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Growth Parameters of Apple Trees of the Aidared Variety Depending on the Rootstock and the Effect of Long-term Fertilization in Monoculture

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ABSTRACT

Background: The results of studies of the influence of long-term fertilization on the growth parameters of apple trees of the Aidared variety on seed and vegetative M.4 rootstocks during repeated cultivation on dark gray podzolic soil were considered.

Methods: The research was conducted during 1990-2016 in the apple tree plantation of the Uman National University of Horticulture in an experiment with long-term use of different fertilization systems.

Result: It was found that the length of shoot growth of the experimental variety depended on the age periods of growth, rootstock and fertilization options. During the period of growth and fruiting, shoot growth was weak (19.4-22.2 cm) in all variants on both rootstocks due to the impact of soil toxin and difficult weather conditions on the re-grown trees. During the fruiting and growth periods, shoot growth was the largest, while during the fruiting period it decreased again, which was due to an increase in fruit yield and lack of moisture for normal growth of experimental trees. A significant increase in tree crown volume (by 38%) during the fruiting period was observed on the seed stock compared to the vegetative M.4.

Key words: Apple tree, Crown parameters, Fertilization, Monoculture, Tree growth, Tree age periods.

INTRODUCTION

An important factor in the intensification of horticulture is highly productive variety and rootstock combinations, which, under certain planting designs and an appropriate system of agronomic measures, ensure high yields and proper marketable quality of fruits at different age periods of tree growth and fruiting (Kondratenko, 2001; Kortleiwe, 2001 and Hrynyk *et al*., 2012). Modern conditions for the introduction of fruit growing involve the cultivation of fruit plantations for a short period of time, while achieving maximum tree productivity with optimal crown parameters. Subsequently, the trees are uprooted and new ones are planted on the same area, replacing the plantation design (variety, rootstock, planting scheme) if necessary to meet the realities of today and the prospects for several decades ahead (Melnyk, 2018; Pramanick *et al*., 2012 and Lauzike *et al*., 2021). At the same time, ensuring high productivity of such fruit plantations is possible by creating optimal conditions for mineral nutrition of trees and optimizing soil fertility indicators both during the period of growing old and new orchards planted in their place. This is achieved primarily through the use of the most efficient fertilization systems. The use of mineral, organic and organo-mineral fertilizers leads to a significant increase in the yield of apple trees (Kai *et al*., 2021; Kopytko *et al*., 2017 and Kowalczyk *et al*., 2022).

The problem of scientifically based fertilizer application in monoculture fruit plantations that are repeatedly grown in one place, depending on changes in soil properties under the influence of fertilizers, as well as age periods of growth and fruiting, remains insufficiently studied. It can be solved only in long-term stationary studies, since the impact of different fertilization systems on changes in soil properties is most thoroughly manifested in their long-term use (Kopytko, 2001; Yakovenko *et al*., 2020; Wang *et al*., 2016); Kozak, 1993 and Sereda *et al*., 1998).

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MATERIALS AND METHODS

The research was conducted during 1990-2016 in the apple tree plantation of the Uman National University of Horticulture on dark gray podzolic soil with humus content in the layer 0-20 cm 2.41%, in the layer 20-40 cm 2.23%,

nitrogen (by nitrification capacity at 14-day composting) 13.4, 12.9 mg/kg soil, respectively, P_2O_5 and K_2O (by Egner-Rheem-Domingo method) 184 and 146 and 289 and 274 mg/kg of soil, pH 5.2, 5.3, absorbed bases (total) 25.0, 26.0 mg-eq/100 g of soil.

The experiment was established by Professor S.S. Rubin in 1931 and was conducted over a 50-year period, after which it was reconstructed by uprooting old trees in 1982 and planting new ones in 1984, while maintaining the previous variants and plots where apple varieties Aidared and Snow Calville on seed stock and Aidared on vegetative M.4 with a feeding area of 7×5 m were planted. The experiment was replicated four times, with seven trees in replication.

The scheme of the long-term experiment (since 1931) includes the following variants: no fertilizers (control), $N_{120}P_{120}K_{120}$, Manure 40 t/ha, 20 t/ha of manure + $N_{60}P_{60}K_{60}$, $N_{120}P_{120}$, $N_{120}K_{120}$, $P_{120}K_{120}$.

Manure and phosphorus and potassium fertilizers are applied in the specified doses every other year in the fall for plowing the soil between the rows and nitrogen fertilizers are applied annually in the spring for cultivation. The soil in the experimental garden is maintained using a steam system. The planting is not irrigated. The climate of the research area is temperate continental with unstable moisture, uneven precipitation and air temperature. Precipitation during the year averages 633 mm, of which 466 mm falls during the growing season (April-September). In our work, the main four variants: no fertilizers (control), $N_{120}P_{120}K_{120}$,, Manure 40 t/ha, 20 t/ha of manure + $N_{60}P_{60}K_{60}$ were used to study the productivity of experimental apple trees according to standardized generally accepted methods (Kondratenko *et al*., 1996). For statistical processing of the research results and determination of the reliability and significance of the experimental data obtained, we used the dispersion and correlation methods of statistical analysis (Yeshchenko *et al*., 2014).

RESULTS AND DISCUSSION

Shoot length

Temperature conditions during the years of the study (1990-2016) differed significantly from the average long-term data. The highest temperatures were observed in 1999-2002 and 2007-2016, with the exception of 2013, when the average annual temperature was much lower and reached 7.4°C (Fig 1). There has been an upward trend in temperature over the past ten years.

Characterising the amount of precipitation over the years of research (Fig 2), we can note their diversity.

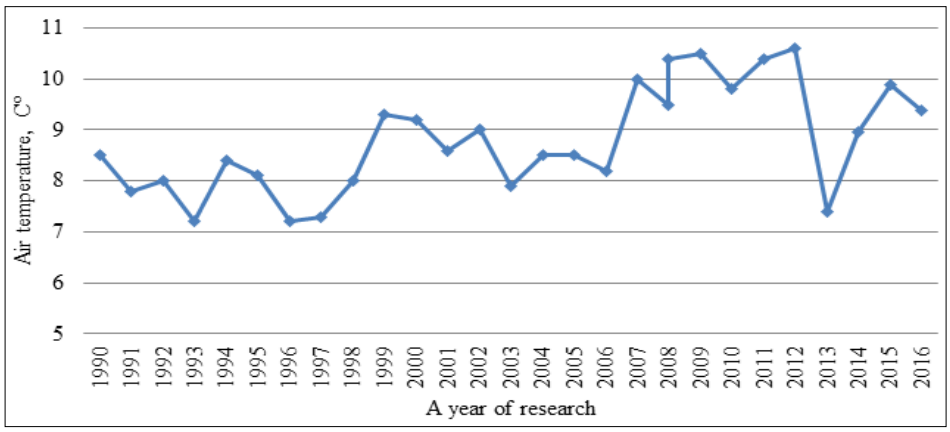


Fig 1: Dynamics of air temperature changes over the years of research (1990-2016).

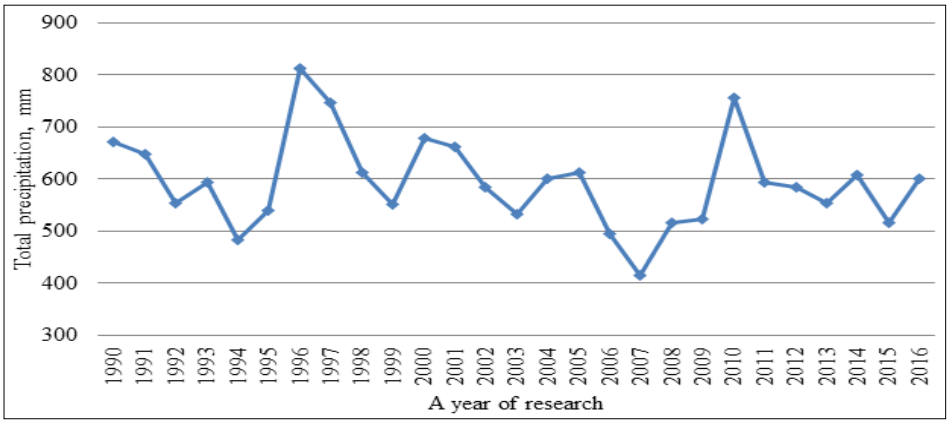


Fig 2: Dynamics of precipitation changes over the years of research (1990-2016).

The highest rainfall was in 1996 (818.9 mm) and 2010 (756.7 mm). The lowest amount of precipitation was in 1994 (482.4 mm), 2006 (495.7 mm) and 2007 (415.9 mm), which adversely affected the growth and fruiting of non-irrigated experimental trees. In the other years studied, the amount of precipitation ranged from 516.1 to 678.2 mm and was close to the long-term average of 633 mm.

The results of the research showed that the growth of shoots on the experimental trees depended on fertilization and age periods of growth and fruiting (Table 1). Trees of the Aidared variety during the period of growth and fruiting were characterized by a weak growth of shoots (19.4-22.2 cm) in all variants on both rootstocks. This was due to the age of the plantations, the impact of replant disease on the re-grown trees and weather conditions (150.6 mm less precipitation than the long-term average), which negatively affected the moisture supply to non-irrigated trees and, consequently, their growth.

During the period of fruiting and growth, an increase in shoot growth was observed in all studied variants. The greatest length of shoots was observed in trees on seed stock under the application of organic-mineral fertilizers (26.1 cm) and on vegetative M.4 under the organic fertilizer system (25.3 cm). This increase in growth was significant compared to the control trees. Shoot growth on vigorous trees on the seed stock was 1.4 cm greater than on less vigorous trees on M.4 at HIPO = 1.3. During the fruiting period, the length of shoots decreased on trees grown on both variety and rootstock combinations in all fertilizer variants, which was due to an increase in fruit yield and lack of moisture for normal growth of experimental trees. The increase in shoot growth was significant during this period under fertilization compared to the control (no fertilization).

From a physiological point of view, the size of shoots and their number in the crown of a fruit tree is an important indicator of the size and intensity of the photosynthetic apparatus because they form the main leaf surface, where the process of photosynthesis is carried out. That is, solar energy is absorbed and accumulated in the biomass of the tree (Zamorskyi, 2012).

The amount of total shoot growth from 1994 to 2016 gradually increased along with the increase in crown habitus. During the period of growth and fruiting, young apple trees of the Aidared variety on seed and vegetative M.4 rootstocks responded most to the application of organic fertilizers, compared to the control, the increase in the total length of shoots was 14 and 9%, respectively. The total shoot growth also increased with the age of the plantations.

The data of the analysis of variance (Fig 3) showed that during the period of growth and fruiting (1990-1996) the rootstock (factor A) had the greatest influence on the total length of shoots of the Aidared variety - 39%, while the influence of fertilizer (factor B) reached 4% and the interaction of factors (AB) - 1%. During the period of fruiting and growth (1997-2003), the influence of rootstock decreased to 14% and fertilization increased to 5%. In the next period of full fruiting (2007-2016), the influence of rootstock reached 34% and the influence of fertilizer-26%.

The degree of development of the feeding area

An important indicator of the dependence of the productivity of a young plantation, in particular the vegetative growth of fruit trees, is the growth of the crown and their utilization of air space. It is known that the optimal level of crown growth and development of the feeding area by fruit trees is 70%. With the age of the trees, the utilization of the feeding area of the apple tree changed and to some extent this indicator depended on the varietal characteristics, type of rootstock and fertilizer options. The development of the nutrition area by trees of the Aidared variety on seed stock in a long-term experiment in 1996 (growth and fruiting period) in the areas of organic and organic-mineral fertilizer systems was 14-11% higher than the control variant (without fertilizer) (Table 2).

The development of the feeding area by trees on the vegetative rootstock M.4 was somewhat lower (1.3 times) than on the vigorous rootstock and the best among the fertilization systems was mineral. The increase in the development of the feeding area by trees on both types of rootstocks was significant in almost all variants with fertilization. During the fruiting and growth periods, trees on

Table 1: The effect of long-term fertilization on the average (cm) and total (m) shoot length on apple trees of the Aidared variety in monoculture.

Rootstock	Fertilization	Indicator in the age group					
		Growth and fruiting (1990-1996)		Fruiting and growth (1997-2003)		Fruiting (2007-2016)	
		cm	m	cm	m	cm	m
Seed	No fertilizer (Control)	20.5	10.8	24.9	24.2	20.1	58.8
	Manure 40 t/ha	21.7	12.3	25.9	27.5	23.1	82.5
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	22.2	12.0	26.1	28.1	23.0	81.2
	$N_{120}P_{120}K_{120}$	20.3	12.1	25.8	25.2	22.1	70.3
Vegetative M.4	No fertilizer (Control)	19.4	8.9	23.5	26.3	19.5	50.2
	Manure 40 t/ha	19.2	9.7	25.3	28.8	23.3	63.8
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	20.1	9.4	24.3	27.9	22.0	58.8
	$N_{120}P_{120}K_{120}$	21.2	9.1	24.2	29.7	22.6	56.7
	LSD_{05}	1.3	0.8	0.8	2.2	1.9	3.4

the seed stock in the variant with mineral fertilizers were better developing the feeding area and on the vegetative M.4-with the application of 40 t/ha of manure. During the fruiting period of 32-year-old trees on seed stock in fertilizer variants, the nutrition area was developed within the optimal level of 71-72%. Trees on the rootstock M.4 did not reach this level, which was due to the unequal feeding area (7×5 m) for trees on a medium-sized rootstock.

Crown volume of apple trees

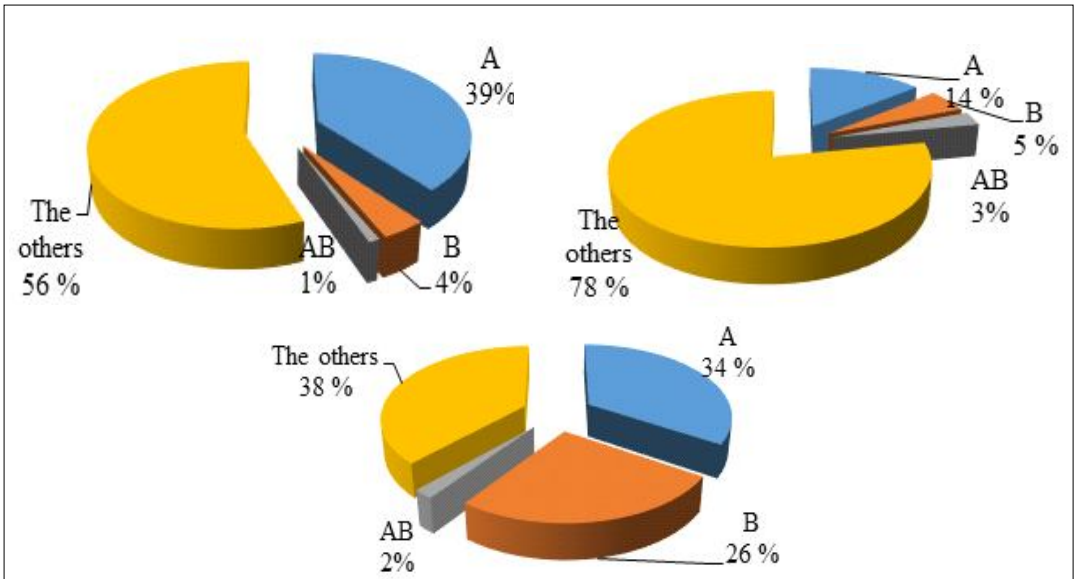
The high productivity of apple and pear plantations is largely due to the optimal balance between growth and fruiting. The volume of tree crown is one of the main indicators of vegetative growth of trees (Table 3). The research data showed that during all age periods of growth and fruiting, the use of different fertilizer options contributed to an increase in the volume of crowns of the studied trees of the Aidared variety on both types of rootstock compared to the control values in the variant without fertilizer.

At a young age of trees (1996), compared to other periods, there was a slight effect of fertilizers on the studied indicator and among the fertilizer options, significantly higher rates were observed for the application of organic and organic-mineral fertilizers compared to the control.

During the period of growth and fruiting (2003), an increase in the volume of the crown of apple trees of the Aidared variety was observed in all variants, in particular, it was the largest in the organic and organic-mineral systems on both rootstocks, respectively, by 23 and 22 and 11% higher than in the control. Characterizing the most productive period of plantation cultivation, the period of fruiting, a significant increase in the volume of tree crown (by 38%) on the seed stock compared to the vegetative M.4 was noted. Among the fertilizer variants, the highest results were

Table 2: The degree of development of the feeding area by apple trees of Aidared variety under repeated culture, %.

Rootstock	Fertilization	Indicator in the age group		
		Growth and fruiting (1996)	Fruiting and growth (2003)	Fruiting (2016)
Seed	No fertilizer (Control)	20.0	40.1	64.7
	Manure 40 t/ha	22.6	44.5	72.1
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	21.3	43.7	70.8
	$N_{120}P_{120}K_{120}$	23.9	45.4	71.5
Vegetative M.4	No fertilizer (Control)	15.2	31.8	55.5
	Manure 40 t/ha	18.5	35.2	68.4
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	17.4	34.1	65.3
	$N_{120}P_{120}K_{120}$	19.1	33.9	63.8
	LSD_{05}	1.5	3.4	6.3

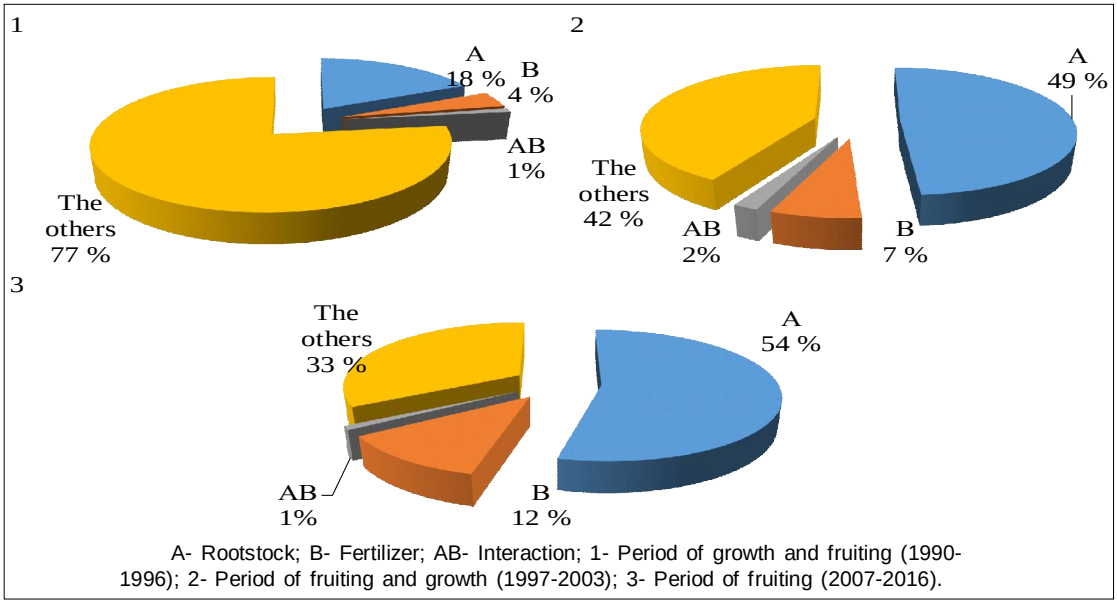


A- Rootstock; B- Fertilizer; AB- Interaction; 1- Period of growth and fruiting (1990-1996); 2- Period of fruiting and growth (1997-2003); 3- Period of fruiting (2007-2016).

Fig 3: Influence of factors and their interaction on the total length of shoots of Aidared variety depending on rootstocks and fertilizer systems in monoculture at different age periods of growth and fruiting.

Table 3: Crown volume of apple trees of the Aidared variety depending on rootstock and fertilizer during repeated culture.

Rootstock	Fertilizers	Indicator in the age group					
		Growth and fruiting (1996)		Fruiting and growth (2003)		Fruiting (2016)	
		m^3	%	m^3	%	m^3	%
Seed	Without fertilizer (Control)	8.5	100.0	32.1	100.0	41.7	100.0
	Manure 40 t/ha	9.7	114.1	39.6	123.4	50.3	120.6
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	9.7	114.1	39.1	121.8	49.5	118.7
	$N_{120}P_{120}K_{120}$	9.5	111.8	38.8	120.9	49.0	117.5
Vegetative M.4	Without fertilizer (Control)	7.8	100.0	25.0	100.0	31.4	100.0
	Manure 40 t/ha	8.3	106.4	27.8	111.2	38.2	121.7
	20 t/ha of manure + $N_{60}P_{60}K_{60}$	8.1	103.8	27.8	111.2	38.0	121.0
	$N_{120}P_{120}K_{120}$	7.9	101.3	26.2	104.8	37.8	120.4
	LSD_{05}	0.6	-	2.1	-	3.2	-



A- Rootstock; B- Fertilizer; AB- Interaction; 1- Period of growth and fruiting (1990-1996); 2- Period of fruiting and growth (1997-2003); 3- Period of fruiting (2007-2016).

Fig 4: Influence of factors and their interaction on the volume of the crown of Aidared trees depending on rootstocks and fertilizer systems during repeated culture at different age periods of growth and fruiting.

obtained by applying organic and organo-mineral fertilizers, but the effect of fertilizers on the crown volume of trees on seed stock decreased compared to the previous period of fruiting and growth. These variants exceeded the control (without fertilizer) by 21 and 19%. In trees on the vegetative rootstock M.4, the effect of fertilizers was significantly higher and exceeded the control by 20-22%.

According to the data of the analysis of variance (Fig 4), in 1996 the influence of rootstocks (factor A) on this indicator reached 18%, while fertilization (factor B) was at the level of 4%. In the period of fruiting and growth (2003) and fruiting (2016), the influence of rootstock was 49 and 54, while fertilizer was 7 and 12%.

CONCLUSION

The length of shoot growth of the experimental variety Aidared depends on the age periods of growth, rootstock and fertilization options. During the period of growth and fruiting, shoot growth is weak (19.4-22.2 cm) in all variants on both rootstocks due to the effect of replant disease on the re-grown trees. During the fruiting and growth periods, shoot growth was highest, while during the fruiting period it decreased again, which was due to an increase in fruit yield and a lack of moisture for normal growth of the experimental trees. Among the fertilization options, the best results were obtained in the variant with 40 t/ha of manure applied in a year.

The development of the feeding area by apple trees is determined by the characteristics of the rootstock and long-term fertilization. During the fruiting period, the index of 34-year-old trees of the Aidared variety on a vigorous rootstock with optimal fertilization at the level of 70.8-72.1%, while the optimum was not reached with a suboptimal feeding area of 7×5 m for trees on a medium-sized rootstock.

Conflict of interest: None.

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