

Management of corky root disease of tomato in participation with organic tomato growers

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ABSTRACT

Corky root disease of tomato, caused by the soil-borne fungus *Pyrenochaeta lycopersici*, is a common and serious problem for organic tomato production. This paper addresses the possibility of developing a management strategy for corky root disease in participation with organic tomato growers in Sweden. The participatory research group consisted of nine organic tomato growers from central Sweden, two extension workers and two researchers. Regular meetings were held so that growers, extension workers and researchers could exchange knowledge on corky root disease management. A number of research issues were identified during group discussions: use of mulch, break crop, grafted tomato plants, composts, composted *Pyrenochaeta*-infested soil, fungivorous nematodes and commercially available bio-control agents based on *Trichoderma*, *Streptomyces* and *Gliocladium* in corky root disease control. The issues were investigated in on-farm experiments and experiments at a research station. The outcomes of the research work were presented in the group in subsequent meetings and assessed in joint discussions. The results from the study showed that a compost with low $\text{NH}_4\text{-N}$ concentration and high Ca concentration reduced corky root disease severity in greenhouse experiments at the research station. However, although the potential of other measures such as use of fungivorous nematodes and commercially available bio-control agents was demonstrated, these measures need further improvement to be adopted in commercial growing conditions.

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1. Introduction

Organic tomatoes are grown in the soil, either in limited beds or straight in the existing soil. Organic fertiliser is applied in the form of farmyard manure, green biomass and/or other fertilisers approved for use in organic production. The growing period is generally shorter than that of conventional tomatoes and varies between 25 and 35 weeks after planting. In Sweden, organic tomato growing areas comprise 1.8 ha, which corresponds to approximately 4% of the total tomato growing area of 45.6 ha (Statistiska Meddelanden, 2007).

The soil-borne fungal disease corky root, caused by the fungus *Pyrenochaeta lycopersici* Schneider & Gerlach, is the most serious problem in organic tomato production in Sweden. Growing tomatoes in the same soil without a break is the main reason why this disease has developed into such a problem (Forsberg et al., 1999). In intensive production systems in Swedish greenhouses the disease

causes 30–40% yield reduction, but losses of up to 75% have been observed in European greenhouses (Forsberg et al., 1999). In organic farming, farmers rely on preventive measures to control plant diseases. These integrate a wide range of cultural practices such as choice of crop rotation, organic manuring, use of selected bio-control agents and growing of resistant cultivars. Grafting the cultivated variety onto a rootstock tolerant to corky root disease is becoming increasingly common in organic tomato production.

Participatory research involving growers has been shown to be a successful step in plant disease management as it encourages local experimentation to determine optimal management strategies (Nelson et al., 2001; Pande et al., 2001; Ortiz et al., 2004). Participatory approaches offer researchers a mechanism to ensure that their work is relevant to growers' needs and conditions (Nelson et al., 2001). In Sweden, participatory research for the development of organic tomato production has been initiated by the Centre for Sustainable Agriculture, Swedish University of Agricultural Sciences, starting from 1999 (Eksvärd et al., 2001; Ögren et al., 2002; K. Eksvärd and J. Björklund, unpublished). The participatory research group today consists of certified tomato growers in Sweden, researchers and advisors/facilitators. The aim

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of the group is to learn more about practical problems concerning organic tomato production in the greenhouse. Lack of knowledge on available plant nutrient requirements in organic tomato production in Sweden has emerged as an important problem. Subsequently, corky root disease was identified as another common problem. It became evident that growers require reliable detection methods to identify the corky root pathogen at an early stage of infection. The present study formed part of the participatory research mentioned above, the main objective of which was to identify solutions for corky root disease management in participation with organic tomato growers. The following research questions arose from the discussions:

- (i) Is it possible to confirm corky root disease infection by molecular methods?
- (ii) Does mulching with fresh green biomass and composted animal manure help to reduce the effect of corky root disease?
- (iii) Does composting of *Pyrenochaeta*-infested soil or incorporation of composts into infested soil reduce corky root disease severity?
- (iv) Is it possible to reduce the effect of corky root disease using break crops?
- (v) Is the use of grafted plants helpful in reducing corky root disease?
- (vi) Can fungivorous nematodes reduce corky root disease in *Pyrenochaeta lycopersici*-infested soil?
- (vii) Is it possible to reduce corky root disease by using commercially available bio-control agents?

Some of the results discussed in this paper have been published previously but constitute important components in the overall outcome of the participatory research.

2. Materials and methods

2.1. Participatory group

The participatory research group in the present study consisted of tomato growers from nine organic farms in central Sweden, two researchers and two extension workers, one of whom acted as facilitator. The work began with meetings of the participatory group, which served as a driving force to build up an ongoing interaction between the growers, advisors and researchers. The knowledge and perspectives of the organic tomato growers experiencing problems with corky root disease were acknowledged and were used to develop the framework for the research work presented here. The research issues identified were investigated in on-farm experiments and in experiments at a research station. The growers were involved in the research station experiments since they took part in the discussions on the concepts and structure of the experiments at the research station and since the *P. lycopersici*-infested soils, the basic materials of the research station experiments, were collected from two of the participating growers' greenhouses. The outcomes of the research work were presented in the group, and joint discussions were undertaken in order to improve the corky root disease management strategy.

2.2. On-farm experiments

On-farm experiments were conducted on four of nine participating farms: Farm 1 in Strängnäs (65°1'N, 17°43'E); Farm 2 in Vaddö (59°58'N, 18°49'E); Farm 3 in Södertälje (59°12'N, 17°39'E); and Farm 4 in Vikmanshyttan (60°16'N, 15°49'E). Three-year experiments (2003–2005 for Farms 1–3; 2004–2006 for Farm 4) with seven treatments were performed on these farms: (A) mulch

with clover-rich green biomass (40–90% clover); (B) mulch with clover-poor green biomass (10–20% clover); (C) mulch with composted animal manure; (D) break crop of winter rye (*Secale cereale* L.); (E) break crop of hairy vetch (*Vicia villosa* Roth); (F) control ungrafted plants; and (G) control grafted plants grafted on Beaufort rootstock, which is considered resistant to corky root disease (Theodoropoulou et al., 2007). On Farm 3 in Södertälje, 2-year experiments (2005–2006) were also performed with the treatment of fungivorous nematodes. An important purpose of the on-farm experiments was to establish the appropriateness of these treatments under commercial conditions and to collect growers' views. The size of the plot was large containing 31–40 tomato plants, to represent realistic commercial conditions. Plots were not replicated at the individual farm sites.

2.2.1. Use of mulching to control corky root disease

The effect of mulching on corky root disease was investigated on three of the farms. A mulch of green biomass or composted animal manure was spread on the soil surface on various occasions during the growing season depending on plant requirements and availability of mulching materials.

2.2.2. Use of break crops to reduce corky root disease

The effects of two break crops, winter rye and hairy vetch, were investigated on one of the farms. This farm has two greenhouses and the grower alternates between tomatoes and cucumbers in these greenhouses. The break crop was sown in the autumn after the cucumber culture and incorporated into soil in the spring before the tomatoes were planted.

2.2.3. Use of grafting to control corky root disease

Treatments A–E with ungrafted plants were compared with two control treatments, one with ungrafted and one with grafted plants.

The quantitative data of these experiments were recorded by the host growers. Tomato yield was recorded at every harvest for 31–40 plants per treatment on all farms. In addition, fruit set (fruits per bunch) was recorded on three 'indicator plants' per treatment. Plant nutrient status in the soil was monitored with regular soil analyses. When the participatory group visited any of the farm trials the treatments were discussed and the farmers' views were recorded by the facilitator.

2.2.4. Detection of *Pyrenochaeta lycopersici* by a molecular method

Tomato plants, grown in the greenhouse by participating growers, were subsequently analysed by participating researchers using a polymerase chain reaction (PCR) method developed by Persson et al. (unpublished) at the Department of Crop Production Ecology, Swedish University of Agricultural Sciences. The tomato plant material was collected from seven treatments (A–G) as described earlier on the four participating farms (Farms 1–4) for 3 years. As primers KORTF and KORTR (5'-CCC TGT CTG ATA CTA CCC GTG TCT-3', corresponding to nucleotides 88–111 and 5'-TGC TTT GAG GCG AGT CCA C-3', complementary sequence to nucleotides 432–415), generating a 345-bp product, were used. The PCR-cycle parameters used in the experiment were: 94 °C for 2 min, 30 cycles with 94 °C for 1 min, 55 °C for 1 min, 72 °C for 90 s, followed by an 8-min extension period. The PCR reaction assay with the primers KORTF and KORTR gave a detection of 0.5–0.1 pg of purified DNA of *P. lycopersici*.

Shortly before terminating the tomato crop, five plants from each treatment in 1 year were sampled for PCR analysis. The aboveground parts were cut off and the roots were thoroughly cleaned with tap water and stored at –20 °C until required. At preparation time, the samples were thawed and 200 mg root material was selected from each plant, including parts with suspected corky root symptoms. The root pieces were further cleaned

in running tap water for 16–20 h to eliminate any residual soil material.

Washed root material was placed in a plastic bag and dipped into liquid nitrogen for 20 s and powdered by beating with a hammer. DNA was extracted from the samples using DNeasy® Plant Mini Kit (QIAGEN Inc, CA, USA). The powder samples were transferred to 1.5-ml plastic tubes containing 1-mm glass beads (filling 1/4 of the glass tube) and 600 µl of AP1 lysis buffer from the kit were added. The tubes were shaken for 45 s in a FastPrep FP120 shaker (Bio101, Thermo Electron Corporation) at maximum speed. The final DNA, 30–50 µl per sample, was stored at –20 °C until analysis. PCR reaction and visualisation of results was performed according to Persson et al. (unpublished). Results are presented as number of positive PCR reactions.

2.2.5. Use of fungivorous nematodes for corky root disease management

The efficacy of the fungivorous nematode *Aphelenchus avenae* Bastian in controlling corky root disease was evaluated on a farm at Södertälje where the corky root pathogen was already present in the soil. Disease severity was recorded by participating researchers, while the host grower was responsible for agronomic procedures until harvest. The trial was conducted on the same soil in two consecutive years. *Aphelenchus avenae* was isolated from a potato field soil in Västergötland, Sweden (58°10'N, 13°34'E). Mass culture production and inoculation of fungivorous nematodes were carried out according to the procedures described in Hasna et al. (2008). The inoculation rate of fungivorous nematodes was 23 nematodes ml⁻¹ soil in the first year (2005) and 50 nematodes ml⁻¹ soil in the second year (2006). In the first year, inoculation was carried out 3 days after transplanting of tomato seedlings, whereas in the second year it was carried out on the same day as transplantation. The initial nematode population in the experimental soil was examined prior to experiments. The experiment was laid out in eight boxes (containing approximately 74 l soil each) separated from each other. There were two tomato plants in each box. The soil of four boxes was inoculated with nematodes, while that of the other four boxes remained non-inoculated (control).

Tomato plants were harvested 5 months after nematode inoculation. Yield was measured as total fruit weight per plant. At harvest, the whole root system of all plants was collected and disease severity was measured on infected roots. The roots were separated from the soil by gentle shaking and rinsed with tap water to remove soil particles. Disease severity in each plant was evaluated by collecting the following three 3-cm sections of root sample: leaving a segment of 5 cm from the root base and then taking a 3-cm sample, leaving 5 cm and then taking another 3-cm sample, leaving 5 cm and then taking another 3-cm sample. The three root samples from each plant were pooled and mixed. From these root samples, 100 pieces from each plant were examined under a stereomicroscope and grouped into three categories as white (healthy root), light brown (initially infected root) and dark brown (severely infected root).

Soil samples (approx. 150 ml) from inoculated and non-inoculated boxes were collected to count the nematode population at the end of the experiment. Nematodes were extracted from 100 ml soil by the Baermann funnel method (Southey, 1986), counted under a stereomicroscope at 25–50× magnification and classified into the following groups: (i) *Aphelenchus avenae*; (ii) other fungivorous nematodes; and (iii) bacterivorous and other (non-fungivorous) nematodes.

2.3. On-station experiments

2.3.1. Composting of corky root-infested soil

Soil naturally infested with *P. lycopersici*, collected from the greenhouse of one grower from the participatory research group in

the vicinity of Uppsala, Sweden (59°49'N, 17°43'E) was composted with fresh red clover (*Trifolium pratense* L.) and dried wheat straw (*Triticum aestivum* L.). Red clover was collected from a field at Krusenberglund, Uppsala, while winter wheat straw was collected from an organic farm in the vicinity of Uppsala. The infested soil, chopped red clover and straw were mixed in proportions of 5:4:1 (dry weight basis) and placed outdoors on a concrete floor in summer 2004. The heap size was about 0.7 × 1 × 1.5 m (h × w × l). The heap was covered with a textile sheet to prevent evaporation. Temperature was measured daily in the centre and on the surface of the compost heap until it reached the ambient temperature. The heap was turned over once a week for 3 weeks to promote aeration and homogeneous conditions. In the beginning of winter 2004, the composted soil was stored at 4 °C until used in summer 2005.

A bioassay was conducted in the greenhouse (18–22 °C temperature and 70% humidity) with the composted soil to assess whether composting of the infested soil helped to reduce the disease infection level. Three-week-old tomato seedlings (cv. Elin, Weibulls®, Sweden) were transplanted into plastic pots each containing 5 l untreated infested soil (control) or composted infested soil (eight replicates). After 10 weeks, at harvest, yield of tomato and corky root disease severity on infected roots were estimated as described in Section 2.2.5.

2.3.2. Use of compost to control corky root disease

Four different types of compost had been evaluated in greenhouse experiments to determine their effect on corky root disease reduction (Hasna et al., 2007). The availability of composts to the organic tomato growers in Sweden was regarded as an important factor during selection of composts. The composts evaluated were a green manure compost (GMC) prepared from red clover mixed with 10–20% (dry weight) chopped straw; two garden waste composts (GC1, GC2) collected from a commercial composting plant in Sala, Sweden (59°55'N, 16°38'E) and consisting of 70% garden waste and 30% horse manure (v/v) with an unknown proportion of straw or peat; and a horse manure compost (HMC) consisting of unknown proportions of horse manure and peat. Horse manure compost was collected from a horse manure pit in Uppsala where it had been composted for 8–9 months. The chemical properties of the composts are described by Hasna et al. (2007). The composts (20% v/v) were mixed with *Pyrenochaeta*-infested soil collected from the greenhouse of a participating grower in the vicinity of Uppsala. Three greenhouse experiments were conducted following a fully randomised design. At harvest, yield of tomato and corky root disease severity on infected roots were estimated as described in Section 2.2.5.

2.3.3. Use of commercially available bio-control agents to control corky root disease

The effects of bio-control agents on corky root disease control were studied in a student's project by Rita Varela at the Swedish University of Agricultural Sciences. Four commercially available bio-control agents were tested against *P. lycopersici* in *in vitro* and greenhouse conditions. The bio-control agents included were Binab TF WP®, which is based on *Trichoderma harzianum* Bisset (IMI 206039) and *T. polysporum* Bisset (IMI206040); Mycostop®, which is based on *Streptomyces griseoviridis* strain K61; Prestop WP®, which is based on *Gliocladium catenulatum* strain J1446; and Glio Mix®, which is based on *Gliocladium* spp.

2.4. Data analysis

2.4.1. Quantitative analysis

Data on corky root disease severity were analysed in SAS (SAS Institute Inc., Cary, NC, USA). To model the probabilities of healthy, initially infected and severely infected roots, a generalised linear

model for ordinal scaled observations was fitted with the GENMOD procedure. The logit link was used and overdispersion within the root was modelled with the option DSCALE.

2.4.2. Qualitative analysis

Qualitative analysis was carried out by the participatory group throughout the duration of the project, with a comprehensive evaluation at the end of the project by all members of the group, including those who did not carry out experiments on their farms. The quantitative data produced on farms by the growers and the experimental data analysed at the research station were background information for this qualitative analysis.

3. Results and discussion

3.1. On-farm experiments

3.1.1. Use of mulching to control corky root disease

Growers viewed mulching as an interesting alternative for corky root disease management since the mulch layer promoted root development and a range of other agrotechnical benefits, such as decreased evaporation from plant beds and inhibition of weed growth. Mulching also provided an opportunity for growers to produce their 'own' plant nutrients on-farm. The main disadvantages growers experienced with the method were that it was labour-intensive, required access to specialist machinery and was weather-dependent. The risk of ammonia damage to plants and the risk of bringing weed seeds and insects into the greenhouse were other disadvantages mentioned. However, two of the three farms that tested mulching with green biomass will continue to do so, as it had become part of their accepted method. The third farm will not continue this practice since there are problems in obtaining the green biomass.

3.1.2. Use of break crops to control corky root disease

The advantage growers experienced with using break crops was that organic material was added to the greenhouse soil in a 'low labour' way. Break crops also contributed to binding and retaining plant nutrients in the soil. A difficulty lay in establishing crops such as hairy vetch if sown too late. The sowing time is probably completely critical for the results. The grower who tested break crops wanted to continue to grow winter rye as it had good effects in that farm's cultivation system. However, growers found it difficult to evaluate this method after such a short time and they believe that break crops can perhaps produce more effects in the longer term.

3.1.3. Use of grafting to control corky root disease

Grafting on Beaufort rootstock gave healthier plants, and thus less disease, higher yields and larger fruit, particularly at the end of the season. The tomatoes were also of a more uniform shape compared with fruit from ungrafted plants. Three of the four farms that carried out experiments will continue with grafted plants. One grower claimed that he would continue with grafting as he believed it produces higher yields. Another grower was doubtful because the taste of the tomatoes was affected by grafting but she was tempted by the extra kilos produced by grafting. However, grafting involved complicated plant propagation, which led to harvest being delayed by 1 week. It sometimes also proved difficult for growers to get access to grafted plants. Grafting led to plants being more vegetative, which in turn led to more pinching-out work for the growers.

3.1.4. Detection of *Pyrenochaeta lycopersici* by a molecular method

On Farm 1, the soil was replaced in 2004 and the infection rate for roots analysed was very low that year. However, in the following

year, nearly all plants analysed by PCR on this farm showed infection (Table 1). The results indicate a rapid recontamination of pathogen-free soil. Plants in treatment G were grafted onto Beaufort rootstock, considered resistant to corky root disease, and the PCR results showed that nearly all plants were infected on all farms investigated (Table 1). Beaufort rootstock may therefore allow the pathogen to multiply and despite high yields, Beaufort rootstock was thus infected with corky root. However, the visible disease symptoms on roots of grafted plants were admittedly considerably less than on those of ungrafted plants and the root system was much larger and stronger. PCR analysis does not quantify infection but simply gives a positive or negative answer, infected or not infected. It does not show how strong the infection is, or how much the plant is damaged. Nevertheless, it is important to verify an infection with sometimes confusing symptoms and to be able to detect the pathogen even before the symptoms are visible. This provides the potential to determine the start of an infection, important knowledge for successful control strategies.

PCR analysis was also used to verify the visual scoring of corky root symptoms. The light and dark brown scores showed clear positive results, while most of the white roots showed negative PCR reactions. However, 10% of the white roots tested showed positive reactions and thus these samples were infected without displaying symptoms. Visual scoring can provide an accurate picture of how strongly and extensively the infection has developed.

The growers were satisfied to know about the possibility of detecting corky root disease infection by PCR methods at an early stage, which is not possible using the naked eye. However, they were aware of the cost of using PCR methods. The results from the PCR analyses made the participatory group aware of how fast the corky root pathogen infested the greenhouse soil and that even Beaufort rootstock was infected. In discussions, the group agreed that if *P. lycopersici* infection is detected very early, then growers can apply some measures such as use of compost to slow down pathogen growth. The group also agreed that grafting cannot be relied upon as the sole countermeasure to corky root disease. There is a need for a combination of measures that prevent multiplication

Table 1

Number of positive PCR reactions for five tomato plants tested in seven treatments (A–G) in three years along with mean yield of tomato from four tomato growing farms (1–4).

	Year	Treatment						
		A	B	C	D	E	F	G
Farm 1	2003	5	3	– ^a	–	–	5	5
	2004	0	0	–	–	–	1	0
	2005	5	5	–	–	–	5	3
	Infected plants (%)	66.7	53.3	–	–	–	73.3	53.3
	Yield (kg m ⁻²)	16.9	15.1	–	–	–	14.6	20.1
Farm 2	2003	1	–	1	–	–	0	0
	2004	0	–	3	–	–	2	0
	2005	3	–	4	–	–	4	4
	Infected plants (%)	26.7	–	53.3	–	–	40.0	26.6
	Yield (kg m ⁻²)	20.6	–	19.4	–	–	19.7	18.8
Farm 3	2003	–	1	3	–	–	3	na
	2004	–	2	4	–	–	4	0
	2005	–	4	2	–	–	5	1
	Infected plants (%)	–	46.7	60.0	–	–	80.0	10.0
	Yield (kg m ⁻²)	–	18.4	21.1	–	–	15.5	19.7
Farm 4	2004	–	–	–	2	4	3	5
	2005	–	–	–	5	5	4	2
	2006	–	–	–	4	5	5	5
	Infected plants (%)	–	–	–	73.3	93.3	80.0	80.0
	Yield (kg m ⁻²)	–	–	–	17.5	17.5	18.2	21.6

A, mulch with clover-rich green mass; B, mulch with clover-poor green mass; C, mulch with composted animal manure; D, break crop of winter rye (*Secale cereale* L.); E, break crop of hairy vetch (*Vicia villosa* Roth); F, control ungrafted plants; G, control grafted plants (grafted on Beaufort rootstocks); na, roots not analysed.

^a Experiments not conducted.

of the fungus, that promote competition with soil organisms and that strengthen plants and promote the development of new roots.

3.1.5. Use of fungivorous nematodes to control corky root disease

The application of *A. avenae* to the infested soil did not reduce corky root disease severity (Fig. 1A,B). The results were similar in both years, although the inoculation rate of fungivorous nematodes was higher in the second year (50 nematodes ml⁻¹ soil) than in the first year (23 nematodes ml⁻¹ soil). However, when *A. avenae* was applied to *P. lycopersici*-infested soil at a rate of 3 or 23 nematodes ml⁻¹ soil in a previous greenhouse experiment, a significant disease reduction was observed (Hasna et al., 2008). In the bioassay conducted in the large production system, infected plants had about 85% infection (Fig. 1A,B), indicating that the soil was heavily infested with *P. lycopersici*. In a soil with a high infestation rate of *P. lycopersici*, the number of fungivorous nematodes is a crucial factor and the number applied in this study might not have been sufficient to reduce disease. In an earlier study, Klink and Barker

(1968) found that the degree of *A. avenae* efficiency in biological control of *Fusarium oxysporum* was directly related to the fungal inoculum level. At the end of the present experiment, the number of fungivorous nematodes in the inoculated soil was low (1–2 nematodes ml⁻¹ soil) in both years.

The growers saw biological control by fungivorous nematodes as an area with great potential – but with many unanswered questions. It is positive that the will and expertise exists to continue research on this. It can be difficult to measure the effects of biological control in commercial growing. Further development work would therefore be capital-demanding, since it would require laboratory research.

There is an opportunity to combine a fungivorous nematode and an antagonistic fungus such as *Trichoderma* sp. in biological control. Soil animals often prefer feeding on plant pathogens rather than saprophytic or antagonistic fungi (Lartey et al., 1986; Friberg et al., 2005). One possible explanation for the preference for plant pathogenic fungi is that they often lack the toxic substances that saprophytes produce (Shaw, 1988). It has proven possible to enhance the control efficacy of damping-off caused by *Pythium* spp. by combined application of *Aphelenchus avenae* and *Trichoderma harzianum* in pot experiments (Jun and Kim, 2004). Several applications of fungivorous nematodes during the growing period of tomatoes might improve the disease control by these bio-control agents.

3.2. On-station experiments

3.2.1. Composting of corky root -infested soil

Corky root disease severity in composted infested soil was significantly ($p < 0.0001$) higher than in the control (infested soil) (Fig. 2). In general, soil-borne plant pathogens are eradicated during composting through three mechanisms: (i) heat generated during the thermophilic phase; (ii) release of toxic products during or after the self-heating process; and (iii) microbial antagonism in the sub-lethal outer temperature zones of heaps or later during the curing phase (Bollen, 1985; Hoitink and Fahy, 1986; Ryckeboer, 2001). Heat is considered the sole factor for eradication of plant pathogens during composting (Bollen, 1985). However, survival of a few soil-borne plant pathogens such as *Fusarium oxysporum* f. sp.

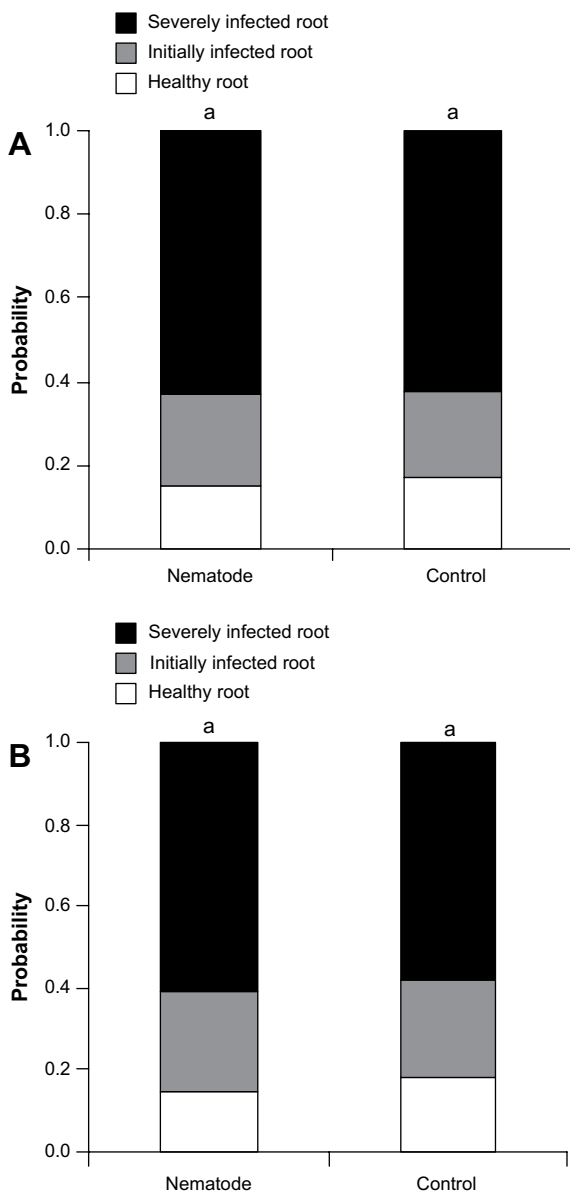


Fig. 1. Effect of *Aphelenchus avenae* on corky root disease severity in infested soil. (A) First year of experiment; (B) second year of experiment. Different letters on top of the bars indicate significant differences ($p < 0.05$).

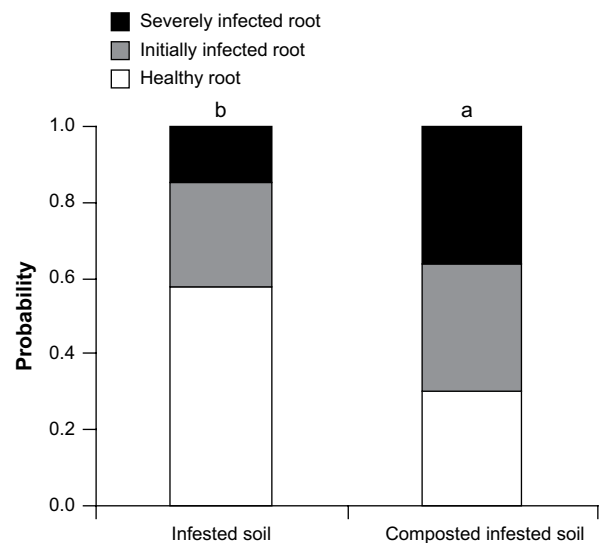


Fig. 2. Severity of corky root disease in infested soil (control) and in composted infested soil. Different letters on top of the bars indicate significant differences ($p < 0.05$).

Tronsmo, 1998; Hjeljord et al., 2001). The growers were most interested in Binab TF WP[®], which is based on *Trichoderma* spp. This was because Binab has already been tested on greenhouse crops such as cucumber to control soil-borne plant diseases in Sweden (<http://www.binab.se/>). Methods for stimulating the antagonist with nutrients during application should be explored further. Introducing the antagonists into soil prior to transplanting of tomato seedlings should also be considered. Prior application and nutrient activation will ensure a good colony of the antagonists in limited bed soils before the plant makes contact with *P. lycopersici*.

In the evaluation, a number of questions about the project work were posed to growers. They were asked to respond by making a tick on a scale of 1 (very negative) to 5 (very positive) (Table 2). All seven questions were given a positive response of between 3.5 and 5. To the question 'Would you consider participating in a new project?' the growers responded with 4.6 to 5. A similarly positive response was given to the question 'Has the SLU participation been valuable?' The three grower members of the group who did not carry out any experiments themselves responded with 3.9–4.5 to the question 'Despite not having any experiments, did you feel part of the group?' The growers claimed that this group work was a good opportunity for them to exchange information on corky root disease with each other, as well as with the researchers.

The present research showed that use of a compost with low NH₄-N concentration and high Ca concentration reduced corky root disease. However, the potential of other measures such as use of fungivorous nematodes, and commercially available bio-control agents cannot be excluded, though these measures need to be improved further to be adopted in commercial growing conditions. The participatory group learned that they cannot rely on just one measure to keep corky root disease below an economically tolerable threshold level. Integration of different control measures is required to maximise disease control of *P. lycopersici* in organic tomato production. At the final meeting, the participatory group agreed that the next issue for the group to consider would be the integration of the different treatments. Careful consideration has to be given to the specific cropping system used by individual growers. The same participatory research approach with on-farm experiments in combination with more detailed studies at the research station would be appropriate.

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