Bulgarian Journal of Agricultural Science, 21 (No 4) 2015, 815-821
Agricultural Academy

GLOBODERA ROSTOCHIENSIS POPULATION DENSITY EFFECT ON POTATO GROWTH AND YIELD. REGRESSION MODELS ESTIMATION

S. MANEVA and Zl. TRIFONOVA
"N. Poushkarov" Institute of Soil Science, Agrotechnology and Plant Protection, Department of Plant Protection, BG -2230 Kostinbrod, Bulgaria

Abstract

MANEVA, S. and Zl. TRIFONOVA, 2015. *Globodera rostochiensis* population density effect on potato growth and yield. Regression models estimation. *Bulg. J. Agric. Sci.*, 21: 815–821

Effect of initial population densities (Pi) of Bulgarian population of *Globodera rostochiensis* on the population dynamics and potato plants growth and yield was investigated in glasshouse and estimated using mathematical models. Potato cv. Nadejda seedlings were inoculated with Pi levels of 0, 0.1, 0.2, 0.5, 1, 2, 4, 8, 16, 32, 64 or 128 second stage juveniles/cm^3 soil. The relation between Pi and final population density (Pf) was linear and DWLS regression described the relation of nematode reproductive index (Ri) and Pi. The linear regression with lg(X+I) transformation has been used to model the Pi and Pf effect on both, potato height and yield. Tolerance limit of potato to *G. rostochiensis* was between 0.5 and 1 juveniles/cm^3 soil. The reduction of yield was significant different at 1.0 Pi. The model predicted that 4.0 Pi caused 50% yield loss and the maximal yield suppression of 87.6% occurred at 128 Pi. Maximum Ri of 27.0 occurred at 4.0 Pi, suggesting an interspecies competition.

Key words: G. rostochiensis, population density, potato growth, yield loss, mathematical model

Introduction

The potato cyst nematode *Globodera rostochiensis* Woll 1923 Bechrens is major pest of the potato crop and it is listed in EC plant health legislation (EC Listed Pests, 2003). It is found in most of the potato growing regions of the world (Turner and Evans, 1998), and is a serious problem for the potato production in Netherlands (Schomaker and Been, 1999), Japan (Takeshi, 1999; Uehara et al., 2005), UK (Haydock and Evans, 2000), Venezuela (Jimenez, 2000), Slovenia (Urek et al., 2007). The nematode, the host and the environment are the three interacting variables influencing the extent of yield loss in infested soils. An understanding of the mechanisms and principles involved in these interacting relationships is basic to being able to predict yield reductions from estimates of pre-planting nematode population densities (Trudgill and Phillips, 1997). The importance of the relationship between crop growth or yield and preplant population densities of many plant nematodes has been well documented by several authors (Ferris,1985; Di Vito et al., 2004; Khanna and Jyot, 2004; Di Vito et al., 2005). Basis of modelling yield loss and population dynamics relations of potato cyst nematodes is that both are strongly density-dependent (Trudgill et al., 1996). To obtain better information on the relationships between population density of *G. rostochiensis* and the potato growth and yield loss many authors have used the tools of mathematical modelling (Elston et al., 1991; Trudgill et al., 1996; Schomaker and Been, 1999; Moxnes and Hausken, 2007; Trudgill, 2008; Hajihassani et al., 2013).

In Bulgaria potato crops are widely cultivated in farms that range in size is from small to large. Both the official control and the information from the research institutions reported that *G. rostochiensis* was detected in Bulgaria in 1978 on the State seed production farm in Govedarci, Samokov region. It has spread slowly and is currently found in the potato production areas in the Sofia, Smolian, Pazardjik and Plovdiv regions (European Commission Report, 2004) and caused severe yield loss to the potato crops (Stoyanov and Trifonova, 1994; Trifonova, 1995; Trifonova, 2000).

The data about the damage caused by *G. rostochiensis* to potato plants usually refer to field conditions under intensive infection of nematode. There is a little knowledge for the

E-mail: svenma@abv.bg

relationship between the plant grow and yield of potato under low population densities.The present investigation was carried out to estimate the effect of increasing densities of a population of *G. rostochiensis* on the growth and yield of potato as well as on the dynamics of the nematode.

Materials and Methods

Growth conditions

The trials were carried out in a glasshouse of Plant Protection Institute, Kostinbrod. The population of *G. rostochiensis* was obtained from an infested potato field in Smolyan region. Cysts were collected by the wet-sieve decantation technique (Southey, 1986). The second stage juveniles (J_2) were obtained by exposing soaked cyst to potato root diffusate (Clarke and Perry, 1977). Collection and storage of cysts and collection of host root diffusate were described previously (Perry and Beane, 1989).

Seed of potato cv. Nadejda were sown in 20 cm diameter and 19 cm deep clay pots filled with 5000 cm^3 (5L) sterilized soil. The plants were sowed to maintain one seedling per pots. When seedlings were approximately 2 weeks old and aqueous suspension with second-stage juveniles was added to each of pots. Appropriate amounts of the inoculum were thoroughly mixed in the soil of each pot to obtain initial population densities (Pi) of 0, 0.1, 0.2, 0.5, 1, 2, 4, 8, 16, 32, 64 or 128 second stage juveniles/cm^3 soil (J_2/cm^3 soil) and the pots were lightly watered. There were five pots for each nematode density. Five pots were not infested and used as control.

Data set recording

The experiments were terminated after 90 days. The soil was air-dried and the final densities were determined by the wet-sieve decantation technique. Cysts were counted then crushed and their eggs contents estimated. Plant height and final population densities of cysts or eggs (Pf) were recorded. The potato yield was determined as tuber weight of each pot (g/pot) at harvest.

Statistical analysis and models

The reproductive index (Ri = Pf/Pi) was calculated per any of the initial nematode density. The data were processed by analysis of variance using F for the test significance and LSD values for significance of the obtained differences between variant and control means at levels $P < 0.05$, 0.01 and 0.001 depending of data dispersion. The variants were arranged in groups by Duncan's multiple-range test. The partial correlation coefficients for any appropriate pair of observed factors were calculated. All calculation was performed using the software developed by one of the authors on the base of standard statistical algorithms for processing of small data sets with biological origin (Sockal and Rohlf, 1980; Maneva, 2007). Regression analysis was used to describe the functional dependence of Pf, plant height and the potato yield losses depending on the respective independent factor. The equation (1) showed the best fit to more of the analyzed data. The dependence of Pf on Pi was described by the model (2). The Distance Weighted Last Square (DWLS) dependency was found between R and Pi.

$$Y = A_1 + A_2 lg (X+I) \quad (1)$$

$$Y = A_2 X \quad (2)$$

where Ai, i = 1, 2 is the model parameters, Y is the respective dependent variable (potato yield, plant height, Pf, R), X is respective independent variable (Pi, plant weight, Pf) and I is the corrector of the curve slope. The statistical estimation of model's fit to the data was performed by the software Statistic 5.0

Results and Discussion

Population development

The final population density at 90[th] day after inoculation (Pf) increased with increase of Pi and is statistically different at Pi ≥ 4 J_2/cm^3 ($P < 0.001$, Table 1, A). Duncan's test grouped all variants with Pi < 4 J_2/cm^3 in a group, and cause separate groups of Pf for every Pi > 4.

All calculated Ri were statistically different compared to control ($P < 0.001$, Table 1, B). According Duncan's test Ri calculated for Pi within (0.1; 0.5) as well as (8; 32) J_2/cm^3 belonged to two different groups, whereas the remaining Ri formed their own groups. The highest Ri was determined at Pi = 4.0 J_2/cm^3 soil. Increasing of Pi of *G. rostochiensis* when Pi < 4.0 J_2/cm^3 increases Ri since Pi > 4.0 decrease Ri, which suggest a intraspecies competition.

There was a good positive correlation between Pf and Pi (r = 0.994, $P < 0.001$, Table 2) which is why the linear regression model with free parameter $A_1 = 0$ fitted the best to the data (R = 0.983, $P < 0.001$; Figure 1, Table 3). There was not well-expressed linear correlation between Ri and Pi (Table 2). The regression analysis showed that DWLS presented the best functional dependence of Ri on Pi (Figure 2). The obtained model predicted that the initial density of *G. rostochiensis* within (20; 36) J_2/cm^3 would cause the highest population reproductivity. For Pi > 64 J_2/cm^3 Ri remained constant but significantly different than the control.

Potato plants growth

After 90 days the symptoms of nematode attack appeared in all pots. Thereafter symptoms become progressively more evident in order of increasing initial density. Increased initial

Table 1
Final number of juveniles and eggs in cm3 soil (Pf) and the Reproductive index (Ri) related with increase of Initial population density (Pi) of G. rostochiensis – significance of mean differences and Duncun's clustering

Initial populat. number of J2/cm3 soil, Pi	A: Final number of J2 and eggs in cm^3 soil (Pf)			B: Reproductive index (Ri) R = Pf/Pi		
	Aver. number of J2 and eggs in cm^3 soil ± Sd of mean	Stat. sign.of the mean diff. and Duncun's		Aver. number of cysts in cm^3 soil ± Sd of mean	Stat. sign.of the mean diff. and Duncun's	
0	0	C	a	0	C	a
0.1	0.75 ± 0.96	NS	a	4.75 ± 0.50	***	b
0.2	1.50 ± 0.58	NS	a	5.00 ± 0.00	***	b
0.5	2.00 ± 0.00	NS	a	4.50 ± 0.47	***	b
1	12.50 ± 3.78	NS	a	12.50 ± 0.89	***	c
2	35.50 ± 4.43	NS	a	19.50 ± 1.29	***	e
4	109.20 ± 6.50	***	b	27.00 ± 2.16	***	g
8	184.20 ± 4.19	***	c	24.00 ± 0.82	***	f
16	307.50 ±78.05	***	d	22.75 ± 0.96	***	f
32	674.70 ±18.89	***	e	22.25 ± 0.50	***	f
64	1211.00±98.54	***	f	17.25 ± 1.71	***	d
128	2070.00±47.61	***	g	18.00 ± 0.82	***	d, e
Test	statistics:					
F =	1130.96			213.55		
Sd =	25.86			0.884		
LSD0.05	52.5			1.794		

C – not infected control, NS – not statistical significant difference, *** - P<0.001

Table 2
Plant height (cm) and the yield related with increase of Initial population density (Pi) of G. rostochiensis – significance of mean differences and Duncun's clustering

Initial populat. numberof J2/cm^3 soil, Pi	A: Plant height, cm			B: Yeld, g/pot		
	Average ± Sd of mean	Significance of mean diff. and Duncun's		Avererage yield ± Sd of mean	Significance of mean diff. and Duncun's	
0	34.50 ± 1.29	C	a	160.70 ± 2.50	C	a
0.1	34.24 ± 1.71	NS	a	149.20 ± 2.50	***	c
0.2	32.24 ± 0.96	NS	b	150.50 ± 1.29	***	b, c
4	18.00 ± 0.82	***	c	85.25 ± 5.38	***	f
8	15.00 ± 0.82	***	d	69.25 ± 0.96	***	g
16	12.50 ± 1.29	***	e	45.00 ± 2.16	***	h
32	13.50 ± 1.29	***	d,e	31.75 ± 1.71	***	i
64	10.50 ± 1.29	***	f	21.75 ± 1.71	***	j
128	9.00 ± 0.82	***	f	14.50 ± 1.41	***	k
Test			statistics:			
F =	363.45			2415.55		
Sd =	0.908			1.639		
LSD0.05	2.3			3.329		

C – not inoculated control, NS – not statistical significant difference, *** - P<0.001

Table 3
Correlations between observed factors – Initial population density of G. rostochiensis (Pi), Final population density (Pf), Reproductive index (R) plant height (cm) and yield (g/pot). i – independent factor, j – dependent factor

rij j → / i ↓	Initil pop. Density (Pi)	Final pop. Density (Pf)	Reproductive index (R)	Plant height, cm	Yield, g/pot3
Pi	1	0.994 ***	0.571 *	-0.682 **	-0.734 ***
Pf		1		-0.411 NS	-0.798 ***
R			1	-0.764 ***	-0.745 ***
Plant height				1	0.974 ***

NS – statistically no significant, * - P<0.05, ** - P<0.01, *** - P<0.001

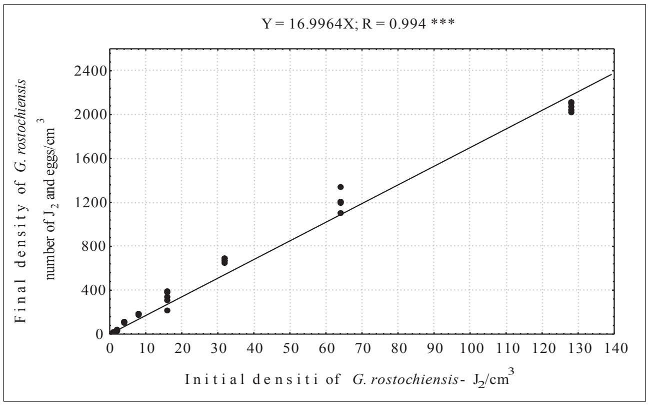

Fig. 1. Functional dependence of final population density of *G. rostochiensis* (number of J_2 and eggs/cm^3 soil) on the initial population density (number of second stage juveniles/cm^3 soil)

Fig. 2. Functional dependence of productive ratio of *G. rostochiensis* (Ri =Pf/Pi) on the Pi

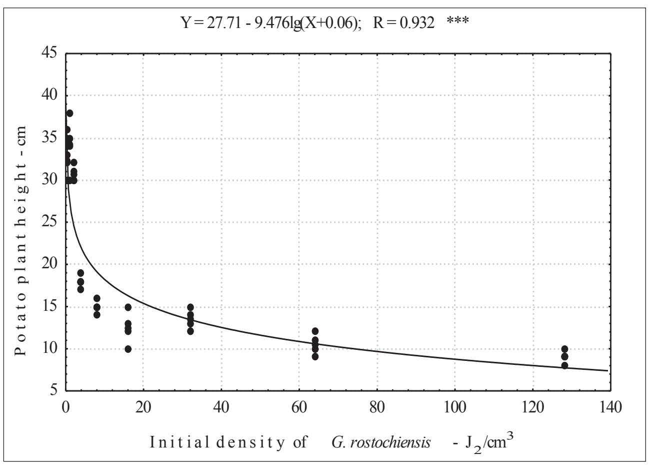

Fig. 3. Functional dependence of potato plant height (cm) on the initial density (Pi) of *G. rostochiensis* (number of second stage juveniles/cm^3 soil)

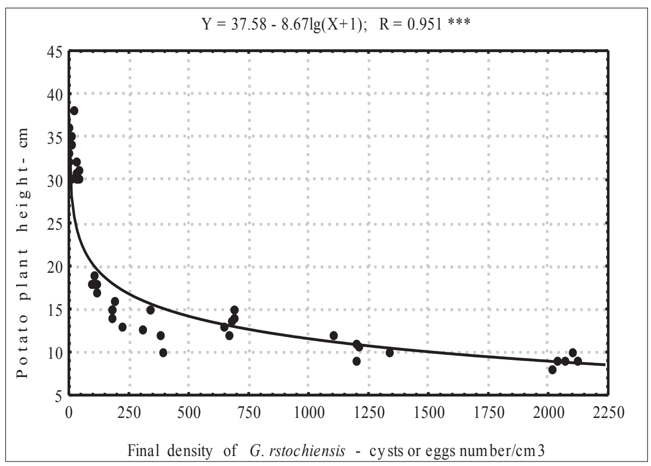

Fig. 4. Functional dependence of potato plant height (cm) on final population density (Pf) of *G. rostochiensis* (number of J_2 and eggs/cm^3 soil)

population of *G. rostochiensis* in the soil had direct effect in decreasing of plant growth. Statistically significant reduction of the plant height compared to control appeared at Pi ≥ 2.0 (Table 2, A). Pi = 4.0 J_2/cm^3 soils caused 47.8% reduction of plant height which reached to 73% at the highest initial inoculum level of 128 J_2/cm^3 soil. The Pi within (0; 1) J_2/cm^3 had similar effect on the plant height and variants belonged to one group (Table 2, A). Plant height correlated negatively with the investigated impact factors Pi, Pf and Ri as the best correlation was found with Ri and Pi (Table 3). The obtained models showed that the initial nematode density Pi < 0.4 (Pf < 109, respectively) does not have a strong effect on plant growth. However, Pi (respectively of Pf) higher than these values has significant influence on the potato plants growth (Figure 3 and Figure 4, Table 4). The experimental data showed that the plant height was 50% reduced at Pi = 4 J_2/cm^3 soil, since the model prediction is that it will appear at Pi = 1 J_2/cm^3 soil.

Potato yield

Yield loss was significantly different from the control even at the lowest Pi = 0.1 J_2/cm^3 soil (P < 0.05, Table 2, B). The reduction of yield measured up 46.2% and 87.6% at Pi = 4 and 128 juveniles/cm^3 soil respectively, which correspond to Pf of 109 and 2070 juveniles and eggs in cm^3 soil. Every one of the investigated Pi determined the yield in a separate group (Table 2, B), which again showed that the impact of Pi is too strong, and even a small increase of Pi causes significant decrease in potato yield. It was estimated that for every one nematode increase there was a loss in tubers at 2 to 24 g/plant. The tolerance limit (T) of potato to *G. rostochiensis* was between 0.5 and 1 juvelines/cm^3 soil. At population densities greater than T, yield was greatly suppressed. The yield correlated negatively with Pi, Pf and Ri and showed a positive correlation with plant height at a very high level (P < 0.001, Table 3). Equation (1) showed good fit to the yield data when the predictors were Pi, and Pf (P < 0.001, Figures 5, 6 and 7, Table 4). The influence of the Pi and Pf is stronger in the lower nematode densities (Pi < 4 J_2/cm^3 soil, J_2 and eggs/cm^3 soil Pf < 109) and this effect was decreased when Pi and Pf were higher than these values. This is in agreement with the modeling estimation of Ri and was a good base for an interspecies competition assumption. The experimental data showed that there was 13.7% yield reduction at Pi = 1 J^2/cm^3 soil. The model predicted that it could occur at Pi = 0.5 J_2/cm^3 soil.

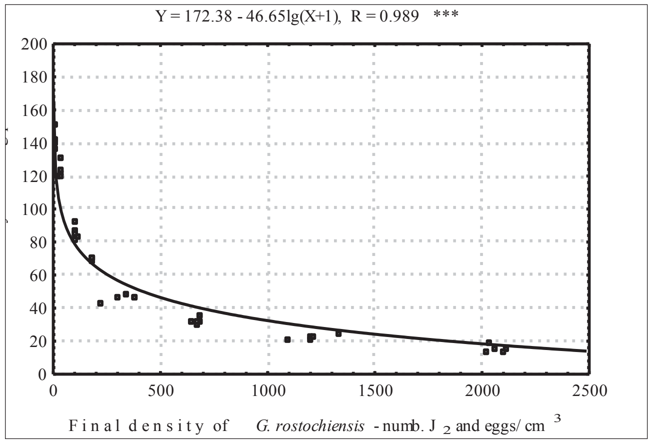

Fig. 6. Functionaal dependence of potato yield (g/pot) on the final population density (Pf) of *G. rostochiensis* (number of J_2 and eggs/cm³ soil)

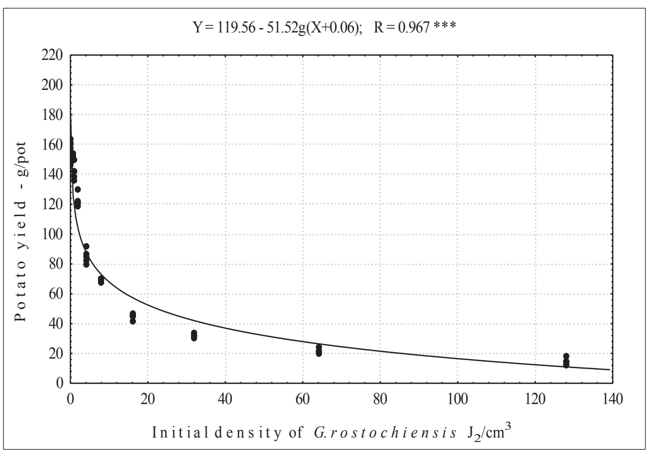

Fig. 5. Functionaal dependence of potato yield (g/pot) of the initial population density (Pi) of *G. rostochiensis* (numbers of second stage juveniles/cm³ soil)

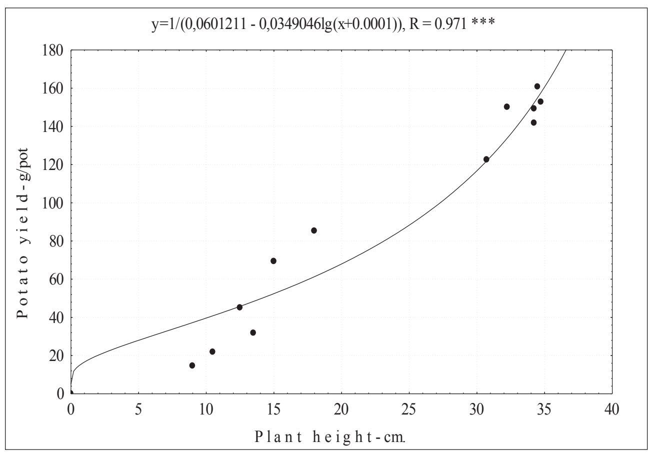

Fig. 7. Functional dependence of potato yield (g/pot) on the plant height (cm)

Discussion

The leaf symptoms (stunting and yellowing) associated with nematode attack commonly appear late in the season and can be misrepresented as being a normal characteristic of an early maturing potato cultivar. To predict yield losses associated with *G. rostochiensis* it is necessary to determine the nematode population density in the soil before planting rather than by visual observation of leaf symptoms and plant growth (Greco and Moreno, 1992). The final densities severity increases with increasing of inoculum level of *G. rostochiensis.* That is confirming the high damage potential of the nematode and its reproduction capacity. Even that increasing of Pi cause Pf increase, Ri increases till Pi < 4.0 J_2/cm^3 soil and for Pi ≥ 4.0 decrease. This might be due to competition for food and space in high inoculum levels. The root system remains relatively smaller and thinner which means that it cannot provide enough root area for larvae feeding (Phillis, 1991). In the present study the pathogenic level for *G. rostochiensis* to affect the growth of potato was 2 J_2/cm^3 soil which is in accordance with the earlier findings of Helmut and Gerhard (1974). They reported that the tolerance limit for late species of potatoes is equal to 300 larvae in 100 g soil. In our study the potato yield was significantly reduced even at the lowest Pi = 0.1 J^2/cm^3, which showed a great effect of *G. rostochiensis* on potato growth and yield. Damage caused by low population densities of *G. rostochiensis* has also been observed in Germany (Helmut and Gerhard, 1974). Jimenez et al. (2000) reported that tuber yield response to Pi fitted the model: $y = m + (1\text{-}m)\, zPi$, and a tolerance limit (T) of potato to *G. rostochiensis* of 0.5 eggs/cm^3 soil was derived, when the hosts were potato plants cv. Kennebec. This was confirmed by our investigation, carried out with potato plants cv. Nadejda. In our experiment the reproductive rate of the nematode was increased threefold at Pi = 1 J_2/cm^3 soil, which was much less than that reported in Italy (Greco et al., 1982) and in the spring potato in Chile (Greco and Moreno, 1992), but larger than that occurring in the early to late winter potato in Chile Accordingly, it is clear that the earlier and more precise predicting of potential yield loss is very important.

Potato cysts nematodes are particularly suitable for analyzing by mathematical models because they have only one generation per year, potato is their only field host and the juvenile nematodes within the egg are very durable (Trugill et al., 1996). Moxnes and Hausken (2007) also reported that mathematical description for the population dynamics of the parasite potato cyst nematodes could provide realistic predictions. Hajihassani et al. (2013) reported that the best fitting models for predicting of potato yield loss depending on initial nematode population density were Exponential fit (EF), Logistic model (LM), Monomolecular model (MM), Rational function (RF) and Harris model (HM). The obtained models in our study confirmed this. The relation between Pi and Pf has found to be linear and DWLS regression described the dependence of Ri on the Pi. The linear regression with lg(X+I) transformation of the predictors has been used to model the Pi and Pf effect on both, potato height and yield. All solute models had a coefficient R close to1.00 and the statistically good parameters of the models at level of significance P < 0.001 (Table 4). The good fit of the models to the data showed a well expressed functional dependence of the nematode development, potato growth and yield on the initial and final density of *G. rostochiensi.* The models improved the subjective estimation, describing the common trends of the processes. The model predicted that an interspecies competition appeared after Pi = 2 and the nematode population interspecies competitive abilities decreased significantly if Pi > 4 J^2/cm^3 soil. According Jimenez et al. (2000) model estimation, 50% and minimum yield appeared at Pi = 32 and 256 egss/cm^3 soil respectively. In our study the minimal potato yield was found out at the same Pi but the 50% yield loss occurred for Pi = 4 J_2/cm^3 soil.

Conclusions

Differences in environmental conditions, length of the potato growth cycle and differences in the cultivars may reflect on differences in the reproduction rates of the nematode. Results of our experiment showed that the potato plants development and its yield strongly depend on the initial density of the population of *Globodera rostochiensis,* a fact confirmed of many other authors. To provide suitable management strategies for potato cyst nematodes, information is required on the extent of damage they cause on a regional basis. Mathematical models developed in this article provided a useful tool for predicting yield losses from knowledge of the nematode population at planting and which could be a better basis for control measures.

References

Clarc, A. I. and R. N. Perry, 1997. Hatching of cyst nematodes. *Nematol.*, **23**: 350-368.

EC Listed Pests, 2003. http://www.defra.gov.uk/planth/pestpics/qic2004/QIC65.pdf

Elston, D. A., M. S. Phillips and D. L. Trudgill, 1991. The relationship between initial population density ofpotato cyst nematode *Globodera pallida* and the yield of partially resistant potatoes. *Revue Nénlatol.*, **14** (2): 221-229.

Europian Commission, 2004. DE(SANCO)/7320. Final Report on a Mission Carried out in the Republic of Bulgaria. http://ec.europa.eu/food/fs/inspections/pi/reports/bulgaria/pi_rep_bulg_7302-004en.pdf

Di Vito, M., B. Parisi and F. Catalano, 2004. Effect of population densities of *Meloidogine incognita* on common bean. *Nematol. Mediter*., **32**: 81-85.

Di Vito, M., A. M. Simeone and F. Catalano, 2005. Effect of the root-knot nematode *Meloidogine javanica* on the growth of a peach (*Prunus persica*) rootstock in pots. *Nematol. Mediter*., **33**: 87-90.

Ferris, H., 1985. Density dependent nematode seasonal multiplication rates and over winter survivorship. A critical point model, *J. Nematol*., **17**: 93-100.

Greco, N. and I. Moreno, 1992. Influence of *Globodera rostochiensis* on yield of sumer, winter and spring sown potato in Chile. *Nematropica,* **22**: 165-173.

Greco, N., M. di Vito, A. Brandonisio, I. Giordano and G. De Marinis, 1982. The effect of *Globodera pallida* and *G. rostochiensis* on potato yield. *Nematol.,* **28**: 379-386.

Hajihassani, A., E. Ebrahinian and M. Hajihasani1, 2013. Estimation of Yield Damage in Potato Caused by Iranian Population of *Globodera rostochiensis* with and without Aldicarb under Greenhouse Conditions. *Int. J. Agric. and Biol*., **15**: 352-356.

Haydock, P. P. J. and K. Evans, 2000. Potato cyst nematodes – a serious problem for the UK potato industry. In: BCPC Conference Pest and Diseases, Brighton, UK. Proc., **3**: 901-906 (abstract).

Helmut, S. and M. Gerhard, 1974. Uber die Auswirkungen unterschiedlicher boden-versenchungen mit *Heterodera rostochiensis* Woll auf Wachctum and Ertrag einer spatreifenden Kartofelsorte. *Archii fur Phytopatol. Pflanz.,* **10**: 35-42.

Jimenez, N., R. Crozzoli and N. Greco, 2000. Effect of *Globodera rostochiensis* on the yield of potato in Venezuela. *Nematol. Mediterr.,* **28**: 295-299 (abstract).

Khanna, A. S. and J. Jyot, 2004. Pathogenicity of *Meloidogine incognita* on Dinathus caryophillus. *Nematol. Mediterr.,* **32**: 125-126.

Maneva, S., 2007. Mathematical Models in Plant Protection. *PhD thesis*, pp. 201.

Moxnes, J. F. and K. Hausken, 2007. The population dynamics of potato cyst nematodes. *Ecological Modelling,* **207**: 339-348.

Perry, R. N. and J. Bine, 1989. Effects of certain herbicides on the in vitro hatch of *Globodera rostochiensis* and *Heterodera schachtii*. *Revue de Nematol.,* **12**: 191-196.

Phillis, J. D., 1991. Assessment of potato yield loss caused by potato cyst nematode *Globodera rostochiensis*. *Nematol. Mediterr.*, **19**: 345-347.

Schomaker, C. H. and T. H. Been, 1999. A model for infestation foci of potato cyst nematode *Globodera rostochiensis* and *G. pallida*. *Nematol.,* **89**: 583-590.

Sokal, R. R. and F. J. Rohlf, 1980. Biometry. *Freemen and Company*, San Francisco, 859 pp.

Sounthey, Y. F., 1986. Laboratory Methods for Work with Plant and Soil Nematodes. *London Ministry of Agriculture, Ficheries and Food*, Her Majesty Stationary Office, 148 pp.

Stoyanov, D. and Z. Trifonova, 1994. Potato cyst nematode. *Plant Protect.,* **35**: 18-19.

Takeshi, T., 1999. Ecology of the potato cyst nematode, *Globodera rostochiensis.* Nagasaki Prefecture, 3. Relationship Between Preplant Egg Density of *Globodera rostochiensis* and Amount of Infestation and Tuber Yield. In: *Proc. of the Assoc. for Plant Protect. of Kyushu*, **42**: 72-75.

Trifonova, Zl., 1995. Use of some systemic nematocides for controlling potato cyst nematode *Globodera rostochiensis*. *Bulg. J. Agric. Sci.,* **1**: 433-438.

Trifonova, Zl., 2000. Distribution of *Globodera rostochiensis* in Bulgaria. *Macedonian Agric. Review,* **47**: 63-64.

Trudgill, D. L., M. S. Phillips and C. A. Hackett., 1996. The base of predictive modelling for estimating yield loss and planning potato cyst nematode management. *Pestic. Sci.,* **47**: 89-94.

Trudgill, D. L. and M. S. Phillips, 1997. Nematode population dinamics, threshold levels and estimation of crop losses. Plant Nematode Problems and Their Control in Near East Region, FAO Production and Protection Pappers – 144. http://www.fao.org/docrep/v9978e/v9978e07.htm

Trudgill, D. L., 2008. Yield losses caused by potato cyst nematodes: a review of the current possition in britan and prospects for improvement. *Annals of Appl. Biol.,* **1**: 181-198 (on-line).

Turner, S. and K. Evans, 1998. The origin, global distribution and biology of potato cyst nematodes (*Globodera rostochiensis* Woll and *G. pallida* Stone). In: R. Y. Marks and B. B. Brodie (Eds.) Potato Cyst Nematodes, Biology, Distribution and Control. *CAB International*, Wollingford, UK.

Uehara, T., A. Kushida, K. Itou, T. Narabu and Y. Momota, 2005. Discrimination of three cyst-forming nematodes of the genus *Globodera* (Nematode: Heteroderidae) from Japan based on PCR-RFLP of ribosomal DNA. *Appl. Entom. and Zool*.**, 40: 537-543.**

Urek, G., S. Sirca, S. Geric, P. Dolnicar and P. Strajnar, 2007. The influence of potato cyst nematode *G. rostochiensis* infestation on different potato cultivars. *J. Central Europ Agric.,* **9**: 71-76.

Received February, 2, 2015; accepted for printing May, 22, 2015