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Weed populations are affected by tillage systems and fertilization practices in organic flax (*Linum usitatissimum* L.) crop

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Abstract

Flax is a weak competitor against weeds. To obtain high yield of flax, good weed management practices must be implemented. Field experiments were conducted during 2009 and 2010 to determine the effects of tillage systems and fertilization on weed flora in organic flax crop (*Linum usitatissimum* L.). The experiments were laid out in a split-plot design with four replicates having three main plots (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and three sub-plots (compost, vetch and faba bean as green manure). The total weed densities were significantly different among the tillage systems. In NT plots, the presence of wheat residues clearly reduced weed number. Crop residues mainly affect light interception, temperature and moisture of the soil. Differences in nitrogen availability of the fertilizers had a large effect on weed density and biomass. The lowest weed density was found in compost plots. Moreover, the highest density of competitive weeds (*Amaranthus retroflexus*, *Chenopodium album*, *Convolvulus arvensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Datura stramonium*, *Setaria verticillata*, *Sinapis arvensis* and *Solanum nigrum*) was found under MT and CT systems, while the lowest was found in NT plots. In addition, concerning the density of non-competitive weeds, there were no significant differences among the tillage systems. Moreover, there were no significant differences in the density of non-competitive weeds between the organic fertilization treatments. No-tillage and low nitrogen fertilization appeared to contribute to the suppression of weeds.

Keywords: Conventional tillage, compost, competition, flax, weed, minimum tillage, no-tillage.
Abbreviations: CT-conventional tillage; LAI-leaf area index; MT-minimum tillage; NT-no tillage.

Introduction

Flax (*Linum usitatissimum* L.) is an important species cultivated as an oil seed crop in some areas of the world). Flax is planted early in the spring and is harvested in mid summer. Flax seed, also known as flaxseed or linseed, contains 20%-40% oil (Zhang et al., 2011). Demand for certified organic grown flax has increased due to a rise in consumer demand for food products rich in omega-3 oil (Carlson et al., 2006). Price premiums for organically grown flax are often very high, which regularly exceed $25 per bushel (Shirtliffe et al., 2007). Flax seed oil is rich in linolenic acid (omega-3 fatty acid), and is being accepted in the diet by an ever-growing number of people (Zhang et al., 2011). Flax seed can be used for both industrial and food products, including a wide variety of nutraceuticals and health foods (Fofana et al., 2011). Flax is a weak competitor against weeds, thus imposing high costs for weed management. Weeds can reduce both yield and quality of flax. In conventional flax production, weeds are controlled with pre- and post-emergent synthetic herbicides (Carlson et al., 2006), which are not allowed in organic production. Consequently, because of its poor competition with weeds, flax is one of the most difficult crops to grow organically (Shirtliffe et al., 2007). Cultivation and hand hoeing are common practices used in organically grown flax crops. Organic flax producers should consider using an early-flowering cultivar and delay seeding until most weeds have emerged (late May/early June). Moreover, a cover crop may contribute significantly to weed management (Shirtliffe et al., 2007). Paulsen et al. (2006) reported that weeds were efficiently suppressed in organic flax crop combinations with wheat (*Triticum aestivum*) or false flax (*Camelina sativa*). A legume cover crop (*e.g.* red clover and alfalfa) can also be seeded with flax (Carlson et al., 2006). Limited information about weed management strategies is available for organic farmers. Therefore, the aim of this study was to determine the effects of (a) tillage system and (b) organic fertilization on weed flora in an organic flax crop.

Results

Flax growth

The LAI, there were no significant differences (Table 1) between the CT, MT and NT systems. The lowest LAI (0.81-1.13) was found under the CT system. There were significant differences in LAI between the green manures (vetch and faba bean) and compost treatment. The lowest LAI was found in compost plots. Moreover, the lowest height (14.5-16.2 cm) of flax plants was found in compost plots, while there were no significant differences among tillage systems.

Total weed density

The number of weeds [redroot pigweed (*Amaranthus retroflexus* L.), field marigold (*Calendula arvensis* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.), lambsquarters (*Chenopodium album* L.), field bindweed (*Convolvulus arvensis* L.), bermudagrass (*Cynodon dactylon* (L.) Pers.), nutgrass (*Cyperus rotundus* L.), jimsonweed (*Datura stramonium* L.), drug fumitory (*Fumaria officinalis* L.), henbit deadnettle (*Lamium amplexicaul*e L.), high mallow (*Malva sylvestris* L.), hooked bristlegrass (*Setaria verticillata* (L.) P. Beauv.), wild mustard (*Sinapis arvensis* L.), London rocket (*Sisymbrium irio* L.), black nightshade (*Solanum nigrum* L.), common sowthistle (*Sonchus oleraceus* L.), puncturevine (*Tribulus terrestris* L.), dwarf nettle (*Urtica urens* L.)] was assessed. Concerning the total weed density there were significant differences (Table 2) between the CT, MT and NT systems. The highest density of weeds was found under MT (at 40 DAS, in 2009: 95.4 weeds m^{-2} for faba bean green manure, 106.7 weeds m^{-2} for vetch green manure and 80.2 weeds m^{-2} for compost treatment; and in 2010: 104.1 weeds m^{-2} for faba bean green manure, 153.1 weeds m^{-2} for vetch green manure and 78.7 weeds m^{-2} for compost treatment); while the lowest was found in NT plots. There were also significant differences in the density of weeds between the green manure (vetch and faba bean) and compost treatments. The lowest weed density was found in compost plots.

Total weed dry matter

Concerning the weed biomass, there were significant differences among the tillage systems (Table 3). The lowest dry matter of weeds was found under MT, while the highest in NT plots (in 2009: 378 kg ha^{-1} for faba bean green manure, 451 kg ha^{-1} for vetch green manure and 298 kg ha^{-1} for compost treatment; and in 2010: 464 kg ha^{-1} for faba bean green manure, 562 kg ha^{-1} for vetch green manure and 308 kg ha^{-1} for compost treatment). There were also significant differences in the dry matter of weeds (40 DAS) between the green manure (vetch and faba bean) and compost fertilization.

Density of annual and perennial weeds

Concerning the density of annual weeds, there were significant differences (Table 4) between the CT, MT and NT systems. The highest density of weeds was found under MT, while the lowest was found in NT plots (in 2009: 14.3 weeds m^{-2} for faba bean green manure, 15.4 weeds m^{-2} for vetch green manure and 12.3 weeds m^{-2} for compost treatment; and in 2010: 16.9 weeds m^{-2} for faba bean green manure, 14.5 weeds m^{-2} for vetch green manure and 15.6 weeds m^{-2} for compost treatment). There were also significant differences in the density of annual weeds between the green manure (vetch and faba bean) and compost treatment. The lowest density was found in compost plots. Moreover, concerning the density of perennial weeds, there were no significant differences among the tillage systems. In addition, there were no significant differences in the density of perennial weeds between the organic fertilization treatments.

Density of competitive and non-competitive weeds

Weeds were categorized as competitive (*Amaranthus retroflexus*, *Chenopodium album*, *Convolvulus arvensis*, *Cynodon dactylon*, *Cyperus rotundus*, *D. stramonium*, *Setaria verticillata*, *Sinapis arvensis* and *Solanum nigrum*) and non-competitive (*Calendula arvensis*, *Capsella bursa-pastoris*, *F. officinalis*, *Lamium amplexicaul*e, *M. sylvestris*, *Sisymbrium irio*, *Sonchus oleraceus, T. terrestris* and *U. urens*). The competitive weeds grow more rapidly; have upright growth habit and large leaves. Concerning the density of competitive weeds, there were significant differences (Table 5) between the CT/MT systems and the NT system. The highest density of competitive weeds was found under the MT and CT systems in both years, while the lowest was found in NT plots (in 2009: 22.6 weeds m^{-2} for faba bean green manure, 23.1 weeds m^{-2} for vetch green manure and 19.1 weeds m^{-2} for compost treatment; and in 2010: 23.9 weeds m^{-2} for faba bean green manure, 28.1 for vetch green manure and 23.5 weeds m^{-2} for compost treatment). There were also significant differences in the density of competitive weeds between the green manure (vetch and faba bean) and compost treatments. The lowest density was found in compost plots. Concerning the density of non-competitive weeds, there were no significant differences between tillage systems except for NT which was significantly lower than under MT in both years in compost-treated plots and in faba bean green manure plots in 2009.

Weed community

Concerning the values of the Shannon-Weiner (H) index, there were significant differences between the CT and MT systems and the NT system (Table 6). The highest values were recorded in NT plots; hence weed flora in NT system had high species evenness. This index is increased either by having additional unique species, or by having greater species evenness (Booth et al., 2003). There were also significant differences between the green manures (vetch and faba bean) and compost treatment. The lowest value of H index was found in compost plots.
In terms of the studied weeds related parameters, no interaction between fertilization and tillage system was found.

Discussion

Flax growth

Tillage system can affect growth of flax. Concerning the LAI, there were no significant differences among the tillage systems. Moreover, the lowest height and LAI of flax plants was found in compost plots. A previous study has shown that flax growth and seed plus oil yields in conservation tillage systems (MT and NT) were significantly higher than those in CT plots. The highest seed yield (1761 kg ha^{-1}) and oil yield (670 kg ha^{-1}) were found under MT (Bilalis et al., 2010). Moreover, there were significant differences for root growth among the tillage systems. The highest root weight was found in the no-tillage system (Bilalis et al., 2010). Flax has low leaf area, height and an open canopy structure; which make it a weak competitor against weeds.

Tillage system

Weeds are one of the greatest limiting factors to efficient organic crop production. The adoption of conservation tillage

Table 1. 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 height of flax.

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
	LAI			LAI		
	2009			2010		
CT	1.13	1.09	0.89	1.04	0.97	0.81
MT	1.28	1.34	0.94	1.11	1.14	0.86
NT	1.35	1.42	1.03	1.22	1.34	0.98
$LSD_{tillage}$ (p=0.05)	*0.07*			*0.08*		
$LSD_{fertilization}$ (p=0.05)	*0.13*			*0.10*		
	Height (cm)			Height (cm)		
	2009			2010		
CT	21.2	19.5	14.5	26.2	27.2	16.2
MT	20.6	19.2	15.2	25.7	25.8	15.7
NT	21.4	20.1	15.4	26.0	25.6	16.0
$LSD_{tillage}$ (p=0.05)	*1.01*			*0.87*		
$LSD_{fertilization}$ (p=0.05)	*2.23*			*1.69*		

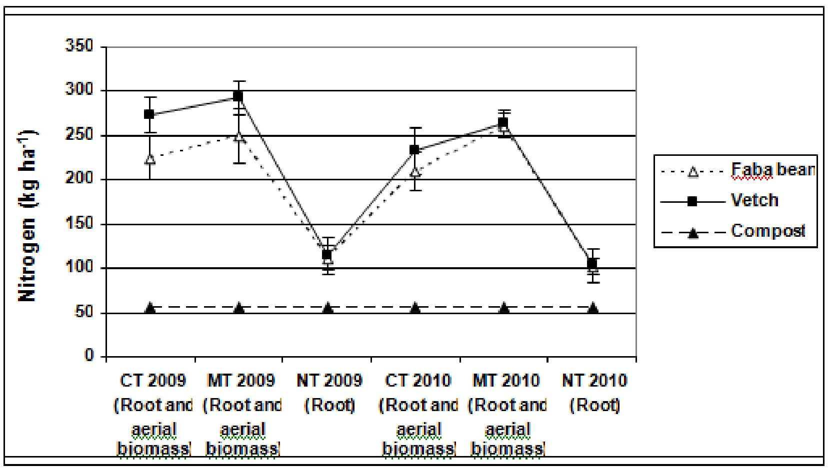

Fig. 1. The total amount of N (mean values ± standard error) incorporated into soil using vetch, faba bean and compost (CT: conventional tillage, MT: minimum tillage, and NT: no-tillage).

practices that include NT or MT has been shown to lead to shifts in weed communities (Bilalis et al., 2001). No tillage and a high residue level appeared to contribute to the suppression of most weed species (Amuri et al., 2010). Concerning the total weed density and biomass, there were significant differences (Table 2) between the CT, MT and NT systems. The highest density and biomass of weeds were found under MT, while the lowest were found in NT plots. In NT plots, the presence of wheat residues clearly reduced weed number. Crop residues mainly affect light interception, temperature and moisture of the soil. Under any tillage system, the use of crop residues to cover soil can suppress weeds (Bilalis et al., 2003). Teasdale et al. (1991) reported that under NT treatment, rye or hairy vetch residue reduced total weed density by an average of 78% compared to the treatment without a cover crop. There were also significant differences in the density of annual and competitive weeds among the tillage systems. The highest density of weeds was found under MT, while the lowest was found in NT plots. The MT system favored the weeds with small seeds (*Amaranthus retroflexus*, *Setaria verticillata* and *Sinapis arvensis*). O'Donovan and Mcandrew (2000) found that spring seeding populations of common lambsqarters, field pennycress (*Thlaspi arvense* L.), ball mustard (*Neslia paniculata* (L.) Desv.) and green foxtail (*Setaria viridis* (L.) Beauv.) were lowest in the NT system. Dorado and Lopez-Fando (2006) observed that the highest weed densities for *Anthemis arvensis* L., *Lolium rigidum* Gaudin and *Hirschfeldia incana* (L.) Lagr.-Foss (biennial) were found in NT plots. *Anthemis arvensis* and *Lolium rigidum* may be well suited to the NT system because of its small seed size and adaptation to surface germination. On the other hand, biennial weeds such as *Hirschfeldia incana* may increase in a NT system because the root system is not disturbed. Regarding the density of non-competitive and perennial weeds, there were no significant differences among the tillage systems. Bilalis et al. (2001) reported that perennial weeds had higher density under the NT system because their roots cannot be destroyed by this type of cultivation. The main benefit of CT systems is a highly significant decline of perennial weeds (Demjanova et al., 2009). In our study, the NT system had no effect on the density of perennial weeds because this system was applied only for three years. The highest values of Shannon-Weiner (H) index were also recorded in NT plots, hence weed flora in the NT system had high species evenness because wheat straw controlled the competitive weeds (*Amaranthus retroflexus*, *Chenopodium album*, *D. stramonium*, *Setaria verticillata*, *Sinapis arvensis* and *Solanum nigrum*), which had the highest density in other treatments.

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 weed density (m^{-2}) at 40 and 70 DAS (days after sowing).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
		40 DAS			40 DAS	
		2009			2010	
CT	37.2	40.2	32.1	48.9	46.8	36.4
MT	95.4	106.7	80.2	104.1	153.1	78.7
NT	25.6	24.7	21.0	27.2	25.2	20.8
$LSD_{tillage}$ (p=0.05)		*10.65*			*7.43*	
$LSD_{fertilization}$ (p=0.05)		*3.07*			*2.79*	
		70 DAS			70 DAS	
		2009			2010	
CT	46.7	48.9	38.6	47.9	53.1	33.3
MT	48.6	51.47	47.3	49.7	52.0	49.7
NT	30.7	30.8	27.1	32.3	31.2	28.9
$LSD_{tillage}$ (p=0.05)		*4.92*			*5.32*	
$LSD_{fertilization}$ (p=0.05)		*2.18*			*3.15*	

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 weed dry matter (kg ha^{-1}) at 70 days after sowing (DAS).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
		70 DAS			70 DAS	
		2009			2010	
CT	768	834	657	954	923	746
MT	1029	1163	987	1184	1388	1066
NT	378	451	298	464	562	308
$LSD_{tillage}$ (p=0.05)		*103.4*			*125.6*	
$LSD_{fertilization}$ (p=0.05)		*45.9*			*68.4*	

Fertilization treatments

In general, weeds accumulate and utilize nutrients more efficiently compared to crops, thus gaining a competitive advantage for other growth resources, particularly light (Tuor and Froud-Williams, 2002). Weeds respond differentially to nitrogen. Differences in nitrogen availability of the fertilizers had a large effect on weed density and biomass. Information on the response of weeds to different levels of soil fertility is required to develop fertilizer management strategies as components of integrated weed management programs (Blackshaw et al., 2003). Symbiotic nitrogen fixation by legumes is an important source of N to agriculture, particularly under organic farming conditions (Riesinger and Herzon, 2010). There were significant differences between the green manure (vetch and faba bean) and compost treatments in the density and biomass of weeds. The lowest weed density and biomass were found in compost plots. The main reason for differences in weed emergence and growth between different organic fertilization methods may be attributed to the rate of N application (Fig. 2). Sweeney et al. (2008) reported that emergence of lambsquarters and ladysthumb (*Polygonum pericaria* L.) increased as the rate of N application increased. Other researchers have also reported that the competitive ability of crops and weeds can be significantly affected by fertilizer application. For example, Mohammadi and Amiri (2011) reported that the critical period of weed control in crops depends on many factors including supply and availability of nutrients. In the present study, between the green manure (vetch and faba bean) and compost treatments there were significant differences in the density of annual and competitive weeds (*Amaranthus retroflexus*, *Chenopodium album*, *D. stramonium*, *Setaria verticillata*, *Sinapis arvensis* and *Solanum nigrum*). The lowest density was found in compost plots. There were no significant differences in the density of perennial and non-competitive weeds between the organic fertilization treatments. Blackshaw and Brandt (2008) found that the competitive ability of the low N-responsive species Persian darnel (*Lolium persicum* Boiss. & Hohen) was not influenced by N rate. Conversely, the competitiveness of the high N-responsive species redroot pigweed (*Amaranthus retroflexus* L.) progressively improved as N rate increased. Therefore, NT and a low nitrogen fertilization level appeared to contribute to the suppression of weeds.

Materials and methods

Experimental design

A flax crop (*Linum usitatissimum* L. cv. Everest) was established in the 'organic' experimental field of Agricultural University of Athens, Greece (23.43E, 34.58N). The soil was a 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**.** Prior to this experiment, the field was under wheat cultivation. 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, direct sowing in wheat residue; within the row hand tilling (5 cm deep) performed before flax sowing], and

Table 4. Effects of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on density (m^{-2}) of annual and perennial weeds at 70 DAS (days after sowing).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
	Annual weeds			Annual weeds		
	2009			2010		
CT	31.2	33.8	23.4	33.4	40	21.8
MT	34.4	35.5	32.1	37.5	40.6	28.1
NT	14.3	15.4	12.3	16.9	14.5	15.6
$LSD_{tillage}$ (p=0.05)		*4.39*			*6.12*	
$LSD_{fertilization}$ (p=0.05)		*1.20*			*2.68*	
	Perennial weeds			Perennial weeds		
	2009			2010		
CT	15.5	15	15.2	14.4	13.1	11.4
MT	14.2	15.9	15.1	12.2	11.4	10.4
NT	16.4	15.4	14.7	15.4	16.6	13.3
$LSD_{tillage}$ (p=0.05)		*2.03*			*3.42*	
$LSD_{fertilization}$ (p=0.05)		*2.68*			*2.11*	

Table 5. Effects of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on density (m^{-2}) of competitive and non competitive weeds at 70 DAS (days after sowing).

Tillage system	Organic fertilization					
	Faba bean	Vetch	Compost	Faba bean	Vetch	Compost
	Competitive weeds			Competitive weeds		
	2009			2010		
CT	38	41.3	29.3	37.8	45.8	25
MT	37.4	39.9	34.0	36.7	35.2	27.4
NT	22.6	23.1	19.1	23.9	28.1	23.5
$LSD_{tillage}$ (p=0.05)		*4.83*			*1.82*	
$LSD_{fertilization}$ (p=0.05)		*2.55*			*3.67*	
	Non-competitive weeds			Non-competitive weeds		
	2009			2010		
CT	8.6	7.5	9.3	10	7.2	8.3
MT	11.1	11.5	13.2	13	16.8	11.1
NT	8	7.7	7.9	8.3	3.1	2.0
$LSD_{tillage}$ (p=0.05)		*4.16*			*4.42*	
$LSD_{fertilization}$ (p=0.05)		*2.77*			*2.79*	

three sub-plots [vetch (*Vicia sativa* L.) as green manure, faba bean (*Vicia faba* L.) as green manure, and compost; consisting 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 and faba bean were sown on 21st November 2008 and 10th 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 plots.

Planting, irrigation and weed control

Flax was sown at a depth of 1 cm by hand in rows 20 cm apart. 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 sowing (DAS) and was completed within 12 DAS. Concerning the percent emergence, there were no significant differences among the treatments. The field area was irrigated three times. A sprinkler irrigation system was set up on plots. The total quantity of water applied was 250 mm. 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).

Sampling, measurements and methods

Legumes

Biomass samples were taken at the same time as incorporation. To determine biomass, 5 plants were selected at 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 keeping for 24 h in water + $(NaPO_3)_6$ + Na_2CO_3. The root dry weight was determined after drying for 48 h at 70°C. The N% (Fig. 1) of the aerial biomass, root systems and compost were investigated with the Kjeldahl method (Bremner, 1960). Finally, the total N was calculated as follows:

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

Flax

The leaf area index (LAI), height (cm) and dry weight of flax were assessed. For the computation of leaf area and height, 10 plants were randomly selected from each plot. Leaf area was measured using an automatic leaf area meter (Delta-T

Table 6. Effects of tillage system (conventional tillage: CT, minimum tillage: MT and no-tillage: NT) and organic fertilization (faba bean, vetch and compost) on the Shannon-Weiner index, 70 days after sowing (DAS).

Tillage system	Organic fertilization		
	Faba bean	Vetch	Compost
	Shannon-Weiner		
	2009		
CT	0.92	1.07	0.78
MT	0.75	0.86	0.62
NT	1.62	1.74	1.58
$LSD_{tillage}$ *(p=0.05)*	*0.34*		
$LSD_{fertilization}$ *(p=0.05)*	*0.08*		
	Shannon-Weiner		
	2010		
CT	1.01	1.22	0.82
MT	0.82	0.98	0.71
NT	1.78	1.91	1.59
$LSD_{tillage}$ *(p=0.05)*	*0.26*		
$LSD_{fertilization}$ *(p=0.05)*	*0.12*		

Devices Ltd). Thus, the measurements on a plant basis were converted into an LAI by multiplying with the average crop density of each plot.

Weeds

The number and dry weight of the dominant weeds were assessed. A wooden square quadrat (40 × 40 cm) was placed at random three times in each plot. Weeds in the 40 × 40 cm area were counted for each species present, and fresh and dry matter were determined. Weed assessments were made at 40 and 70 DAS as follows:

1. Density per unit area (no. m^{-2}).
2. Dry weight (g m^{-2}). Weeds were cut and roots were discarded. The remaining material was placed in paper bags in an oven at 65°C for 72 hours. Dry matter was then determined.

Weed population analysis

The initial density and population of weeds in the experimental area was unvarying. The species diversity of weed groups was characterized using the Shannon-Weiner index (H) (Krebs, 1978; Booth et al., 2003):

$$H = -\sum (Pi)(\ln Pi)$$

where Pi is the fraction of the weed density belonging to the i^{th} species in a given group. The index is increased either by having additional unique species, or by having greater species evenness. The population has a maximum index only when each species in the population is evenly represented. For calculation of this index, the software Species Diversity and Richness III (Pisces Conservation Ltd 2002) was used.

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. All comparisons were made at 5% level of significance.

Conclusion

Regarding organic agriculture system, NT can affect weed emergence and growth. The lowest density of weeds was found in NT. In NT plots, the presence of wheat residues clearly reduced weed number. Crop residues mainly affect light interception, temperature and moisture of the soil. Moreover, weeds respond differentially to nitrogen. Differences in nitrogen availability of the fertilizers had a large effect on weed density and biomass. The lowest density of competitive weeds was found in compost plots. Finally, our study indicated that the NT system can be used successfully for the suppression of weeds in organic flax crop.

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