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MAIZE AND LEGUMES ROOT GROWTH AND YIELD AS INFLUENCED BY ORGANIC FERTILIZATION, UNDER MEDITERRANEAN ENVIRONMENTAL CONDITIONS

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ABSTRACT

Field experiments were conducted to determine the effects of green manures on growth and yield of maize crop. This study also evaluated the effects of two different composts on nitrogen fixation and growth of legume crops. The experiments used a split-plot design with three replicates, three main plots (control - no treatment, compost 1 and compost 2) and three sub-plots (vetch, faba bean and pea). The legumes root growth was affected by the compost application. The highest root diameter, density and dry weight was found under organic fertilization treatments (compost 1 and 2). Nitrogen fixation was also affected by the compost application. The highest root and above-ground N % was found under compost 1 treatment. Moreover, the highest above-ground biomass was found under organic fertilization treatments (compost 1 and 2). Faba bean and vetch had higher biomass in comparison to pea, and both these species accumulated significantly more N than pea. The maize root growth was affected by the organic fertilization. The highest leaf area index, root and aboveground dry weight were found in the plots where vetch was used as a green manure. The lowest yield was found in the plots where pea was used as a green manure. The main reason for differences in maize growth between green manure treatments may be attributed to the rate of N mineralization of each green manure. The results suggest that vetch is the optimum species for use as green manure.

Key words: green manure, compost, legumes, maize, organic agriculture, yield.

INTRODUCTION

Management methods that decrease requirements for agricultural chemicals are needed in order to avoid adverse environment impacts (Bilalis et al., 2009). The use of green manure and compost are two of the basic cultivation techniques of Organic Agriculture. The utilization of green manures as alternatives to reduce the use of mineral fertilizers is considered a good agricultural practice. Legumes have already become very popular in sustainable cropping practices, as they fix atmospheric nitrogen, which can be transferred to a subsequent crop through mineralization of the legume residues (Pypers et al., 2005). However, the effect of each green manure on soil properties and crop yield depends upon its chemical composition (Tejada et al., 2008).

Vetch, pea and faba bean are legume species well adapted to the soil and climate conditions of Mediterranean region, including Greece. They can also be cultivated as plants for green manure, during the period between two major crops (Bilalis et al., 2010a). These legumes can be seeded at the beginning of October and then cut and incorporated into the soil at the end of April. Application of compost is also considered a beneficial management practice. Data obtained by other researchers (Basso and Ritchie, 2005; Bilalis et al., 2010a, b; Quattara et al., 2008; Sangakkara et al., 2004) clearly demonstrated the beneficial effects of legumes on the yields of the following crops (cotton, flax, wheat).

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The aim of this study was to determine the effects of green manures on plant growth and yield of maize crop, and the performance of legumes fertilized with compost fertilizers.

MATERIAL AND METHODS

Experimental field

The experiments were established in the organic experimental field of the Agricultural University of Athens (23.43 E, 34.58 N) in 2004 and 2005. The soil was clay loam (29.8% clay, 34.3% silt and 35.9% sand) with pH 7.24, NO_3-N 9.4 mg kg^{-1} soil, P 11.2 mg kg^{-1} soil, K 161 mg kg^{-1} soil.

Experiment 1 - Legumes

The experiment was set up on an area of 650 m^2 according to the split-plot design with three replicates, three main plots (control-no treatment; compost 1: 2500 kg ha^{-1}, 10% N, 8% P ad 12%; and compost 2: 2500 kg ha^{-1}, 1.5 % N, 1% P ad 4.5%) and three sub-plots (vetch, faba bean and pea). The compost 1 was made from legume residues and farmyard manure, and the other from seaweed (*Posidonia oceanica*) and farmyard manure. The main plot size was 54 m^2 and the sub-plot size was 18 m^2. Vetch (*Vicia sativa* cv. Alexander), faba bean (*Vicia faba* cv. Valencia) and pea (*Pisum sativum* cv. Carumbi) were sown on 25 November 2003 and 2004 at rates of 150, 400 and 250 kg ha^{-1}, respecttively. Legumes were sown by hand in rows of 20 cm apart at a depth of 3 cm. Weeds were controlled by hand at 50 days after sowing.

For the computation of above-ground biomass (dry weight), 10 plants were randomly selected in each plot, at 130 DAS (days after sowing). The dry weight (yield) was determined after drying for 72 h at 70ºC. Root samples were collected 130 DAS and from the 0-25 cm layer by using a cylindrical auger (25 cm length, 10 cm diameter) at the midpoint between successive plants within a row. For each sample, roots were separated from soil after standing for 24 h in water + $(NaPO_3)_6$ + Na_2CO_3. The root dry weight was then determined after drying one of the paired samples for 48 h at 70ºC. For the determination of the density and diameter of roots, the root samples were placed on a high-resolution scanner using DT software (Delta-T Scan version 2.04; Delta-T Devices Ltd, Burrwell, Cambridge, UK). The total nitrogen of the root and above-ground biomass were determined by the Kjeldahl method (Bremner, 1960) using a Buchi 316 device.

Experiment 2 - Maize

Legumes were incorporated by one rotary hoeing on 15 April 2004 and 2005 and subsequently maize (*Zea mays* L. Mitic F_1) was hand-sown on 5 May 2004 and 2005 at same plots. Maize was planted at 80 cm row spacing, at an approximate density of 78000 plants ha^{-1}. Leaf area was measured using an automatic leaf area meter (Delta-T Devices Ltd). Thus, the measurements on a per plant basis (cm^2 plant^{-1}) were converted into a leaf area index (LAI) by multiplying this value by the average crop density of each plot. For the computation of dry weight, 5 plants were randomly selected in each plot.

The dry weights of all plant parts were determined after drying for 72 h at 70ºC. For the compu-tation of yield, 10 plants were harvested per plot and all yield measurements were made at 14% seed moisture content. Root samples were collected 150 DAS and from the 0-25 cm layer by using a cylindrical auger. For each sample, roots were separated from soil. The root density, diameter and dry weight were then determined. Harvest index (HI) and sustainable yield index (SYI) were also calculated. Sustainable yield index (SYI) was developed by Singh et al. (1990). The SYI and HI indices were calculated as follows:

$$SYI = \frac{Ym - Sd}{Ymax}$$

and

$$HI = \frac{\text{grain yield}}{\text{total dry biomass}}$$

where, *Ym i*s the mean yield, *Sd* the standard deviation, *Ymax* is the maximum yield obtained under a set of management practices.

Statistical analysis

For calculating analysis of variance and comparisons of means, Statistica software

(StatSoft 1996) was used. The LSD test was used to detect and separate the mean treatment differences. Correlation analyses were used to describe the relationships between root parameters and yield. All comparisons were made at the 5% level of significance. The results were presented as two year averages.

RESULTS AND DISCUSSION

Legumes growth and nitrogen fixation

The legumes root growth was affected by the compost application (Table 1). The highest root diameter, density and dry weight was found under compost 1 and compost 2. Composts application increased roots biomass, mostly when compost 1 was applied to soil. This compost, which had a high *N* content, stimulated root growth to a greater extent than compost 2. Pea had lower root biomass (1120-1530 kg ha^{-1}) in comparison to other legumes (vetch and faba bean). The highest root density (3.84 cm cm^{-3}, 4.36 cm cm^{-3} and 4.21 cm cm^{-3} for control, compost 1 and compost 2, respectively) was found in vetch crop. The highest root diameter (0.94 cm, 1.06 cm and 0.97 cm for control, compost 1 and compost 2, respectively) was found in faba bean crop.

The nitrogen present in roots has often been ignored in the N economy of cropping systems, because roots are thought to contain only small amounts of N (10-15% of the total plant N) (Kumar and Goh, 2000). Our results indicated that legumes roots contain 24-49% of the total plant N (Tables 1 and 2).

Table 1. Effects of organic fertilization (control, compost 1 and compost 2) on root density, root diameter, root biomass, N % and total N

Treatments	Root density (cm cm^{-3})	Root diameter (cm)	Root biomass	N %	Total N (kg ha^{-1})
Pea					
Control	1.43	0.62	1120	1.82	20.4
Compost 1	2.28	0.71	1530	2.20	33.6
Compost 2	1.76	0.65	1320	2.19	28.9
$LSD_{5\%}$	*0.35*	*0.03*	*185*	*0.12*	*6.7*
Vetch					
Control	3.84	0.57	2540	2.24	56.9
Compost 1	4.36	0.61	3220	2.37	76.3
Compost 2	4.21	0.58	2950	2.29	67.5
$LSD_{5\%}$	*0.41*	*0.02*	*250*	*0.07*	*8.9*
Faba bean					
Control	1.80	0.94	3250	2.14	69.5
Compost 1	2.27	1.06	3830	2.40	91.9
Compost 2	1.84	0.97	3450	2.28	78.6
$LSD_{5\%}$	*0.14*	*0.05*	*330*	*0.11*	*9.6*

Nitrogen fixation was also affected by the compost application. The highest root and above-ground N % was found under compost 1 treatment (Tables 1 and 2).

The lowest total N that accumulated on legumes crops was found in pea crop (83.5 kg ha^{-1}, 126.9 kg ha^{-1} and 105.1 kg ha^{-1} for control, compost 1 and compost 2, respect-tively). The amount of total N that accumu-lated on vetch plants and incorporated into the soil was 115.2 kg ha^{-1}, 166.9 kg ha^{-1} and 146.3 kg ha^{-1} for control, compost 1 and compost 2, respectively. Also, the amount of total N that accumulated on vetch plants and incorporated into the soil was 194.4 kg ha^{-1}, 277.6 kg ha^{-1} and 246 kg ha^{-1} for control, compost 1 and compost 2, respectively. The highest above-ground biomass was found under organic fertilization treatments (compost 1 and 2). Faba bean had higher biomass (10320-13860 kg ha^{-1}) in comparison to other legumes (vetch and pea). The main reason for high dry biomass in the treatment with compost 1 plots may be attributed to N content. Data obtained by others researchers (Basso and Ritchie, 2005; Leroy et al., 2007) demonstrated the beneficial effects of compost on growth of the following crops (i.e. maize).

Table 2. Effects of organic fertilization (control, compost 1 and compost 2) on above-ground biomass, N %, total above-ground N and total N

Treatments	Above-ground biomass (kg ha^{-1})	N %	Total above-ground N (kg ha^{-1})	Total N (root and above-ground) (kg ha^{-1})
Pea				
Control	4100	1.54	63.1	83.5
Compost 1	5360	1.74	93.3	126.9
Compost 2	4620	1.65	76.2	105.1
$LSD_{5\%}$	*452*	*0.08*	*11.2*	*17.9*
Vetch				
Control	5120	1.14	58.3	115.2
Compost 1	7250	1.25	90.6	166.9
Compost 2	6680	1.18	78.8	146.3
$LSD_{5\%}$	*853*	*0.03*	*13.2*	*22.1*
Faba bean				
Control	10320	1.21	124.9	194.4
Compost 1	13860	1.34	185.7	277.6
Compost 2	13080	1.28	167.4	246.0
$LSD_{5\%}$	*984*	*0.05*	*14.8*	*24.4*

Maize growth and yield

The maize root growth was affected by the green manures (Table 3). The highest root dry weight was found in the plots where vetch was used as a green manure (5855 kg ha^{-1}, 5395 kg ha^{-1} and 5216 kg ha^{-1} for compost 1, compost 2 and control, respectively). The main reason for differences in root growth between green manures treatments may be attributed to the rate of N mineralization of each fertilizer (Bilalis et al., 2010b). Also, the highest root biomass (4645 kg ha^{-1}, 5855 kg ha^{-1} and 4320 kg ha^{-1} for faba bean, vetch and pea, respectively) was found in legumes plots fertilized with compost. The highest maize root density (9.13 cm cm^{-3}, 13.36 cm cm^{-3} and 11.49 cm cm^{-3} for control, compost 1 and compost 2, respectively) was also found in the plots where vetch used as a green manure. The lowest root diameter (0.86 cm, 0.93 cm and 0.95 cm for control, compost 1 and compost 2, respectively) was found in the plots where pea was used as a green manure. Data obtained by others researchers (Bilalis et al., 2009; Sangakkara et al., 2004) demonstrated the beneficial effects of legumes on the root growth of the following crops (tobacco, maize).

Table 3. The effect of organic fertilization on maize root dry weight, root diameter and root density

Treatments	Faba bean	Vetch	Pea	*$LSD_{5\%}$*
Root dry weight, kg ha^{-1}				
Control	4040	5216	3595	*947*
Compost 1	4645	5855	4275	*935*
Compost 2	4355	5395	4320	*691*
$LSD_{5\%}$	*342*	*373*	*460*	
Root diameter, cm				
Control	0.97	1.02	0.86	*0.04*
Compost 1	1.12	1.21	0.93	*0.06*
Compost 2	1.03	1.14	0.95	*0.04*
$LSD_{5\%}$	*0.05*	*0.07*	*0.05*	
Root density, cm cm^{-3}				
Control	8.03	9.13	7.43	0.97
Compost 1	11.12	13.36	9.26	2.32
Compost 2	8.47	11.49	8.46	1.97
$LSD_{5\%}$	1.89	2.39	1.03	

The highest above-ground dry weight was found in the plots where vetch was used as a green manure. Above-ground biomass had positive and significant correlation (Table 4) with root density (r=0.82**, p<0.01, r=0.85**, p<0.01 and r=0.65, p<0.05 for vetch, faba bean and pea, respectively). The highest biomass (32770 kg ha^{-1}, 3410 kg ha^{-1} and 32430 kg ha^{-1} for faba bean, vetch and pea, respectively) was found in legumes plots fertilized with compost 1. The highest leaf area index (2.80, 4.42 and 2.94 cm cm^{-3} for control, compost 1 and compost 2, respectively) was also found in the plots where vetch was used as a green manure.

Table 4. Correlation coefficients[1)] between plant parameters of maize

Parameter	Green manure		
	Vetch	Faba bean	Pea
Root length density * LAI	0.82**	0.76**	0.79**
Root length density * Grain yield	0.78**	0.75**	0.95***
Root density * Above-ground dry weight	0.82**	0.85**	0.65*
Root dry weight * LAI	0.72*	0.79**	0.71*
Root dry weight * Grain yield	0.82**	0.80**	0.75**

[1)]r was calculated using the linear equation.
*, **, ***, significant at p ≤ 0.05, 0.01 and 0.001, respectively.

It must be noted that even if faba bean seems to supply soil with higher amount of total N than vetch, maize growth was more affected by vetch and less by faba bean incorporation. Substantially, the slower decomposition of faba bean residues can be easily explained by their higher maturity when they were incorporated, in contrast to vetch and pea (beginning of flowering stage). Therefore, faba bean residues contained higher quantities of lignin, which were responsible for the lower decomposition rate of residues (Singh et al., 1992). Pypers et al. (2005) also reported that nitrogen release from *Tithonia diversifolia* with the highest lignin content occurred more gradually compared to the three legumes (*Flemingia congesta, Mucuna pruriens, Pueraria phaseoloides*).

The lowest yield (15660 kg ha^{-1}, 17510 kg ha^{-1} and 16030 kg ha^{-1} for control, compost 1 and compost 2, respectively) was found in the plots where pea used as a green manure. Maize yield had positive and significant correlation with root dry weight (r=0.82**, p<0.01, r=0.80**, p<0.01 and r=0.75**, p<0.01 for vetch, faba bean and pea, respectively). Data obtained by other researchers (Bilalis et al., 2010a, b; Quattara et al., 2008; Sangakkara et al., 2004) demonstrated the beneficial effects of legumes on the yields of the following crops (cotton, flax, wheat).

Concerning harvest index (Table 5) we can readily observe relatively high values for all legume green manure treatments (>0.5). The highest harvest index (0.559, 0.569 kg ha^{-1} and 0.570 for control, compost 1 and compost 2, respectively) was found in the plots where vetch used as a green manure. The highest sustainable yield index (0.856, 0.902 and 0.895 for control, compost 1 and compost 2, respectively) was found in the plots where vetch used as a green manure. In contrast, the lowest sustainable yield index was found in the plots where pea used as a green manure. Efthimiadou et al. (2010) reported that the sustainability yield indices (sustainable yield index and agronomic efficiency) showed that the maize crop is more stable under combined organic and inorganic fertilization, compared with mineral fertilization.

Table 5. The effect of organic fertilization on maize dry weight, leaf area index (LAI), harvest index (H.I) and sustainable yield index (SYI)

Treatments	Faba bean	Vetch	Pea	$LSD_{5\%}$
Leaf area index (LAI)				
Control	2.28	2.8	1.69	*0.63*
Compost 1	3.94	4.42	2.79	*0.95*
Compost 2	2.84	2.94	1.93	*0.63*
$LSD_{5\%}$	0.96	1.02	*0.65*	
Dry weight, kg ha^{-1}				
Control	29720	31730	28650	*2393*
Compost 1	32770	34180	32430	*1050*
Compost 2	31220	33250	29630	*2110*
$LSD_{5\%}$	1839	831	*2219*	
Yield				
Control	17110	17750	15660	*619*
Compost 1	18960	19440	17510	*1137*
Compost 2	17470	18960	16030	*1143*
$LSD_{5\%}$	1109	985	*482*	
Harvest index (HI)				
Control	0.576	0.559	0.546	*0.034*
Compost 1	0.579	0.569	0.539	*0.014*
Compost 2	0.559	0.570	0.541	*0.020*
$LSD_{5\%}$	0.023	0.015	*0.025*	
Sustainable yield index (SYI)				
Control	0.725	0.856	0.645	*0.091*
Compost 1	0.771	0.902	0.652	*0.084*
Compost 2	0.767	0.895	0.649	*0.109*
$LSD_{5\%}$	*0.020*	*0.019*	*0.032*	

CONCLUSIONS

Our results indicated that the legume growth and nitrogen fixation was affected by the compost application. The highest root and above-ground N % was found under compost 1 treatment. Faba bean and vetch had higher biomass in comparison to pea, and both these species accumulated significantly more N than pea.

Green manures also greatly affected the growth of maize. Vetch and faba bean green manures increased root mass of maize plants. The highest biomass and yield of maize was measured under vetch green manure. Moreover, the sustainable yield index showed that the maize crop was more stable under vetch green manure compared with faba bean and pea green manures.

Concerning the organic agriculture system, the growth and yield of maize can be improved by the best choice of a suitable green manure crop.

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