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Effect of green manure cover crops on tomato greenhouse production

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Abstract. *Cover crops are an important component in sustainable vegetable production with main purpose to reduce the use of synthetic inputs, especially nitrogen fertilizers. The aim of the current study was to evaluate the effect of cover crops as hairy vetch (Vicia villosa Roth), winter pea (Pisum sativum L.) and white mustard (Sinapis alba L.) on (i) greenhouse tomato yield and fruit quality and (ii) root-knot nematodes infestation. The experiment was carried out during two consecutive years (2014 – 2015) in an unheated greenhouse at Maritsa Vegetable Crops Research Institute. Cover crops were grown before the main crop and plowed under and incorporated into the soil a week before transplanting the tomato plants. Control plots did not receive green manures. Two variants of fertigation were applied – optimal and 50% reduced amount of nitrogen fertilizer. Green manures did not change significantly the yield of tomato plants as well as did not influence on fruit quality parameters as brix, total sugars and titrable acidity. A slight negative effect was observed on Vitamin C content in tomato fruits. By green manuring with hairy vetch a reduction of the amount of nitrogen fertilizer used for fertigation could be achieved. Hairy vetch and white mustard as green manures suppressed to some extent the development of Meloidogyne spp.*

Keywords: hairy vetch, winter pea, white mustard, yield, root-knot nematodes

Introduction

The growing concern about food security and safety as well as about environment pollution by agricultural chemicals has led to the concept of sustainable agriculture. It is an alternative for solving fundamental and applied issues related to food production in an ecological way, since the conventional agriculture is no longer suited to feeding humans and preserving ecosystems (Lal, 2008; Lichtfouse et al., 2009). High intensity of greenhouse production often led to application of excessive nitrogen fertilizers. Those might lead to low N use efficiency and bring about environmental impacts. Another important issue for greenhouse grown vegetables, causing huge economic losses, is nematode infestation (Bird and Kaloshian, 2003). Root knot nematodes (*Meloidogyne* spp.) are a concern to both smallholders and commercial producers involved in intensive tomato cultivation (Wang et al., 2008; Kamran et al., 2010). Urgent actions are needed to overcome these problems, alternative sources of nitrogen as well as natural means for nematode control are of paramount importance to ensure sustainability in greenhouse vegetable production.

Among crop rotations, use of organic manures, natural pesticides, etc. cover crops are an important component of sustainable agriculture practices. Cover cropping involves growing a crop over winter before a spring sown crop. Before reaching of full maturity cover crops are usually terminated with tillage or mowing. Their biomass could be incorporated into the soil (green manure) or placed on soil surface as organic mulch. The roles of cover crops are to fix nitrogen, to recycle nutrients, to add organic matter in soil, to contribute to plant protection from weeds, pests and diseases (Abdul-Baki and Teasdale, 1998; Abdul-Baki et al., 1997; Liebman and Staver, 2001; Kumar et al., 2005). In this way, one of the main outcomes of cover crops usage is the reduced need of synthetic fertilizers and pesticides during the cash crop cultivation (Abdul-Baki and Teasdale, 1998; Abdul-Baki et al., 1996; Sainju et al., 2001; Araki et al., 2006). Commonly grown as green manures are grasses, legumes and *Brassica* species. Legume species have an ability to fix atmospheric nitrogen, resulted in high N-content of the residues, hence low C/N ratio, ensuring fast decomposition and providing nutrients for subsequent crop (Lu et al., 2000). They are also found to reduce nematode populations (Morris and Walker, 2002). *Brassica* species produce glucosinolates as nematocidal and biocidal and possess great potential as bio-fumigants (Kago et al., 2013). Green manure cover crops are widely used in low-input and organic systems. In conventional agriculture cover crops have been found to retain up to 6 kg N/da over their growing period (Christian et al., 1992; Richards et al., 1996; Shepherd and Lord, 1996) and could substitute to some extent synthetic fertilizers, thus to become an essential component of integrated plant production systems.

The beneficial effect of green manure cover crops has been well demonstrated in open fields, where cover crop is grown before the cash crop, usually during the winter (Borowy, 2013). In the greenhouses, the intensive production and cash crops rotation during the whole year limit the usage of cover crops. Nevertheless, green manuring offers several advantages that is worth to be investigated in greenhouse conditions. Therefore, the aim of the current study was to evaluate the effect of cover crops as hairy vetch (*Vicia villosa* Roth), winter pea (*Pisum sativum* L.) and white mustard (*Sinapis alba* L.) on (i) greenhouse tomato yield and fruit quality and (ii) root-knot nematodes infestation.

Material and methods

The experiment was carried out during two consecutive years (2014-2015) at Maritsa Vegetable Crops Research Institute, Bulgaria. Tomato variety Dimerosa (Enza Zaden, the Netherlands) was grown in an unheated greenhouse. It is a pink fruited beef tomato hybrid for fresh consumption with indeterminate growth

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habit.

Experimental conditions and design

Tomato seeds were sown on 23-24 of January (days varied depending on the year) in foamed polystyrene plug trays with 198 inverted pyramid cells, filled with peat moss and perlite in the ratio 1:1 (v/v). One seed per cell was sown. At the stage of first true leaves (on 1-2 of March) the plants were pricked out in plastic pots, containing 0.5 L of mixture peat moss and perlite in the ratio 1:1 (v/v). On 2-3 of April plants were transplanted in soil supplemented with mineral fertilizers in amounts determined in accordance with the recommendations following the analysis. Fertilizers were applied as base dressing and post-planting fertigation. Phosphorus and potassium were supplied in the following rates: P_2O_5 26 kg/da and K_2O 50 kg/da. In half of the treatments nitrogen rate were 30 kg/da, which was assumed as optimal rate and symbolized further in the text as 100%N. The other half of the treatments received 1/2 reduced amount of nitrogen (15 kg/da) and symbolized further in the text as 50%N. Harvesting period began on 3-7 of June and ended on 22-24 of July. Plant density was 3.5 plants per m^2. Tomato plants were trained at wires and pruned to a single stem by removing all side shoots. The growing tip was pinched off at the fourth cluster. During both experimental years, sprayings were applied at label level in accordance with the recommendations, following the diagnostics of pest infestations and disease incidence. Weeds were controlled manually throughout the whole experimental period. Irrigations were performed on 3-4 day intervals with average amount of water 15-40 L m^{-2}. During the cultivation irrigation, plant protection, regular cultural practices, etc. were applied as needed, uniformly through all experimental plots.

Seeds from hairy vetch, winter pea and white mustard were sown in September previous year with following seeding rates: hairy vetch – 10 kg/da, winter pea – 20 kg/da; white mustard – 2.3 kg/da. Cover crops were plowed under and incorporated into the soil at flowering stage, a week before transplanting the tomato plants.

Experimental treatments were as follows: 1. Control 50%N – plots supplied with total 15 kg/da nitrogen without green manure; 2. Control 100%N – plots supplied with total 30 kg/da nitrogen without green manure; 3. Tomato 50%N + hairy vetch; 4. Tomato 100%N + hairy vetch; 5. Tomato 50%N + winter pea; 6. Tomato 100%N + winter pea; 7. Tomato 50%N + white mustard; 8. Tomato 100%N + white mustard. Each treatment was presented in triplicate; each replication was composed of eight tomato plants. Plot size per each treatment was 85 m^2. The experimental design was a randomized complete block.

Research indexes

Fruits were harvested weekly at the fully-ripening state, (visually assessed according to a color scale from 1 to 8, where 1 corresponds to mature green and 8 to deep pink). The yield from the first three harvests was considered as early yield. The total yield was calculated by combining the yield from all harvests. Mean fruit weight and number of fruits per plant were also determined.

For quality analysis fruits were picked two times during the maximum fruiting named as: harvest I (20-21 of June) and harvest II (10-11 of July). Harvest I was composed by fruits from first and second cluster, while harvest II – by fruits from third and fourth cluster. An average sample from 20 fully ripened fruits, homogenized to juice, was used for the analysis of total soluble solid content (TSS), expressed in Brix and determined with a hand-held refractometer; ascorbic acid content by Tillman's reaction (Tillmans et al., 1932); titrable acidity by using titration with NaOH and total sugars by iodometric determination method of Schoorl-Regenbogen.

The experiment was conducted on naturally nematode infested soil. Six soil cores (20 cm deep) were collected and combined for nematode analysis from each plot. Soil samples were taken before cover crops sowing (initial population: Pi) and at the tomato harvest (final population: Pf). Nematodes were extracted from 100 g soil sub-samples for each treatment, using a modified Baermann funnel technique (Rodriguez-Kabana and Pope, 1981). Second-stage juveniles (J2) were counted at ×40 magnification. Reproduction factors (Rf) for root-knot nematodes were calculated by dividing the final population densities at termination of cover crop by initial population densities of root-knot nematode prior to cover crop planting (Rf= Pf/Pi). At harvest, five plants were removed from each plot and rated for root knot nematode galling on a 0 to 4 scale, where: 0 - no infestation, 1– slight infestation (up to10% of root system is infested), 2–average infestation (10–25% from the root system is infested); 3–high infestation (26–50% from the root system is infested); 4–very high infestation (above 50% from the root system is infested and part of roots are dead) (by Stoyanov, 1980). Effectiveness was calculated based on population density by Henderson–Tilton formula (Henderson and Tilton, 1955).

Results of the study were analysed by standard statistical procedure using Statistica 10 package (StatSoft, Tulsa, USA). Data were subjected to Duncan's Multiple Range Test to separate means at $P<0.05$. Three-way ANOVA with experimental year, nitrogen supply and treatment as fixed factors was applied.

Results and discussion

Yield and yield components

Analysis of variance showed that the year of the experiment (Year) as well as cover crops (Treatment) are major factors influenced significantly on early and total yield of tomato (Table 1). Early yield was strongly influenced by the year of the experiment, which factor contributed to 78% of the total variation. Total yield was more influenced by the factor Treatment where 32% from the total variation was due to this factor. A considerable influence was identified of the interaction between Year and Treatment (Y*T). Considerable contribution to the total variation (15% and 36%) had so called error, which suggested that factors other than examined influence tomato early and total yield. The amount of nitrogen fertilizer, applied as side dressing during vegetation did not influenced on tomato yield. The absence of significant difference between Control 100%N and Control 50%N treatments indicate that the frequent application of synthetic N fertilizer even at lower dose meet the needs of tomato crop. This put under question which is optimal dose of nitrogen fertilizer. There were absence of influence of the two way interactions Y*N and N*T and the three-way interaction Y*N*T on both early and total tomato yield.

The established strong influence of the experimental year as well as the strong influence of other factors was probably due to the differences in the microclimate between the two years. The experimental greenhouse was unheated, with very limited options to control the microclimate. Because the cover crops were grown during the winter season the very low temperatures and wide temperature amplitudes during 2014 had a negative effect on the establishment of cover crops, resulted in 15% lower biomass than that in 2015.

Table 1. Analysis of variance for the effect of the Year (Y), the amount of nitrogen fertilizer (N) and the treatment (T) on tomato early and total yield

Source of variation	df	Type III Sum of Squares		Type III Sum of Squares	
		Early yield	Total yield	Early yield	Total yield
Y	1	57629656.4***	1726839.1 *	77.55	3.34
N	1	561017.4	705214.3	0.75	1.37
T	3	3806771.2 *	16542970.8 ***	5.12	32.04
Y*N	1	143128.4	898365.6	0.19	1.74
Y*T	3	498826.0	7668622.5 *	0.67	14.85
N*T	3	615418.3	1167690.1	0.83	2.26
Y*N*T	3	255047.3	4575910.5	0.34	8.86
Error	32	10805483.9	18340282.9	14.54	35.53
Corrected total	47	74315349.0	51625895.8		

*, **, *** - significance at 5%, 1% and 0.1% probability level, respectively

Due to the considerable influence of the year of the experiment on tomato yield the results from the two years are presented separately in Table 2. During the first experimental year early yield varied between 604.5 and 1341.6 kg/da without difference between treatments. During the second year early yield was considerably higher, compared to the first year. The lowest early yield (2705.0 kg/da) was measured in the treatment with White mustard, which received half amount nitrogen fertilizer. The Control treatment, dressed with whole amount nitrogen fertilizer resulted in the highest early yield – 4160.4 kg/da. In the rest of the treatments the early yield varied between 2818.4 and 3462.1 kg/da without differences. The trend observed here is that during both experimental years the lowest yield was measured in White mustard 50%N and Winter pea 50%N treatments, while the highest was in Control 100% N and Control 50%N treatments. Early yield is associated with higher price of tomatoes during the first 3 weeks of the season contributing to higher profits. The results from the current study showed that green manuring esp. with white mustard and winter pea could reduce to some extent the early yield of tomato. This negative effect was higher when plots received reduced dose nitrogen fertilizer. In a similar study Abdul-Baki et al. (1996) observed that tomato harvest season was 3 weeks longer with mulch from hairy vetch.

During the first experimental year total tomato yield was more influenced by cover crops in the treatments with decreased amount of nitrogen fertilizer (50%N). Highest yield was observed in Hairy vetch treatment, which exceeded the control with 21%. These results are in accordance with Sincik et al. (2008), who found that the economically optimum N rate is average of 3 kg N/da lower for potato following green manure legume cover crops compared to the control. In White mustard treatment, the total yield was 25% less than the control. In the treatments dressed with the whole amount of nitrogen fertilizer Hairy vetch and White mustard did not influenced significantly the total tomato yield. The opposite results were obtained in Winter pea treatments: in plots dressed with decreased amount of nitrogen fertilizer total tomato yield was similar to the control, while in plots dressed with the whole amount of nitrogen fertilizer the yield was lower than the control. During the second experimental year the differences among treatments were not so distinguishable. There were no significant differences between controls and cover crops treatments in both 50%N and 100%N plots. Under the conditions of decreased nitrogen fertilization, the highest yield was obtained from the control and white mustard plots – 8251.5 and 7633.0 kg/da. In Hairy vetch and Winter pea plots the total tomato yield was non-significantly lower than the control. In fully fertilized plots, highest tomato yield was obtained from Hairy vetch treated plots (7362.6 kg/da) and from control plots (7206.0 kg/da). In the rest of the treatments the yield was insignificantly lower. By green manuring with hairy vetch a reduction of the amount of nitrogen fertilizer used for fertigation could be achieved.

According to Thönnissen et al. (2000) green manure should be

Table 2. Tomato yield (kg/da) as influenced by cover crops and nitrogen supply and experimental year

Treatment	Year 2014				Year 2015			
	Early yield	Total yield	Early yield	Total yield	Early yield	Total yield	Early yield	Total yield
Control 50%N	1257.8	ns	6990.8	bc	3462.1	ab	8251.5	a
Control 100%N	1341.6	ns	7591.4	ab	4160.4	a	7206.0	ab
Hairy vetch 50%N	1149.5	ns	8453.3	a	3170.4	ab	7067.4	ab
Hairy vetch 100%N	1056.9	ns	7461.7	ab	2933.9	ab	7362.6	ab
Winter pea 50%N	815.1	ns	6364.8	b-d	2818.4	ab	6732.9	ab
Winter pea 100%N	1017.9	ns	5793.5	cd	3383.1	ab	6040.4	b
White mustard 50%N	604.5	ns	5264.0	d	2705.0	b	7633.0	a
White mustard 100%N	838.5	ns	6351.2	b-d	2980.3	ab	7011.7	ab

Values in columns, followed by different letters are statistically different according to Duncan's Multiple Range Test, P<0.05; ns – non-significant difference

supplemented with N fertilizer to ensure optimal tomato yields as well as green manuring is more effective in unfertile soils. Other authors observed an inverse relationship between yield after green manuring and rate of N applied (Sincik et al., 2008). In the current study in most cases there was no positive effect of green manuring on yield of the tomato crop most likely because the frequent application of synthetic N fertilizer that meet the needs of tomato crop even at low dosage. Lack of impact of green manures on subsequent crop yield is a common observation (Jackson et al., 1993; Knott, 1996; Baggs et al., 2000). A number of factors as soil type, temperature and moisture, the type of cover crop, cultivation techniques, etc. influence on the mineralization rates of incorporated plant material (Baggs et al., 2000). Although no clear yield benefits of green manures were found in this study it is likely that they may have become apparent in subsequent seasons by increased mineralization of organic matter, indicating the need for long-term experiments as well as by optimization of management practices that manipulate the release of N.

Factors that have significant influence on fruit weight and number are the experimental year and the treatment (Table 3). The amount of nitrogen fertilizer as well as two- and three way interactions between factors did not influenced on the examined parameters. In the first experimental year highest number of fruits (19) was observed in both Hairy vetch treatments, while the lowest (15) – in White mustard 50%N treatment. During the second experimental year fruit number varied between 17-20 fruits per plant without significant differences among treatments, irrespectively of the amount of the nitrogen fertilizer. Inconsistent between the experimental years were the data for average fruit weight. In the first year Hairy vetch 50%N treatment resulted in the highest fruit weight – 125.1g. In the second year the highest fruit weight was obtained from White mustard 50%N treatment – 121.5g. But the differences with the controls were insignificant. In both years Winter pea 100%N treatment resulted in the lowest tomato fruit weight.

Fruit weight can be a component of fruit quality that affects the market value of the product. The heavier fruits obtained with Hairy vetch 50%N during the first year and with White mustard 50%N during the second year, compared to those of the other variants adds to the marketing value of the product and, consequently, to profits.

Fruit quality

Analysis of variance showed that harvest time and treatment are the main factors, influencing the examined fruit quality parameters (data not shown). That is the reason why the data for each harvest for each year are presented and discussed individually (Table 4). During the first experimental year in harvest I Brix varied between 5.1-5.7%. A significant difference was observed only between Winter pea 100%N and White mustard 50%N treatments. In harvest II brix values in all treatments were higher than that in harvest I. Lowest brix was measured in White mustard 50%N treatment (5.8%), while Hairy vetch, Winter pea 100%N and White mustard 100%N treatments resulted in the highest brix of tomato fruits. The highest content of total sugars in harvest I was established in Winter pea 100%N, which remain comparatively high during the harvest II. Lowest values were observed in Hairy vetch 50%N, White mustard 100%N treatments in harvest I and White mustard 50%N treatment in harvest II. In contrast to the other studied parameters, which values increased during the second harvest, titrable acidity was not influenced by the harvest time. However, differences between treatments were more pronounced in harvest II. Higher than control titrable acidity was observed in Winter pea 50%N, Hairy vetch 100%N and White mustard 100%N treatments. Ascorbic acid content of tomato fruits in harvest was not influenced by the cover crop. In harvest II tomato fruits were richer in ascorbic acid in Control 50%N, Hairy vetch and Winter pea 100%N treatments (27.2-28.1 mg/100g). Low ascorbic acid content (25.5 mg/100g) was measured in Winter pea 50%N and White mustard 50%N treatments. During the second experimental year brix, total sugars content and titrable acidity were similar for all treatments in both harvests. Some differences were established in ascorbic acid content. In harvest I Hairy vetch 50%N treatment resulted in decreased content of vitamin C in tomato fruits. In harvest II lower than control values of ascorbic acid were observed in Hairy vetch 100%N and Winter pea 100%N treatments.

It is well known the effect of water availability, mineral nutrients, nutrient source, plant growth regulators etc. on fruit quality (Dumas et al., 2003; Toor et al., 2006), but limited research is available on the influence of cover crops on chemical parameters of fruit quality. It has been reported that green manure treatments gave highly

Table 3. Tomato fruit number per plant and average fruit weight as influenced by cover crop, nitrogen supply and experimental year

Treatment	Fruit number/plant				Average fruit weight, g			
	Year 2014	Year 2015	Year 2014	Year 2015	Year 2014	Year 2015	Year 2014	Year 2015
Control 50%N	18.7	a	19.9	ns	106.7	a-c	118.8	ab
Control 100%N	17.7	ab	19.3	ns	122.8	ab	107.3	ab
Hairy vetch 50%N	19.4	a	19.1	ns	125.1	a	106.3	ab
Hairy vetch 100%N	18.6	a	19.0	ns	114.6	a-c	110.6	ab
Winter pea 50%N	18.3	a	17.2	ns	99.2	c	112.0	ab
Winter pea 100%N	17.3	ab	18.4	ns	96.9	c	94.5	b
White mustard 50%N	15.0	b	18.2	ns	100.2	c	121.5	a
White mustard 100%N	17.7	ab	19.2	ns	103.2	bc	104.4	ab
		Y	N	T	Y*N	Y*T	N*T	Y*N*T
Significance between levels	Fruit number	*	0.702	*	0.647	0.202	0.174	0.500
	Fruit weight	0.812	0.220	*	0.100	0.152	0.650	0.183

Values in columns, followed by different letters are statistically different according to Duncan's Multiple Range Test, $P<0.05$; ns – non-significant difference; *, **, *** - significance at 5%, 1% and 0.1% probability level, respectively

Table 4. Tomato fruit quality parameters as influenced by cover crops, nitrogen supply and experimental year

Treatment	Harvest I (1-2 Cluster)								Harvest II (4-5 Cluster)							
	B*, %		TS, %		TA, %		AA, mg/100g		B*, %		TS, %		TA, %		AA, mg/100g	
Year 2014																
Control 50%N	5.5	ab	2.9	ab	0.48	a	17.6	ns	6.2	ab	3.5	ab	0.45	bc	27.6	a
Control 100%N	5.4	ab	2.8	ab	0.46	ab	16.7	ns	6.2	ab	3.6	a	0.43	c	26.9	ab
Hairy vetch 50%N	5.2	ab	2.7	b	0.45	ab	17.2	ns	6.5	a	3,8	a	0.49	ab	27.2	a
Hairy vetch 100%N	5.5	ab	2.9	ab	0.48	a	17.4	ns	6.5	a	3.8	a	0.49	ab	28.1	a
Winter pea 50%N	5.3	ab	2.9	ab	0.46	ab	17.7	ns	6.2	ab	3.6	a	0.50	a	25.5	b
Winter pea 100%N	5.7	a	3.1	a	0.48	a	17.7	ns	6.4	a	3.7	a	0.45	bc	27.7	a
W. mustard 50%N	5.1	b	2.8	ab	0.46	ab	15.9	ns	5.8	b	3.3	b	0.46	a-c	25.5	b
W. mustard 100%N	5.3	ab	2.7	b	0.44	b	17.3	ns	6.4	a	3.7	a	0.49	ab	26.5	ab
Year 2015																
Control 50%N	6.1	ab	3.2	ns	0.62	ns	19.9	ab	6.3	ns	3.4	ns	0.56	ns	24.4	ab
Control 100%N	6.2	a	3.2	ns	0.61	ns	20.2	a	6.3	ns	3.4	ns	0.55	ns	25.3	a
Hairy vetch 50%N	5.7	b	2.8	ns	0.59	ns	17.0	c	6.3	ns	3.0	ns	0.58	ns	23.3	b
Hairy vetch 100%N	6.1	ab	3.3	ns	0.63	ns	18.0	a-c	6.4	ns	3.1	ns	0.54	ns	23.2	b
Winter pea 50%N	5.9	ab	3.3	ns	0.60	ns	17.7	bc	6.3	ns	3.3	ns	0.54	ns	22.9	b
Winter pea 100%N	6.0	ab	3.3	ns	0.64	ns	18.1	a-c	6.4	ns	3.4	ns	0.56	ns	23.4	b
W. mustard 50%N	5.9	ab	3.2	ns	0.58	ns	18.6	a-c	6.3	ns	3.0	ns	0.55	ns	23.7	ab
W. mustard 100%N	5.9	ab	3.2	ns	0.59	ns	19.2	a-c	6.2	ns	3.1	ns	0.56	ns	23.7	ab

* B – Brix; TS – Total sugars, TA – Titrable acidity, expressed as % citric acid; AA – Ascorbic acid
Values in columns, followed by different letters are statistically different according to Duncan's Multiple Range Test, P<0.05; ns – non-significant difference

significant effect on total soluble solids of green okra pods over the control treatment, whilst total acidity, fibre and pectin contents were unaffected (Benjawan et al., 2007). Tomato fruit density, firmness, and total soluble solids were not influenced by cover crops in a study of Nair (2011). In the current study the results about fruit quality parameters were inconsistent, indicating the need for further research.

Nematode population density in soil and infestation on tomato roots

Initial results from the nematode sampling and analysis showed a large variation in populations among the treatments. During the first experimental year the initial population densities (Pi) of root-knot nematodes varied between 458 and 608 J_2 per 100 g soil (Table 5). Significant differences between treatments were observed in the final population densities. The lowest value of Pf was recorded in Hairy vetch 50%N treatment, followed by Hairy vetch 100%N and White mustard 100%N, with the lowest value of the reproduction factor (Rf) – in Hairy vetch 50%N treatment. The highest values of Pf (583 and 564 J_2 per 100 g soil) and Rf (1.3 and 1.2) as well as the highest degree of root galling (3.0 and 3.4) were recorded in the Control 50%N and Control 100%N treatments, respectively. The use of cover crops as green manure decreased population densities of root-knot nematodes in the soil and attack of tomato plants compared with the control treatments. At the end of the experiment among the tested cover crops the highest rate of root galling (2.6 and

Table 5. Effect of green manure on population densities, reproduction factor and root galling severity of root-knot nematodes (*Meloidogyne* spp.) in greenhouse tomato during 2014

Treatment	Root-knot nematodes per 100 g soil			Rate of root galling (0–4)	Effectiveness (%) Henderson-Tilton
	Initial population (Pi)	Final population (Pf)	Reproduction factor (Rf)		
Control 50%N	466^{b}	583^{a}	1.3	3.0^{a}	-
Control 100%N	458^{b}	564^{a}	1.2	3.4^{a}	-
Hairy vetch 50%N	520^{ab}	238^{c}	0.4	0.6^{c}	63.10
Hairy vetch 100%N	562^{ab}	320^{bc}	0.6	1.2^{bc}	54.76
Winter pea 50%N	613^{a}	480^{ab}	0.8	2.6^{ab}	37.41
Winter pea 100%N	507^{ab}	420^{b}	0.8	2.4^{ab}	32.73
W. mustard 50%N	608^{a}	400^{b}	0.6	1.4^{bc}	47.32
W. mustard 100%N	494^{b}	364^{bc}	0.7	1.8^{bc}	40.16

a,b,c – Duncan's Multiply Range Test, P<0.05

Table 6. Effect of green manure on population densities, reproduction factor and root galling severity of root-knot nematodes (*Meloidogyne* spp.) in greenhouse tomato during 2015

Treatment	Root-knot nematodes per 100 g soil			Rate of root galling (0–4)	Effectiveness (%) Henderson-Tilton
	Initial population (Pi)	Final population (Pf)	Reproduction factor (Rf)		
Control 50%N	534^{bc}	686^{a}	1.2	2.6^{a}	-
Control 100%N	487^{bc}	652^{a}	1.3	2.4^{a}	-
Hairy vetch 50%N	760^{a}	380^{bc}	0.5	1.2^{b}	61.08
Hairy vetch 100%N	560^{bc}	466^{ab}	0.8	1.8^{ab}	37.84
Winter pea 50%N	508^{bc}	493^{ab}	0.9	1.8^{ab}	24.46
Winter pea 100%N	603^{b}	544^{ab}	0.9	2.0^{ab}	32.62
W. mustard 50%N	420^{c}	266^{c}	0.6	1.4^{b}	53.70
W. mustard 100%N	746^{a}	528^{ab}	0.7	2.0^{ab}	37.13

a,b,c – Duncan's Multiply Range Test, P<0.05

2.4, respectively) and the lowest effectiveness (37.41% and 32.73%, respectively) were recorded in Winter pea 50%N and Winter pea 100%N treatments. The lowest rate of root galling (0.6) and the highest effectiveness (63.10%) were observed in Hairy vetch 50%N treatment (Table 5).

During the second experimental year the nematode population densities (Pi) before cover crops sowing varied between 420 and 760 J_2 per 100 g soil (Table 6). The final population density was lowest (266 J_2 per 100 g soil) in White mustard 50%N treatment, with the lowest reproduction factor (Rf) in Hairy vetch 50%N and White mustard 50%N, 0.5 and 0.6 respectively. The highest values of Pf, Rf and rate of root galling was recorded in Control treatments. The treatment with Hairy vetch 50%N, followed by White mustard 50%N have the lowest degree of root galling (1.2 and 1.4, respectively) and the highest effectiveness – 61.08% and 53.70%, respectively.

In this study Hairy vetch and White mustard, were found to suppress gall formation when applied as green manure. This correlates with previous studies, in which *in vitro* tests showed that, in most cases, a reduction of nematodes occurs with the application of brassica crops as green manure in comparison with the application of non-brassica crops (Mojtahedi et al., 1991). Kruger et al. (2015) in bioassays were found significant suppression of *M. javanica* by white mustard when applied as green manure. The effect involved is most probably due to the glucosinolates in the tissue of the brassicas (Brown and Morra, 1997).

A significant disadvantage of green manure cover crops to be applied in greenhouse is that they require cultivation before the cash crop, e.g. the greenhouse should not be used for a couple of months. One approach to overcome this disadvantage is to grow the cover crops in the field and after mowing to place the residues in the greenhouse. Using such method Kumar et al. (2005) showed that the responses of tomato plants to cover crops seen in the field can be mimicked under greenhouse conditions.

Conclusions

Tomato early yield, fruit number per plant and fruit weight were not significantly affected neither by reduced rate of N application nor by green manure cover crops. Cover crops influenced slightly the total tomato yield and this influence was inconsistent within the two experimental years, indicating the need for long term experiments. Based on the obtained results following assumptions could be made: hairy vetch green manure can affect positively the total yield of tomato irrespectively from the dose of nitrogen fertilizer; winter pea may have a slight negative effect on total tomato yield especially in fully fertilized plots; white mustard may have negative or positive influence on tomato yield especially in plots with decreased dose of nitrogen fertilizer. Green manure cover crops did not influence on fruit quality parameters as brix, total sugars and titrable acidity. No significant influence was observed also on the ascorbic acid content at the beginning of the harvest. But during the harvest of fruit from 4-5 cluster a negative effect on vitamin C content was observed from three examined cover crops in both N treatments. By green manuring with hairy vetch a reduction of the amount of nitrogen fertilizer used for fertigation could be achieved. Hairy vetch and white mustard green manures reduced root-knot nematode infestation on tomato greenhouse production.

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