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Full Length Research Paper

Effects of different water, phosphorus and magnesium doses on the quality and yield factors of soybean (*Glycine max* L.) in Harran plain conditions

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This study reports the effects of magnesium (Mg) and phosphorus (P) fertilizer dosage and different water levels, on the plant growth, yield and quality factors of soybean. The field study used a random block design with three replications and was conducted over two years, 2006 and 2007. Four different P doses (0-4-8-12 kg P da^{-1}) and three different Mg doses (0-4-8 kg Mg da^{-1}) were applied with three different water levels (I_1, I_2, I_3). Cumulative pan values obtained from a Class A pan evaporation pool were 33% for I_1, 67% for I_2, and 100% for I_3. Yield per decare (da), thousand-grain weight, harvest index, soil biomass, oil content, and protein content increased with increased water, phosphorus and magnesium levels. Increased water levels did not affect root and stem dry items amount dry mass, however, the similar features increased with increased Mg and P levels.

Key words: *Glycine max* L., water level, phosphorus, magnesium, productivity, quality.

INTRODUCTION

Population of the world is driving the need for increased food production. Vegetable oil consumption, which has a significant role in human health, has increased in proportion to population growth. This has resulted in a shortage of vegetable oil, both in Turkey and globally. Increasing shortfalls in vegetable oil availability highlight the need for oil plants that provide higher agricultural yields.

International production data shows that soybean is the most important oil seed plant in USA, China and Italy, compared with canola in France, Canada and Germany; peanut in India; and sunflower in Spain and Turkey. In Turkey, production amounts of oil seed plant in turn are cottonseed, sunflower, soybean, sesame, peanut, canola and saffron (FAO Stat, 2007).

Soybean provides an alternative second yield, and has the potential to be an important source of income for producers (DPT, 1989). Agriculture of soybean covers 33 000 ha in Turkey. Total production is 75 000 t and mean yield is 294.1 kg da^{-1}. Approximately 95% (71,250 t) of Turkeys total yield is from the Mediterranean region (DIE, 2002). Soybean, after the wheat as second product, especially in Cukurova region, has been cultivated extensively over a very short time. Furthermore, with the completion of Southeast Anatolia region (SAR) development, soybean growth is thought in second range in 10% of product design (DPT, 1989). However, as soybean is a new plant for the SAR, there are very few studies of the irrigation and mineral nutritional requirements of the plant in this region.

As irrigation sources are limited, water saving studies has been important in recent years. Several projects have examined how restricted irrigation of plants with high water demands may affect yields. When irrigation sources are limited or irrigation cost is very high, instead of complete irrigation, limited irrigation programs, which provide maximum yield from module water, should be applied. Moreover, as excessive irrigation may lead to salinization, barren on the soil and causes soil erosion;

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Abbreviations: P, Phosphorus; **Mg,** magnesium; **da,** decare; **I,** water level; **h,** hectare; **t,** tonne; **SAR,** Southeast Anatolia region; **TSMS,** Turkish State Meteorological Service; **mg,** milligram; **L,** litter; **S,** sulfur.

however, limited watering may alleviate these negative situations to some extent. Limited irrigation management is based on yield functions, which express the relationship between water and yield (Nairizi and Ryzdewski, 1997).

Shariatmadari and Mermut (1999) found that clay mineral with sepiolite silicate releases very much Mg to the environment and increases P resolution. It was found that P function can be increased by adding Mg to soil with increasing P desorption at the environment with Mg. This finding has great importance in terms of P-availability for plants on calcareous soils.

The yield for each da, grain oil and protein content, thousand grain weight, harvest index, soil biomass, chlorophyll content and root and stem dry were determined for the differing water limitations and P and Mg doses.

MATERIALS AND METHOD

Materials

This study was conducted at Harran University Agriculture Faculty Campus in Turkey during 2006 and 2007. The study used soybean (*glycine max*. L.) type kind Nova. The study site is located at 36º 42' N latitude and 38º 58' E longitude and its altitude is 464 m (DSSRI, 2001)

The research area is within the South East Anatolia region (SAR) climatic region and is affected by the Mediterranean climate; it is hot and dry in summer and warm in winter. In 2006, between June and October, which covers the duration of soybean growth, mean temperature ranged between 20.6 to 30.8℃, mean minimum temperature ranged between 12.8 to 22.8℃, average precipitation was 0 to 0.3 mm, mean relative humidity ranged between 40.8 to 61.5%, and soil temperature ranged between 23.9 to 36.6℃. In 2007, mean temperature was 21.6 to 30.4℃, mean minimum temperature was 16.5 to 23.0℃, mean precipitation was 0.8 to 25.9 mm, mean relative humidity was 36.9 to 47.7%, and soil temperature was 23.3 to 35.0℃ (Table 1) (TSMG, 2006, 2007).

Method

The research methodology used a random block design with three replications. Irrigation was the main plot treatment and P and Mg subjects are sub-units. Four different P doses (0-4-8-12 kg P da^{-1}) and three different Mg doses (0-4-8 kg Mg da^{-1}) were applied with three different water levels (I_1, I_2, I_3). Cumulative pan values obtained from class A pan evaporation pool were applied as 33% for I_1, 67% for I_2, and 100% for I_3. Phosphorus treatments were determined as P_0 (0 kg P da^{-1}), P_1 (4 kg P da^{-1}), P_2 (8 kg P da^{-1}), P_3 (12 kg P da^{-1}) and Mg treatments are determined as Mg_0 (0 kg Mg da^{-1}), Mg_1 (4 kg Mg da^{-1}) and Mg_2 (8 kg Mg da^{-1}).

In the SAR, in soybean production as second yield, high soil temperature is an important factor that restricts bacteria responsible for N fixation. Therefore, bacteria inoculation was not performed during the research. Nitrogen fertilizer, which was applied to plants as ammonium sulfate ($(NH_4)_2SO_4$) with 10 kg N da^{-1} doses, was divided two parts; the first parts was applied during cultivation and the remainder was applied to all parcels equally, prior to flowering. Phosphorus and Mg treatments were applied to the experiment parcels in a similar way to each irrigation part, as shown in the combinations as follows:

P_0Mg_0 P_1Mg_0 P_2Mg_0 P_3Mg_0
P_0Mg_1 P_1Mg_1 P_2Mg_1 P_3Mg_1
P_0Mg_2 P_1Mg_2 P_2Mg_2 P_3Mg_2

The experiment has used triple super phosphorus as P source and magnesium sulfate ($MgSO_4.7H_2O$) as Mg source; these were applied to parcels with cultivation like being the equivalent to plant order and not being two fertilizers consecutively. After cultivation and fertilizer treatments, a drip irrigation system was set up and the first water was applied to the plants. After exiting finished and proper moisture levels of the soil decreased to 40%, partial irrigation was started.

Grain oil content (%) (Anonymous, 1966) was calculated by using the Kjeldahl method (Bremner, 1965) for protein rate; after analyzing total nitrogen, the obtained value was multiplied by a factor of 6.25 (Hartwitz, 1970). Dry root and stem weight (%) were calculated according to Kacar (1972); chlorophyll content was determined according to Arnon (1949). The harvest index was determined according to Kün (1988).

RESULTS AND DISCUSSION

It was found that Mg applications raise P resolutions in soil with the effect of water. As Mg resolves P, and provides be taken by plant and increases bioavailability, the use of P-fertilizer -and therefore the cost of agricultural inputs-can be reduced. This research shows how Mg is effective in cases of reduced irrigation and fertilizing treatment and it provide new method. Moreover, limiting irrigation to conserve water resources, applying limitation water programs, developing plant strains that are resistant to water stress and determining the appropriate irrigation facilities for these kinds of plants are important for this region.

Effect of water, P and Mg treatments on yield for each decare

The yield for each decare changed between 111.07 and 564.50 kg da^{-1} in the first year, and between 107.40 and 533.57 kg da^{-1} in the second year; the maximum yield was obtained from I_3 and P_1Mg_2 treatment in the first year and, in second year, from P_2Mg_2 treatment at the same irrigation level. In the two years of research, the yield for each decare increased with increased water levels (Table 2). Vasiliu et al. (1977), Yavada (1980), Bayrak (1989), Casanova (2000), Saadi and Yazdi-Samadi (1978), Sarma et al. (1976), Saenko (1977), Fernandez et al. (1978), Simiciklas et al. (1989), Muandemele et al. (1988), Specht and Gordon (2000), and Simsek et al. (2001) all reported that increased water levels have a positive effect on soybean yield per da. The findings of this research are consistent with those reported by previous researchers.

Moreover, yield per decare on P and Mg levels increased in both years. In the first year, the maximum yield per da was obtained from I_3 at P_1Mg_2 and, in second year, from P_2Mg_2 combination at the same irrigation combination.

Table 1. Climate in Sanliurfa in between 2006 and 2007 (TSMS, 2007).

Year	Month	Mean Max. temperature (ºC)	Mean Min. temperature (°C)	Mean temperature (ºC)	Mean relative humidity (%)	Mean participation (mm)	Sunrise cal/cm^2)	5 cm soil temperature (°C)
	June	38.0	22.8	30.8	40.8	0.3	605.1	36.6
	July	38.5	24.9	32.2	45.5	0.3	560.5	38.8
	August	40.4	26.0	33.4	44.6	-	462.2	39.0
2006	September	32.3	22.4	27.2	42.3	-	455.4	32.6
	October	25.9	12.8	20.6	61.5	42.5	291.7	23.9
	June	37.2	23.0	30.4	36.9	0.8	614.2	35.0
	July	40.8	27.0	34.0	31.3	8.0	553.2	38.5
	August	39.3	25.4	32.2	41.9	3.2	521.4	37.4
2007	September	36.0	22.0	28.4	36.4	-	427.3	32.6
	October	28.4	16.5	21.6	47.7	25.9	320.6	23.3
	June	44.0	8.3	27.9	32.4	3.0	583.1	32.6
	July	46.8	15.0	33.1	29.6	0.6	561.9	37.2
Many years	August	46.2	15.5	31.2	32.3	0.9	513.0	36.0
(1929-2008)	September	42.0	0.0	26.7	35.1	1.1	436.0	30.6
	October	37.8	1.9	20.1	44.8	23.8	315.1	21.9

Casanova (2000), Bhangoo and Albritton (1972), Paikera et al. (1988), Tomar et al. (1993), Turkhede et al. (1993), Hasnabade et al. (1990), Jayapaul and Ganesaraja (1990), Misra et al. (1990), and Reddy et al. (1990) all reported that different P doses increased soybean yield for each da. Abdel-Gawad et al. (1989) reported that two different times leave fertilizer treatments including Mg and different forms of other micro elements increased soybean yield.

The results confirm that the addition of Mg to soil greatly increased yields compared with global soybean productivity. Moreover, it is understood that, in cases of reduced water and fertilizer application, Mg can play an important role in increasing yields. Although the findings of the research are similar to those reported in the literature, in some combinations, the yield for each da exceeds the values in the literature. Fertilizing with Mg was first suggested by Mermut (1996) and these researchers suggested that the addition of Mg facilitated the uptake of P from soil. The yields achieved in the present study are greater than those reported in the literature, due to the addition of Mg fertilizer.

Effect of water, P and Mg treatments on protein and oil content of grain

In the first year, oil content ranged between 7.26 and 17.37% and between 8.46 and 19.78% in the second year. In the first year, the maximum value was obtained from S_3 and P_3Mg_2 and from P_2Mg_2 treatment in the second year at the same irrigation level. When fertilizer combinations are examined according to water treatments: in the first year, P_1Mg_2 at I_1, P_2Mg_2 at I_2 and P_3Mg_2 at I_3 combinations reached maximum level on protein and oil content of grain. In the second year, P_2Mg_2 at I_1, P_3Mg_2 at I_2 and P_2Mg_2 at I_3 combination reached the highest level on protein and oil content of grain. Moreover, with increasing quantities of water, oil contents increased for all fertilizer combinations in both years. The most notable finding in the first year was that, while Mg increased, oil content also increased; the highest oil yield of I_3 combinations was recorded with the highest Mg dose. Accordingly, it can be suggested that the optimum combination is P_2Mg_2 at I_2 or P_1Mg_2 at I_3. Increased Mg and P doses clearly increased oil contents at I_1 and I_2 and I_2 and I_3

Table 2. Mean values of yield for each (kg da^{-1}) groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006 Irrigation part			Mean	2007 Irrigation part			Mean
	I_1	I_1	I_2		I_3	I_2	I_3	
P_0Mg_0	111.07 s	188.84	107.40 r	130.93 q	335.33 j	128.87 s	326.60 l	191.22
P_0Mg_1	126.83 s	216.28	125.50 qr	139.10 pq	351.17 ıj	139.20 rs	382.80 hu	205.26
P_0Mg_2	132.10 rs	246.73	131.93 q	163.93 o	451.73 d	160.93 pqr	447.17 cd	249.20
P_1Mg_0	134.73 rs	232.73	121.30 qr	174.00 o	406.97 ef	131.17 rs	432.30 def	234.09
P_1Mg_1	140.77 qrs	268.41	140.17 pq	196.90 n	496.43 c	171.93 pq	492.53 b	277.83
P_1Mg_2	162.00 pqr	310.00	156.53 op	216.90 mn	517.90 ab	203.50 o	564.50 a	297.11
P_2Mg_0	207.80 no	321.20	219.83 lm	377.57 gh	418.17 e	369.40 jk	386.40 hıj	338.52
P_2Mg_1	217.40 mno	349.21	239.57 kl	397.97 efg	509.83 bc	424.47 d-e	405.77 f-ı	382.46
P_2Mg_2	235.07 mn	382.52	250.17 k	445.10 d	533.57 a	468.07 bc	444.43 cd	409.61
P_3Mg_0	188.00 op	301.28	219.87 lm	370.27 hı	340.47 j	377.33 ıj	338.50 kl	310.20
P_3Mg_1	243.50 m	339.42	243.40 k	387.83 fgh	379.83 gh	378.70 ıj	396.07 g-j	337.02
P_3Mg_2	345.17 kl	399.19	334.17 j	411.13 e	413.20 e	440.63 cde	411.77 e-h	386.17
Mean	187.04	190.82	284.30	429.55		282.85	419.07	191.22
LSD (0.05)	31.450 (Fertilizer levels* Irrigation parts)				21.010 (Fertilizer levels × Irrigation parts)			

Table 3. Mean values of oil rate and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006 Irrigation part			Mean	2007 Irrigation part			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
P_0Mg_0	8.34klm	8.67j-m	9.58g-m	8.86	10.74ı-l	9.12kl	11.34h-l	10.40
P_0Mg_1	11.55e-l	9.75g-m	10.99e-l	10.76	12.70g-j	13.99d-ı	15.24b-g	13.98
P_0Mg_2	12.73c-ı	10.71e-m	13.75b-e	12.40	16.36a-f	16.35a-f	18.28ab	17.00
P_1Mg_0	9.27ı-m	9.53h-m	11.77d-k	10.19	8.46l	11.35h-l	12.55g-k	10.79
P_1Mg_1	10.18f-m	11.25e-l	12.75c-ı	11.39	12.18g-k	12.59g-k	17.88abc	14.22
P_1Mg_2	13.92a-e	13.5b-f	16.68ab	14.70	14.50c-h	16.56a-f	17.98abc	16.35
P_2Mg_0	10.03f-m	9.63g-m	8.05lm	9.24	12.45g-k	11.65h-l	13.24e-j	12.45
P_2Mg_1	11.12e-l	10.71e-m	12.02d-j	11.28	13.25e-j	13.09e-j	15.52b-g	13.95
P_2Mg_2	13.06c-g	15.62abc	15.26a-d	14.65	16.55a-f	14.17d-l	19.78a	16.83
P_3Mg_0	7.26m	9.61g-m	11.71e-k	9.53	9.84jkl	9.75jkl	12.49g-k	10.69
P_3Mg_1	11.10e-l	10.00g-m	12.99c-h	11.37	11.65h-l	15.37b-g	15.75b-g	14.26
P_3Mg_2	12.52c-i	12.65c-ı	17.37a	14.18	12.99f-j	16.62a-e	17.47a-d	15.69
Mean	10.92	10.97	12.74		12.64	13.38	15.63	
LSD(0.05)	3.495 (Fertilizer levels × Irrigation parts)				3.577 (Fertilizer levels × Irrigation parts)			

irrigation levels. Although maximum oil rates were obtained at P_2Mg_2 doses, an important statistically significant differences and was not found between P_1 and P_2 doses (Table 3).

As Mg is applied to soil as $MgSO_4$, S was effective on vegetable oil content. When examined in terms of oil content, the application of P fertilizer can be reduced by applying $MgSO_4$ to soil. It is understood that, as there was not a significant increase in oil content after increased irrigation, reductions can be made in irrigation levels. These findings indicate important factors for soybean plant management. In 2007 also, Mg had a great effect on oil contents and maximum values (19.8%) were obtained from P_2Mg_2 at irrigation level I_3.

In the first year of the study, protein values varied between 31.94 and 42.24% and between 35.12 and 42.56% in the second year. In the first year, the maximum value was obtained from I_1 and $P_0Mg_{2;}$ and

Table 4. Mean values of protein rate and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006			Mean	2007			Mean
	Irrigation part				Irrigation part			
	I_1	I_2	I_3		I_1	I_2	I_3	
P_0Mg_0	39.02e-h	38.48f-i	32.27no	36.59	38.73e-f	38.10f-l	35.12o	37.32
P_0Mg_1	40.59a-e	39.80c-f	34.01mn	38.14	39.39b-g	38.84d-ı	36.77k-o	38.33
P_0Mg_2	42.24a	41.09abc	36.27jkl	39.87	39.81b-f	40.73abc	41.00ab	40.51
P_1Mg_0	39.12e-h	39.85c-f	31.94o	36.97	38.61e-k	38.66e-j	36.50l-o	37.92
P_1Mg_1	41.41abc	39.94c-f	34.57lm	38.64	39.58b-g	39.44b-g	37.00i-n	38.67
P_1Mg_2	41.88ab	41.19a-d	35.99jkl	39.68	40.13b-e	42.56a	37.92g-l	40.23
P_2Mg_0	38.47f-i	35.67j-m	35.99jkl	36.71	38.80d-j	37.88g-l	35.39no	37.36
P_2Mg_1	38.52f-i	36.63ijk	36.63ijk	37.26	39.57b-g	38.93c-h	35.71mno	38.07
P_2Mg_2	39.12e-h	39.39d-g	37.42hij	38.64	40.13b-e	39.81b-f	36.95j-o	38.96
P_3Mg_0	36.63ijk	36.22jkl	35.35klm	36.07	38.61e-k	37.32h-m	37.05i-n	37.66
P_3Mg_1	38.93e-h	36.82ijk	36.18jkl	37.31	39.85b-f	38.25f-l	37.42h-m	38.50
P_3Mg_2	40.08b-f	37.55g-j	37.55g-j	38.40	40.63bcd	39.81b-f	38.98c-h	39.81
Mean	39.67	38.55	35.35		39.49	39.19	37.15	
LSD(0.05)	1.923 (Fertilizer levels x Irrigation parts)				1.864 (Fertilizer levels x Irrigation parts)			

from I_2 and P_1Mg_2 treatment in the second year. When fertilizer combinations are examined according to water treatments: in the first year, P_0Mg_2 at I_1, P_1Mg_2 at I_2 and P_3Mg_2 at I_3 combinations reached maximum level of protein. In the second year, P_3Mg_2 at I_1, P_1Mg_2 at I_2 and P_0Mg_2 at I_3 combination reached the highest level of protein. Moreover, with increasing irrigation levels, protein values declined for all fertilizer combinations in both study years.

The most notable finding of the study in first year is that protein content increased with increasing Mg application; the highest protein yield of I_1 combinations was recorded at the highest Mg dose. Accordingly, it can be suggested that the optimum combination is P_1Mg_2 I_2 or P_0Mg_2 at I_1. As magnesium is applied to soil as $MgSO_4$, S was effective on protein level. When examined in terms of protein content, the application of P fertilizer can be reduced by applying $MgSO_4$ to soil. It is understood that, as there was no significant increase in protein content after increased irrigation, reductions can be made in irrigation levels. These findings indicate important factors for soybean plant management (Table 4).

In the second year, protein contents varied between 35.12 and 42.56%, and the maximum value was obtained from I_2 and P_1Mg_2 treatment. When fertilizer combinations are examined according to water treatments in the first year, P_3Mg_2 at I_1, P_1Mg_2 at S_2 and P_0Mg_2 at I_3 combinations produced the maximum protein content. Moreover, with increasing irrigation levels, protein values were not affected on all fertilizer combinations. In 2007, Mg highly affected protein increase, and the maximum protein content (42.56%) was obtained from P_1Mg_2 on I_2.

Yetim (2008) reported that soybean vegetable oil values varied between 14 and 24% and protein values varied between 23 and 34%. Sadi and Yazdi-Samadi (1978) found that water and P fertilization in common increase oil content. Fernandez et al. (1978) applied four water levels to Amsoy soybean type; the minimum irrigated plot yielded 267 kg ha^{-1} and the maximum irrigated plot yielded 674 kg ha^{-1}. Hasnabade et al. (1990) reported that, in their research in India, as a result of increasing N, P rates and irrigation frequency, protein and oil contents increased. In our study, P and Mg treatments particularly increased oil and protein contents of the soybean grain. It is thought that the increase in oil and protein contents is related to the effect of Mg.

It is seen clearly that Mg increases soil P resolution and facilitated P-uptake by plants. The oil content of grain increases with this effect of Mg. Sperrazza and Spremulli (1983) found that when Mg, which is effective on protein synthesis, is depleted or includes too much potassium, protein synthesis ceases and magnesium is necessary for many enzyme and enzyme reactions. Moreover, they reported that Mg accelerates phosphorus uptake by plants and this is very important for oil. The research finding of the positive effects of Mg on oil and protein contents suggests that Mg should be used to maximize soy oil yields.

Effect of water, P and Mg treatments on thousand-grain weight

In the first year, grain weight of 1000 grain values varied between 84.50 and 161.37 g, and in second year it varied between 83.93 to 162.67 g. The highest values were

Table 5. Mean values of 1,000 grain weight and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006			Mean	2007			Mean
	Irrigation part				Irrigation part			
	I1	I2	I3		I1	I2	I3	
P_0Mg_0	84.60 o	84.50 o	110.40 kl	93.17	84.63 k	83.93 k	107.57 h	92.04
P_0Mg_1	92.90 no	85.03 o	132.07 e-i	103.33	92.80 jk	85.00 k	131.77 def	103.19
P_0Mg_2	101.67 lmn	93.09 no	142.43 b-e	112.40	102.33 hıj	93.40 ijk	142.63 bc	112.79
P_1Mg_0	85.63 o	90.47 o	141.50 b-e	105.87	85.40 k	90.57 k	137.27 cd	104.41
P_1Mg_1	88.17 o	94.00 mno	146.70 bc	109.62	87.47 k	93.13 ijk	145.10 bc	108.57
P_1Mg_2	90.10 o	105.37 l	161.37 a	118.94	89.97 k	104.27 h	162.67 a	118.97
P_2Mg_0	104.80 lm	120.97 jk	145.17 bc	123.64	104.73 h	120.57 g	144.90 bc	123.40
P_2Mg_1	121.87 ij	124.10 ij	149.20 b	131.72	122.57 fg	123.57 fg	148.83 b	131.66
P_2Mg_2	126.43 hij	130.43 f-j	136.80 c-h	131.22	126.87 efg	130.07 d-g	136.77 cde	131.23
P_3Mg_0	105.84 l	127.20 g-j	132.50 d-ı	121.85	102.97 hi	127.07 efg	132.23 def	120.76
P_3Mg_1	126.10 hij	129.63 f-j	138.37 b-f	131.37	125.33 fg	129.13 d-g	138.03 cd	130.83
P_3Mg_2	143.43 bcd	137.80 c-g	136.53 c-h	139.26	144.70 bc	137.83 cd	137.70 cd	140.08
Mean	105.96	110.22	139.42		105.81	109.88	138.79	
LSD (0.05)	11.060 (Fertilizer levels x Irrigation parts				10.150 (Fertilizer levels x Irrigation parts)			

obtained from I_3 and P_1Mg_2 treatment in both years weight of the 1 000-grain values increased in two years with increased water levels. Simiciklas et al. (1989) and Shou et al. (1991), state that drought stress reduces 1,000 grain weight. The present study is consistent with previous research, in finding that 1,000 grain weight increases or decreases according to water availability. This finding indicates that water availability is very important for soybean yield (Table 5).

Moreover, in the two study years, increasing P and Mg doses increased weight of 1000 grain. Atakisi and Arioglu (1983), Dadson and Acquaah (1984), Sepetoglu and Nasir (1988), Paikera et al. (1988), Jayapaul and Ganasaraja (1990), and Hasnabade et al. (1990) all reported that increased P treatments increased weight of 1,000 grain. Bakaloglu and Aycicegi (2005) found that the mean weight of 1,000-grain the soybean was 104.93 grain g^{-1} and Karasu et al. (2002) reported that this weight varied according to plant types, with a highest value of 194 grain g^{-1}. The weight of 1000-grain found in the present study are consistent with values in the literature, and it is concluded that, according to treatments, these values increased for some fertilizer combinations.

Effect of Water, P and Mg treatments on upper-soil biomass

In the first year of the study, soil biomass values varied between 0.30 and 1.41 t da^{-1} and between 0.34 to 1.49 t da^{-1} in the second year. The maximum value was obtained from S_3 and P_1Mg_2 treatment in the both years. In the second year of our study, the soil biomass increased with increasing water levels (Table 6). In this study, soil biomass values of the both years increased with increased P and Mg doses. Heitholt et al. (2004) reported that biomass values of soybean ranged between 1.25 and 2.13 t da^{-1}. Xiang-Wen et al. (2008) applied different P treatments to 96 different soybean genotypes and found that the treatments increased biomass. The current findings are partly consistent with those in the literature.

Effect of water, P and Mg treatments on root and stem dry matter amounts

In the first year, root dry matter values ranged between 31.00 and 53.91% and between 29.83 and 55.33% in the second year. In the first year, the maximum value was obtained from I_1 and P_2Mg_0 and it from I_2 and P_0Mg_0 treatment in the second year (Table 7). In the first year of the study, stem dry matter values ranged between 23.85 and 44.96% and between 26.92 and 39.14% in the second year. In the first year, the maximum value was obtained from I_1 and P_0Mg_1 and from I_2 and P_1Mg_2 treatment in the second year (Table 8).

In both years of the study, increased water levels decreased root and stem dry matter percentages; and firstly increased stem dry matter amounts then decreased them. Increased P and Mg doses partly affected root and stem dry matter amounts; which showed a particular increase on less irrigated plots. Whitt and Van Bavel (1955) note that 300 kg water is necessary to obtain 1 kg

Table 6. Mean values of upper-soil biomass (t da^{-1}) and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006 Irrigation part			Mean	2007 Irrigation part			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
P_0Mg_0	0.30s	0.46qrs	0.93ghi	0.57	0.34w	0.53s-v	0.84lmn	0.57
P_0Mg_1	0.50p-r	0.61m-q	1.16cde	0.76	0.48u-w	0.59q-v	1.06hij	0.71
P_0Mg_2	0.53o-r	0.70j-n	1.41ab	0.88	0.53s-v	0.75m-p	1.33bcd	0.87
P_1Mg_0	0.44rs	0.62m-p	1.16de	0.74	0.46vw	0.60q-u	1.25c-f	0.77
P_1Mg_1	0.54n-r	0.65l-p	1.32abc	0.84	0.53tuv	0.68o-r	1.36abc	0.86
P_1Mg_2	0.63m-p	0.80i-l	1.46a	0.96	0.67o-s	0.77mno	1.49a	0.98
P_2Mg_0	0.68k-o	0.84ij	1.08efg	0.87	0.72n-q	0.88klm	1.11ghı	0.90
P_2Mg_1	0.72j-m	1.16de	1.12def	1.00	0.80mno	1.19e-h	1.37abc	1.12
P_2Mg_2	0.82ı-k	1.25cd	1.18cde	1.08	0.83lmn	1.27cde	1.46ab	1.19
P_3Mg_0	0.60m-r	0.90hı	0.89hi	0.80	0.56r-v	0.95jkl	0.94jkl	0.82
P_3Mg_1	0.66l-o	1.07efg	1.00fgh	0.91	0.62p-t	1.13fgh	0.99ıik	0.91
P_3Mg_2	0.68k-o	1.26bcd	1.15def	1.03	0.68o-r	1.18e-h	1.22d-g	1.03
Mean	0.59	0.86	1.16		0.60	0.88	1.20	
LSD (0.05)	0.1547 ((Fertilizer levels × Irrigation parts)				0.136 (Fertilizer levels × Irrigation parts)			

Table 7. Mean values of root dry matter (%) level and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006 Irrigation part			Mean	2007 Irrigation part			Mean
	I_1	I_2	I_3		I_1	I_2	I_3	
P_0Mg_0	47.96 a-f	43.59 d-k	48.45 a-e	46.67	47.63 b-f	55.33 a	43.35 f-k	48.77
P_0Mg_1	37.25 l-p	47.80 a-f	46.11 b-g	43.72	42.07 g-l	43.11 f-k	38.75 j-n	41.31
P_0Mg_2	44.49 c-j	50.06 abc	37.73 k-o	44.09	36.13 mn	43.94 e-j	38.64 j-n	39.63
P_1Mg_0	45.96 b-g	41.27 g-m	34.71 n-q	40.65	44.53 d-ı	41.85 g-l	37.46 lmn	41.28
P_1Mg_1	31.11 pq	46.17 b-g	32.45 opq	36.58	45.39 d-h	43.15 f-k	34.31 no	40.95
P_1Mg_2	48.02 a-f	45.12 b-i	41.99 f-l	45.04	39.43 i-n	46.30 c-g	39.62 ı-n	41.78
P_2Mg_0	53.91 a	45.16 b-h	35.73 m-q	44.93	34.99 no	52.51 ab	45.17 d-h	44.22
P_2Mg_1	50.79 ab	38.92 i-n	39.39 h-n	43.03	34.93 no	44.73 d-i	43.22 f-k	40.96
P_2Mg_2	48.00 a-f	38.76 j-n	42.33 e-l	43.03	38.12 k-n	41.06 g-m	29.83 o	36.34
P_3Mg_0	53.62 a	39.57 h-n	35.06 n-q	42.75	51.22 abc	42.12 g-l	41.90 g-l	45.08
P_3Mg_1	31.00 q	44.17 c-j	37.15 l-q	37.44	48.98 b-e	43.30 f-k	40.57 h-m	44.28
P_3Mg_2	49.57 a-d	37.47 k-o	39.03 h-n	42.02	36.16 mn	49.70 bcd	37.47 lmn	41.11
Average	45.14	43.17	39.18		41.65	45.59	39.19	
LSD (0.05)	6.233 (Fertilizer levels x Irrigation parts)				5.402 (Fertilizer levels x Irrigation parts			

dry matter from soybean. Vearela (1998) reported that, when water stress created 40 from 20% at soybean, dry matter amounts were determined to decrease between 25 to 34%. Dadson and Acquaah (1984) found that different doses of N and P fertilizers applied at sowing time with bacteria inoculation increased the dry matter of soybean. The findings of the present study and those in the literature are similar to some extent. Root and stem dry matter values are consistent with values in the literature and varied according to treatments.

Effect of water, P and Mg treatment on chlorophyll amounts

In the first year, total chlorophyll values varied between

Table 8. Mean values of stem dry matter (%) level and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007 years.

Fertilizer level	2006			Mean	2007			Mean
	Irrigation part				Irrigation part			
	I_1	I_2	I_3		I_1	I_2	I_3	
P_0Mg_0	40.76 bc	39.61 bcd	41.86 b	40.74	31.53 cd	31.72 cd	28.64 klm	30.63
P_0Mg_1	44.96 a	34.73 g-j	41.01 bc	40.23	31.97 c	32.05 c	30.68 c-i	31.57
P_0Mg_2	38.70 cde	36.62 e-h	30.89 l-q	35.40	29.36 h-m	31.42 cd	28.27 lmn	29.68
P_1Mg_0	35.77 fghi	31.55 k-p	37.19 d-g	34.83	31.54 cd	31.65 cd	30.49 c-j	31.23
P_1Mg_1	31.38 k-p	33.68 i-l	33.02 i-m	32.70	31.83 cd	28.98 j-m	30.80 c-h	30.54
P_1Mg_2	37.82 def	33.36 i-m	33.15 i-m	34.78	29.00 j-m	39.14 a	29.10 j-m	32.41
P_2Mg_0	29.90 o-r	29.61 o-r	32.17 j-o	30.56	28.39 k-n	31.21 c-f	31.07 c-g	30.22
P_2Mg_1	29.25 pqr	28.37 qr	32.74 j-n	30.12	28.72 klm	30.38 d-j	29.84 e-k	29.65
P_2Mg_2	29.50 o-r	31.51 k-p	35.62 f-ı	32.21	29.23 i-m	28.51 klm	26.92 n	28.22
P_3Mg_0	41.70 b	23.85 s	33.87 h-j	33.14	29.64 f-l	31.83 cd	29.54 g-m	30.34
P_3Mg_1	29.17 pqr	29.98 n-r	29.00 pqr	29.39	29.64 f-l	31.39 cde	28.21 lmn	29.75
P_3Mg_2	29.83 o-r	27.18 r	30.70 m-q	29.24	28.41 k-n	34.88 b	28.06 mn	30.45
Mean	34.90	31.67	34.27		29.94	31.93	29.30	
LSD (0.05)	2.836 (Fertilizer levels x Irrigation parts)				1.567 (Fertilizer levels x Irrigation parts)			

44.50 and 79.41 mg L^{-1} and the maximum values were obtained from I_1 and P_1Mg, I_2 and P_1Mg_0, I_3 and P_1Mg_1 treatments (Table 9). Moreover, there was too little difference among irrigations and close values were obtained on I_3. In the second year, total chlorophyll values varied between 36.68 to 74.85 mg L^{-1} and the maximum values were obtained from I_3 and P_1Mg_1 treatment (Table 10).

In the both years of our study, total chlorophyll amount varied for all fertilizer combinations in relation to increased water applications. In the first year, chlorophyll amount increased partly with increased water levels and small differences occurred between irrigation levels. In the second year also, total chlorophyll amount increased with increased irrigation levels. At three irrigation levels, chlorophyll level was affected and increased with increased P and Mg levels.

In conclusion, Mg increased plants uptake of P. Total chlorophyll increased on increased P and Mg doses. Sperrazza and Spremulli (1983) reported that Mg is found in chlorophyll composition; each chlorophyll molecule consists on Mg atom and Mg is at the centre of the chlorophyll molecule. If there is insufficient Mg availability, photosynthesis does not occur. Moreover, when Mg, which is effective on protein synthesis, is insufficient or includes too much K, protein synthesis stops and magnesium is necessary for many of enzyme and enzyme reactions. Moreover, they stated that Mg accelerates uptake of phosphorus by plants, and Mg is found abundant at seed and this is very important for oil. The findings of the present study verify the thoughts of Sperrazza and Spremulli (1983). However, it should not be forgotten that, during soybean fertilization, Mg was not applied to the soil. As Mg (with sulfur) increases oil content, it should be taken into consideration with regard to oil plant yields.

Effect of water, P and Mg treatments on harvest index

In the first year, root dry matter values ranged between 21.14 and 51.40% and between 21.88 and 48.88% in the second year; the maximum value was obtained from I_1 and P_3Mg_2, I_1 and P_3Mg_2 treatment (Table 11). In the second years of study, increased water and phosphorus levels increased harvest index values. Part of the increase was associated with increased magnesium doses (Table 11). Hume et al. (1989) noted that if it is not water stress, harvest index values of soybean range between 47 to 56%; Weilenmann and Luquez (2000) reported a range between 40 to 49%.

Oktem (2005) considers a high harvest index demands too much grain and too little chaff. He suggests that one of the biggest goals of plant producers is to reach 50% harvest indexes; however, the index of 35 to 40% achieved with current growing methods and plant types is much lower than demanded. The findings of this study have some similarities with previous studies and there are some differences in these values for some fertilizer combinations.

Conclusions

In conclusion, the present study found that yield increased with increased water amount and P and Mg treatments. The highest yield was obtained from I_3 (100)

Table 9. Average values of total chlorophyll (mg L^{-1}) and groups occurred on different irrigation levels, fertilizer combinations and dates in 2006.

Fertilizer level	Irrigation												Total mean
	I_1				I_2				I_3				
	Date			Mean	Date			Mean	Date			Mean	
	1*	2*	3*		1*	2*	3*		1*	2*	3*		
P_0Mg_0	57.16cd	59.45cd	73.77ab	63.46	57.43i-m	58.45g-m	63.70c-h	59.86	58.06i-m	53.56l-o	54.98j-o	55.53	59.62
P_0Mg_1	56.97cd	60.23cd	50.47e	55.89	59.68f-k	53.62lm	62.70e-ı	58.67	55.00j-o	52.16mno	60.34g-j	55.83	56.80
P_0Mg_2	59.47cd	61.11c	57.81cd	59.47	56.32klm	59.42f-l	64.84b-f	60.19	54.98j-o	54.03k-o	75.99a	61.67	60.44
P_1Mg_0	57.37cd	58.95cd	78.46a	64.92	57.26i-m	61.26e-k	70.28ab	62.93	53.87k-o	51.51no	73.41ab	59.60	62.49
P_1Mg_1	57.23cd	59.91cd	79.41a	65.52	61.73e-k	58.64g-m	64.34c-g	61.57	57.06i-n	53.32l-o	72.09abc	60.82	62.64
P_1Mg_2	56.58cd	61.46c	72.37b	63.47	58.50g-m	57.85h-m	69.48abc	61.94	58.72h-l	59.58g-k	73.45ab	63.92	63.11
P_2Mg_0	59.53cd	59.39cd	58.21cd	59.04	57.17i-m	57.05i-m	70.90a	61.71	55.78i-o	50.24op	55.37j-o	53.80	58.18
P_2Mg_1	68.22b	59.37cd	54.97de	60.85	58.40h-m	53.12m	63.36d-h	58.29	57.22i-n	58.06i-m	74.82a	63.37	60.84
P_2Mg_2	56.40cd	59.34cd	71.42b	62.39	61.02e-k	58.01h-m	66.25a-e	61.76	61.36f-i	64.21e-h	70.19a-d	65.25	63.13
P_3Mg_0	59.50cd	60.46cd	57.71cd	59.22	57.12ı-m	55.90klm	68.73a-d	60.58	57.83i-m	56.95i-n	67.08c-f	60.62	60.14
P_3Mg_1	56.59cd	59.78cd	59.66cd	58.68	56.73j-m	56.99i-m	62.40e-j	58.71	57.38ı-n	58.65h-l	68.08b-e	61.37	59.59
P_3Mg_2	55.68cde	60.20cd	70.89b	62.26	58.01h-m	59.61f-k	67.87a-d	61.83	55.15j-o	44.50p	65.47d-g	55.04	59.71
Average	58.39	59.97	65.43		58.28	57.49	66.24		56.87	54.73	67.61		
Total mean		61.26				60.67				59.74			
LSD (0.05)	5.907 ((Fertilizer levels x Irrigation parts x Date)												

*Measurement.

irrigation part and P_1Mg_2 (564.50 kg da^{-1}) treatment at first year; and in second year, it was obtained from the same irrigation part and P_2Mg_2 (533.57 kg da^{-1}) treatment. Lower yield was obtained from irrigation parts on which water stress was applied. Yield increased by applying Mg to soil and much higher yields were obtained compared with world soybean yields; this suggests that Mg can play an important role in increasing soybean yields in situations where water and fertilizer treatments must be decreased. Moreover, thousand-grain weight, harvest index, upper-soil biomass and chlorophyll content increased with increased water, P and Mg levels. Root and stem dry matter amounts were not greatly affected by increased water levels, but did increase with increased P and Mg levels.

In this study, increased water and P and Mg treatments increased oil content and the highest values were obtained from I_3 irrigation part and P_3Mg_2 (17.37%) treatment in the first year; and were obtained from the same irrigation part and P_2Mg_2 (19.78%) treatment in the second year. In the first year of the study, protein amount decreased with increased water amount and, in the second year, protein amounts were not affected. Phosphorus and Mg treatment increased protein levels. The highest values were obtained from I_1 irrigation part and P_0Mg_2 (42.24%) treatment; in the second year, the highest values were obtained from I_2 irrigation part and P_1Mg_2 (42.56%) treatment. The most notable finding related to oil and protein on I_1 is that oil and protein amount increased with increased Mg. As magnesium is applied to soil as $MgSO_4$, sulphur (S) was effective on oil content. P fertilizer dose can be decreased by applying $MgSO_4$ to soil. It is understood that, as there was not a significant increase in oil content after increased irrigation, savings can be made in irrigation. These findings reveal important points for soy plant management. It is understood that, with the start of irrigation on Harran Plain, soybean can be included in sowing turn. The findings of this study, which show that high quality soy yield, can be obtained while

Table 10. Average values of total chlorophyll (mg L^{-1}) and groups occurred on different irrigation levels, fertilizer combinations and dates in 2007.

Fertilizer level	Irrigation												Total mean
	I_1				I_2				I_3				
	Date			Mean	Date			Date	Date			Mean	
	1*	2*	3*		1*	2*	3*		1*	2*	3*		
P_0Mg_0	57.54a-f	57.16c-h	41.47l	52.06	57.80cd	55.57f	50.62h	54.66	58.02c-h	57.90c-i	59.27bc	58.40	55.04
P_0Mg_1	58.11abc	57.20c-h	39.60l	51.64	58.99bc	56.80def	51.18gh	55.65	57.05d-ı	57.61c-i	58.62b-e	57.76	55.02
P_0Mg_2	57.98a-d	55.83e-h	51.75ı	55.18	57.62c-f	57.33c-f	46.10ıj	53.68	58.77b-e	57.47c-i	54.93jk	57.06	55.31
P_1Mg_0	59.56a	55.35h	44.65k	53.19	58.46bcd	58.97bc	52.97g	56.80	58.38b-f	57.62c-i	57.04d-i	57.68	55.89
P_1Mg_1	58.44abc	55.44gh	40.66l	51.51	58.46bcd	57.49c-f	55.66ef	57.20	58.98bcd	57.02d-i	74.85a	63.62	57.44
P_1Mg_2	58.16abc	59.26ab	40.83l	52.75	58.16bcd	58.04cd	36.68k	50.96	58.22b-g	57.38c-i	56.21g-j	57.27	53.66
P_2Mg_0	58.18abc	55.98d-h	50.99i	55.05	58.12bcd	58.61bcd	51.49gh	56.07	58.04c-h	58.08c-h	60.27b	58.80	56.64
P_2Mg_1	57.45b-g	55.45gh	46.86j	53.25	55.68ef	58.93bc	61.12a	58.58	57.37c-i	58.81b-e	55.95ij	57.38	56.40
P_2Mg_2	58.38abc	56.97c-h	45.98jk	53.78	57.65cde	60.13ab	47.67i	55.15	58.93bcd	58.27b-f	56.84e-j	58.01	55.65
P_3Mg_0	58.21abc	57.26b-h	51.09ı	55.52	58.27bcd	57.47c-f	53.00g	56.25	58.50b-e	56.42f-j	57.19d-i	57.37	56.38
P_3Mg_1	57.57a-f	57.03c-h	46.17jk	53.59	58.51bcd	56.72def	45.07j	53.44	58.52b-e	58.10c-g	58.16c-g	58.26	55.10
P_3Mg_2	57.69a-e	55.54fgh	45.24jk	52.82	57.71cde	57.41c-f	48.04l	54.39	53.22kl	52.15l	56.03hij	53.80	53.67
Ort.	58.11	56.54	45.44		57.95	57.79	49.97		57.83	57.24	58.78		
G.Ort		53.36				55.24				57.95			
LSD(0.05)					2.063 (Fertilizer levels × Irrigation parts × Date)								

*Measurement.

Table 11. Mean values of harvest index (%) and groups occurred on different irrigation levels and fertilizer combinations in 2006 and 2007.

Fertilizer level	2006			Mean	2007			Mean
	Irrigation part				Irrigation part			
	I1	I2	I3		I1	I2	I3	
P_0Mg_0	35.75 d-i	27.98 j-o	36.69 c-g	33.47	31.20 h-l	25.21 m-p	39.86 bc	32.09
P_0Mg_1	25.15 m-p	22.63 op	33.33 e-j	27.03	26.29 l-p	23.69 op	33.65 f-j	27.88
P_0Mg_2	25.18 m-p	23.25 nop	32.33 f-k	26.92	24.74 nop	21.88 p	34.10 d-l	26.91
P_1Mg_0	31.14 g-l	21.14 p	36.79 c-g	29.69	26.97 l-p	28.76 j-o	32.73 g-k	29.49
P_1Mg_1	26.05 l-p	26.45 k-p	37.52 c-f	30.01	26.89 l-p	27.38 l-o	36.65 c-g	30.31
P_1Mg_2	26.17 l-p	25.15 m-p	38.82 b-e	30.05	23.51 op	28.11 k-o	34.78 c-i	28.80
P_2Mg_0	30.67 h-m	43.67 b	35.75 d-i	36.70	30.49 i-l	43.21 b	37.85 c-g	37.18
P_2Mg_1	30.19 i-m	36.65 c-g	36.14 d-h	34.33	29.93 ı-n	33.52 f-j	37.44 c-g	33.63

Table 11. Contd.

P_2Mg_2	28.62 j-n	37.57 c-f	37.57 c-f	34.59	30.02 i-m	35.16 c-i	36.95 c-g	34.05
P_3Mg_0	31.45 g-l	42.42 bc	37.65 c-f	37.17	39.29 bcd	39.07 b-e	36.34 c-h	38.23
P_3Mg_1	36.88 c-g	35.67 d-ı	39.60 bcd	37.39	39.50 bc	38.73 b-f	38.56 b-f	38.93
P_3Mg_2	51.40 a	35.34 d-i	35.88 d-i	40.75	48.88 a	34.84 c-i	33.85 e-j	39.19
Mean	31.52	31.49	36.51		31.48	31.63	36.06	
LSD(0.05)	5.942 (Fertilizer levels × Irrigation parts)				5.268 (Fertilizer levels × Irrigation parts)			

making water and fertilizer savings should be conveyed to producers, and the findings may inform other studies related to soy in this region.

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