield values of each treatment and their Duncan test classes were given in Table 3. ANOVA and Duncan classification tests were also done for the average of the two years because the homogeneity test was positive, which meant that both years could be evaluated as a whole.

Data obtained from the 2-year study showed that grain yield was significantly ($p < 0.01$) affected by soil water deficits. On the other hand, yields of specific treatments were closely dependent on precipitation and its distribution during the crop cycle. As is evident, moisture stress during the flowering stage resulted in serious grain yield reduction. The yield of any treatment exposed to water stress at one or two growth stage was significantly lower than the fully irrigated (FYR) control treatment during two experimental years. The highest yield was obtained in the FYR treatment that was classified as the first group alone with 2.85 t/ha. This was followed by FY and FR treatments that were placed in the second and third groups with 2.55 and 2.40 t/ha, respectively. Flowering (F) period proved to be the most important period to determine the yield in relation to water deficit. Because (F) treatment took place in the treatments producing highest yield under the conditions one time irrigation were applied.

The thousand grain weight values of the treatments for average of the years and their Duncan test classes are given in Table 3. These show that average parameters are not affected by water deficits in the soil profile. The highest average weight of thousand grains was recorded in the fully irrigated (FYR) control treatment. This was followed by the treatment containing flowering (F), yield formation (Y) and ripening (R) stages. The lowest average weight was recorded in the rain fed treatment.

As presented in Table 3, grain oil contents of the treatments are similar and no statistically significant differences were found among them.

3.2. Seasonal Irrigation Water Requirements and Evapotranspiration

Irrigation water amounts applied to the experimental treatments and seasonal water consumption values for average of the years are presented in Table 4.

Table 3. The effect of irrigation treatment on grain and oil yield with thousand grain weight.

Experimental treatments	Grain yield (t/ha)	Grain yield decrease (%)	Thousand grain weight (g/1000)	Rate of oil (%)	Oil yield (t/ha)
FYR	2.85 a	–	8.7	36.2	1.03
FY	2.55 ab	10.5	8.3	35.0	0.89
FR	2.40 abc	15.8	8.0	34.7	0.83
YR	2.24 abcd	21.5	8.0	35.2	0.79
F	2.10 bcd	26.6	8.0	35.3	0.74
Y	1.94 cd	31.9	7.7	34.3	0.67
R	1.74 de	39.1	7.7	33.5	0.58
Rain fed	1.37 e	52.1	7.3	32.7	0.45
x (overall mean)	2.15		7.96	34.61	
Sx	0.47		0.42	1.10	
Sd	0.17		0.15	0.39	
Cv	7.72		1.87	1.13	
Year	**		ns	ns	
Year*treatment	**		ns	ns	

** Means within columns not followed by the same letter are significantly different at the $p < 0.01$ level by Duncan's multiple range test.

Table 4. Seasonal irrigation water quantities, saving, use efficiencies and evapotranspiration of linseed for the treatments.

Experimental treatments	Irrigation number	Irrigation (mm)	Irrigation water saving (%)	Irrigation water use efficiencies (kg/ha/mm)	Total water use efficiencies (kg/ha/mm)	ET (mm)
FYR	3	270	–	10.6	3.9	730
FY	2	165	38.9	15.5	4.1	626
FR	2	175	35.2	13.7	3.8	636
YR	2	200	25.9	11.2	3.4	661
F	1	70	74.1	29.9	3.9	532
Y	1	95	64.8	20.5	3.5	557
R	1	105	61.1	16.6	3.1	567
Rain fed	–	–	100.0	–	3.0	463

Total irrigation water applied to irrigation treatments was strongly affected by the amount and distribution of precipitation during the experiment years. The differences among the treatments irrigated once were the proof for this. The highest amount of irrigation water was applied to the treatment of ripening stage (R) and this was followed by the yield formation stage (Y) and flowering stage (F), whose soil moisture was partially sufficient. The amount of irrigation water applied to the treatments in both years are close to each other.

The seasonal ET values increased with the increasing rate of irrigation water amount. The lowest ET was obtained from the no irrigation treatment with average 463 mm, which was followed by F, Y and R treatments irrigated once. The highest ET was recorded in the FYR treatment, irrigated three times, with 730 mm water application

In addition, for both years, the biggest saving in irrigation water was obtained in the treatments irrigated only once at flowering (F) stage while the lowest was in ripening (R) stage.

3.3. The Irrigation and Total Water Use Efficiency of Linseed

The irrigation water use efficiencies (IWUE) and the total water use efficiencies (TWUE) of the treatments for the average of years are presented in Table 4.

Using average values, the highest TWUE was obtained from FY treatment with 4.1 kg/ ha/mm while the lowest TWUE was observed in rain fed treatment with 3.0 kg /ha/mm. As for the IWUE, the highest and lowest rates were recorded as 29.9 kg/ha/mm in F treatment and 10.6 kg/ha/mm in FYR treatment, respectively.

3.4. The Water Use Function and Yield Response Factor for Linseed

The crop water production function obtained using seasonal ET and grain yield of linseed for all treatments is presented in Fig. 1. There was a polynomial relationship between ET and grain yield (y) express by y = – 0.000002 ET^2 + 0.0049 ET (R^2 = 0.57). Using this relationship, grain yield of linseed in this region can be predicted from ET. But, when using the produced equation, the upper limit of the independent variable should not be exceeded. It should also be noted that the yield_ET relation can vary with agronomic practices and irrigation water quality.

The slope of the fitted regressions represents the yield response factor (k_y), being 1.32 in Fig. 2. The k_y values for the experimental years of 2011 and 2012 were 1.50 and 0.93, respectively. The reason for a higher k_y value in 2011 was that the average temperature during the growth period was higher in this year than that of 2012. This situation increased the sensitivity of the crop to water and therefore decreased the yield as well. Yield response factor (k_y) for each specific growth period proved to be an important criterion to decide which stage was the most sensitive to water. The k_y values of the growth stages were 1.47, 1.33 and 1.22, respectively for F, Y and R stages, thus revealing the F stage as the most critical period of linseed to water.

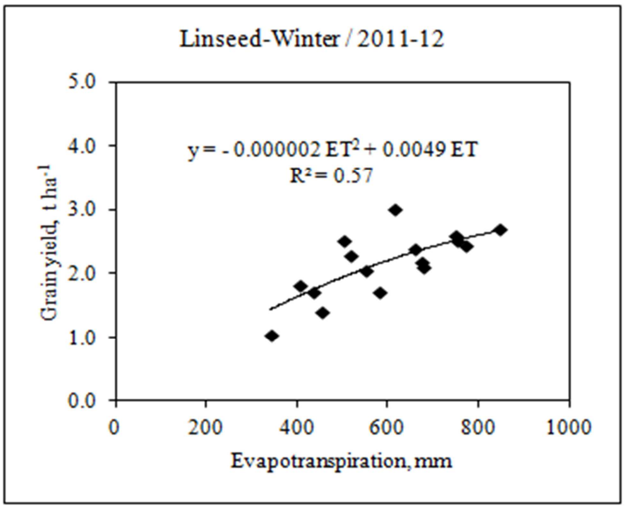

Fig. 1. Relationship between seasonal evapotranspiration and grain yield. P < 0.01 level.

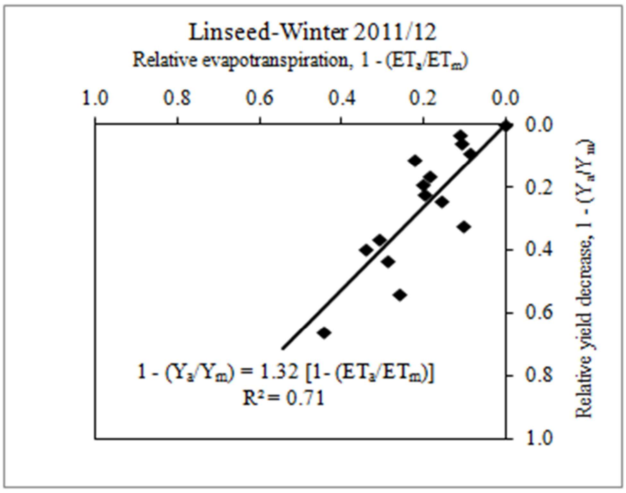

Fig. 2. Relationship between relative evapotranspiration deficit 1 – (ET_a/ET_m) and relative yield decrease 1 – (Y_a/Y_m). P < 0.01 level.

3.5. The Plant Growth Components of Linseed

The plant growth components of the treatments for the average of years are presented in Table 5. The average values obtained for several variables were: the highest and the lowest plant height 75.3 and 57.7 cm; first of branch height 60.7 and 41.7 cm; number of branches per plant 8 and 6; number of capsule per plant 24 and 14; number of grain per capsule 9 and 7 were obtained from FTR and rain fed treatments, respectively.

Table 5 implies that the effect of irrigation o plant height and the first branch height are more significant in comparison to the number of grain per capsule.

Table 5. The effect of irrigation treatments on plant growth components of linseed.

Experimental treatments	Plant height (cm)	First branch height (cm)	Number of branches per plant	Number of capsule per plant	Number of grain per capsule
FYR	75.3 a	60.7 a	8	24	9 a
FY	73.0 ab	54.0 ab	7	23	8 ab
FR	71.3 ab	54.0 ab	7	23	8 ab
YR	69.0 ab	52.7 abc	7	19	8 ab
F	68.0 ab	51.7 abc	7	16	7 b
Y	62.7 ab	50.0 abc	6	16	7 b
R	60.7 ab	44.7 bc	6	16	7 b
Rain fed	57.7 b	41.7 c	6	14	7 b
x (overall mean)	67.2	51.2	6.8	18.9	7.6
Sx	6.1	5.88	0.71	3.94	0.75
Sd	2.16	2.08	0.25	1.39	0.26
Cv	3.21	4.06	3.69	7.38	3.46
Year	**	**	ns	ns	**
Year*treatment	**	**	ns	ns	**

** Means within columns not followed by the same letter are significantly different at the $p < 0.01$ level by Duncan's multiple range test.

4. Conclusion

There is limited research and therefore limited data is available on linseed production under irrigated conditions at regional and country level.

The results showed that irrigation treatment affected grain and oil yield, seasonal evapotranspiration, yield response to water, water use efficiency Evapotranspiration of linseed increased with the number of irrigations and the amount of irrigation water. Linseed was mostly affected by water shortage in the soil profile due to omitted irrigation during the sensitive flowering stage whereas affected less in ripening stage. Therefore, if irrigation water is limited, flowering stage irrigation should be given priority while ripening stage can be omitted.

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