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Response of organic linseed (*Linum usitatissimum* L.) to the combination of tillage systems, (minimum, conventional and no-tillage) and fertilization practices: Seed and oil yield production

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Abstract

Limited tillage systems, especially no-tillage, have become widespread in recent years. The no-tillage practice is widely adopted worldwide for erosion control and to maintain soil fertility. Field experiments were conducted to determine the effects of tillage systems and organic fertilization on the growth, yield and oil content of flax crop (*Linum usitatissimum* L.). The experiments, conducted during 2009 and 2010, were laid out in a split plot design with four replicates, three main plots (conventional tillage, minimum tillage and no-tillage) and the three sub-plots (compost, vetch and faba bean as green manure). The soil organic matter and total nitrogen were higher in soils subjected to conservation tillage systems (minimum and no-tillage) than under conventional tillage. The highest leaf area index (LAI), dry weight and arbuscular mycorrhizal (AM) root colonization was found in conservation tillage systems. There were no significant differences between the organic fertilization treatments concerning the LAI, dry weight and AM root colonization. There were significant differences for root growth between the tillage systems. The highest root weight was found in the no-tillage system. Moreover, the highest seed yield (1761 kg ha^{-1}) and oil yield (670 kg ha^{-1}) were found with minimum tillage. There were statistically significant differences between minimum tillage and conventional tillage. Vetch and faba bean green manures had a significant effect on oil content. A high correlation was observed between oil yield and oil content. Our results indicated that conservation tillage systems enhance organic matter in soils and increase oil yield of flax.

Keywords: Arbuscular mycorhizal fungi, Compost, Flax, Green manure, *Linum usitatissimum* L., No-tillage, Oil content, Tillage.
Abbreviations: CT-conventional tillage; LAI-leaf area index; MT-minimum tillage; NT-no tillage.

Introduction

Flax or linseed (*Linum usitatissimum* L.) belongs to the Linaceae family that consists of 9 genus and 150 species. It is the only species in this family that has economic as agronomic values (Copur *et al.,* 2006). Flax seed is used for oil production and also in food industries because of its nutritional merits, essential polyunsaturated fatty acids, such as a–linolenic acid, and rich supply of soluble dietary fiber (Mohammadi *et al.*, 2010). It is grown in some parts of the world, particularly Canada (35%), Argentina (21.8%), China (18.9%), India (13.8), and the U.S (11.3%) (Madhusudhan, 2009). A 100 g portion of flaxseed provide 1890 kJ and 450 kcal energy and contains approximately about 41% oil, 20% protein, 8% moisture, 4% ash and 27% total dietary fiber. Also, flaxseed is known to be nature's best source of omega-3 oil. Flaxseed is the richest source of a-linolenic acid (Madhusudhan, 2009). Because of its high a-linolenic acid content, flaxseed has an omega-3/omega-6 fatty acid ratio of 1:0.3. Limited tillage systems, especially those of no-tillage, have become widespread in recent years. The no-tillage practice is carried out worldwide for erosion control and to maintain soil fertility. From an economic point of view, the use of minimum tillage and no-tillage practices provides significant energy savings (compared to conventional tillage) in on-farm use of fuel and in machine operation (Zenter *et al.*, 2004). Alvarez and Steinbach (2009) observed that aggregate stability and water infiltration rate were higher in soils subjected to limited tillage systems than under plow tillage. Limited data are available regarding the performance of flax grown under limited tillage systems. Conservation tillage showed a yield benefit over conventional tillage of 7%, 12.5%, and 7.4 % for field pea, flax and spring wheat grown on cereal stubble (Lafond *et al.*, 2006). Much of the yield increase was due to an increase in soil water in the 0-30 cm soil layer with no-tillage and minimum tillage. Maintaining and improving soil quality is crucial if agricultural productivity and environment quality are to be sustained for future generations (Reeves, 1997).

The adoption of limited tillage systems leads to soil improvement but also generates the necessity of increased nitrogen fertilizers to sustain crop yields (Alvarez and Steinbach, 2009). Data obtained by other researchers (Abedi *et al.*, 2010; Basso and Ritchie, 2005; Bilalis *et al.*, 2009; Bilalis *et al.*, 2010; Quattara *et al.*, 2008; Kazemeini *et al.* 2010) clearly demonstrate the beneficial effects of green manures and composts on the yields of crops (cotton, tobacco, wheat, maize). Moreover, Astier *et al.* (2006) observed that green manure and tillage had a significant effect on maize grain yield, and N and P uptake, with conventional tillage with vetch as green manure performing better than no-tillage. Also, soil organic C and total N were significantly higher under no-tillage than under conventional tillage. The aim of this study was to determine the effects of (a) tillage system and (b) organic fertilization on plant growth and oil content of flax crop. Limited data are available regarding performance of flax grown under organic cropping systems.

Material and methods

Experimental design

A flax crop (*Linum usitatissimum* L. cv. Everest) was established in the experimental 'organic' field of the Agricultural University of Athens (23.43E, 34.58N). The soil was clay loam (29.8% clay, 34.3% silt and 35.9% sand) with pH=7.24, EC 0.54 mS cm^{-1}, NO_3-N 12.4 mg kg^{-1} soil, P 13.2 mg kg^{-1} soil, K 201 mg kg^{-1} soil, Fe 67.3 mg kg^{-1} soil and Mg 1045 mg kg^{-1} soil**.** The experiment was set up on an area of 759 m^2 (33 m × 23 m) according to the split plot design with four replicates, three main plots (conventional tillage: CT, moldboard plowing at 20-25 cm, followed by one rotary hoeing at 5-10 cm; minimum tillage: MT, chiseling at 20 cm depth followed by one rotary hoeing at 5-10 cm; no-tillage: NT: no tillage, direct sowing (in the row, hand tilling (5 cm deep) was performed before flax sowing)) and three sub-plots (vetch as green manure, faba bean as green manure and compost – consisting of a mixture of farmyard manure and legume residue (Complemumosan by Vassilopoulos S.A.), applied at a rate of 2500 kg ha^{-1}). The sub-plot size was 17 m^2. Vetch (*Vicia sativa* L.) and faba bean (*Vicia faba* L.) were sown on 21 November 2008 and 10 November 2009 at a rate of 100 kg ha^{-1}. Vetch crop, faba bean crop and compost were incorporated into the soil on the 13th of April 2009 and 20th of March 2010. The aerial biomass of legumes was incorporated into the soil only in MT and CT. Some meteorological data of the experimental site are presented in Figure 1.

Planting, irrigation and weed control

Flax was sown by hand in rows 20 cm apart at a depth of 1 cm. The field was sown on 24th of April 2009 and 1st of April 2010 at a rate of 40 kg ha^{-1}. Plant emergence started 6 days after planting and was completed within 12 days after planting. Concerning the emergence percentage, there were no significant differences between treatments. The field area was irrigated 3 times. A sprinkler irrigation system was set up on plots. The total quantity of water was 250 mm. Finally, weeds were controlled by hand, with two hoeings being carried out. This practice is one of the basic weed control methods of Organic Agriculture (EN 834/2007).

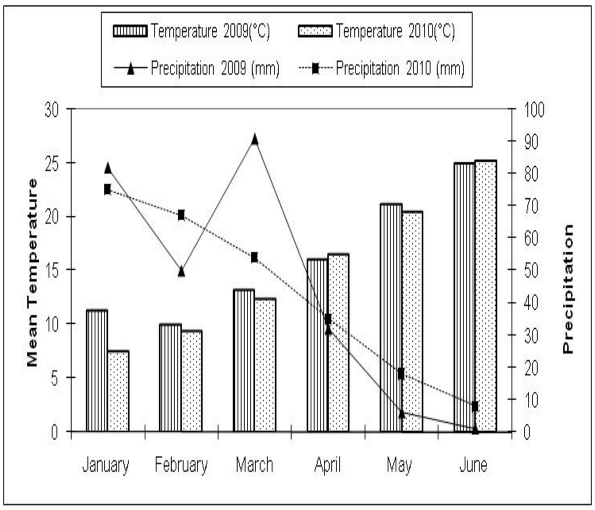

Fig 1. Meteorological data (temperature: °C and precipitation: mm) for the experimental site during the experimental periods (January-June, 2009 & 2010).

Sampling, measurements and methods

Soil properties: Organic matter (%) and total N (%), 61 days after sowing (DAS). Organic matter was an important measurement because green manure and compost were incorporated into the soil. The organic matter was determined by the Walkey-Black method (Walkey and Black, 1934), for the 0-15 cm depth for every plot. The total nitrogen was determined by the Kjeldahl method (Bremner, 1960) using a Buchi 316 device in order to combust and extract the soil samples. Three samples of 100 cm^3 per plot were taken.

Legumes

Biomass samples were taken at the same time as incorporation. To define biomass, 5 plants were selected in 2 different places in each plot. A root sample was collected from the 0–25 cm layer using a cylindrical auger (25 cm length, 10 cm diameter). 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 determined after drying for 48 h at 70ºC. The N% of the aerial biomass, root systems and compost was investigated with the Kjeldahl method. Finally, the total N was calculated as follows:

$$Total\,N = \%N \times \text{Dry weight of aerial biomass}(\text{kg ha}^{-1}) + \%N \times \text{Dry weight of root system}(\text{kg ha}^{-1}).$$

Flax

Vegetative traits: Leaf area index (LAI), dry weight (kg ha^{-1}), dry weight of roots, arbuscular mycorrhizal (AM) root colonization, 75 DAS. *Yield and yield components:* Seed yield (kg ha^{-1}), 1000 seed-weight (g), oil content and oil yield (kg ha^{-1}), 96 DAS. For the computation of leaf area and dry weight, 10 plants were randomly selected in each plot. The dry weights of all plant parts were determined after drying for 48 h at 70ºC. Leaf area was measured using an automatic leaf area meter (Delta-T Devices Ltd). Thus, the measurements on a plant basis were converted into an LAI by multiplying by the average crop density of each plot. Two root samples were collected 75 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. The second sample was cleaned and stained with trypan blue in lactophenol, according to the method of Phillips and Hayman (1970) and the percentage of root length colonized by AM fungi was determined microscopically with the gridline-intersection method (Giovanetti and Mosse, 1980) at a magnification of ×30-40. The plants were harvested by hand on 29th of July 2009 and 5th of July 2010. The flax seed yield also was determined by manually harvesting the capsules of the flax plants in the two centre rows of each plot. The percentage oil content was determined according to the method of Zhang *et al.* (2008). The flax was cleaned by hand carefully to remove foreign materials such as other seeds, stones and small stalks. The cleaned flax was dried for 12 h at 105°C in an oven, and then crushed into powder in a grinder with a mesh size range of 0.45-1.2 mm. The resulting powder was kept in a vacuum dryer until use. Flax powder (10 g) was mixed with *n*-hexane (100 ml) in a flask and extracted in an ultrasonic waterbath at 50W, at a temperature of 30°C for 10 min. The extracts were filtered through Whatman No. 1. filter paper under vacuum, and the solution was collected and concentrated with a rotary evapor-

Table 1. Influence of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on organic matter (%) and total nitrogen (%) of soil.

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
Experiment 2009	Organic matter			Total nitrogen		
CT	2.39	2.33	2.36	0.07	0.09	0.12
MT	2.34	2.37	2.41	0.09	0.11	0.13
NT	2.54	2.52	2.57	0.11	0.12	0.16
$LSD_{tillage}$ *(p=0.05)*	0.21 $(F=19.07^{**})$			0.007 $(F=119.48^{***})$		
$LSD_{fertilization}$ *(p=0.05)*	0.22 $(F=1.71^{ns})$			0.03 $(F=0.10^{ns})$		
Experiment 2010	Organic matter			Total nitrogen		
CT	2.46	2.48	2.35	0.11	0.13	0.12
MT	2.56	2.57	2.43	0.12	0.11	0.12
NT	2.66	2.63	2.54	0.14	0.15	0.16
$LSD_{tillage}$ *(p=0.05)*	0.14 $(F=26.77^{**})$			0.006 $(F=124.09^{***})$		
$LSD_{fertilization}$ *(p=0.05)*	0.07 $(F=6.43^{ns})$			0.05 $(F=0.07^{ns})$		

*The LSD (p=0.05) for tillage systems and organic fertilization are also shown. F-test ratios are from ANOVA. Significant at **p=0.01, *** p=0.001, ns: not significant.*

Table 2. Effects of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on leaf area index (LAI) and dry weight (kg ha^{-1}) of flax.

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
Experiment 2009	LAI			Dry weight		
CT	1.41	1.24	1.29	2377	1853	1625
MT	1.78	1.89	2.34	3938	2438	2392
NT	3.01	2.75	2.42	4559	6984	5872
$LSD_{tillage}$ *(p=0.05)*	0.07 $(F=12.98^{**})$			980 $(F=13.43^{*})$		
$LSD_{fertilization}$ *(p=0.05)*	1.04 $(F=0.09^{ns})$			1210 $(F=14.78^{*})$		
Experiment 2010	LAI			Dry weight		
CT	1.81	1.89	1.78	2654	2678	2591
MT	2.58	2.83	2.77	4324	4027	3876
NT	2.48	2.69	2.71	4521	4875	4376
$LSD_{tillage}$ *(p=0.05)*	0.06 $(F=13.54^{**})$			1123 $(F=14.01^{*})$		
$LSD_{fertilization}$ *(p=0.05)*	0.96 $(F=0.19^{ns})$			698 $(F=1.78^{ns})$		

*The LSD (p=0.05) for tillage systems and organic fertilization are also shown. F-test ratios are from ANOVA. Significant at *p=0.05, **p=0.01, ns: not significant.*

ator to acquire the flax oil. The acquired flax oil was further dried in a vacuum dryer to remove any residual *n*-hexane. Finally, the oil yield was calculated as follows:

$$Oil\ \ yield\ = \%Oil \times Seed\ \ yield\ (kg\ \ ha^{-1})$$

Statistical analysis

For calculating analysis of variance and comparisons of means, Statsoft software (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 growth parameters and yield components. All comparisons were made at the 5% level of significance.

Results and discussion

Soil properties

Enhancement of soil quality and biodiversity in agroecosystems are important benefits of conservation tillage system (Miyazawa *et al.*, 2004). The lowest organic matter and total N were found under CT (Table 1). There were no statistically significant differences between MT and NT systems. Moreover, there were no significant differences between the organic fertilization treatments concerning the organic matter and total N. Alvarez and Steinbach (2009) found that the improvement of aggregate stability was higher in poorer structured soils, with an average increase of 70% under NT in relation to plow tillage. In addition increases of bulk density under NT in comparison to plow tillage were generally small, averaging 4%, but cone penetration increased by 50% in many soils. Maintaining and improving soil quality is crucial if agricultural productivity and environmental quality are to be sustained for future generations.

Flax growth and yield

Little information is currently available on flax growth and yield with conservation tillage practices. The general category of conservation tillage includes specific practices such as NT, ridge tillage, reduced tillage, shallow tillage and strip tillage (Kabir, 2005). The lowest dry weight and LAI was found under CT (Table 2). There were statistically significant differences between MT and NT systems (LAI: $F=12.98$, $P<0.01$ and $F=13.54$, $P<0.01$ for 2009 and 2010, respectively). Although in the 2009 experiment NT had the highest LAI and highest dry weight, in the 2010 experiment, this system had the highest dry weights but lower LAI. The main reason for lower LAI in 2010 may be attributed to climatic conditions. As presented in Figure 1, the precipitation during January-February 2010 was higher than the corresponding period in 2009. Also, the temperature in 2010 during this period was lower than that in 2009. Thus, under the NT system, flax leaf area was influenced by water stress (high soil moisture). The main reason for this may be

Table 3. Effects of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on dry weight of roots (mg cm^{-3} of soil) and AM root colonization (% of root surface) of flax.

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
Experiment 2009	Dry weight of roots			AM root colonization		
CT	0.83	0.53	0.58	47.89	43.71	48.36
MT	0.60	1.05	0.80	61.93	62.86	65.98
NT	0.51	0.55	0.93	52.34	50.67	51.76
$LSD_{tillage}$ *(p=0.05)*		0.17 $(F=6.78^{*})$			2.87 $(F=6.45*)$	
$LSD_{fertilization}$ *(p=0.05)*		1.37 $(F=1.50^{ns})$			6.01 $(F=1.85^{ns})$	
Experiment 2010	Dry weight of roots			AM root colonization		
CT	0.75	0.81	0.66	47.04	44.45	48.23
MT	0.86	0.98	0.79	62.33	64.37	63.78
NT	1.08	1.01	0.97	55.63	54.72	55.29
$LSD_{tillage}$ *(p=0.05)*		0.09 $(F=11.41^{*})$			2.56 $(F=7.89*)$	
$LSD_{fertilization}$ *(p=0.05)*		0.42 $(F=1.67^{ns})$			6.34 $(F=1.75^{ns})$	

*The LSD (p=0.05) for tillage systems and organic fertilization are also shown. F-test ratios are from ANOVA. Significant at *p=0.05, ns: not significant.*

Table 4. Effects of organic fertilization (faba bean, vetch and compost) on seed yield (kg ha^{-1}) and 1000-seed weight (g) under three tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
Experiment 2009	Seed yield			1000-seed weight		
CT	1366	1418	1346	3.76	3.74	3.89
MT	1554	1647	1533	3.86	3.84	3.72
NT	1167	1417	1547	3.93	4.09	4.08
$LSD_{tillage}$ *(p=0.05)*		98.23 $(F=20.79^{**})$			$0.12(F=6.32^{*})$	
$LSD_{fertilization}$ *(p=0.05)*		52.10 $(F=11.52^{**})$			$3.81(F=0.35^{ns})$	
Experiment 2010	Seed yield			1000-seed weight		
CT	1389	1478	1312	3.85	3.82	3.86
MT	1712	1761	1689	3.93	3.91	3.95
NT	1457	1526	1401	4.05	4.03	4.11
$LSD_{tillage}$ *(p=0.05)*		93.74 $(F=23.75^{**})$			0.09 $(F=7.61^{*})$	
$LSD_{fertilization}$ *(p=0.05)*		73.38 $(F=17.36^{**})$			4.06 $(F=0.27^{ns})$	

*The LSD (p=0.05) for tillage systems and organic fertilization are also shown. F-test ratios are from ANOVA. Significant at *p=0.05, **p=0.01, ns: not significant.*

attributed to the presence of residues on the soil surface. Leaves are more sensitive to water stress than stems are. Thus, in 2010, there were no significant differences in dry weight (leaves and stems) between NT and MT systems. Couture *et al.* (2004) observed that flax can successfully be grown under MT and NT systems on different soil types. For LAI and dry weight (Table 2), there were no significant differences between the organic fertilization treatments. There were significant differences for root growth ($F=6.78$, $P<0.01$ and $F=11.41$, $P<0.01$ for 2009 and 2010, respectively) between the tillage systems (Table 3). In the 2010 experiment, the NT system gave the highest root dry weights for all organic fertilizer treatments, whereas in 2009, this system gave the lowest root dry weights with both vetch and faba beans but the highest with compost. The main reason for higher root biomas in the NT system (2010) may be attributed to soil biopores. Iijima et al. (2005) reported that continuous no-tillage contributed to maintenance of biopores, which are formed by the activities of soil organisms such as earthworms and the decay of plant roots. Also, the main reason for differences in root growth between organic fertilization treatments may be attributed to the rate of N mineralization of each fertilizer. Sidiras *et al.* (1999) reported that the highest root weight of vetch crop was found under the NT system and the lowest for CT. Higher AM root colonization was recorded for conservation tillage systems (MT and NT). The highest AM root colonization was found under MT (in 2009: 61.93% for faba bean green manure, 62.86% for vetch green manure and 65.98% for compost treatment; and in 2010: 62.33% for faba bean green manure, 64.37% for vetch green manure and 63.78% for compost treatment). Conventional tillage practices reduce AM hypha survival and proliferation thus reducing benefits of the symbiosis to associated plants and soils. Tillage has a significant influence on the sporulation of some species and non-Glomus AM fungi tend to be more abundant in untilled soil (Jansa *et al.*, 2002). There is a speculation that in NT systems, plants may follow old root channels and potentially encounter more AM fungal propagules than plants growing in soil that has been tilled (Kabir, 2005). Concerning the root biomass and AM root colonization (Table 3), there were no significant differences between the organic fertilization treatments. The results suggest that the N released from all the fertilization treatments (green manures and compost) was sufficient to maintain good growth. The highest seed yield (1761 kg ha^{-1}) and oil yield (670 kg ha^{-1}) were found under MT (Table 4 and 5). There were statistically significant differences between MT and CT. The lowest seed yield (1167 kg ha^{-1}) was found under the NT system with faba bean green manure, while the highest (1761 kg ha^{-1} and 1647 kg ha^{-1}, for 2010 and 2009, respectively) was found in vetch green manure plots ($F=11.52$, $P<0.01$ and $F=17.36$, $P<0.01$ for 2009 and 2010, respectively). The main reason for high seed yield in vetch green manure plots may be attributed to N content. The lowest seed yield and 1000-seed weight were found under the CT system. There were no significant

Table 5. Effects of organic fertilization (faba bean, vetch and compost) on oil yield (kg ha^{-1}) and oil content (%) under three tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
Experiment 2009		Oil Yield			Oil content	
CT	518	517	482	37.92	36.46	35.81
MT	614	621	564	39.51	37.70	36.79
NT	484	549	581	41.47	38.74	37.56
$LSD_{tillage}$ *(p=0.05)*		28.21 ($F=10.64^{**}$)			0.34 ($F=89.22^{***}$)	
$LSD_{fertilization}$ *(p=0.05)*		109.15 ($F=2.21^{ns}$)			1.08 ($F=7.01^{*}$)	
Experiment 2010		Oil Yield			Oil content	
CT	515	543	474	37.12	36.78	36.16
MT	667	670	624	38.98	38.06	36.96
NT	598	602	556	41.03	39.44	37.76
$LSD_{tillage}$ *(p=0.05)*		28.21 ($F=10.64^{**}$)			0.39 ($F=78.41^{***}$)	
$LSD_{fertilization}$ *(p=0.05)*		109.15 ($F=2.21^{ns}$)			0.96 ($F=7.34^{*}$)	

*The LSD (p=0.05) for tillage systems and organic fertilization are also shown. F-test ratios are from ANOVA. Significant at *p=0.05, **p=0.01, *** p=0.001, ns: not significant.*

Table 6. Correlation coefficients[a] between plant-yield parameters of flax.

	Y	O	OY	DWR	DW	LAI	TN
Seed yield (Y)	-	0.86***	0.89***	ns	0.65***	0.73***	0.41**
Oil content (O)		-	0.96***	ns	0.59***	0.61***	0.44**
Oil yield (OY)			-	ns	0.56***	0.64***	0.55***
Dry weight of roots (DWR)				-	0.83***	0.79***	ns
Dry weight (DW)					-	0.73***	0.41**
LAI						-	0.54***
Total N of soil (TN)							-

*[a]r was calculated using the linear equation. Significant at *p=0.05, **p=0.01,***p=0.001, respectively. ns: not significant.*

differences between the organic fertilization treatments concerning the 1000-seed weight. Vetch accumulated the highest total N (Figure 2). Diepenbrock and Porksen (1992) reported that 80 kg ha^{-1} N resulted in highest yield performance (2440 kg ha^{-1}). Limited data are available regarding performance of flax grown under limited tillage systems. Conservation tillage showed a yield benefit over conventional tillage of 12.5% for flax crop (Lafond *et al.*, 2006). However, Mandal *et al.* (1994) found no significant difference in flax seed yields between CT and NT. Khakbazan *et al.* (2009) have also reported that flax production with wheat as preceding crop together with reduced tillage and lesser use of P application was the most economical treatment. Moreover, the lowest oil content was found under CT (Table 5). There were statistically significant differences between MT and NT (*F=89.22, P<0.001* and *F=78.41, P<0.001* for 2009 and 2010, respectively). The highest oil content was found under the NT system (37.56-41.47%), while the lowest (35.81-37.92%) was found under CT (Table 3). The highest oil content was found in faba bean (41.47%) and vetch green manures (39.44%). The main reason for high oil content in green manure plots may also be attributed to N content (Figure 2).

Correlations between biomass, yield and oil content

Correlation coefficients among traits are given in Table 6. Dry weight correlated with dry weight of roots and LAI (*r=0.83, P<0.001* and *r=0.79, P<0.001* respectively). Flax seed yield had positive and significant correlation with LAI and dry weight (*r=0.73, P<0.001* and *r=0.65, P<0.001*, respectively). Dordas (2010) also reported that flax seed yield was correlated with the yield components, biomass growth rate and seed growth rate. Moreover, Diepenbrock and Porksen (1992) reported that the relationship between seed yield or capsule mass and total biomass and between seed weight and total capsule mass were distinctly promoted towards seeds and capsules, respectively. Oil yield was positively correlated with seed yield and oil content (*r=0.89, P<0.001* and *r=0.96, P<0.001* respectively), a result expected, as both traits are closely related to oil yield. Copur *et al.* (2006) observed that the correlation of oil content with seed yield was positive but insignificant. There was a positive correlation between oil content, seed yield and total N of soil. Dordas (2010) also reported that seed yield was correlated with N uptake rate.

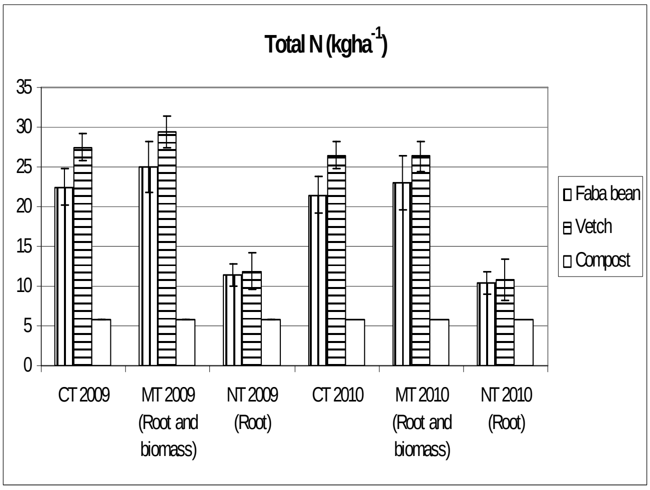

Fig 2. The total amount of N (kg ha^{-1}; mean values ± standard error) incorporated into soil using vetch, faba bean and compost (conventional tillage: CT, minimum tillage: MT, and no-tillage: NT).

Conclusion

Our results indicate that the highest LAI, dry weight and AM root colonization were found under conservation tillage systems. There were no significant differences between the organic fertilization treatments concerning the LAI, dry weight and AM root colonization. The soil organic matter and total N were higher in soils subjected to MT than under CT. Moreover, the highest seed and oil yield was recorded under MT. Finally, vetch and faba bean green manures had a significant effect on flax oil content. Concerning the organic agricultural system, conservation tillage can affect flax growth and enhance the soil quality.

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