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Influence of various biofertilizers on root growth dynamics in sweet cherry (*Prunus avium* L.) cv. 'Vanda'

Sławomir Głuszek[1], Lidia Sas-Paszt[1], Edyta Derkowska[1], Beata Sumorok[1], Mirosław Sitarek[2]*

[1]Department of Microbiology and Rhizosphere, The National Institute of Horticultural Research, Skierniewice, Poland

[2]Department of Cultivars Testing, Nursery and Genetic Resources, The National Institute of Horticultural Research, Skierniewice, Poland

**Corresponding author: slawomir.gluszek@inhort.pl*

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Abstract: The experiment was established in the Pomological Orchard of The National Institute of Horticultural Research in Skierniewice in a system of randomized blocks. The aim of the experiment was to investigate the impact of innovative organic fertilizers: BioIlsa, BioFeed Ecomix, biostimulator Ausma and mycorrhizal inoculum Mykoflor on the fine roots growth characteristics of 'Vanda' sweet cherry trees in comparison with NPK mineral fertilization. The experiment involved five combinations, in three repetitions of three trees each, treated with tested preparations. The study assessed the influence of fertilization on the lifespan of the roots, the depth of their formation, their diameter and survivorship using minirhizotron camera. The highest numbers of roots were found in the treatment where the plants were fertilized with NPK and the lowest following the use of the biofertilizer BioFeed Ecomix. The longest lifespan was shown by the roots of the trees treated with BioFeed Ecomix – 347 days, and the shortest – by those fertilized with the Ausma – 225 days. The lifespan of the roots increased with their diameter. The roots that lived the longest had a diameter in the range from 0.9 to 1.0 mm – 568 days, and the shortest-living were the roots with a diameter smaller than 0.3 mm – 238 days. The roots that formed in late autumn and winter had the shortest median lifespan of 159 days, while the roots formed in the spring where characterized by the longest lifespan of 300 days. The lifespan of the roots formed close to the soil surface was the shortest – 225 days, while that of the roots formed at a depth of 10 to 20 cm was the longest – 326 days. Biological origin, organic nitrogen rich fertilizers positively influence on fine roots lifespan and longevity. Mineral fertilization increases number of new formed roots.

Keywords: minirhizotrons; organic fertilizers; root lifespan; root longevity; rootstock

The sweet cherry (*Prunus avium* L.) is a fruit crop species grown in Poland both by amateurs and in commercial production (Rozpara et al. 2000, 2004; Rozpara, 2008). According to the statistical yearbook, the area under commercial sweet cherry orchards in 2017 was more than 9.5 thousand hectares, and the fruit harvest in 2016 – more than 53 thousand tons (GUS 2018). The cultivation of sweet cherry in Poland is associated with a risk of frost damage to the trees in winter and damage to the flowers by spring frosts. Therefore, the selection of the right location for the orchard, raised above the surrounding terrain, is essential for achieving success in fruit production (Rozpara 2013). Another problem is diseases, such as bacterial canker (*Pseudomonas syringae pv. syringae* van Hall and *P.s. pv. morsprunorum* Wormald)

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(Sobiczewski, Schollenberger 2002) and pests, e.g. the cherry fruit fly (*Rhagoletis cerasi* L.) (Rozpara et al. 2010) or the spotted-wing drosophila (*Drosophila suzuki* Matsumura) (Łabanowska, Piotrowski 2015), whose larvae feed on the flesh of the fruit.

There are many varieties of sweet cherry grown in Poland, of which only some have been studied to evaluate their suitability for organic agriculture under the country's conditions (Głowacka, Rozpara 2015). One of the varieties gaining in popularity is the cultivar of Czech origin 'Vanda'. In Poland, the trees of this cultivar grow moderately vigorously and bear fruit very abundantly. The fruits are medium sized, weighing up to 8 g, dark red, with red, medium-juicy flesh, little prone to cracking when it is raining. They are very tasty and are used as a dessert fruit and for processing (Grzyb et al. 2008; Stachowiak et al. 2014).

In both the commercial and amateur cultivation of sour cherry, the selection of the rootstock, apart from the cultivar, is also of crucial importance because it determines tree growth vigour and productivity as well as an adequate supply of minerals. A good rootstock for this cultivar, recommended by many authors, is 'GiSelA 5' (*P. cerasus* L. × *P. canescens* L.) (Grzyb et al. 2008; Blažková et al. 2010; Sitarek, Bartosiewicz 2013). Trees grafted onto it grow by about 30–50% less vigorously than on *Prunus avium* seedlings, produce very good crops, and are relatively resistant to pests and diseases (Stehr 2005; Sitarek et al. 2005). It should be noted, however, that if the annual rainfall is less than 450 mm, the trees grafted onto this rootstock require irrigation (Franken-Bembenek 2005).

The growth and yielding of sweet cherry trees are also considerably affected by the cultivation conditions, including fertilization. An important role is played by, for example, the inoculation of the plants with useful microorganisms and the use of balanced organic fertilization. Symbiotic fungi take part in the formation of associations with the roots of most vascular plants, including symbiotic associations with arbuscular mycorrhizal fungi (Smith, Read 2008). They stimulate the uptake of water and minerals from the soil, act as protection against pathogens and pests, increase resistance to abiotic stress, and favourably affect soil productivity under different agronomic conditions (Sofo et al. 2012; Cavagnaro et al. 2015). Their importance in the life and cultivation of horticultural plants has been extensively described (Głuszek et al. 2008). Mycorrhizal fungi, on their own or as part of consortia with other beneficial microorganisms, are increasingly being used in horticultural production due to their favourable impact on the health status of plants, the extent of cropping and quality of the fruit obtained (Malusà et al. 2007; Baum et al. 2015; Rouphael et al. 2015). The sweet cherry is one of the species that form mycorrhizae with arbuscular mycorrhizal fungi (AMF). The use of AM fungi in the cultivation of sweet cherry is common in the production of nursery material propagated *in vitro* and in the acclimatization of micropropagated plants under field conditions (Aka-Kaçar et al. 2010) and in the nursery (Świerczyński, Stachowiak 2012; Grzyb et al. 2015).

In addition to mycorrhization or application of beneficial microorganisms, modern cultivation of sweet cherry trees, in order to improve the growth and fruiting of the trees, also takes advantage of products made from natural raw materials that act as a fertilizer or stimulate the growth of plants by modifying metabolic pathways, called biofertilizers, bioregulators or biostimulants (du Jardin 2015). They are obtained from, for example, sea algae, hydrolyzed waste from animal or plant production, terrestrial plants, or raw by-products of food production (Żurawicz et al. 2006; Battacharyya et al. 2015; Colla et al. 2015). They not only affect the growth of the plants but can also modify the occurrence and activity of soil microorganisms, such as bacteria or mycorrhizal fungi (Sas Paszt et al. 2015).

Balanced fertilization and mycorrhization not only stimulate the development of the aerial parts of plants but also play an important role in the development of the roots. The roots of plants exude organic acids and phenolic compounds that affect the availability and uptake of ions of mineral components in the rhizosphere and the functioning of the soil microbiome (Chaparro et al. 2013). The dynamics of root growth and development in the soil depend on several factors, such as temperature, the presence of water, availability of minerals, and also on the presence of other soil organisms, especially microorganisms (Noguchi et al. 2013; McCormack, Guo 2014; Verbon, Liberman 2016). Root growth can also be affected by insects and soil mesofauna, which are important objects of research conducted with the minirhizotron technique (Joslin, Wolfe 1999).

Studies on the growth of roots of fruit plants are conducted in many scientific centres in the world. Most of them use invasive techniques consisting of damaging the roots taken from the soil in a de-

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structive way (Tracy et al. 2015). One of the non-destructive techniques allowing continuous observation of roots under natural and controlled conditions is the minirhizotron technique. It is widely used to study the root systems of not only plants growing in natural habitats, such as forests, steppes and deserts, but also of agricultural and horticultural crops. The use of this technique in fruit crops has been presented in a review by Głuszek et al. (2013). The minirhizotron technique involves the use of transparent tubes placed in the root zone of plants, outside of which periodic observations are made using a specialist minirhizotron camera. Despite many advantages, this method has some limitations that are the reason why it is not used more extensively (Majdi 1996). Understanding the relationship between the use of biofertilizers and the root lifespan and depth of root formation will allow precise determination of doses of these biofertilizers with regard to the most favourable times of their application in order to ensure effective uptake of minerals by the roots of plants. The aim of the study was to investigate whether there are differences between the dynamics of fine roots development of sweet cherry trees fertilized with innovative organic fertilizers and mineral fertilizers.

MATERIAL AND METHODS

The study was conducted in the Pomological Orchard in Skierniewice (Central Poland, N 51°57', E 20°09') on an existing experiment about the impact of application of biopreparations or mycorrhizal inoculum on sweet cherry trees (*Prunus avium* L.) of the cultivar 'Vanda' grafted on 'GiSelA 5' rootstock. The trees were planted in the spring of 2007 at a spacing of 4.0 m × 2.0 m on graded Class IV soil (medium quality pseudo–podsolic soil), with pH–6.0, 1.3% of organic matter and macroelements content (% DW): 2.37% N, 0.15% P, 1.35% K, 0.22% Mg, 1.64 Ca%. Microelements content in soil was (mg/kg): 3.2 mg/kg of B, 13.5 mg/kg of Cu, 1 084 mg/kg of Fe, 96.6 mg/kg of Mn and 11.8 mg/kg of Zn. The experiment was designed in five treatments with nine trees per treatment, with three replications, each with 3 trees per plot (45 trees in total). Fertilization with organic preparations was compared to the standard mineral fertilization. The orchard was irrigated via a computer-controlled irrigation system. Plant protection against pests and diseases was carried out in accordance with the current Fruit Plant Protection Programme (Hortpress, separated and updated for each year of the experiment). Trees after the second spray against cherry fruit fly (*Rhagoletis cerasii* L.) were covered with a plastic net to protect fruits against birds. After the fruit harvest net was removed from trees. The assessment of the yielding of 'Vanda' sweet cherry trees covered the years 2011, 2013 and 2014. In 2012, spring frosts destroyed all the flowers and the trees did not bear any fruit. The fruits from each plot were harvested by hand and then weighed, determining the yield in kg per tree. Weeds under trees were removed by using glyphosate herbicides: Roundup 360 SL or similar glyphosate based products at 4–5 L/ha in 200–300 L of water, applied directly on weed leaves with tractor sprayer. The sprays were applied in May, July and September. Small weeds adjacent to the tubes are removed manually to avoid potential affecting of the results readings.

The weather conditions (air temperature and precipitation) were showed in Figure 1.

The fertilizers or biopreparations were applied each spring in the following doses for each tree in the treatment:

Mineral fertilizers: ammonium nitrate (35.1 g/tree), granular triple superphosphate (57.3 g/tree), and potassium sulphate (7.7 g/tree) (equivalent of doses 70 kg N/ha, 60 kg P_2O_5/ha, 80 kg K_2O/ha).

Mycorrhizal inoculum – product of MYKOFLOR, Końskowola Poland) – 1 g containing 10^6 propagules of arbuscular mycorrhizal fungi: *Rhizophagus intraradices, R. clarus, Funneliformis mosseae, Claroideoglomus etunicatum*, on an organic carrier (powdered high peat). The inoculum was applied manually to the root system zone of planted trees at the time of establishing the experiment at 200 g per tree, and afterwards 200 g of inoculum to the soil each year in the spring (late April or early May according to weather conditions).

BioIlsa – organic fertilizer produced by ILSA (Italy), containing 12.5% N, applied at a dose of 2.4 g/tree in the spring (late April or early May according to weather conditions).

BioFeed Ecomix – organic fertilizer produced by AgroBio Products (Netherlands), containing NPK 7.5% : 4% : 4%, used at a dose of 100 g/tree in the spring (late April or early May according to weather conditions).

Ausma – organic product based on an extract from the needles of the Scots pine (*Pinus sylvestris* L.), produced by Biolat (Latvia), was applied 3 times by spraying with 0.1% solution 9, 6 and 3 weeks before the anticipated fruit harvest.

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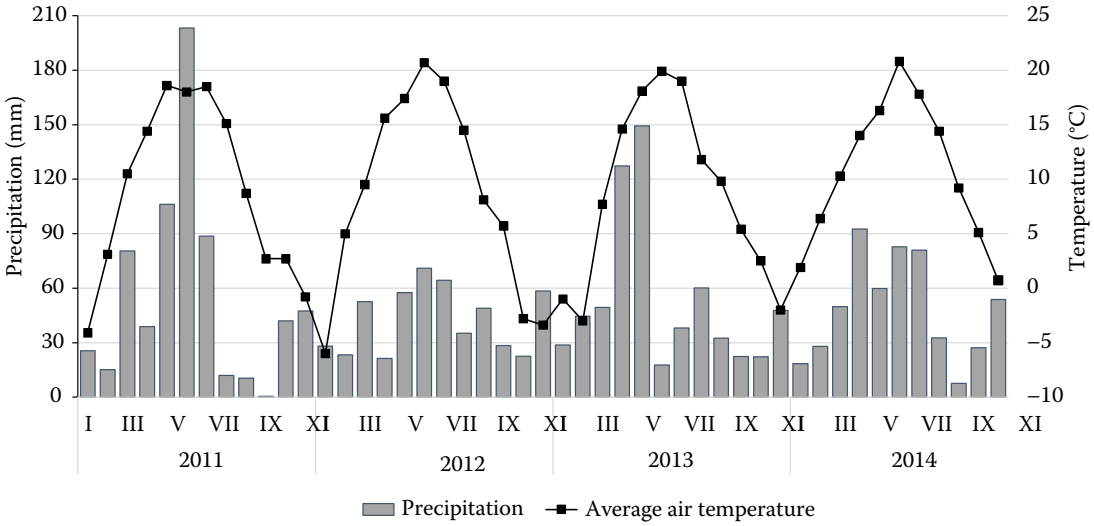

Figure 1. Air temperature and precipitation during experiment period (soil temperature data are not available for experiment period)

Minirhizotron tubes with a length of 1 meter, an outer diameter of 6 cm, and an internal diameter of 5.2 cm were installed under randomly selected trees. one tube on each of 3 replication of each experimental combination in the autumn of 2010. Cores were cut out of the soil profile to a depth of 70 cm with angle of 30 degrees from vertical using a steel cylindrical tube with a length of 2 m and an external diameter of 6 cm installed in a guide made of steel pipe and angle bars. Images of the root systems were taken with a minirhizotron camera BTC100X Minirhizotron Video Microscope (Bartz Technology Corporation, Carpinteria, CA, USA) with an index handle for controlling the camera's position, and a portable microcomputer with dedicated software BTC ICAP, (Bartz Technology Corporation, Carpinteria, CA, US) for recording and managing the obtained images of roots (according to Ferguson, Smucker 1989).

Observations and image recordings of the roots began in March 2011. In each year of the study (2011–2013), observations of the roots were carried out 9 times at monthly intervals from March to November in each growing season. The study extended over three consecutive years (2011–2013 seasons) and included two additional sessions in the spring of 2014 to take into account the winter dying of roots. After the completion of observations, the photographs were manually transferred to another computer, managed and placed in separate folders, according to requirements of the computer program RootFly (Clemson University, Clemson, S.C., USA) used for measurements of root growth parameters such as time of first observation, time of last observation, and directly measured root diameter and length of visible roots fragments in each replication. The program counts root lifespan and saves the root's status data for each measurement session. Depth of root formation was calculated on the base of analysed images vertical size and angle of minirhizotron tune installation using Pythagorean theorem. All observed roots were considered as individuals belonging to one level of a categorical variable (treatment, season) or for the continuous variable (diameter, depth). Each measured root had an associated estimate lifespan, which was automatically calculated as the time between the recorded root appearance and disappearance. The roots observed at the first session (beginning of the study) were excluded from the analysis, nor were the roots still alive (censored roots) in the last analysed session. Median lifespan values for roots of all categories were obtained from the points at which half of the roots originally present had disappeared. RootFly program calibration was conducted with a photo of graph paper placed on minirhizotron tube surface and taken with the camera used in the experiment, as a number of pixels per 10 millimetres.

Obtained raw numerical data (*.csv file) were transferred, imported and managed using Microsoft Excel 2010 software (Microsoft, Redmont,

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Table 1. Influence of bioproducts and mineral fertilization on the lifespan of roots and yielding of 'Vanda' sweet cherry trees (IO Pomological Orchard, 2011, 2013 and 2014)

Treatment	*n*	MLS (days)	Fruit yield (kg per tree)			
			2011	2013	2014	$\bar{X}$
NPK	2 158^{e}	264^{b}	11.34^{a}	12.63^{a}	17.98^{a}	13.98^{a}
Mycorrhizal inoculum	1 992^{d}	283^{c}	15.99^{c}	17.30^{c}	22.79^{b}	18.69^{b}
BioIlsa	1 829^{c}	301^{d}	14.46^{ab}	15.30^{ab}	22.72^{b}	17.49^{b}
BF Ecomix	998^{a}	347^{e}	15.51^{c}	18.38^{c}	22.84^{b}	18.91^{b}
Ausma	1 392^{b}	225^{a}	14.18^{ab}	15.13^{ab}	22.86^{b}	17.39^{b}

n – number of the observed roots in each class; MLS – median lifespan of the observed roots in each class (value calculated); class marked vertically with the same letter, hasn't got significant differences between values compared by Tukey's test; $\bar{X}$ – average yield for 3 years

Washington, US). Statistical analysis was conducted with Statistica 10 software (Statsoft Inc. Tulsa, Oklahoma, US) using Kaplan-Meier methods for the estimation of roots survivor. The Tukey's test was used for testing the general hypothesis concerning of differences among survival curves. The Wilcoxon test with Gehan modification was used to test specific comparisons of the survival functions between each class of the observations. Root lifespan value was calculated as a median value – the point at which half of the roots originally present have disappeared (according to Baddeley and Watson 2005), using life value of all roots in each class of measured parameters included for analysis (described as *n* in tables).

RESULTS

The obtained results indicate that there were significant differences in root median lifespan of visible root numbers between the treatments. Fertilization with the BioFeed Ecomix significantly extended the median lifespan of sweet cherry roots. The number of observed roots was lower for BioFeed Ecomix than of the roots treated with the other biofertilizers. The roots with the shortest median lifespan were the roots of the trees treated with the Ausma and also those treated with mineral NPK fertilizers (225 days and 264 days, respectively). NPK fertilizers had the most favorable influence on the total number of observed roots (2 158 individuals per treatment). Large numbers of them were also observed after the applications of the mycorrhizal substrate and the fertilizer BioIlsa – 1 992 and 1 829, respectively (Table 1, Figure 2). The effect of fertilization on fruit yield was significant only in the case of trees fertilized with mineral fertilizers, where the average yield obtained during experiment period was significantly lower than for the other fertilizer combinations (Table 1).

Depending on depth, the highest number of roots (more than 6 800) were found at a depth corresponding to the typical arable layer extending from 0 to 30 cm. In deeper layers, the number of roots gradually decreased. The roots with the longest median lifespan of 326 days were the roots formed at a depth of 11–20 cm, and with the shortest lifespan – those formed at a depth of less than 10 cm – 225 days (Table 2, Figure 3).

The highest number of the observed sweet cherry roots (6 749 individuals) had a diameter in the range from 0.3 to 0.6 mm. The lowest number of roots was observed in the groups with a diameter of less than 0.3 mm and with a diameter greater than 1 mm – 159

Table 2. Influence of root formation depth on the lifespan of roots (IO Pomological Orchard)

Depth of root formation (cm)	*n*	MLS (days)
0–10	2 682^{e}	225^{a}
11–20	2 582^{d}	326^{c}
21–30	1 575^{c}	286^{b}
31–40	972^{b}	279^{b}
41–50	558^{a}	299^{bc}

n – number of the observed roots in each class; MLS – median lifespan value of the observed roots in each class (value calculated); class marked vertically with the same letter, hasn't got significant differences between values compared by Tukey's test

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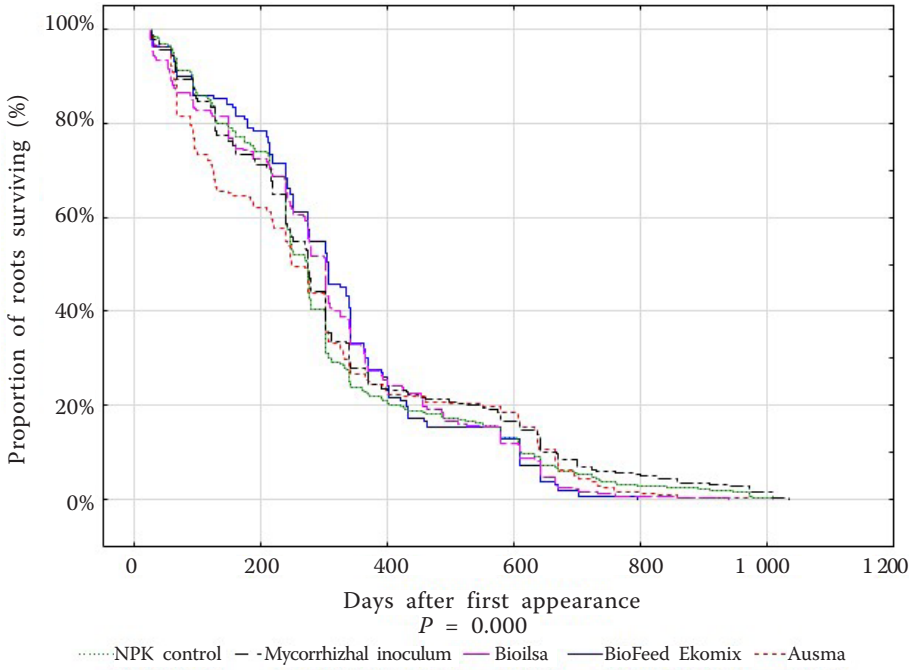

Figure 2. Kaplan-Meier curves of root survival probability after the application of biofertilizers

P – probability c 2 calculated according to the Mantel procedure

and 99, respectively. The median lifespan of the roots increased with their diameter. Roots with a diameter greater than 0.9 mm lived for over one year (approximately 505 days), whereas those that had a diameter of less than 0.3 mm lived for a significantly shorter time (239 days). There are no significant differences between median lifespans of the roots in the range from 0.2 mm to 0.6 mm. Also, for roots with a diameter from 0.7 to 0.9 and with a diameter bigger than 1 mm, differences weren't statistically significant (Table 3). Survivorship estimates are shown in Figure 4.

The roots formed in the spring (April–June) lived longer than those that formed in the other months of the growing season. Their lifespan is estimated to be 315 days. The roots that formed in July, August and early autumn lived an average of 261 days. The shortest median lifespan was recorded in late autumn and winter – 159 and 175 days, respectively

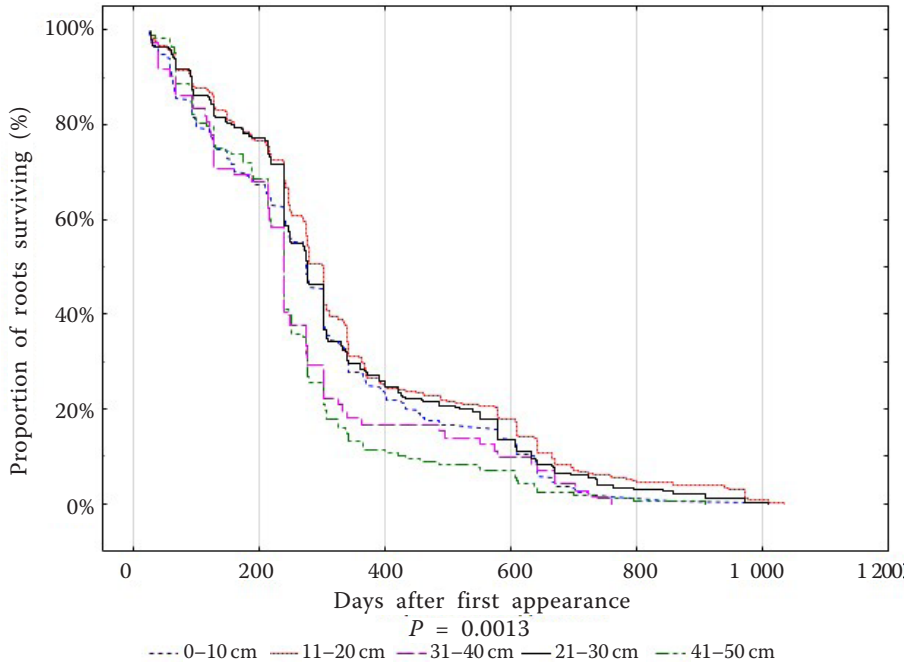

Figure 3. Kaplan-Meier curves of root survival probability for depth groups (cm) in the soil profile. Roots are grouped into depth classes to aid presentation

P – probability c 2 calculated according to the Mantel procedure

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Table 3. Influence of root diameter on the lifespan of roots and yielding of 'Vanda' sweet cherry trees (IO Pomological Orchard)

Root diameter (mm)	*n*	MLS (days)
0.2–0.3	159[c]	239[a]
0.3–0.4	1 633[g]	253[b]
0.4–0.5	3 459[i]	279[c]
0.5–0.6	1 657[h]	277[c]
0.6–0.7	625[f]	303[d]
0.7–0.8	365[e]	340[e]
0.8–0.9	248[d]	374[f]
0.9–1.0	124[b]	568[h]
> 1.00	99[a]	441[g]

n – number of the observed roots in each class; MLS – median lifespan value of the observed roots in each class (value calculated); class marked vertically with the same letter, hasn't got significant differences between values compared by Tukey's test

Table 4. Influence of formation time on the lifespan of roots and yielding of 'Vanda' sweet cherry trees (IO Pomological Orchard)

Month of first observation	*n*	MLS (days)
March	127[b]	159[a]
April	168[d]	337[h]
May	547[f]	303[f]
June	1 729[h]	306[g]
July	3 595[i]	273[e]
August	1 596[g]	251[d]
September	385[e]	275[e]
October	145[c]	245[c]
November	77[a]	175[b]

n – number of the observed roots in each class; MLS – median lifespan value of the observed roots in each class (value calculated; class marked vertically with the same letter, hasn't got significant differences between values compared by Tukey's test

(Table 4). Less than 50 percent of the roots survived over a period of one year (Figure 5).

DISCUSSION

The applied biofertilizers improved the dynamics of growth and development of sweet cherry roots in comparison to NPK mineral fertilization. The survival of the formed roots was influenced by all factors: diameter, the depth at which they were growing in the soil, the time of their formation, and fertilization.

Influence of fertilization on root lifespan. The availability of nutrients in the soil, especially macroelements, affects the development of the root system in different ways. Observations of root growth dynamics carried out in various experiments have shown that the response of plants to fertilization varies from increasing the median root lifespan, through the absence of a marked influence on root length, to the shortening of root lifespan (Pregitzer et al. 1993; Baldi et al. 2010; McCormack, Guo 2014). Addition of readily available forms of nitrogen pro-

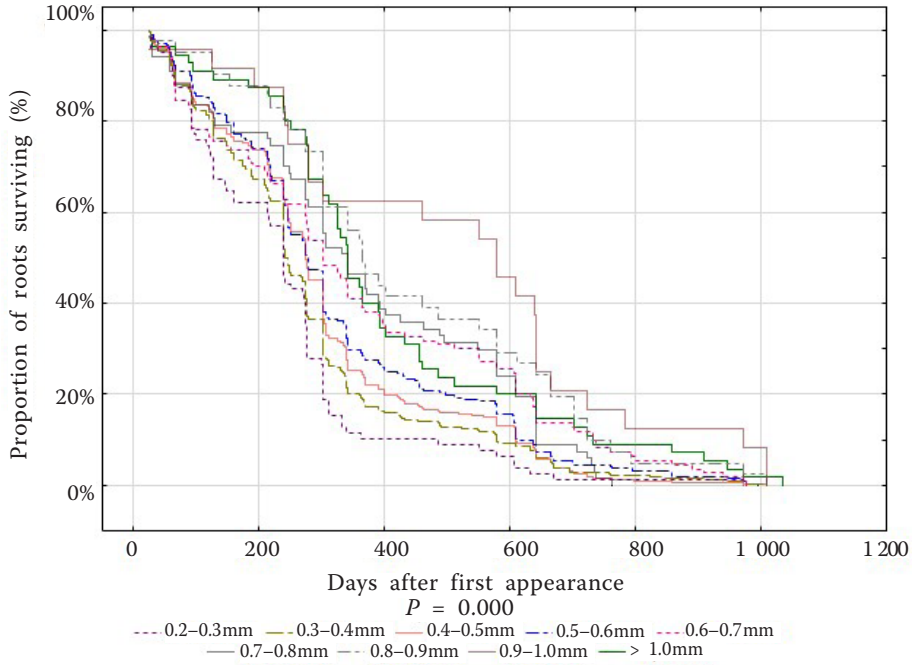

Figure 4. Kaplan-Meier curves of root survival probability for roots belonging to six different diameter classes (mm). Roots are grouped into diameter classes to aid presentation

P – probability c2 estimated according to the Mantel procedure

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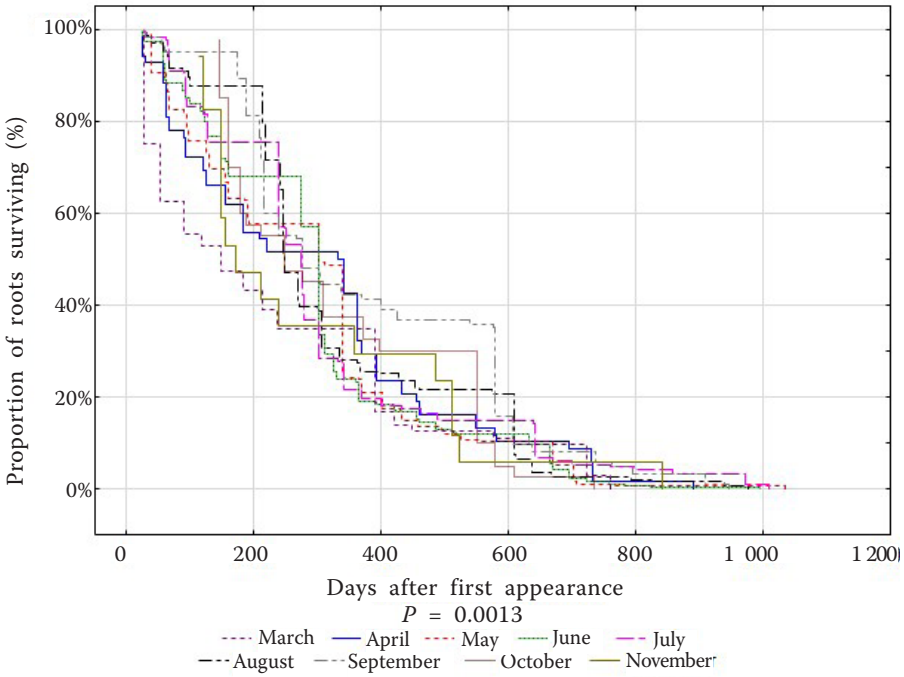

Figure 5. Kaplan-Meier curves of root survival probability for roots first observed in different months

P – probability c 2 estimated according to the Mantel procedure

motes the formation of new roots by the plant and increases the rate of metabolic processes, including root respiration (Ceccon et al. 2016).

High concentrations of nitrate ions in the soil can cause a reduction in the median lifespan of sweet cherry roots in comparison with the roots of plants not fertilized with a mineral nitrogen fertilizer (Artacho, Bonomelli 2016). This phenomenon has also been observed in other species of trees. In the study by King et al. (2002), the observed lifespan of fine and coarse roots of trees grown on a forest plantation of loblolly pine (*Pinus taeda*) was the shortest for the trees fertilized with nitrogen. Peach (*Prunus persica* L.) trees fertilized with compost had a significantly longer median lifespan of fine roots than the trees fertilized with mineral fertilizers and the non-fertilized control trees (Baldi et al. 2010).

Fertilization has a marked influence on the number of roots formed. In our study, the highest number of roots were observed in the combination where the trees were fertilized with NPK, and the lowest where they were formed by the trees fertilized with BioFeed Ecomix. By contrast, Baldi et al. (2010) had observed that peach trees fertilized with mineral fertilizers produced fewer roots than the trees fertilized with compost. In a different experiment, Baldi and Toselli (2013) studied the effect of using compost and cow manure in the cultivation of peach (*Prunus persica* L.) on the growth and survival of the roots of these trees. They found that cow manure increased the formation of new roots in comparison with the roots fertilized with compost. The trees fertilized with compost formed roots mainly at a depth of 21–40 cm, whereas the trees fertilized with cow manure formed roots mainly in the 61–80 cm layer of the soil profile. The lifespan of the roots was longer under the influence of fertilization with cow manure than with compost, and was strongly correlated with the depth of their occurrence.

Root formation time as influenced by the growing season. The time of year is one of the most important factors affecting the dynamics of root development. The most intensive formation of new roots by sweet cherry trees was observed after the fruit harvest, whereas during fruit development and ripening the formation of new roots was weaker (Table 1). The phenomenon of intensive development of new roots after the fruit harvest is explained by the statement that in the genus *Prunus* the formation and ripening of the fruit requires plant metabolites to be directed during this period towards fruit development, and to a smaller extent towards the development of other parts, including the roots (Flore, Layne 1999; Abrisqueta et al. 2008). Similar relationships had been shown by Bonomelli et al. (2012) under the conditions of central Chile. The authors observed a rapid increase in the number of roots formed by sweet cherry trees immediately after harvest, with a more intense growth occurring in the soil mulched with plastic film than in the soil not covered with it.

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The intensity of the post-harvest formation of new roots in sweet cherry is also influenced by the availability of minerals in the soil. Artacho and Bonomelli (2016) observed that the formation of new roots is more extensive in the soil fertilized with a nitrogen fertilizer than in the soil without fertilization. In addition, the authors observed a much weaker formation of new roots and increased mortality of the already formed fine roots during winter. In their view, the dying of roots is dependent on external factors such as temperature and water content in the soil, whereas the formation of new roots is primarily influenced by endogenous factors. The finding that endogenous factors influenced the dynamics of root development in apple trees grafted onto various rootstocks and grown under controlled greenhouse conditions had also been reported by Ma et al. (2013). Their research showed that different combinations of rootstocks, dwarfing interstocks and scions had an influence on the intensive formation of roots at different times. The lifespan of the roots also depended on the time of their formation. Baddeley, Watson (2005), studying wild cherry trees (*Prunus avium* L.), observed that the roots that formed in the spring and summer were characterized by the highest survivorship, whereas those that formed during the winter season had the shortest lifespan. Similar relations were found by Głuszek et al. (2015) while studying the dynamics of root growth and development in four varieties of sour cherry (*Prunus cerasus* L.) grafted onto *Prunus mahaleb* (L.) rootstock. In the case of this rootstock, the roots formed in late spring and summer had the longest, similar, median lifespans, whereas the roots formed during the winter were characterized by the shortest median lifespan. The correlation between root lifespan and the time of root formation has also been observed in other species of fruit plants, e.g. apple [*Malus sylvestris* (L.) Mill. var. *domestica* (Borkh.) Mansf.] (Psarras et al. 2000) and peach (*Prunus avium* L.), which form the lowest number of roots in the winter and during the last stages of fruit development and ripening (Basile et al. 2007). By contrast, Baldi et al. (2010) demonstrated that the roots surviving the longest were those formed in late summer. The longer lifespan of the roots formed in the spring and summer may be associated with the metabolic activity of plants, mainly with the increased transport of assimilates from the shoots to the roots and larger reserves of carbohydrates and other metabolites in the roots during the growing season (Anderson et al. 2003). In a study by Atucha et. al. (2013), the lifespan of avocado (*Persea americana* Mill) roots formed in the spring was by 59–61% longer than of the roots formed in the summer and autumn.

Root lifespan as influenced by root diameter. In the study presented here, it was observed that the roots with a diameter greater than 0.8 mm had the longest median lifespan of 14 months. The roots with a diameter of less than 0.3 mm had the shortest lifespan of just under 8 months. Similarly, other authors have pointed to root diameter as one of the factors determining the survivorship of plant roots (Wells, Eissenstat 2001; Anderson et al. 2003; Baddeley, Watson 2005; Wu et al. 2013). Baddeley and Watson (2005) showed that root diameter was the most important factor in the survival of the roots of wild cherry trees (*Prunus avium* L.). The longest-surviving roots were those with a diameter greater than 0.5 mm, whereas those with a diameter of less than 0.2 mm had the shortest lifespan. Similar relations have been found in sour cherry (*Prunus cerasus* L.). Also, the survivorship of the roots of sour cherry trees grafted onto Mahaleb rootstock varied according to root diameter. The roots with a diameter smaller than 0.2 mm lived for the shortest time, whereas the longest-living were the roots with a diameter greater than 0.75 mm (Głuszek et al. 2015). Similar correlations have been reported for other species of trees of the genus *Prunus* (Wells et al. 2002).

Root survival as influenced by soil depth. The factors that affect the depth of root formation in the soil profile are the temperature and water content of the soil (Bevington, Castle 1985; Kaspar, Bland 1992). For plants grown in the temperate zone, the soil temperature is usually lower in the surface layers of the soil, in which the roots are exposed to high temperatures during the summer and very low temperatures during the winter, especially in the absence of snow cover. In addition, high temperatures of the soil during the summer increase the intensity of metabolic functions in the roots and contribute to their faster growth and withering. On the other hand, low temperatures reduce the intensity of root respiration (Pregitzer et al. 1998), which prolongs the lifespan of roots (McCormack, Guo 2014). In some cases, high temperatures of the soil during the summer are the reason that the highest number of roots are formed in the deeper layers of the soil (Baldi et al. 2010). The study by Atucha et al. (2013) demonstrated that avocado (*Persea americana* Mill) trees formed more roots

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with a larger diameter in the upper layers of the soil (down to 30 cm), whereas a larger number of roots were observed at a depth of 30–60 cm, but with a smaller diameter. In the study by Baddeley and Watson (2005) carried out on wild sweet cherry (*Prunus avium* L), the shortest-living roots formed at a depth of 10 cm, while those that formed at a depth of 20 cm had the longest median lifespan. Roots that formed in the deeper layers of the soil (below 20 cm) lived for a significantly shorter time. Artacho and Bonomelli (2016), in a two-year experiment with the sweet cherry (*Prunus avium* L) cultivar 'Bing' on 'GiSelA 6' rootstock, observed that the roots that formed in the surface layer of the soil (0–25 cm) had the shortest lifespan, whereas the lifespan of the roots that formed at depths below 25 cm was considerably longer. Similar correlations have been reported for other *Prunus* species, like peach (*Prunus persica* L.), whose roots in the shallowest soil layer lived for a very short time (about 3 months) in comparison with the roots that formed at greater depths, which lived for over 7 months (Baldi et al. 2010).

Fruit harvest. Organic fertilization also influenced fruit yield. Flores et al. (2015), in an experiment on 'Lapins' sweet cherry trees after application of a bio-inoculant and organic matter / organic preparations, observed an 8% increase in fruit yield. Beneficial effects of the use of preparations of organic origin on the growth and yielding of fruit plants has also been reported by other authors. Lisek et al. (2016) found that the highest marketable yield of Solaris' grapevines was collected from the vines fertilized with the biopreparation BioIlsa (22.0 kg/vine), mineral fertilizers, manure (21.4 kg/vine) and with the biopreparation BF Ecomix (21.2 kg/vine). The highest yield from 'Regent' grapevines was collected after the combined application of NPK fertilization with manure (22.1 kg/vine), mineral fertilization with BF Ekomix (20.6 kg/vine) and after inoculation with a mycorrhizal substrate (20.0 kg/vine). The combined use of mineral fertilizers and bioproducts stimulated the vegetative growth of plants in both cultivars studied. Filipczak et al. (2016) observed that 'Elkat' strawberry plants were most productive after soil application of the biopreparation BF Ecomix with the addition of phosphate and potassium fertilizers (575 g/plant), NPK mineral fertilization and the biopreparation BioIlsa (530 g/plant). Foliar application of the biopreparation Ausma increased the growth and yielding of strawberry plants in comparison with the control plants.

CONCLUSIONS

The obtained results allow the hypothesis to be made about the influence of the way the sweet cherry trees are fertilized on the number of formed roots and their lifespan in relation to the yield obtained, where easily soluble and deeply migrating artificial fertilizers can force the rapid development of roots, while at the expense of yields, organic fertilizers with a slow release of mineral components will promote a longer root life and thus the plant will not have to produce so much of it and can produce bigger yield. Proving this hypothesis will require further investigation in this regard.

The results can be used to improving the fertilization programs for sweet cherries and other pomological crops trees based on the use of organic and mixed (organic-mineral) fertilizers.

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