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The evaluation of rootstock and management practices to counteract replant disease in an apple orchard

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Abstract: The aim of the research was to evaluate effects of different rootstocks and management practices to counteracting replant disease in an apple orchard. The experiment was conducted in the Experimental Orchard of the National Institute of Horticultural Research in Dąbrowice, Poland, in 2014–2020. Apple trees of the cultivar 'Ligolina' were planted in autumn of 2013 at spacing of 3.8 × 1.4 m in the rows of an apple orchard that had been grubbed up in spring. The following experimental setups were used: (i) two types of rootstocks of different growth vigour (M.9, P14); (ii) replacement of soil in rows of trees with virgin soil; (iii) fertigation with ammonium phosphate; (iv) control (cultivation in the exhausted soil). Replantation significantly limited the growth of apple trees by reducing the cross-sectional area of the tree trunk, and the number and length of annual shoots. Fruit yields of apple trees grown on the replantation site were significantly lower than those of the trees grown in virgin soil. The use of ammonium phosphate fertigation had a positive effect on the growth and yield on the replantation site, especially when it was combined with the use of a stronger-growing rootstock (P14). The most effective environmentally friendly method of eliminating the apple replant disease is the replacement of the exhausted soil with virgin soil, i.e. soil that has not been used for growing fruit trees before.

Keywords: ammonium phosphate, apple orchard, replantation, soil fatigue, virgin soil

INTRODUCTION

The planting of fruit trees in the area of a recently grubbed up orchard, especially trees of the same species, e.g. apple trees, results in their impaired growth, reduced productivity, and even dying off. It may be caused by the so-called replant disease, the etiology of which includes a set of biotic and abiotic factors detrimental to plant growth. Among them are, for example, accumulation of harmful microorganisms in soil, including pathogenic bacteria and fungi, poor soil structure, inappropriate pH, and increased concentration of toxic synthetic and natural substances (Sobiczewski *et al.*, 2009). Intensive fruit and nursery production in recent years means that the importance of replant disease continues to increase, especially in areas where it is not possible to plant trees in the so-called "virgin soil", soil which was not used to grow trees of the same species.

The problem of replant disease in Poland was raised over 30 years ago (Rebandel, 1987; Rebandel and Szczygieł, 1995), but the first publications on this subject in the world literature date back to 1954 (Fritzsche and Vogel, 1954). Despite the many years of research into the causes and methods of mitigating replant disease, it is difficult to directly determine which detrimental factors are present in a given orchard, both in qualitative and quantitative terms. This makes it difficult to decide on the choice of a remedial measure to counteract the disease. The highest effectiveness can be obtained by using synthetic fumigants and other preventive chemicals to disinfect soil (Pacholak, Zydlik and Zachwieja, 2004; Sobiczewski *et al.*, 2014; Sobiczewski *et al.*, 2018). However, a significant limitation may be the high cost of their use, as well as threats they pose to the environment. Chemical agents often eliminate diseases associated with replantation, but they can also reduce soil biological activity, which in turn reduces plant growth and yield (Gur, Luzzati and Katan, 1998). Therefore, more and more attention is paid to the possibilities of using natural resources and measures regarded as broadly understood integrated plant production. The priority goal for this method is to modify the soil environment so that it becomes again conducive to the growth and productivity of plants. Because trees do not grow well on exhausted soils, one of the methods of improving tree growth is the use of an appropriate rootstock (Kruczyńska *et al.*, 1997). A strongly growing rootstock in soils with symptoms of fatigue may have a growth vigour similar to that of a rootstock growing in a virgin soil (Zydlik, 2012). In many cases, this method can be sufficiently effective and its implementation does not generate any additional costs. Some authors describing the problem of soil fatigue (Slykhuis, 1988; Utkhede and Smith, 1993; Utkhede and Smith, 1994) have reported on the action of phosphorus as having a beneficial effect on the development of the root system. In exhausted soils, this element may prove to be a decisive factor for a successful tree growth. The most effective method of counteracting the orchard replant disease is crop rotation, and preferably planting new orchards in soils that have not been previously used for fruit production. Unfortunately, in many regions, sites of this type are not available (Tryngiel-Gać *et al.*, 2015; Sobiczewski *et al.*, 2018).

The aim of the research was to evaluate the effects of different rootstocks and management practices on counteracting replant disease in an apple orchard.

MATERIAL AND METHODS

EXPERIMENT SETUP

The experiment was conducted in the Experimental Orchard of the National Institute of Horticultural Research in Dąbrowice, Poland in 2014–2020 (Sad Doświadczalny Instytutu Ogrodnictwa – Państwowego Instytutu Badawczego, Dąbrowice). Apple trees of the cultivar 'Ligolina' were planted in autumn of 2013 at 3.8 × 1.4 m spacing in the rows of an apple orchard that had been grubbed up in the spring. Tests conducted on 8-week-old 'Antonówka' apple seedlings (unpublished data) showed that the plot was affected by the replant disease, commonly known as "soil fatigue". Uniform mineral fertilisation with NPK 12-11-8 (YaraMila Complex) was applied to the entire plot in the spring, in two split doses of 250 kg·ha^{-1} each. In the first two years after planting, 1/2 and 3/4 of the dose was applied, respectively. Diseases and pests were controlled as they occurred, as recommended by the Integrated Pest Management. A drip line (DripNet PC, Netafim, Israel) was used for irrigation, with emitters spaced every 60 cm, each with a delivery rate of 1.6 dm^3·h^{-1}. Irrigation was applied on the basis of soil moisture measurements performed with capacitive probes, and the frequency of irrigation and amount of water supplied depended on the forecast irrigation needs, as well as the distribution and amount of rainfall.

The following experimental combinations were used:

- two types of rootstocks of different growth vigour – dwarfing rootstock M.9 and vigorously growing rootstock P14; the M.9 rootstock is a typical dwarfing rootstock, currently the most widely used in Europe; apple trees grafted on this rootstock require fertile soils with normal water relations. A major disadvantage of M.9 is the poor rooting of trees (Czynczyk *et al.*, 2002), which in the case of the replant disease may constitute an additional stress and cause trees to die off; P14 is one of the semi-dwarfing rootstocks; its advantages include very good rooting and resistance to environmental stress (Czynczyk *et al.*, 2002);
- replacement of the soil in the rows of trees with a virgin soil not previously used for growing fruit trees;
- fertigation with ammonium phosphate (KRISTA™ mono-ammonium phosphate – MAP NP 12-61) of 24.4 kg·ha^{-1} in 10 split doses administered each year, once a week in the period of May–July. In the first two years after planting, 3/4 of the adopted dose was used;
- control – cultivation in the exhausted (fatigued) soil.

The experiment was set up in a block design, in 3 replications, with 4 trees in each replication, according to the following plan:

- trees grown in virgin soil / rootstock M.9,
- trees grown in virgin soil / rootstock P14,
- trees grown in fatigued soil / rootstock M.9,
- trees grown in fatigued soil / rootstock P14,
- trees grown in fatigued soil fertigated with ammonium phosphate / rootstock M.9,
- trees grown in fatigued soil fertigated with ammonium phosphate / rootstock P14.

Measurements and observations:

- vegetative growth was assessed by measuring the length of annual shoots longer than 5 cm (during first 4 years of experiment) and by measuring the cross-section of the trunk in the autumn of each year;
- yielding of the trees was assessed by determining the average fruit yield per tree (kg per tree);
- fruit quality was expressed as the average fruit mass determined with the formula:

$$m_{\mathrm{av}} = \frac{y_t}{n_t} \tag{1}$$

where: m_{av} = average fruit weight (g), y_t = total yield from a tree (g), n_t = number of fruits from that tree.

The data from the experiment were statistically processed using the analysis of variance in the Statistica PL 10.0 software. The significance of differences between means was determined with Duncan's test at $p < 0.05$. Meteorological monitoring was conducted with an iMetos automatic weather station.

WEATHER CONDITIONS

The average monthly air temperature during the growing season from April to October in 2014–2020 differed slightly from the multiyear average (Tab. 1). The coldest year was 2020, and the warmest 2018.

The period of the research was characterised by relatively high precipitation. Monthly totals of precipitation during the growing season were higher than the multiyear average, in 2014 by 63.6 mm, in 2016 by 87.4 mm, in 2017 by 211.4 mm, in 2018 by 62 mm, and in 2020 by 179.6 mm. 2015 and 2019 were an exception, since in the period April–October, the recorded precipitation was respectively 151.4 mm and 71.4 mm lower than the data for the multiyear period (Fig. 1).

Table 1. Average monthly air temperature (°C) in Skierniewice in 2014–2020 as compared with multiyear average (1993–2013)

Year	Temperature in month						
	Apr	May	Jun	Jul	Aug	Sep	Oct
2014	10.0	13.7	15.8	20.7	17.9	14.4	9.0
2015	8.2	13.1	16.7	19.5	21.6	14.8	7.0
2016	9.2	14.9	18. 5	19.0	18.3	15.1	7.3
2017	7.2	13.9	17.8	18.5	19.3	13.6	9.9
2018	13.2	16.5	18.5	20.3	20.2	15.1	9.6
2019	9.6	12.5	21.7	18.3	19.8	13.9	10.1
2020	8.0	11.1	17.7	16.8	18.9	14.0	9.3
Multiyear average (1993–2013)	**8.7**	**13.9**	**16.9**	**19.1**	**18.8**	**13.2**	**8.3**

Source: own study.

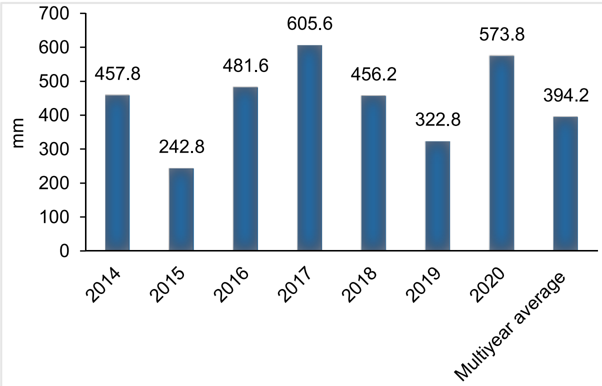


Fig. 1. Total precipitation in the growing season (April–October) in Skierniewice in 2014–2020 as compared with multiyear average (April–October, 1993–2013); source: own study

The specific distribution of precipitation in the analysed period also deserves attention (Fig. 2). The highest total amount of precipitation was recorded in 2017, in which 165.8 mm of rain was recorded in September. In terms of the amount of precipitation, according to the classification proposed by Kaczorowska (1962), 2015 can be classified as very dry – the total annual precipitation was 62% of the multiyear average, with the highest precipitation recorded in October (52 mm), and the lowest in August (6.2 mm).

RESULTS AND DISCUSSION

The growth of trees, as measured by the cross-sectional area of their trunks and the number and length of annual shoots, varied significantly depending on the year, rootstock, and the experimental variant used. In the first two years after planting, the trees growing in the exhausted soil showed impaired growth. The trees in this combination grafted on the M.9 rootstock had the smallest trunk diameter. The highest increase in the trunk diameter was recorded for trees planted in virgin soil. Regardless of the method used to counteract the replant disease, the increase in the diameter of trees grafted on the stronger-growing P14 rootstock was the highest. After seven years of cultivation, no interaction was found between the method used to relieve the replant disease and the growth vigour (expressed by trunk diameter) of the trees grafted on different rootstocks. However, since autumn of 2019, on plots where ammonium phosphate was used, a relatively large difference could be seen between diameters of trees grafted on the M.9 rootstock and those grafted on P14. It seems that the use of fertigation with ammonium phosphate on the exhausted soil stimulated the growth of trees grafted on the P14 rootstock more strongly (Fig. 3).

The annual shoot growth was measured during the first four years of the experiment. In 2014, the lowest number of long shoots was observed on trees grafted on the P14 rootstock planted in the virgin soil, but at the same time those shoots were the longest. The highest number of annual shoots was recorded on the trees grafted on P14 fertigated with ammonium phosphate, and the shortest ones on the P14 rootstock in the control combination (exhausted soil). In 2015, no statistical differences in the number of long shoots were observed; as in 2014, the trees on the P14 rootstock planted in the virgin soil had the longest new shoots, while the shortest ones were found again on the P14 rootstock in the control combination. Since 2016, a significant influence of rootstock and treatment on the number and length of annual shoots was observed. The lowest number of long shoots was observed on trees grafted on the M.9 rootstock planted in virgin soil (in 2016) and in the variant with ammonium phosphate fertigation (in 2017); however, the results did not show statistically significant differences from the other variants with this rootstock. The highest number of annual shoots was recorded on trees grafted on the P14 rootstock in the combination with ammonium phosphate fertigation (2016), and in virgin soil (2017); however, the differences were not significant compared with the P14 control. The shortest new growth was observed in the control combination on trees grafted on M.9, and

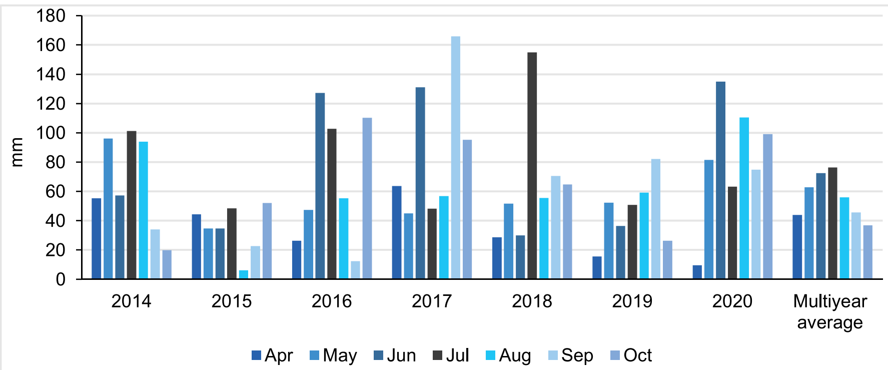


Fig. 2. Average monthly precipitation in Skierniewice in 2014–2020 as compared with multiyear average (1993–2013); source: own study

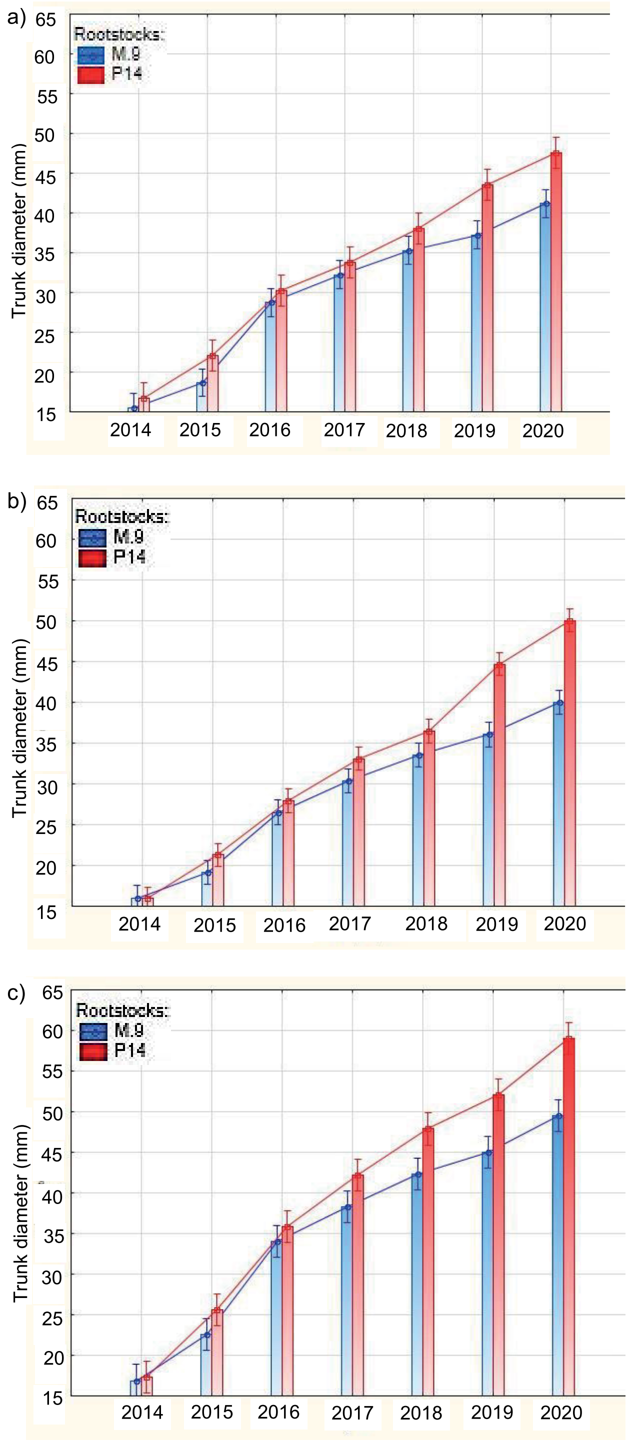


Fig. 3. Trunk diameter of 'Ligolina' apple trees depending on the rootstock and experimental combination: a) control, b) ammonium phosphate, c) virgin soil; source: own study

Table 2. Vegetative growth of 'Ligolina' apple trees in 2016–2020, depending on the rootstock and experimental combination

Year	Rootstock	Control	Ammonium phosphate	Virgin soil
Annual shoots (amount per tree)				
2014	M.9	10.75 bc	9.67 abc	9.17 ab
	P14	10.08 abc	11.64 c	8.33 a
2015	M.9	22.16 a	23.09 a	23.08 a
	P14	19.67 a	24.60 a	24.00 a
2016	M.9	20.75 a	20.09 a	19.92 a
	P14	29.41 b	31.91 b	32.00 b
2017	M.9	21.75 a	20.80 a	21.17 a
	P14	33.09 b	32.91 b	39.18 b
Annual shoots average (cm)				
2014	M.9	12.73 a	13.51 a	13.84 a
	P14	12.25 a	14.64 ab	18.00 b
2015	M.9	19.54 bc	14.12 a	21.44 c
	P14	13.11 a	16.73 ab	27.39 d
2016	M.9	16.73 a	17.40 a	20.88 b
	P14	18.14 ab	24.36 c	24.11 c
2017	M.9	17.97 a	19.60 ab	21.47 bc
	P14	18.59 ab	24.77 c	24.48 c

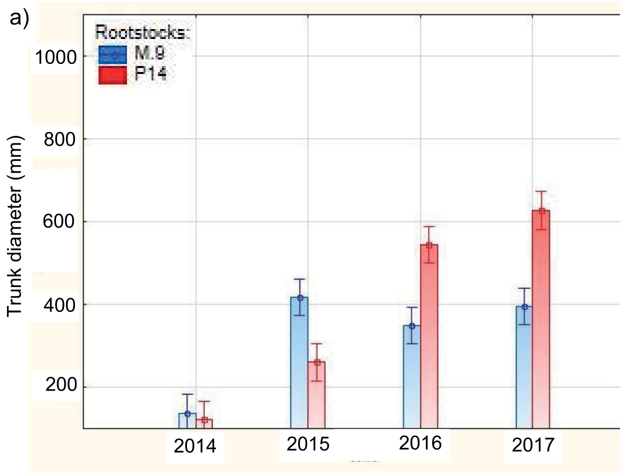
Explanations: statistical analyses for individual parameters were performed separately for each experimental year; means marked with the same letter do not differ significantly at the significance level of 0.05.
Source: own study.

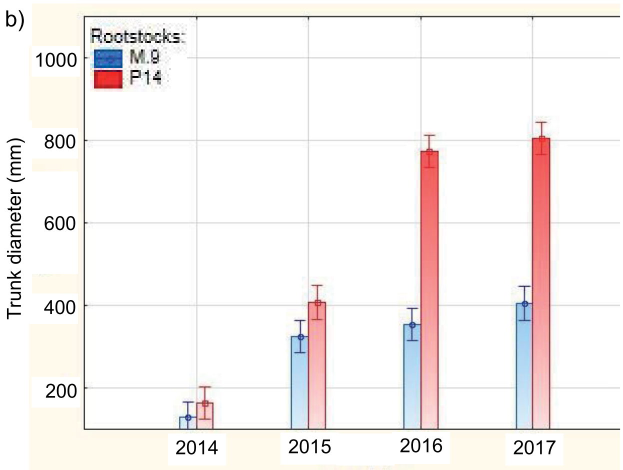
the longest on those on the P14 rootstock fertigated with ammonium phosphate (Tab. 2).

In 2014, no differences in the total annual shoot growth were observed between the experimental combinations. In 2015, the lowest total growth of long shoots was recorded in the control combination on trees grafted on P14, and the highest on trees grown on the same rootstock in virgin soil. Since 2016, a significant influence of the rootstock and treatments on the total annual growth of trees was observed. The highest total increase in the length of annual shoots was recorded for trees grafted on the P14 rootstock planted in virgin soil and subjected to ammonium phosphate fertigation, whereas trees grafted on the M.9 rootstock in the control combination had the lowest total increase in new growth (Fig. 4).

An interesting fact is that in the control plots in the first two years after planting, trees grafted on the P14 rootstock had a shorter total length of annual shoots than those grafted on the dwarfing M.9 rootstock. In the case where ammonium phosphate fertigation was used, this phenomenon did not occur at all. This may suggest that despite potentially vigorous growth in the first years of cultivation, trees grafted on the P14 rootstock are particularly sensitive to the negative impact of the replant disease. The effects of this disease, however, can be overcome with additional nitrogen and phosphorus fertilisation.

The trees began bearing fruit in 2015, but in the first two years it was difficult to assess the impact of treatments applied. In 2015, no differences were observed in the tested experimental variants, while in 2016 the phenomenon of biennial bearing was observed, and fruit yields were at such a low level that it was not possible to evaluate the fruit harvested. In 2017–2019, the trees in the control combination produced the lowest yields, both on the M.9 rootstock and on P14. In 2017, no differences in yield were observed compared with ammonium phosphate fertigation, while trees planted in virgin soil gave the highest yields. In 2018, the highest yields were obtained in the combination fertigated with





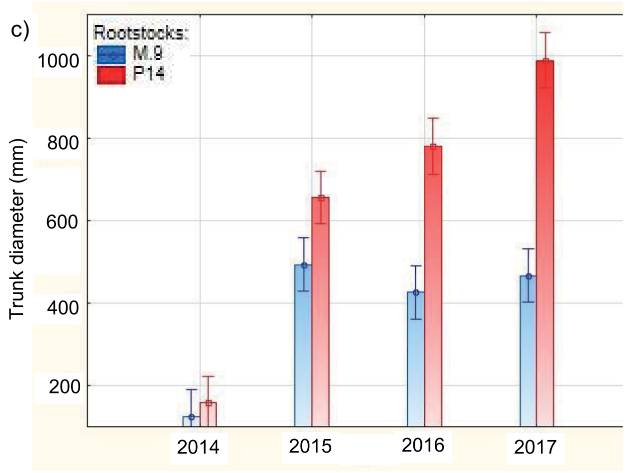


Fig. 4. Total annual growth of 'Ligolina' apple trees, depending on the rootstock and the experimental combination: a) control, b) ammonium phosphate, c) virgin soil; source: own study

Table 3. Fruit yields of 'Ligolina' apple trees in 2017–2019, depending on the rootstock and experimental combination

Year	Yield (kg per tree) for rootstock and combination			
	rootstock	control	ammonium phosphate	virgin soil
2017	M.9	8.80 a	9.88 ab	14.42 c
	P14	9.35 a	10.20 ab	13.35 bc
2018	M.9	1.75 a	5.17 ab	7.69 b
	P14	1.80 a	13.61 c	9.00 bc
2019	M.9	8.40 ab	13.13 bc	14.62 c
	P14	3.95 a	13.31 bc	12.07 bc
The sum of the average yield (2017–2019)	M.9	18.95 a	28.18 a	36.73 b
	P14	15.10 a	37.12 b	34.42 b

Explanations as in Tab. 2.
Source: own study.

ammonium phosphate on the P14 rootstock; they were significantly higher than the yields of trees grafted on the M.9 rootstock planted in virgin soil. In 2019, trees grafted on M.9 planted in virgin soil produced the most abundant fruit crop, and the yield differed significantly from that in the control (Tab. 3).

In 2020, it was not possible to assess the yield. Spring frosts severely damaged flowers and fruit buds. Moreover, the phenomenon of biennial bearing was observed. Throughout the experiment, only single trees were yielding in different experimental combinations (Photo 1).

Photo 1. The phenomenon of biennial bearing in 2020 (phot.: *A. Gać*)

Establishing an orchard in place of the previous one (replantation) had a significant impact on the vegetative growth and yielding. Throughout the experiment, poor vegetative growth of trees planted in exhausted soil was observed. These results were consistent with the results published by other authors, where a significantly weaker growth of trees had been observed, even 5 years after replantation (Krzewińska *et al.*, 2008; Laurent, Merwin and Thies, 2008; Reginato, Córdova and Mauro, 2008; Zydlik, 2010; Zydlik, 2012; Tryngiel-Gać *et al.*, 2015). The reason for the impaired growth may be poor rooting of trees on the grubbed-up site of the old orchard (Bingye and Shengrui, 1998), and this in turn may be caused by a decrease in the number of hairy roots and the formation of "bird nests" (Mai and Abawi, 1981; Trottin-Caudal, 1985). It is believed that the new root systems in the exhausted soil show a relatively low capacity for nutrient uptake (Fallahi *et al.*, 1984; Pacholak *et al.*, 1992) and the deficiency of essential nutrients causes physiological stress and impaired tree growth. In the study, from the third year on after replantation, a beneficial effect of fertigation with ammonium phosphate on the growth of trees was observed, as measured by the total as well as the number and average length of annual growth, especially where the P14 rootstock was used. These observations confirm results found in the work of Głowacka *et al.* (2017), in which the author emphasises that phosphorus contributes to the formation of an abundant root system, thus reducing tree sensitivity to environmental stresses, and enables intensive uptake of minerals from soil. The beneficial effect of phosphorus on apple tree growth is also reported by other authors. According to their works, the growth of apple trees had been significantly improved by introducing organic matter into diseased soil and enriching it with fertiliser containing ammonium phosphate or superphosphate (Neilsen, 1994; Wilson, Andrews and Nair, 2004; Kelderer *et al.*, 2016). In the present study, a beneficial effect of the P14 rootstock on the growth of trees in the "fatigued soil" was also noted. These observations confirm those made by Zydlik (2012), who reports that trees grafted on dwarfing or semi-dwarfing clone rootstocks are more sensitive to soil fatigue than trees growing on more vigorous rootstocks. The rootstock determines the most important properties of apple trees, such as growth vigour, early fruiting, productivity, fruit size and quality, resistance to frost and resistance to diseases and pests (Czynczyk, 1997). That is why fruit growers pay so much attention to the proper selection of rootstocks for specific cultivars (Kruczyńska *et al.*, 1997; Szczygieł and Buczek, 1999). The observed positive effect of the use of a stronger growing rootstock could not be seen until the 3rd or 4th year after replantation. In fact, in 2015, trees in the control combination grafted on the P14 rootstock showed a lower total increase in annual growth than trees grafted on a weaker-growing M.9 rootstock. However, when analysing the results in individual years, it can be noticed that, from the very beginning of the experiment, there were practically no statistically significant differences between the growth of trees on the M.9 rootstock in combination with the time-consuming and costly replacement of soil with virgin soil and tree growth resulting from the use of the more vigorous P14 rootstock only. Therefore, it seems advisable to conduct further research on the use of stronger-growing rootstocks, such as M.26, P1, or M7. An additional observation made in this study was the interaction between the use of the P14 rootstock and fertigation with ammonium phosphate. It seems that the introduction of phosphorus compounds into soil stimulated stronger tree growth when combined with the use of this rootstock. The most effective method of eliminating the replant disease proved to be the replacement of exhausted soil with virgin soil, i.e. soil not previously used for growing fruit trees. In this combination, a much stronger growth of trees was recorded as compared with the control combination for both rootstocks used. This observation supports those in the works by many authors around the world (Laurent *et al.*, 2008; Reginato *et al.*, 2008; Zydlik, 2010; Zydlik, 2012; Sobiczewski *et al.*, 2018). The disadvantages of this method are high labour consumption and high cost. Moreover, with the intensification of fruit production, soil that has not been previously used for growing fruit trees may not always be readily available.

Benefits of the applied treatments on reducing the effects of the replant disease could also be seen in the assessment of the yield. Trees in the control combination (on exhausted soil) produced lower fruit yields than those in the other variants of the experiment. These results confirm those reported by other authors who have claimed that replantation brings a major reduction in yields when a new orchard is planted in the same area after grubbing up the old one (Campanha *et al.*, 2004; Brown and Koutoulis, 2008; Tustin *et al.*, 2008; Zydlik, 2012). In the experiment, both fertigation with ammonium phosphorus and the replacement of soil in the orchard increased the yield, although differences were not always statistically proven. In this case, spring frosts turned out to be a problem, as they damaged flowers and increased the effect of biennial bearing. 'Ligolina' is, admittedly, characterised by high quality fruit of good storability, but it shows a tendency of biennial bearing, especially on poorer sites (Żurawicz *et al.*, 2003). The use of a stronger growing rootstock did not have a significant effect on fruit yield, but slightly higher yields were obtained from trees grafted on the P14 rootstock, especially in the combination with ammonium phosphate fertigation. The impact of the replant disease on changes in the average fruit size had been noted by Zydlik (2012), where the smallest fruits were obtained from apple trees planted directly in the area of grubbed-up fruit trees. In our experiment, however, no differences in the size of fruit were observed, regardless of the rootstock or the combination used. The average fruit size ranged from 175 g to as much as 226 g, which confirms the data from the literature that 'Ligolina' produces medium or large-sized fruits of 170–210 g; very uniform in terms of shape and size (Żurawicz *et al.*, 2003).

CONCLUSIONS

1. Replantation significantly limited the growth of apple trees by reducing the cross-sectional area of the trunk and the number and length of annual shoots.
2. Fruit yields of apple trees grown on the replantation site were significantly lower than those of trees grown in virgin soil.
3. The use of ammonium phosphate fertigation had a positive effect on the growth and yielding of trees on the replantation site, especially when combined with the use of a stronger-growing rootstock.
4. The use of the P14 rootstock reduced effects of the replant disease, contributing to better growth and yield. However, this not occurred until the 3rd or 4th year after replantation.

5. When using the P14 rootstock, the application of phosphorus fertilisers (ammonium phosphate) significantly improved the growth and yielding of 'Ligolina' apple trees.
6. The most effective environmentally friendly method of eliminating the apple replant disease is to replace exhausted soil with virgin soil, i.e. soil that has not been used for growing fruit trees before.

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