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# Snow manipulation as an alternative nematode control strategy

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## Abstract

Within the limitations of restricted choice of nematicides, research attempts shall be directed to developing alternative nematode control strategies. A correlative study was conducted to compare the effect of snow manipulations over the soil temperature with the laboratory results of potato rot nematode (*Ditylenchus destructor* Thorne) survival. Soil temperature was measured by data loggers buried in 5 cm soil under thick snowpack, densified snow base and under the bare ground from where the snow was removed. The results confirm the suggestion that the natural snow cover isolates the ground surface from the negative temperature extremes, and the consequent survival of potato rot nematodes is not likely to be reduced. On the other hand, snow densification prior to the arrival of a cold front resulted in a significant temperature drop down to −2ºC, which may cause more than 50% mortality of the most temperature sensitive age group, i.e. younger larvae. The most efficient soil temperature manipulation was snow removal, which may result in 90% mortality of adults and fourth-stage juveniles in exposed soil strata. None of the tested treatments were able to guarantee 100% mortality of any of the life stages involved in the comparison. We suppose the methods are appropriate for further efficiency testing in heavily infested fields, especially in small scale and ecologically sustainable agriculture.

Key words: soil temperature, snowpack densification, snow removal, *Ditylenchus destructor*, survival.

## Introduction

Potato rot nematode (*Ditylenchus destructor* Thorne) is a polyphagous pest known to have caused occasionally serious economic damages, especially, in Eastern European potato production. *Ditylenchus* hatch from eggs as vermiform second-stage juveniles (J2), since the first molt precedes eclosion. The juvenile grows and undergoes three more molts (J3, J4 and adult) to become a mature male or female. Within the limitations of restricted choice of nematicides available in Europe (none of which are currently registered in Estonia), nematode control efforts have to cope mostly with alternative strategies even in intensive agriculture. Because potato rot nematode is capable of remaining viable in soil (Švilponis et al., 2008), presence of economically significant contamination in the field depends to a great extent on the level of overwintering survival. Weed suppression has been reported as one of the key factors to potato rot nematode control (Andersson, 1971). However, in modern farming, there are rising concerns about the effect of weed control regimes on biodiversity, as higher biodiversity usually confers greater ecosystem stability. Hence, rather than eliminating species, task is to find methods to restore and maintain natural balance within the cropping system.

The geographic range of a pest population is limited mainly by the availability of host plants and the suitability of the climatic conditions. The extent to which pest managers can employ negative temperature extremes to protect the crop depends upon their ability to manipulate exposure of pests typically to naturally occurring cold temperatures by removing insulation (Hoy, 1997). Snow is well known for its low thermal conductivity insulating underlying soil, with significant effect for physical and biological processes. Even though, there are no studies of spatial variability in snow cover and the winter soil environment as related to potato rot nematode overwintering mortality, Milner et al. (1992) have shown a successful attempt to manage Colorado potato beetle, *Leptinotarsa decemlineata* Say using an artificially mulched trap crop. In the 0–15 cm soil strata, where most of the adult beetles overwintered, after the removal of mulch and snow cover, temperatures dropped from 0 to −11.7°C, whereas in undisturbed plots, temperature remained close to 0°C. Adult survival was significantly higher in snow-covered, unmulched controls and mulched habitats (=26%) than in disturbed habitats (=7%) (Milner et al., 1992). Even though some earlier work suggests that preventing snow covering the ground has no significant effect on the relative abundance of soil nematodes (Sulkava, Huhta, 2003), others have demonstrated that freezing plays an important role both in soil physical properties and community composition, as reviewed by Henry (2007).

Early winter tilling or turning of the soil is a well known pest management practice in vegetable gardens, because it exposes over-wintering insects to winter conditions. This has been a recommended control strategy also for limiting root-nematode survival (Heinz, Goellner Mitchum, 2010). For North-West Russia, among other specific pest management measures, snow rolling to reduce soil temperature in the depth of tillering node against snow mold has been recommended in winter cereals (Nikolaev, 2009). In our study, we measured the effect of snowpack densification and snow removal on the soil temperature, in order to estimate the influence of the soil temperature manipulations on the potato rot nematode winter survival.

## Materials and methods

The experiment was conducted at the Tõnisson Experimental Garden, Estonian University of Life Sciences, at Eerika near Tartu, Estonia (58º21′ N, 26º40′ E) on sandy loam *Stagnic Luvisol* (*LVj*) in WRB classification (Reintam et al., 2008) from January 13 until April 12, 2011. The test plots were located at the centre of an open field with winter rye as a cover crop (cabbage as previous culture) in a radial arrangement as shown in Figure 1. After the demarcation of the plots and digging out the bare ground under the natural snowpack of 52 cm, the data loggers (LogTag Model, TRIX-8 Temp. Logger, Micro *DAQ*.com, China), isolated from the soil humidity, were buried in 5 cm soil as it has been demonstrated that *Ditylenchus dipsaci,* a species related to *D. destructor*, is most abundant in crown soil of the host plant (Simmons et al., 2008).

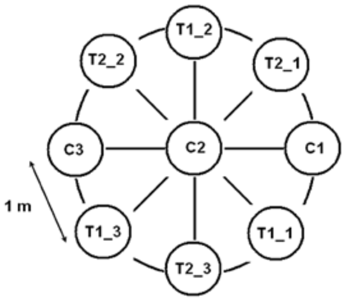



***Figure 1.*** Arrangement of control plots (C) and test plots (T1 and T2) in three replications for the soil temperature manipulation experiment, with T1 marking the snow removal treatments and T2 the snow densification treatments

The snow cover was carefully restored in control and snow densification treatments. To increase density and reduce the isolation capacity of the snow, 50 cm diameter plots were trampled down by boots into a flat solid base, which measured 17–21 cm in depth. To test the effect of reduced snowpack thickness, snow was completely removed on 50 cm diameter plots. Even when the snowpack of the control plots was compacted during the onset of the experiment because of unavoidable disturbances while the data loggers were set in their places, the original snow cover thickness was quickly restored by snowfall and wind, which resulted in 60–63 cm deep snowpack by January 26, when the natural undisturbed snow layer measured 63 cm. To keep the fresh snow accumulation on treated plots at less than 10 cm level by the arrival of a cold front, the snow treatments were carried out on 19, 24 and 26 January and 14 February. The arrival of the cold front was recorded on 12 February, when the mean daily air temperatures fell below −10ºC (min. −17.2ºC) and it lasted until 25 February, when the mean temperature was −13.2ºC (min. −21.5ºC). Measurements were programmed to be recorded automatically every 30 minutes. The data loggers were excavated and the measurements retrieved in spring after the snow melt and daily average temperature rose above 0.5ºC. The effect of snow manipulations was compared by repeated measures *Anova*, for the period after the last snow treatment on 14 February until the passing of the cold front. Because of the ethical and licensing considerations, the experimental garden was not contaminated with infective nematodes but the temperature records were compared with the results of an earlier laboratory experiment.

## Results and discussion

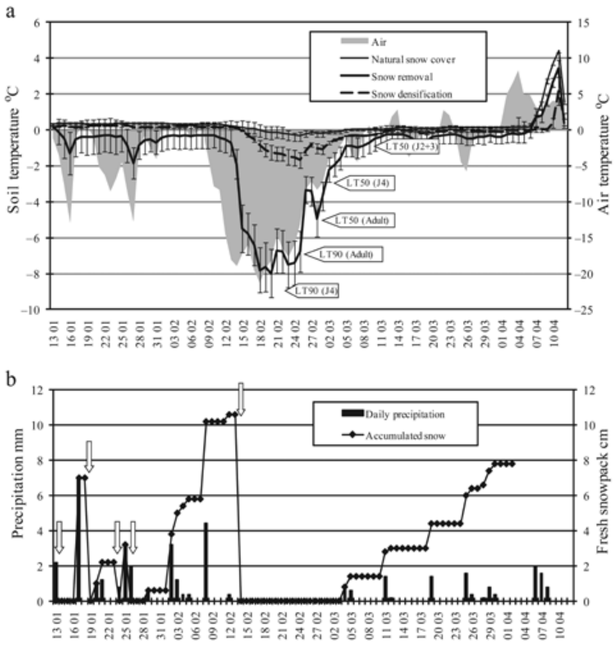
Soil temperature readings as well as the mean air temperatures and daily precipitation are presented in Figure 2. There was a statistically significant difference in mean soil temperatures between the treatments ($F_{4, 142}$ = 498.7, $p < 0.001$), with the significant interaction of date and temperature ($F_{44, 142}$ = 1.49, $p$ = 0.04). Fisher LSD analysis revealed that snow removal treatment was significantly different from the other manipulations in all the compared measurement points, while the differences between the control and the soil densification treatment appeared only after February, 19. The results were compared with our earlier experiment on cold tolerance of potato rot nematode post-eclosion stages, which had been kept in subzero temperature regimes for 24 h. The mortality estimations for 50% and 90% of population of the nematode are given in Table.

***Table.*** Probit model for mortality and lethal temperatures (LT50 and LT90) with confidence limits (95% *CL*) for development stages of *Ditylenchus destructor* after exposure to subzero temperatures for 24 h

| Age group | Model equation* *Mortality* = | LT50, °C (95% *CL*) | LT90, °C (95% *CL*) |
|---|---|---|---|
| J2 + 3 | 0.3 + 0.7 × *Φ* (−0.680 − 0.121 × *temp*) | −0.94 (−3.37, 6.09) | −14.49 (−28.01, −11.07) |
| J4 | 0.275 + 0.725 × *Φ* (−1.353 − 0.261 × *temp*) | −3.29 (−4.88, 2.17) | −9.36 (−14.80, −7.77) |
| Adult | 0.25 + 0.75 × *Φ* (−4.482 − 0.808 × *temp*) | −5.46 (−6.24, 3.91) | −7.36 (−8.51, −6.57) |

*Notes.* The data on younger juveniles (second- and third-stage juveniles, J2 and J3) is combined. Adapted from Švilponis et al. (2011). *Φ* – normal cumulative distribution function; * – probit model and lethal temperatures were corrected for control mortality at 22°C using Abbott's formula.

While the minimal subzero temperatures during the passage of the cold front in control did not exceed −0.8°C, the snow densification and snow removal manipulations resulted in minimum temperatures of −2.1°C and −10.3°C respectively. In another experiment lasting from September 29, 2010 until May, 2011, the surface temperatures under undisturbed natural snow cover in Tartu ranged at lowest between +0.7°C and −0.2°C with subzero temperatures lasting from February 22 to March 02 (Hiiesaar et al., unpublished data). This indicates that lethal temperatures for mortality of 50% of the younger juvenile stages of potato rot nematodes may be obtained by snow densification but more laborious snow removal may result in soil temperature drop to the level necessary for 90% mortality of older juveniles and adults, even though lower lethal temperature for adults (−15°C) was not achieved.




*Note.* (a) block arrows indicate lethal temperatures for 50% (LT50) and 90% mortality (LT90) of post-eclosion stages (adults, fourth-stage juveniles J4 and combined second- and third-stage juveniles J2 + 3) of potato rot nematode in 24 h exposition to subzero temperatures (according to Švilponis et al., 2011); (b) block arrows denote the dates of snow treatment.

***Figure 2.*** The effect of a snow treatment on mean (± SD) soil temperatures at 5 cm depth (a); mean daily precipitation (according to the Laboratory of Environmental Physics, http://meteo.physic.ut.ee) and accumulated snow cover thickness (calculated roughly by the rule: 1 mm precipitation = 1 cm snow) from January 13 until April 12, 2011 (b)

***The deeper the soil, the higher the temperatures.*** Some nematodes have exhibited seasonal vertical distribution fluctuations. The natural populations of Heterorhabditid and Steinernematid nematodes migrated to deeper layers during summer, presumably to avoid the unfavourable environmental conditions caused by high temperatures or lack of humidity (Garcia Del Pino, Palomo, 1997). Studies examining temperature gradient fluctuations have indicated that differences in the rate of thermal adaptation by a nematode can reverse the net direction it moves vertically in response to soil surface heating and cooling (Dusenbery, 1988). When movement of *Ditylenchus phyllobius*, *Steinernema glaseri* and *Heterorhabditis bacteriophora* was largely random relative to the thermal surface, *Rotylenchulus reniformis* and *Meloidogyne incognita* oriented towards it (Robinson, 1994). The oriented locomotion of plant parasitic nematodes in response to thermal and moisture gradients in winter is to be studied in more detail.

Overwintering survival of the soil dwelling pests is determined not only by cold tolerance and ability for vertical migration but also their resistance to dehydration. Benoit et al. (1988) have shown that water accumulated in frozen soil layers by migration to the freezing point. The result was less moisture at deeper soil depths. By inducing soil freezing, this may influence potato rot nematode survival indirectly, since the deeper soil moisture will be reduced beyond optimal limits, which possibly damages the individuals dwelling beyond the freezing zone. *Ditylenchus destructor* is very susceptible to desiccation, in contrast to their related species *D. dipsaci*, a pest sometimes inhabiting aerial parts of host plants where they may experience high rates of water loss and which is capable of anhydrobiosis (Perry, 1977). Desiccation may be an important stress responsible also for mortality of *Meloidogyne hapla* second-stage juveniles in frozen conditions (Forge, MacGuidwin, 1992). In contrast, snow accumulation has been shown to increase gravimetric soil moisture and associates with a decline in abundance of nematodes typically found in dry soils but an increase in nematodes associated with moist soil (Ayres et al., 2010). Since potato rot nematodes are only important in moist conditions, we may assume that large scale snow removal has probably stronger effect on potato rot nematodes than can be concluded from our initial soil temperature manipulation experiment.

As our snow compaction test was begun on a relatively warm day (air temperature +0.8ºC), on slightly molten multi-layered snow structure, optimal final density was not obtained. After removing of the snowpack, burying the data loggers and returning the composite snow aggregates, the treatment effected in reducing the snowpack thickness only for 68% (from 52.6 to 17 cm). The resulting soil temperatures were too high to cause significant winter mortality in all but at the LT50 (J2 + 3) level. Thermal conductivity of the compacted snow could be considerably improved if snow-treatment was initiated early in the season while the snowpack is still lower than 10 cm, or in subzero temperatures, when snow crystals would break instead of sublimation.

One possibility for further improving the effect of soil temperature manipulation is by the use of mulch or ground cover as recommended by Hoy (1997). Since soil under mulch remains at higher temperatures than bare soil, a rapid temperature drop can be provoked if the snow and mulch get removed immediately before the arrival of the cold front (Milner et al., 1992). The faster the temperature drops, the smaller the possibilities that pests would have a chance for cold hardening or acclimatory changes of the basic cell structural components (Koštal, 2010). However, because the labour costs for removing the mulch are high as it cannot be easily raked off when frozen and snow-covered, this strategy will probably be feasible only in limited size fields (Hoy, 1997). In order to elaborate more conclusive results for integrated pest management strategies, this correlative study will be continued as a series of field experiments in collaboration with farms exposed to potato rot nematode infestation.

## Conclusions

1. A sufficient proportion of nematodes survive winter conditions in potato-growing areas of Northern Europe to produce economically significant infestations, despite the rigors of the winter soil environment. Natural snow cover guarantees temperature conditions adequate for potato rot nematode overwintering.

2. Snow cover thickness and density manipulations resulted in significant reduction of temperatures in the upper soil layer during a cold front. The most effective treatment was snow removal, by which temperatures below −10.3°C were achieved. This is less than required to guarantee the mortality of the 50% of all the post-eclosion stages of *Ditylenchus destructor* as well as 90% of adults, which may considerably affect the winter survival of potato rot nematode population.

3. Snow densification by trampling in smaller areas or snow-rolling in larger fields as well as snow removal can be promising methods for reducing nematode population densities in heavily infested soils. The novel

plant protection techniques may be suitable for practicing in sustainable agriculture.

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# Sniego dangos storio ir tankumo įtaka nematodų išgyvenimui

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## Santrauka

Dėl riboto nematicidų pasirinkimo tyrimų metu siekta sukurti alternatyvias nematodų kontrolės priemones. Siekiant palyginti manipuliavimo sniegu poveikį dirvožemio temperatūrai, atliktas koreliacinis tyrimas, panaudojant bulvių puvinio nematodo (*Ditylenchus destructor* Thorne) išgyvenimo laboratorinių tyrimų rezultatus. Dirvožemio temperatūra matuota duomenų registravimo prietaisais, įkastais dirvožemyje 5 cm gylyje po stora sniego danga, po sutankinto sniego danga ir dirvoje, nuo kurios sniegas buvo pašalintas. Tyrimų rezultatai patvirtino prielaidą, kad natūrali sniego danga dirvos paviršių izoliuoja nuo neigiamų temperatūrų ekstremumų (kraštutinumų) ir dėl to bulvių puvinio nematodų išgyvenimo tikimybė nesumažėja. Kita vertus, dėl sniego sutankinimo prieš užeinant šaltam oro srautui temperatūra smarkiai sumažėjo iki −2º C, o tai gali sukelti didesnį nei 50 % temperatūrai jautriausios grupės, t. y. jaunų lervų, mirtingumą. Efektyviausia dirvožemio temperatūros manipuliacija buvo sniego pašalinimas, kuris tiriamame dirvos sluoksnyje galėjo lemti 90 % suaugusių ir ketvirtos stadijos jauniklių mirtingumą. Nė vienas iš tirtų metodų neužtikrino 100 % mirtingumo visose tirtose nematodų stadijose.
Galima teigti, kad šis metodas yra tinkamas toliau tiriant jo efektyvumą nematodais smarkiai užkrėstuose laukuose, ypač mažuose ir ekologiškai tvariuose ūkiuose.

Reikšminiai žodžiai: dirvožemio temperatūra, sniego dangos tankinimas, sniego pašalinimas, *Ditylenchus destructor*, išgyvenimas.