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Response of Silage Maize (*Zea mays* L.) to Nitrogen Fertilizer after Different Crops in a Semi Arid Environment

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Abstract: The use of legume crops in maize rotation systems may decrease the need for nitrogen (N) fertilization and increase total output. The effect of previous crops (wheat, barley, lentil, Hungarian vetch, and fallow) and different N fertilization rates (0, 120, 160, 200, and 240 kg of N ha^{-1}) on yield and N content of silage maize (*Zea mays* L.) were evaluated under irrigated conditions in Diyarbakır, Turkey, during the 1999-2000, 2000-2001, and 2001-2002 growing seasons. Dry matter yield varied between 10,068.2 and 16,480.4 kg ha^{-1}. It was determined that Hungarian vetch was a suitable rotation crop, and that 200 kg of N ha^{-1} was the best N fertilization rate for silage maize production across years and N rates. Moreover, according to the previous crop × N fertilization rate interaction, the highest dry matter yield was obtained from 240 kg of N ha^{-1} after barley. Silage maize following Hungarian vetch in rotation did not respond to the application of more than 120 kg of N ha^{-1}, in terms of dry matter and N yields, while in barley-maize and wheat-maize these 2 parameters increased in response to every level of N fertilization applied. Additionally, fallow-maize and wheat-maize did not respond to the application of more than 200 kg of N ha^{-1}. The legumes showed potential as previous crops that could replace fallow and cereals in silage maize production by reducing the amount of N fertilizer used on silage maize without significantly decreasing dry matter and N yield. Nonetheless, the cereals demonstrated high dry matter yields, based on annual production. According to regression analysis, the highest dry matter and N yields were obtained from the application of 198, 254, 211, 80, and 210 kg of N ha^{-1} after previous crops of wheat, barley, lentil, Hungarian vetch, and fallow, respectively.

Key Words: Silage maize, yield, N yield, previous crops, nitrogen rate, nitrogen saving, cereal, legume

Yarı Kurak Koşullarda Farklı Ön Bitkilerden Sonra Yetiştirilen Silajlık Mısırın (*Zea mays* L.) Azot Uygulamalarına Tepkisi

Özet: Mısır münavebe sistemlerinde baklagil bitkilerinin kullanımı ile azot kullanımı azalmakta ve toplam gelir miktarı artabilmektedir. Bu çalışmada ön bitki (buğday, arpa, mercimek ve Macar fiği ve nadas) ve farklı azot dozlarının (0, 120, 160, 200 ve 240 kg N ha^{-1}) silajlık mısırın verim ve azot içeriğine etkileri üç yıl süreyle (1999-2000, 2000-2001 ve 2001-2002) Diyarbakır sulu koşullarında değerlendirilmiştir. Çalışmada kuru madde verimi 10068.2-16480.4 kg ha^{-1} arasında değişmiştir. Yıl ve azot dozu uygulamalarının ortalamalarına göre macar fiğinin silajlık mısır için en uygun ön bitki olduğu ve 200 kg N ha^{-1} azot uygulamasının yeterli olduğu belirlenmiştir. Ön bitki azot dozu interaksiyonuna göre en yüksek kuru madde verimi 240 kg N ha^{-1} azot × arpa uygulamasından elde edilmiştir. Arpa-silajlık mısır ve mercimek-silajlık mısır münavebe sisteminde mısır bitkileri azot dozu artışlarına kuru madde ve azot verimi yönünden olumlu cevap verirken, Macar fiğinin ön bitki olduğu rotasyonlarda bu özellikler için 120 kg N ha^{-1} üzerindeki dozlarda artış gözlenmemiştir. Ayrıca nadas-silajlık mısır ve buğday-silajlık mısır münavebe sisteminde 200 kg N ha^{-1}'ın üzerindeki doza olumlu tepki gözlenmemiştir. Silajlık mısır üretiminde nadas ve tahıllar yerine baklagillerin ön bitki olarak kullanılmasının kuru madde ve azot veriminde düşüş olmaksızın azotlu gübre miktarının azaltılmasında önemli bir potansiyele sahip olduğu bulunmuştur. Ancak yıllık toplam kuru madde üretimi bakımından en yüksek kuru madde tahılların ön bitki olarak kullanılmasıyla elde edilmiştir. Regresyon analizi sonuçlarına göre en yüksek kuru madde ve N verimi buğday, arpa, mercimek, Macar fiği ve nadas için sırasıyla 198, 254, 211, 80, 210 kg N ha^{-1} dozlarından elde edilebilir.

Anahtar Sözcükler: Silajlık mısır, verim, N verimi, ön bitki, azot dozu, azot tasarrufu, tahıl, baklagil

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Introduction

Silage maize has high energy value, is easy to ensile, has high intake characteristics, and is easy to grow under suitable environmental conditions. Under such conditions, the theoretical limits of biomass yield may be over 25 t of dry matter ha^{-1} (Barriere et al., 1997). Silage maize yield and quality are affected by a number of agronomic practices, including seeding rate, plant density, and mineral fertilization. Forage legumes are widely used as previous crops to improve soil fertility and to increase the yield of subsequent crops in rotation. They are an effective source of nitrogen (N) and also enhance the cycling of phosphorus and other nutrients for subsequent crops (Haynes et al., 1993). In addition to the N that is added to the soil when legumes are turned under, green manure may increase organic matter, soil microbiological biomass, and infiltration of water, as well as lower soil bulk density (McGuire et al., 1998). The use of N fertilization has increased due to an increase in its availability and a rapid decrease in the use of legumes in cropping systems (Badaruddin and Meyer, 1994); however, with renewed interest in legumes, the effects of green manure on following crops are receiving more attention in various cropping systems. Substantial quantities of mineral N are added to soils in intensive cultural systems that use rotation. In contrast to mineral N content, which is immediately available to plants and may be easily quantified, the release of N from organic forms is dependent on the mineralization process (Beauchamp, 1986). The quantification of organic N mineralization from previous crops on these systems is an important step toward improving N use efficiency and reducing losses to the environment (Trindade et al., 2001).

Adams et al. (1970) reported that corn yields following annual green manure crops were greater than for continuous corn, even though as much as 180 kg of N ha^{-1} had been applied to the soil. Mitchell and Teel (1977) observed that no-tillage corn grown without N fertilization following hairy vetch (*Vicia villosa* Roth.) and crimson clover (*Trifolium incarnatum* L.) mixtures produced yields as high as corn grown with the application of 112 kg of N ha^{-1}. Similarly, the N supplied by a hairy vetch cover crop was sufficient to produce corn yields approximately equivalent to fertilizing with 170 kg of N ha^{-1} (Utomo et al., 1990). Ebelhar et al. (1984) killed annual legume cover crops with herbicides and reported that hairy vetch annually supplied the corn with biologically fixed N equivalent to fertilizing with approximately 90-100 kg of N ha^{-1}. Big flower vetch (*Vicia grandifolia* W. Koch.) and crimson clover provided less N than hairy vetch in their study.

The present study aimed to assess the performance of silage maize grown with different levels of N fertilization following various previous crops.

Materials and Methods

Site and Climate

Field trials were conducted during the 1999-2000, 2000-2001, and 2001-2002 growing seasons in a research field at Dicle University, Agricultural Faculty, Diyarbakır, Turkey, which is located in a semi-arid region (lat 37°54 N, long 40°14 E; altitude: 660 m above sea level). Mediterranean and East Anatolian continental climates are dominant in this region. Mean annual temperature was 15.8 °C, mean rainfall was 481.6 mm, and mean relative humidity was about 53.8% (Table 1). Mean temperature is about 30 °C in July and August. Mean temperature can be a low as 7 °C in December and January. The earliest frost in the region usually occurs at the end of October and the last frost takes place at the end of April. Nearly 98% of annual rainfall in the region occurs between September and July. The humidity peaks in winter (70%) and is lowest (27%) in summer. Mean rainfall was higher in 2001 than in 2000 and 2002; 2001's mean was higher than the long-term mean (Table 1). Mean temperature in 2000 and 2001 was higher than the long-term mean, while the mean in 2002 was similar to the long-term mean. Soils in the experimental area were poorly structured alluvial material or limestone. The main characteristics of the soil (depth: 0-50 cm) used in the experimental site were as follows: soil texture: clay; $CaCO_3$: 7.8%; pH: 8.1; organic matter: 1.5%. The soil contained 6.2 and 205 mg kg^{-1} extractable P and K, respectively.

Experimental Details

The field experiment was conducted in an experimental field that was previously cultivated with 2 winter legumes and 2 winter cereals, and without previous crop (fallow) for 3 years. In addition, 5 rates of N fertilization were applied to subsequent silage maize. This irrigated experiment was conducted to evaluate double cropping maize after the removal of wheat, barley, lentil, Hungarian vetch, and fallow.

The study employed a split-plot randomized complete block design with 3 replications. The previous crop

Table 1. Mean monthly rainfall (mm), temperature (°C), and relative humidity (%) in 2000, 2001, and 2002, and long-term means (1929-2002).

Months	Temperature (°C)				Rainfall (mm)				Relative humidity (%)			
	2000	2001	2002	Long-term	2000	2001	2002	Long-term	2000	2001	2002	Long-term
January	1.3	4.0	0.7	1.7	70.9	14.9	31.2	73.5	74	68	77.0	76
February	2.5	5.0	5.6	3.5	58.2	72.4	46.1	67.1	64	66	58.0	72
March	7.0	11.4	9.4	8.1	30.7	126.1	73.0	67.9	51	69	64.0	65
April	15.3	14.3	12.2	13.8	33.0	54.0	65.0	70.5	57	64	69.4	63
May	20.5	16.7	17.9	19.3	6.1	86.9	34.9	42.1	37	60	48.8	56
June	28.0	26.7	26.3	25.9	0.3	0.0	1.3	7.0	21	26	29.7	37
July	33.4	31.6	31.0	31.0	0.0	0.0	0.0	0.7	13	22	19.9	27
August	30.4	30.2	29.8	30.3	0.0	0.0	0.0	0.5	20	25	22.2	27
September	24.7	24.7	25.0	24.8	0.9	0.0	5.5	2.7	27	27	27.9	32
October	16.7	16.3	18.6	17.0	35.1	67.0	15.7	31.1	47	50	41.9	48
November	9.4	7.0	10.2	9.6	34.0	52.2	36.6	54.0	54	60	55.3	67
December	4.3	5.1	4.0	4.1	113.6	131.7	74.4	71.5	79	61	71.0	76
Mean/Total	16.1	16.1	15.9	15.8	382.8	605.2	383.7	481.6	45.3	49.8	48.7	53.8

treatments were the main plots, and N rates were the sub-plots. The sub-plot size was 2.8 5 m. The previous crop treatments included fallow, wheat, barley, lentil, and Hungarian vetch. The N rates applied to silage maize were 0 (N0), 120 (N1), 160 (N2), 200 (N3), and 240 (N4) kg of N ha^{-1}. All previous crops were planted in the middle of November. Silage maize was planted 15-20 June after harvest of lentil and Hungarian vetch, 20-25 June after harvest of barley, and 25-30 June after harvest of wheat. Silage maize after fallow was planted at the same time as the wheat treatment. Supplemental water was given twice for wheat and barley, and once for lentil and Hungarian vetch.

Previous crops were removed from the plot area by raking immediately prior to sowing. Maize (TTM-815 cv.) was planted in 4 rows with 70-cm spacing. The plant population was approximately 119,040 plants ha^{-1}. Half of the N fertilizer and all (100 kg ha^{-1}) of the P_2O_5 were applied at the time of sowing, and the remaining N was top dressed 35 days after sowing. Plots were clean-weeded twice with the use of hands-hoes. All plots were irrigated at intervals of 7-10 days, according to leaf phenology.

Dry matter yield of maize was determined by cutting plants in 2 rows in the center of each plot at a stubble height (10 cm). Samples were dried at 65 °C for 48 h and weighed. N content of the plants was determined using a Leco FP-528 N analyzer. N yield was determined by multiplying dry matter content by N content.

Linear or non-linear regression models were tested to determine which N fertilization rate produced the highest dry matter and N yields. Cubic regression curves, which better explain the effects of N fertilization for all application methods, were used.

Results were analyzed using MSTAT-C software, and comparison of means was accomplished with Tukey's least significant difference test (LSD) at $P = 0.05$. Regression analysis was performed with SPSS software.

Results

Grain yield and biomass weight of the previous crops are presented in Table 2. The response to the environment of the cereals (wheat and barley) and legumes (lentil and Hungarian vetch) was different within the same year. The cereals had the highest grain and biomass yields in 2000, whereas the legumes had the lowest. Among previous crops, barley had the highest grain yield and biomass all 3 growing seasons.

N content and dry matter yield were significantly affected by year, previous crop, and N fertilization rate, as shown in Table 3; however, the effect of year was not significant for N yield. Dry matter yield had a positive relationship with N content over growing seasons. A similar pattern was observed for N yield. Previous crops significantly affected all the investigated traits. Hungarian vetch was the most successful previous crop, in terms of N

Table 2. Mean grain and biomass yield of previous crops in 2000, 2001, and 2002.

Previous crops	Grain Yield (kg ha^{-1})			Biomass Yield (kg ha^{-1})		
	2000	2001	2002	2000	2001	2002
Wheat	4990	4600	4800	12,690	12,000	12,580
Barley	6400	5900	6340	13,120	12,020	13,090
Lentil	1100	1250	1180	3750	3950	4060
Hungarian vetch	600	850	900	3500	3950	4070

Table 3. N content, N yield, and dry matter yield of silage maize, according to year, previous crop, and N fertilization rate.

Year	(N content) g kg^{-1}	(N yield) kg ha^{-1}	(Dry matter yield) kg ha^{-1}
2000	13.5b	200.3	14,887.1 a
2001	14.4a	200.0	13,905.6 b
2002	14.2a	193.7	13,635.9 b
Previous crop			
Wheat	12.6d	175.0c	13,733.4 b
Barley	13.6c	192.5b	14,000.2 b
Lentil	15.0a	215.0a	14,326.1 ab
Hungarian vetch	14.9a	222.2a	14,875.6 a
Fallow	14.0b	193.7b	13,779.0 b
N rate (kg ha^{-1})			
N0 (0)	12.9c	154.3d	11,859.2 d
N1 (120)	13.9b	193.7c	13,830.7 c
N2 (160)	14.3a	205.5b	14,405.0 b
N3 (200)	14.5a	223.3a	15,441.0 a
N4 (240)	14.6a	221.6a	15,178.6 a
cv.	5.51	10.69	9.15
Previous crops (a)	**	**	*
N rates (b)	**	**	**
a × b	**	**	**

[1]Means followed by the same letter are not significantly different at the 0.05 level according to the LSD test.
*F-test significant at $P \leq 0.05$; **F-test significant at $P \leq 0.01$.

and dry matter yields. Use of wheat and barley as previous crops decreased N content, N yield, and dry matter yield.

Increasing the amount of N fertilizer generally had favorable effects on all the traits (Table 3); however, N content, N yield, and dry matter yield did not increase after application of 200 and 240 kg of N ha^{-1}. Increasing N fertilization from N0 to N4 increased the N content of wheat, barley, and fallow (Table 4). Without N fertilizer (N0), variation in N yield among the previous crops was large, and N yield declined in the following order: Hungarian vetch > lentil > fallow > barley > or < wheat (Table 5). Dry matter yield increased from N0 to N2 in lentil and from N0 to N1 in Hungarian vetch, while increases continued to N3 in wheat and fallow, and to N4 in barley (Table 6).

Regression analysis showed that the relationship between the N fertilization rate, and dry matter and N yields was significant for all previous crops ($P < 0.05$), except for the dry matter yield of Hungarian vetch ($P < 0.10$) (data not shown). The curves simulated in the prediction of dry matter and N yields for the different N fertilization rates are given in Figure. According to the

Table 4. Previous crop × N fertilization rate interactions for N content (g kg^{-1}) of silage maize (3-year average).

Previous crops	N rate (kg of N ha^{-1})				
	0	120	160	200	240
Wheat	12.4 k	13.2 jk	14.1 hi	15.0 g	15.2 fg
Barley	12.8 k	14.9 gh	15.6 efg	15.8 def	15.9 def
Lentil	16.3 a-e	16.6 a-d	16.6 a-d	16.8 a	16.5 a-d
Hungarian vetch	16.0 b-f	16.8 abc	16.5 a-d	16.5 a-d	16.8 ab
Fallow	13.7 ij	15.6 efg	15.9 def	16.0 c-f	16.2 a-e

* Means followed by the same letter are not significantly different at the 0.05 level according to the LSD test.

Table 5. Previous crop × N fertilization rate interactions for N yield (kg ha^{-1}) in silage maize (3-year average).

Previous crops	N rate (kg of N ha^{-1})				
	0	120	160	200	240
Wheat	794.3 kl	916.9 jk	1035.9 ij	1394.0 a-d	1327.1 b-e
Barley	731.6 l	1141.8 hi	1274.3 d-g	1409.2 ab	1458.7 a
Lentil	1199.3 gh	1298.8 b-g	1419.9 ab	1386.0 a-d	1415.9 ab
Hungarian vetch	1241.1 e-h	1492.6 a	1412.1 ab	1402.5 abc	1396.8 a-d
Fallow	856.3 k	1202.4 fgh	1280.9 c-g	1385.1 a-d	1326.9 b-f

* Means followed by the same letter are not significantly different at the 0.05 level according to the LSD test.

Table 6. Previous crop × N fertilization rate interactions for dry matter yield (kg ha^{-1}) of silage maize (3-year average).

Previous crops	N rate (kg of N ha^{-1})				
	0	120	160	200	240
Wheat	11,405.9 hi	12,361.9 gh	13,012.0 fg	16,480.4 a	15,406.8 a-d
Barley	10,068.2 j	13,544.3 efg	14,446.1 de	15,737.9 abc	16,204.6 ab
Lentil	12,992.7 fg	13,785.9 ef	15,130.8 bcd	14,583.5 cde	15,137.5 bcd
Hungarian vetch	13,734.8 ef	15,762.5 abc	15,145.0 bcd	15,023.8 bcd	14,712.3 cde
Fallow	11,094.3 ij	13,698.8 ef	14,291.4 de	15,379.2 a-d	14,431.6 de

* Means followed by the same letter are not significantly different at the 0.05 level according to the LSD test.

results of cubic equations, which were obtained for each previous crop, the highest dry matter yield in silage maize can be obtained by applying 97, 196, 216, 223, and 294 kg of N ha^{-1} after previous crops of Hungarian vetch, fallow, lentil, wheat, and barley, respectively (Table 7). Similarly, the highest N yield in silage maize can be obtained by applying 80, 198, 210, 211, and 254 kg of N ha^{-1} after previous crops of Hungarian vetch, wheat, fallow, lentil, and barley, respectively. N fertilization estimations showed that the N fertilization rates that resulted in the highest dry matter yields could decrease potential N yield; however, it was possible to obtain high dry matter yields without significantly decreasing the N fertilization rates that produced the highest N yields.

Discussion

Legumes are superior previous crops, compared to non-leguminous crops, because they fix atmospheric N (Vyn et al., 2000). Similarly, use of legumes as previous crops in the present study out-yielded cereal and fallow in terms of all traits, especially N yield (Table 3). Considerable variation in N fixation can occur even among legume species (Hesterman et al., 1992). Moreover, in the present study slight differences were observed between the effects of lentil and Hungarian vetch as previous crops. Other favorable effects of legumes can stem from residues that contain a considerable amount of N and have relatively low C/N residue, leading to more rapid release of N than from cereal residue, which contains less N (Janzen and Kucey, 1988; Gilmour et al., 1998). In comparing the present study's cropping systems, without a sufficient supply of N fertilization, the Hungarian vetch produced more N and dry matter than the other previous crops.

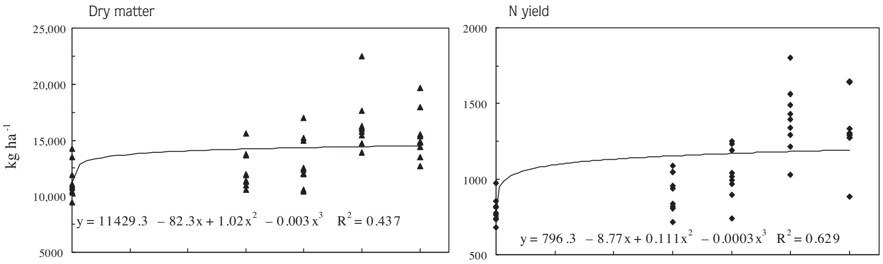
On the other hand, a barley-maize double-cropping sequence would increase annual biomass production. At the same time, it greatly reduces soil erosion during the cool season, but this cropping does not reduce the hazard of nitrate leaching. In the present study total dry matter production of cereal-silage maize rotation, on the basis of annual production, was 43% higher than that of legumes across year and N rates. Nonetheless, dry matter production in the cereals fertilized with N0 was 35% higher than that in the legumes (Tables 2 and 3). The price of cereals and legumes should be taken into account when both plant families are compared in silage maize rotation, as grain legumes usually command 2 times the price of cereals in Turkey

In evaluating the effects of previous crops of Hungarian vetch, it must be considered that low-level N fertilization (< 120 kg of N ha^{-1} or 80 kg of N ha^{-1}, estimated from regression), resulted in the highest levels of all the investigated traits in silage maize (Table 3). When maize relied exclusively on soil-derived N (N0), the systems in which wheat, barley, and fallow were used as previous crops produced extremely low N yields, in comparison to lentil and Hungarian vetch. Thus, wheat, barley, and fallow seem to have very high N requirements in order to attain maximum maize N and dry matter yields.

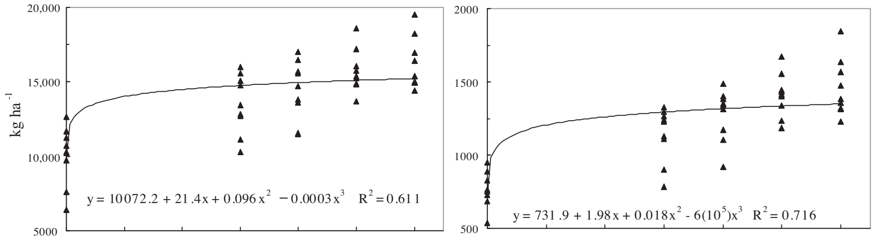
After legumes, silage maize yielded 38.5 kg of N ha^{-1} more than the cereals did across all N rates (Table 3). The residual N effects of legumes observed in the present study correlate well with the findings published by Badaruddin and Meyer (1994), and Dalal et al. (1998); both reported that mineral N in root zone soil following grain legumes is often 30-60 kg ha^{-1} higher than after cereal crops in the same environment. N content obtained by legume-silage maize rotations with N0 were higher than that obtained with the highest N rate (N4) of cereal-silage maize rotation. N yield and dry matter yield of legume-silage

Table 7. Estimated highest dry matter and N yields in silage maize for different N fertilization rates, based on regression curve estimation.

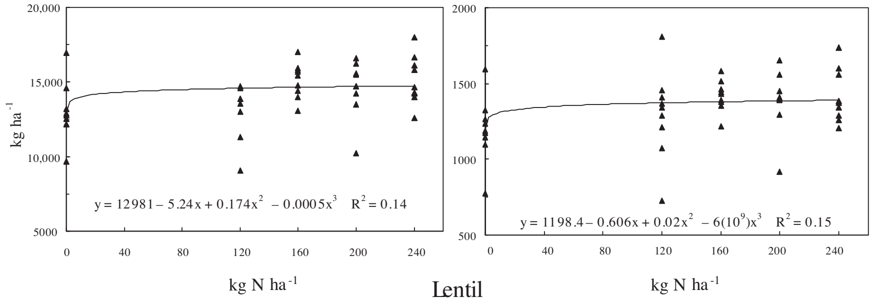
Previous crops	N Rate (A)	Dry matter (A)	N Rate (B)	N yield	Dry matter (B)	Dry matter loses %
	(kg of N ha^{-1})	= (kg ha^{-1})	(kg of N ha^{-1})	= (kg ha^{-1})	= (kg ha^{-1})	1 - (A/B) × 100
Wheat	223	= 16,083	198	= 1091	= 15,722	= 2.2
Barley	294	= 17,050	254	= 1477	= 16,597	= 1.5
Lentil	216	= 14,929	211	= 1415	= 14,925	= 0.1
Hungarian vetch	97	= 15,816	80	= 1490	= 15,770	= 0.3
Fallow	196	= 14,921	210	= 1375	= 14,855	= 0.4



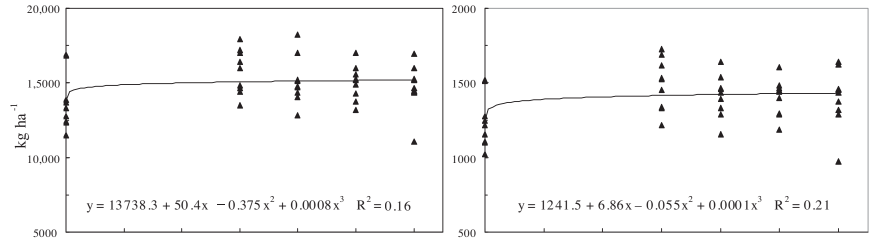
Wheat



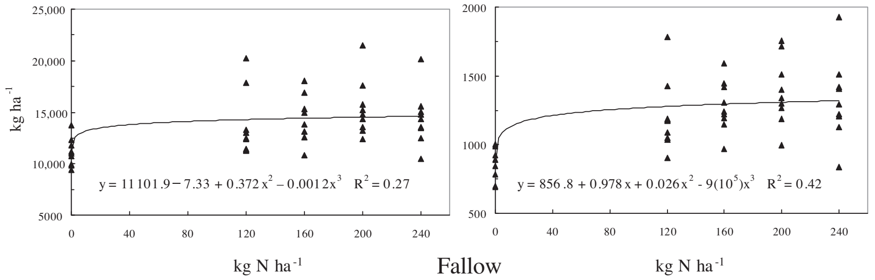
Barley



Lentil



Hungarian vetch



Fallow

Figure. Regression curve for estimation of dry mattrer (column 1) and N yield (column 2) of silage maize accodring to N fertilization rate after different previous crops.

maize rotations with N0 were equivalent to cereal-silage maize rotation with N2; however, the differences in dry matter yield between the legume-maize and cereal-maize rotations were minimal in terms of the applied rates of N fertilization. (Table 6). In order to achieve high dry matter production in the case of cereals as a previous crop, maize required slightly more N when compared to rotation with previous crop legumes. These findings are consistent with the results of Turgut et al. (2005), who reported that sweet corn yields after annual green manure of legume reached a plateau after fertilization with 120 kg of N ha^{-1}. Based on regression analysis, it is possible to save 146 kg of N ha^{-1} with 80 kg of N ha^{-1} fertilization following Hungarian vetch, with higher N content and a decrease in dry matter yield of only 1.9%. The growth potential with low N-input conditions provides an indication of the potential return from the investment made by farmers for Hungarian vetch-silage maize rotation systems.

Conclusions

This study suggests that annual legumes are potentially good previous crops to use instead of fallow and cereals in silage maize production in a semi-arid Mediterranean-type climate. Legumes were the most suitable species for use as previous crops, and resulted in high N and dry matter yields with limited N fertilization. Our results also indicate that N fertilization applied to silage maize can be reduced by 90 kg ha^{-1} if it is preceded by annual legumes. The choice between lentil and Hungarian vetch is a matter of farmer preference for home consumption, market price, and long-term rotational needs for avoiding pests and diseases. When the evaluation was made on an annual basis and low N input conditions (120 kg of N ha^{-1}), we observed that the cereals had high dry matter yields; however, the availability of cereals for cereal-silage maize rotation should be analyzed in terms of returns to land and labor.

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