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Feasibility to Neutralize Replant Disease under the Recultivation of an Apple Orchard

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ABSTRACT

Background: It is expedient to reduce or remove a negative effect of replant disease on new plantations after the old uprooted ones. To solve this problem, it is necessary to carry out the direct researches aimed at identifying the reasons for a negative effect of toxic soil conditions on young fruit plantations.

Methods: A vegetative trial, aimed at studying the effect of replant disease on the planted young apple trees after the uprooting of a 34-year-old apple plantation which was grown on the plots after a 50-year-old experimental orchard with apple fertilization systems, was established in spring of 2019.

Result: It has been found out in a vegetative trial that the growth of young apple trees weakens considerably in the first two years after planting one-year-old trees. The neutralization of replant disease, when dark grey opodzolic heavy loam soil was fertilized with manure, took place due to enriching it with organic substances. As a result, all the indicators of soil fertility increased and different bio-toxic compounds, which had a negative effect on mineral nutrition of young fruit plants, on their growth process and fruiting, neutralized faster and more intensively.

Key words: Apple tree, Champion, Phyto-mass, Replant disease, Replant site, Roots.

INTRODUCTION

There is a certain increase in the negative response of re-planted weak cultivars on dwarf rootstock, as their root system is in superficial soil layers where the main mass of the roots of the previous trees was. In these conditions, with low initial yield capacity, no return on investment, made when the orchard was planted, takes place. Hence, more and more attention is paid to the overcoming of replant disease both in scientific research and production sphere (Yakovenko and Melnyk, 2015; Melnyk and Yakovenko; 2017; Henfrey and Baab, 2013; Wiedmer and Thalheimer, 2013; Moroz, 1990; Yakovenko *et al.*, 2020). The necessity to re-plant new industrial fruit plantations on the site of the uprooted old ones predetermines a more detailed studying of replant disease and the ways to overcome it or at least reduce its negative effect on young newly planted plants.

The land sites from which old plantations were removed undergo significant changes. This is predetermined by abiotic (the reduction of humus content, nutrition elements, the worsening of water-physical properties, the change in a soil environment reaction and its pollution with toxic chemical substances, *etc.*) and biotic factors (the accumulation of harmful micro-organisms, in particular nematodes). Alongside with this, there is a statement that the products of tree vital activity, so called root discharges (phyto-toxins), are accumulated in large amount in the soil after the orchard is uprooted, as well as a large number of roots which decompose after uprooting (Yakovenko and Melnyk, 2015; Sedov, 2005; Yao *et al.*, 2006; Szczygiei and Zepp, 1998; Sedov *et al.*, 1997; Hoestra, 1994; Vliegen-Verschure, 2013; Grodzinskiy *et al.*, 1978; Rutkowski *et al.*, 2000; Benizri *et al.*, 2005; Azher *et al.*, 2020; Singh *et al.*, 2019).

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The research conducted by (Henfrey and Baab, 2013) has proved that cultivars and rootstock respond differently to replant disease. For instance, trees of cultivar Jonagold suffered less than those of cultivar Braeburn.

They were higher by three times in a fresh soil than those which were re-planted. This refers to rootstock as well. Trees on rootstock PB 9 in a fresh soil showed a weaker growth than those on M9 and in replant site trees on rootstock PB 9 had a stronger growth. A similar relation was recorded in the studies conducted in Moldova (Fulga and Dadu, 1991), there it was established that tress on rootstock M 27 reacted more strongly to replant disease than those on MM106.

The studies conducted by (Fulga and Dadu, 1983) confirmed that in the site of an uprooted 30-year-old orchard a smaller increase of trunk thickness-by 20%, as compared with those which were grown on the plots of field crop rotation and a summary increase of shoots-by 10-20% were seen in the first year after planting. In the following years the effect of replant disease on growth indicators increased.

Zydlik, Z. (2017) found out in the research that a harmful effect of replant disease in new quarters of the orchard, replanted after uprooted old plantations, was higher in the places where, according to her statements, more optimal conditions for tree growth and development were created. According to the author, optimal conditions in the orchard had a positive effect on the development of harmful micro-flora and nematodes, which is why tree growth and development were inhibited.

One of the efficient ways which can reduce a negative effect of replant disease on young plants is rational fertilization, namely enriching the soil with an organic substance (Szczygiei, 2003, Yakovenko and Kopytko, 2007). Combined fertilization-organic fertilizers and nitrogen-has a positive effect on the activity of soil microorganisms (Styła and Sawicka (2004); Zydlik and Pacholak, 2004).

Another opinion concerning the effect of mineral fertilizers on the weakening of replant disease is supported by (Sedov *et al.*, 1997). In the research conducted by us, the application of high rates of mineral fertilizers on the area after the cultivation of an old orchard did not reduce a negative effect of replant disease which was caused by discharged toxins in the process of decomposition of plan residues and roots after uprooting. Similar statements can be found in other publications which contain the results of the research conducted in various soil-climatic zones (Hudiakov and Marshunova, 1970; Gurin, 2016). However, the authors do not pay attention to the fact that high rates of mineral fertilizers could inhibit microbiological processes in the soil.

In the research, carried out in a long-term trial with different apple fertilization systems at Uman NUH, a positive effect in overcoming replant disease was established when organic and organic-mineral fertilizers were applied (40 t ha^{-1} of manure and 20 t ha^{-1} of manure+$N_{60}P_{60}K_{60}$). In particular, as the researchers confirm, replant disease was lower under replanted apple plantations due to the enhanced biological activity of the soil environment and correspondingly, the neutralization of toxic substances in the orchard soil (Kopytko *et al.*, 2008).

Materials and Methods

A vegetative trial aimed at studying the effect of replant disease on the planted young apple trees was established in spring of 2019. One-year-old apple trees on weak rootstock M.9 T337, cultivar Champion, were planted in cylindrical plastic containers (h-30 cm, d-35 cm). Dark-grey opodzolic soil of the container was taken from the 0-30 cm layer in the uprooted 34-year-old apple orchard (it was grown on the plots of the 50-year-old experimental orchard where apple fertilization systems were applied) and in the nearby field where the orchard was not grown. Each container contained 20 kg of soil. First 5 containers were filled with the soil from the field, they were the control. Other 5 containers were filled with small roots (400 g), taken from the control site during uprooting of the orchard which was not fertilized for 84 years. Next 5 containers were also filled with control unfertilized soil from the orchard with a double quantity of roots (800 g) and 5 containers more-with the orchard soil, taken from the sites which were fertilized with cattle manure (40 t/ha every other year) during a 84-year period and with the roots (426 g in each container).

Thus, a vegetative trial included 4 variants in 5 replications: 1) soil from the field (control); 2) unfertilized soil from the orchard with a single quantity of roots; 3) unfertilized soil from the orchard with a double quantity of roots; 4) soil fertilized with manure with a single quantity of roots. The last variant had the most fertile soil by all indicators (physical, biological and agro-chemical) which was proved by many years of the research in a long-term trial with fertilization systems of the apple orchard.

When young apple trees were grown in vegetative containers, placed in a soil layer at 30 cm depth, during two seasons of 2019 and 2020, soil moisture at 70-80% WHC was maintained with help of periodic watering.

The establishment of a trial and the measurement of the increase of vegetative organs (trunk diameter, length of one-year-old shoots, leaf size) and fruiting record and mass determination of the parts of experimental plants-all this was done according to appropriate technique (Moiseichenko, 1993; Yeshchenko *et al.*, 2014; Kondratenko and Bublyk, 1996).

Results and Discussion

Agrochemical indicators of soil

When a vegetative trial was established, dark grey opodzolic soil in various variants was characterized with different indicators of soil fertility (Table 1).

The content of organic substances was the highest in the orchard of the first (50 years) and the second (34 years) generations which was fertilized with manure for a long period of time and their content was similar (lower only by 0.19%) in the soil from the field where no orchard was grown. The unfertilized soil from the uprooted orchard had the lowest content of organic substances (by 1.01 1.02%). The soil in all variants was sufficiently supplied with nitrite nitrogen and labile phosphorus compounds. There were sufficiently enough labile forms of potassium for apple trees in the manure fertilized soil according to the levels defined as a result of many years of the research done. Potassium amount was less (by 59 mg/kg) in the soil from the field and the lowest level (by 84-85 mg/kg less than in the manure fertilized soil) was recorded in the unfertilized soil from the orchard. The most acid reaction of the soil environment was in the unfertilized soil, but generally it was within an optimal range for apple trees. But, as to the microbiological processes in the soil, in particular for nitrification ones, it was more acid in the unfertilized soil and less favorable.

Growth indicators

In the first year (2019) the control variant on the soil from the field had the highest increase of a trunk diameter, it was almost the same on the manure fertilized soil with apple tree roots after uprooted trees, but on the unfertilized soil with a single and double quantity of roots the increase was considerably lower-by 0.4 and 0.5 mm or by 10 and 12% from the control, respectively (Table 2). In the following year the same regularity of trunk thickening was recorded, a total increase of its diameter in the season of 2020 was higher by 0.7-1.9 mm and it was the lowest in the variant with a double quantity of roots in the unfertilized soil in the orchard. However, according to the results of the mathematical evaluation using a disperse method, the last decrease was insignificant, as compared with trunk thickening in the variant with a single (400 g) root quantity in the soil taken from the orchard.

The indicators of the increase of one-year old shoots and those of a leaf surface area differed in a similar way. It is to be stated that the regularities of their changes in some years were not seen in the variants with a single root quantity (400 g) and a double (800 g) quantity in the unfertilized soil from the uprooted old orchard where young apple trees were grown. In general, the growth indicators of vegetative organs of young apple trees did not differ significantly in the variants with a single (400 g) and double root quantity from the orchard (800 g per 20kg of the soil) in both years of growing young trees in a vegetative trial, however in most cases, namely in the first year after planting, a tendency to weaken growth processes was recorded in the unfertilized soil with a larger root quantity.

Phyto-mass balance

Total phyto-mass, in particular the above-ground part (wood and bark) of three-year-old apple trees of cultivar Champion, was larger and in fact the same in the control soil from the field and the field which was fertilized with manure for a long period of time (84 years), when 40 t/ha of manure was applied every other year (Table 3, Fig 1). But their increase was somewhat larger in the first soil (from the field), as when young trees were planted in the control variant, on the average, they were lighter by 15 g (2,7%). This difference in the mass of young trees was due to a larger above-ground part of one-year-old trees as well as their roots which resulted in a better renewal of a root system in the variant with the manure fertilized soil from the orchard.

Generally in the structure of phyto-mass of young apple trees the largest share belonged to wood with bark-46-48%, the smallest one belonged to dry leaves-7-8%, which was similar in all the variants of the trial and there were no significant differences among them. However there was a tendency to reducing a leaf surface area and increasing a root quantity in the unfertilized soil from the orchard, but the reduction of its size was small and insignificant.

Young apple trees began to fruit in the following year after planting one-year-old trees. The largest number of flowers and fruit was in the variant with the manure fertilized soil from the orchard with roots-426 g per 20 kg-5-10 fruit per tree, in the control variant-3 9 fruit and the smallest number of flowers and fruit was in the unfertilized soil from the orchard with roots-400 g per 20 kg-2-5 fruit, with 800 g of roots 3-6 fruit. Accordingly, the average mass of all apples on the tree was the largest in the variant of the manure fertilized soil from the orchard, but it overweighed the fruit mass only by 1 g in the control in the soil from the field. The smallest (by 49 g or by 25%) average mass of fruit dry matter was in the soil from the orchard with a single root quantity (400 g), at a double root quantity (800 g) it was larger and differed from the mass of control fruit in the soil from the field by 34 g (17%), its reduction in both variants was significant as compared with the mass of control fruit.

Thus, replant disease occurred when young apple trees, cv. Champion, were grown in the first two years after planting

Table 1: Content of organic and mineral substances of nutrition and response of soil environment (soil layer-0-30 cm) in a vegetative trial.

Variant	Organic substances (humus)%	$N\text{-}NO_3$	P_2O_5	K_2O	pH
		mg kg^{-1} of soil			
Soil from the field (control)	2.93	40.3	156	198	5.6
Unfertilized soil from the orchard with apple tree roots 400 g per 20 kg	2.10	36.8	119	173	5.3
Unfertilized soil from the orchard with apple tree roots 800 g per 20 kg	2.11	37.1	120	172	5.2
Fertilized soil with manure from the orchard with apple tree roots 426 g per 20 kg	3.12	42.9	193	257	5.5
$LSD_{0,01}$	0.20	2.6	8	11	0.3

Table 2: Growth indicators of three-year-old apple trees, cultivar Champion, calculated per one tree in a vegetative trial.

Variant	Increase of trunk diameter, mm		Increase of one-year old shoots, cm		Leaf surface area, m^2	
	2019	2020	2019	2020	2019	2020
Soil from the field (control)	4.1	5.7	173	305	0.28	0.76
Unfertilized soil from the orchard with apple tree roots 400 g per 20 kg	3.7	5.1	147	257	0.26	0.72
Unfertilized soil from the orchard with apple tree roots800 g per 20 kg	3.6	4.9	139	263	0.24	0.74
Manure fertilized soil with apple tree roots 426 g per 20 kg	3.9	5.8	158	300	0.29	0.77
$LSD_{0,01}$	0.3	0.5	16	25	0.02	0.05

Table 3: Structure of phyto-mass (dry mass) of three-year-old apple trees, cultivar Champion, in a vegetative trial.

Variant	All phyto-mass*		Structure of phyto-mass							
			Wood with bark		Roots		Leaves		Fruit	
	g	%	g	%	g	%	g	%	g	%
Soil from the field (control)	794	100/100	367	46	173	22	56	7	198	25
Unfertilized soil from the orchard with apple tree roots 400 g per 20 kg	698	88/100	319	46	166	24	54	8	149	21
Unfertilized soil from orchard with the apple tree roots 800 g per 20 kg	716	90/100	330	46	169	24	53	7	164	23
Manure fertilized soil the orchard with from apple tree roots 420 g per 20 kg	795	100/100	370	46	172	22	54	7	199	25
$HIP_{0.01}$	36	-	21	-	13	-	4	-	23	-

*In the enumerator there is a percent of all phyto-mass in every variant as compared with control plants in the soil from the field. In the denominator there is a percent of all phyto-mass in every variant to compare a share of phyto-mass of some organs with it.

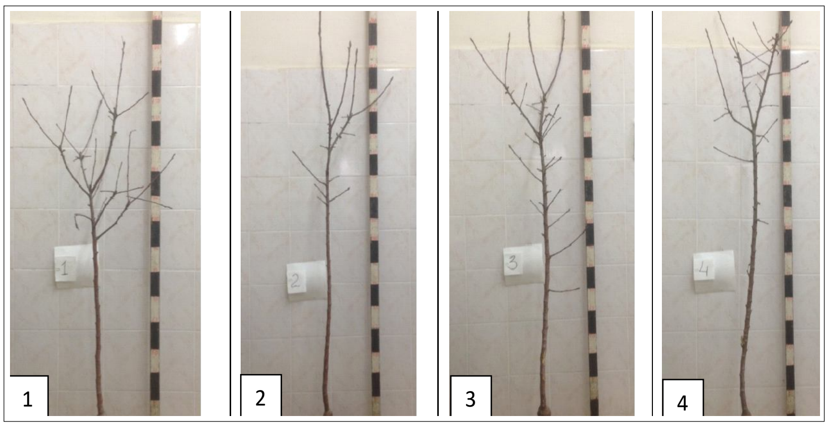

Fig 1: Above-ground part of a three-year-old apple tree, cultivar Champion (2020), grown in a vegetative trial. 1-In the unfertilized soil from the orchard with apple tree roots -400 g per 20 kg; 2-In the unfertilized soil from the orchard with apple tree roots -800 g per 20 kg; 3-In manure fertilized soil from the orchard with apple tree roots 426 g per 20 kg; 4-In the soil from the field (control).

one-year-old trees in the soil from the uprooted apple orchard which resulted in weakening the growth of their vegetative organs (in particular a trunk diameter) and also in reducing fruit mass in the first year of fruiting of three-year-old apple trees. Probably this weakening was not associated with the saturation of the soil with the roots of old uprooted trees, some authors of the corresponding publications support this idea (Szczygiei and Zepp, 1998; Sedov *et al*., 1997; Hoestra, 1994; Vliegen-Verschure, 2013; Grodzinskiy *et al*., 1978), as in the variants with a single root quantity in the soil (400 g or 2% from the soil mass) and a double root quantity (800 g-4%) no significant difference in mass increase of vegetative organs and fruit was recorded.

In industrial conditions when fruit trees are replanted after the uprooting of old plantations, such saturation of the soil with the roots of the old trees does not occur (the research of a fertilization system of apple trees (Kopytko, 1986) proves that the mass of small roots does not exceed 0,02% from the soil mass in the layer 0-40 cm). As a rule, larger roots are removed from the soil in the process of uprooting old trees and before planting new ones. Which is why, minor root remains in the soil of the new fruit plantations in the place of the old uprooted ones can hardly cause replant disease. Most likely it results from some other reasons, namely, the availability of toxic substances in the soil left after a long-term regular intensive application of pesticides to control diseases, pests and weeds in the orchard or when the soil loses other positive properties of soil fertility.

CONCLUSION

It has been found out in a vegetative trial that the growth of young apple trees weakens considerably in the first two years after planting one-year-old trees in the unfertilized (84 years without fertilization) dark grey opodzolic heavy loam soil mixed with their roots (400 and 800 g per 20 kg of soil) from the uprooted old orchard. But this weakening is not explained by a saturation degree of the soil with the roots left, because the growth indicators of vegetative organs and general phyto-mass of the three-year-old apple trees in the corresponding variants do not differ significantly; although in the first year after planting (2019) there is a tendency towards further growth weakening along with the increase in the soil saturation with the roots from the uprooted old apple trees.

The neutralization of replant disease, when dark grey opodzolic heavy loam soil was fertilized with manure, took place due to enriching it with organic substances (by 48.6 and 6.5% as compared with the unfertilized soil from the orchard and from the field, respectively); as a result, all the indicators of soil fertility increased, in particular humus content and biological activity of the soil environment and different bio-toxic compounds, which had a negative effect on mineral nutrition of young fruit plants, on their growth process and fruiting, neutralized faster and more intensively.

Conflict of interest: None.

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