

Vegetative Growth and Productivity of Apple Trees in a Replanted Orchard in Estonia

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Abstract. Long-term cultivation of fruit trees leads to soil fatigue. It is a condition caused by the combined effects of adverse physical, chemical, and biological soil factors. In the experiment, the removal of an old apple orchard during its amortization phase was studied using stump grinding with a stump grinder. In the old apple orchard, intercrops such as cereals, white sweet clover (*Melilotus albus*), and many-leaved lupine (*Lupinus polyphyllus*) were grown. The intercrops were cultivated for four years. The selected apple cultivars for the experiment were ‘Antei’, ‘Auksis’, ‘Lobo’, ‘Tiina’, and ‘Vahur’, all grafted onto the dwarfing rootstock B9. In the old orchard, stump grinding combined with the use of green manure over four years improved tree height and trunk thickness in the new planting. Flower bud formation and fruit development depended strongly on the cultivar-rootstock combination. Fruit set and yield formation in apple orchards are determined primarily by the genetic characteristics of each cultivar. Tree height and trunk diameter continue to reflect the effects of soil preparation carried out up to a decade earlier. In a fully productive orchard, the average total yield per tree is higher in the variant with grinded stumps, although this had no effect on the average fruit weight.

Key words: *Malus*, renovation of old orchard, green manure, replanted apple orchard, apple replant disease, stump grinding.

Introduction

Soil fatigue is a well-known problem in agriculture. It causes weaker shoot and root growth and leads to lower yields. The issue affects both annual and perennial crops when grown as monocultures for long periods. It is observed in both annual and perennial crops when grown in monocultures over extended periods. When old apple orchards are replanted, the new trees often fail to grow well in the same soil. Soil fatigue in apple orchards has many causes. These include nematodes, harmful and harmless microbes, toxic compounds from decaying roots, poor soil structure, and nutrient imbalances (Abakumova & Univer, 2020). Negative effects usually appear 3–4 years after replanting an apple orchard and may persist for up to 12 years (Sedov, Muravjov, & Serova, 2002).

Fruit tree cultivation techniques are constantly evolving. Currently, orchard rows are kept in grass cover, and pruned branches are shredded and left on-site. When eliminating an old orchard, stump grinding

allows the organic matter stored in wood to remain at the site and return to the natural nutrient cycle. Further research is needed to assess the long-term effects of using stump grinding as a renovation method in old apple orchards. In orchard renovation, it is essential to find environmentally friendly methods to mitigate the negative effects of soil fatigue to avoid potential economic losses. When establishing a new orchard, it is recommended to plant tree rows in the inter-rows of the old orchard and to apply compost, wood chip mulch, grass clippings or humic acid preparations along the rows (Lavelly, 2022; Leinfelder & Merwin, 2006).

The aim of this study is to determine whether young apple trees should be planted in the old tree rows—where the stumps have been ground—or in the old inter-rows. The experiment evaluates the long-term effects of decomposing wood mass and root systems, resulting from stump grinding and green manure crop cultivation, on the growth and yield of new apple trees.

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Materials and Methods

The study area had previously been used for apple cultivation for 25 years. The old orchard was established in 1985 using vigorous ‘Antonovka’ seedling rootstocks. The planting pattern was 7×5 m (285 trees per ha). Until 2002, black fallow was maintained in the inter-rows, after which natural grass cover was allowed to grow. The old orchard was dismantled in 2010. Trees were felled, and stumps were ground with a stump grinder to a depth of 20 cm in spring 2011. The grass cover in the inter-rows was crushed with a disc harrow, ploughed, and cultivated.

To study the long-term effects of monoculture, the experiment was established in 2011 using the apple cultivars ‘Antei’, ‘Auksis’, ‘Lobo’, ‘Tiina’, and ‘Vahur’, grafted onto the dwarfing rootstock B9. The planting pattern was 3.5×1.66 m (1720 trees per ha). New apple trees were planted so that the first row coincided with the location of the old tree stumps, and the second row was placed in the former inter-row.

The experimental area was divided into three sections: section A was planted in 2011, section B in 2015 (i.e. four years later), and section C in 2019 (i.e. eight years later). In preparing the soil for sections B and C, green manure crops were sown in 10-meter-wide monoculture strips: cereals (oats, barley), white sweet clover and many-leaved lupine. The green manure crops were not fertilized. A black fallow variant was used as a control. For each green manure crop, 12 trees of one cultivar were planted, totaling 60 trees per variant in 5 replications. This article focuses on the data collected from section B during the years 2015–2024.

The soil in the test area was weakly podzolised sandy loam (LkI), with agrochemical properties (Mehlich 3 method) as follows: pH_{KCl} 5.9, P 123, K 169, Ca 1460, and B 0.42 mg kg⁻¹. Each spring, ammonium nitrate was applied at a rate of 60 kg/ha of nitrogen to the tree rows. A grass seed mix, including white clover, was sown in the inter-rows. Apple trees were shaped into a free-form spindle crown. A standard plant protection schedule of 3 fungicide and 2 insecticide sprayings was used. Bearing trees were pruned to reduce crown width and thin the canopy. Terminal shoots longer than 40 cm were pruned to

40 cm and apical flower buds were removed from shorter ones at least. In 2023, the tops of trees taller than 2.5 meters were cut. Tree trunk diameter (mm) and height (cm) were measured. Yield (kg) was weighed, and average fruit weight (g) was calculated based on harvested fruit count.

Statistical analysis was performed using multifactorial ANOVA. Duncan’s test was used for multiple comparisons to determine significantly different levels (p < 0.05).

Results

Over a four-year period, the green biomass yield of cover crops was 5.17 t ha⁻¹ for cereals, 7.96 t ha⁻¹ for white sweet clover (*Melilotus albus* Medik.), and 10.98 t ha⁻¹ for lupine (*Lupinus polyphyllus* Lindl.). The chemical composition of the aerial biomass differed significantly among the green manure species (Table 1). White sweet clover and lupine accumulated more than twice the amount of nitrogen compared to cereals. The phosphorus (P) and potassium (K) content remained relatively similar across species, while the calcium (Ca) content in white sweet clover and lupine biomass was nearly five times higher than that in cereals.

In the first growing season (2015), trunk diameter was measured in both spring and autumn. The spring measurements reflected the initial physiological condition of the trees at planting. Trunk diameter varied significantly between cultivars. By autumn, a statistically significant difference between planting treatments had emerged (Table 2). From the second year onward, trees planted on grinded stump rows exhibited greater trunk diameters (by 0.7–2.3 mm) compared to those in the inter-row treatment. Among cultivars, ‘Antei’ and ‘Tiina’ developed the thickest trunks.

Tree height was influenced by both the pre-planting soil preparation method and the genetic characteristics of the cultivar. In the second growing season, the average height of trees planted on grinded stump rows reached 147 cm, compared to 133 cm for those planted in inter-rows. This significant difference persisted in subsequent years. In 2017, the length of terminal shoots was

Table 1

Chemical Composition of Green Manure Dry Matter (%), average of 2011–2014

Green Manure Crop	N	P	K	Ca	Mg
Cereal	1.109	0.330	2.328	0.234	0.145
White sweet clover	2.652	0.343	2.378	1.035	0.332
Many-leaved lupin	2.471	0.343	2.729	1.076	0.288

Source: Research findings.

Table 2

Trunk Diameter (mm) in a Young Apple Orchard, 2015–2018

Cultivar	Spring 2015		Autumn 2015		2016		2018	
	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	13.8 c	12.4 c	15.3 b	14.4 c	20.0 b	18.2 b	29.9 c	26.5 c
Auksis	14.8 a	14.2 a	15.2 b	14.1 c	20.7 b	19.4 b	33.1 b	29.7 b
Tiina	14.5 a	14.2 a	16.2 a	15.5 b	23.0 a	21.3 a	33.5 b	33.5 a
Antei	14.3 b	14.6 a	16.7 a	16.5 a	22.8 a	22.3 a	35.6 a	34.8 a
Vahur	13.4 c	13.2b	14.9 b	14.7 c	19.3 c	16.6 c	29.1 c	25.0 c
Average	14.0 A	13.7 A	15.7 A	15.0 B	21.2 A	19.5 B	32.2 A	29.9 B

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

Table 3

Vegetative Growth Indicators of Apple Trees (Tree Height and Terminal Shoot Length, cm) in 2016–2018

Cultivar	Tree Height, cm				Lenght of Terminal Shoot			
	2016		2018		2017		2018	
	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	146 b	134 b	202 b	198 c	49.0 b	45.0 b	24.0 c	22.0 d
Auksis	129 c	118 c	190 c	180 d	43.0 c	38.0 c	28.0 b	25.0 c
Tiina	158 a	136 b	232 a	212 b	54.0 a	49.0 ab	32.0 a	29.0 b
Antei	159 a	156 a	235 a	236 a	54.0 a	52.0 a	28.0 b	32.0 a
Vahur	143 b	121 c	193 bc	181 d	44.0 c	32.0 d	28.0 b	29.0 b
Average	147A	133 B	210 A	201 B	49.0 A	43.2 B	28.1 A	27.4 A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

Table 4

Number of fruits per tree in a young apple orchard, 2016–2018

Cultivar	2016		2017		2018	
	Fr	Br	Fr	Br	Fr	Br
Lobo	8.1 a	5.0 b	6.1 b	3.0 c	9.4b	10.2b
Auksis	6.2 b	5.4 b	9.1b	8.6b	20.2a	25.0a
Tiina	0.5 d	0.9 d	1.7c	1.8c	5.3bc	4.2c
Antei	7.6 a	10.9 a	21.7a	23.2a	22.4a	24.2a
Vahur	4.0 c	2.2c	9.5b	9.1b	4.3 c	10.4b
Avarage	5.3 A	4.9 A	9.6 A	9.1 A	12.3A	14.8A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

significantly greater in the grinded stump row variant. However, in 2018, shoot length declined across all treatments, with no statistically significant differences observed between planting variants (Table 3).

Dwarf rootstocks typically initiate flower bud development during nursery stages. The number of fruits per tree (Table 4) varied markedly by cultivar, whereas differences between planting locations were not statistically significant. 'Tiina' exhibited minimal fruit set—producing fewer than one fruit per tree in year two, fewer than two in year three, and four to five fruits in the fourth year. In contrast, 'Antei' consistently produced higher fruit numbers: 10.9 fruits per tree in 2016, 23.2 in 2017, and 24.2 in 2018.

While no immediate effect of stump grinding was observed on initial tree yield (Table 5), cultivar-specific differences were highly significant. 'Antei' produced the highest yield, followed by 'Auksis',

while 'Tiina', 'Vahur', and 'Lobo' showed lower productivity.

By the fifth growing season, the trees had reached an average height of 2 meters (Table 6). Cultivar-related differences remained evident: 'Antei' and 'Tiina' produced the tallest trees, whereas 'Auksis' and 'Vahur' remained shorter. Annual height increments continued – 25–28 cm in 2020, 27–33 cm in 2021, and 0–16 cm in 2022. From 2020 onward, a significant difference emerged between planting variants, with trees on grinded stump rows exhibiting consistently taller crowns. In 2022, fruit load caused crown drooping in 'Antei' and 'Lobo'.

In the fifth year (2019), average trunk diameters ranged from 28.5 to 41.2 mm (Table 7). Significant variation was observed among cultivars, with 'Tiina' and 'Antei' exhibiting the greatest trunk girth, and 'Vahur' the least. Trees planted on grinded stump rows

Table 5

Average Yield per Tree (kg) in a Young Apple Orchard, 2016–2019

Cultivar	Average Yield, kg								Total Yield, kg	
	2016		2017		2018		2019			
	Fr	Br	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	0.7	0.6	0.7	0.4	1.1	1.1	2.0d	0.9c	4.5c	3.0c
Auksis	0.9	0.8	1.1	1.1	1.9	2.7	9.4a	6.5a	13.3a	11.1a
Tiina	0.1	0.1	0.3	1.3	0.6	0.8	2.7d	1.5c	3.6c	3.7c
Antei	1.3	2.1	3.2	3.0	3.9	4.0	4.2c	3.2b	12.6a	12.3a
Vahur	0.4	0.1	1.1	1.0	0.4	1.0	5.5b	3.1b	7.1b	5.2b
Average	0.68A	0.74A	1.28A	1.36A	1.58A	1.92A	4.7A	3.0B	8.2A	7.1A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

Table 6

Tree Height (cm) in a Bearing Apple Orchard, 2019–2023

Cultivar	2019		2020		2021		2022		2023	
	Fr	Br	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	205c	198c	232c	221c	260b	245bc	278c	243b	260a	244a
Auksis	190d	176d	212d	198d	234c	220d	260d	239b	264a	226a
Tiina	221b	212b	254b	239b	287a	266b	306b	291a	268a	255a
Antei	235a	235a	266a	265a	317a	300a	333a	254b	250a	254a
Vahur	195cd	181d	223cd	204cd	252bc	227cd	258d	233c	227b	265a
Average	209A	200A	237A	225B	270A	252B	286A	252B	254A	249A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

Table 7

Trunk Diameter (mm) in a Bearing Apple Orchard, 2019–2024

Cultivar	2019		2020		2021		2022		2024	
	Fr	Br	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	36.2b	31.6b	42.5c	36.8c	45.1b	40.4c	51.5c	46.7c	64.0b	56.0bc
Auksis	37.9b	33.6b	42.8c	37.5c	46.2b	41.7bc	53.4b	45.2c	64.3b	49.2b
Tiina	41.2a	40.2a	48.9a	46.9a	55.2a	52.0a	61.1a	60.6a	71.6a	73.2a
Antei	40.9a	39.3a	46.2b	43.9b	49.4ab	48.5ab	55.4b	54.8b	61.1b	62.7b
Vahur	34.2c	28.5c	39.3d	32.0d	41.4c	35.1c	50.0cd	41.5d	52.2c	59.2bc
Average	38.1A	34.6B	43.9A	39.4B	47.5A	44.5B	54.2A	49.8B	62.6A	60.0A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$)

Table 8

Average Yield per Tree (kg) in a Bearing Apple Orchard, 2020–2024

Cultivar	Average Yield per Tree, kg								Total yield, kg	
	2020		2021		2022		2024			
	Fr	Br	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	2.5 d	1.8 d	14.0ab	9.6b	7.9b	5.2 b	26.6ab	18.9b	53.3b	37.3bc
Auksis	5.6 c	3.9 c	16.1a	10.4b	4.7bc	3.4 b	22.5b	12.6c	49.1bc	30.4c
Tiina	7.9 b	6.4 b	13.4b	11.1ab	13.8ab	14.1 a	15.7c	10.8c	51.5b	42.5b
Antei	11.2 a	10.2 a	15.6ab	13.4a	16.6a	14.2 a	30.6a	27.7a	76.8a	67.7a
Vahur	4.0 cd	3.7 c	14.5ab	9.7b	9.6b	8.4 b	18.9bc	13.7bc	49.1b	36.7bc
Average	6.2A	5.2A	14.7A	10.8B	10.5A	9.1A	55.9A	16.7B	55.9A	42.9B

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

Table 9

Fruit Weight (g) in a Bearing Apple Orchard, 2020–2024

Cultivar	2020		2021		2022		2024		Average	
	Fr	Br	Fr	Br	Fr	Br	Fr	Br	Fr	Br
Lobo	114 c	128 c	107 c	108 c	116 c	121 b	178b	172b	129b	132b
Auksis	105 c	106 d	77 d	87 d	120 c	104 c	142c	147c	111c	111c
Tiina	143 b	138 b	134 a	132 b	149 b	160 a	211a	215a	159a	161a
Antei	153a	147 a	142 a	142 a	168 a	159 a	187b	179b	162a	157a
Vahur	114 c	101 d	124 b	115 c	115 c	108 c	141c	146c	123b	117c
Average	126 A	124 A	117 A	117 A	134A	130A	172A	172A	137A	136A

Source: Research findings.

Note: Fr – trees planted on former rows, Br – trees planted between rows. Letters A, B (planting method) and a, b, c (varietal differences) indicate statistically significant differences (Duncan test, $p < 0.05$).

developed significantly thicker trunks than those in inter-rows, a trend that persisted in subsequent years.

In 2019, the average yield per tree was 4.7 kg in the grinded stump variant and 3.0 kg in the inter-row variant (Table 3), indicating a statistically significant effect of stump grinding on productivity. Although no difference was recorded in 2020 (Table 8), the difference re-emerged in 2021. Over the four-year observation period (2020–2024), the cumulative yield per tree was significantly greater in the grinded stump treatment (55.9 kg) compared to the inter-row treatment (42.9 kg). Cultivar effects remained significant, with ‘Antei’ achieving the highest total yield and ‘Auksis’ the lowest.

Fruit mass was determined primarily by cultivar and was not significantly influenced by planting location (Table 9). ‘Tiina’ and ‘Antei’ produced significantly larger fruits compared to ‘Auksis’, ‘Lobo’, and ‘Vahur’. As commonly observed, fruit size was inversely related to total yield per tree. In the high-yielding year 2021, the average fruit mass was 117 g across cultivars. A late frost during flowering in spring 2023 led to near-total crop failure. However, in 2024, favorable conditions resulted in a higher fruit set and increased average fruit weight compared to previous years.

Discussion

In this century, significant changes have occurred in apple cultivation technology compared to the 1980s–1990s in Estonia. The introduction of dwarf rootstocks enables the establishment of dense plantations (over 1000 trees per hectare), earlier fruiting, and more productive apple orchards. In the orchard, the spaces between rows are kept in grass, and the branches pruned during crown thinning are left in the orchard and shredded by a maintenance mower. In contrast, in older, vigorous apple orchards, the trees are growing farther apart (6–8 m). The branches pruned during crown thinning are removed from the orchard and burned. The orchard floors and row spaces are kept weed-free through tillage or cultivation (Univer, Haak, & Tiirmaa, 2009). Continuous tillage of the soil helps control weeds but depletes humus, reduces nutrient content, and damages soil structure. To improve soil, green manure crops are recommended, as they enrich the soil with organic matter, promoting humus regeneration and activating microbial activity (Luik & Talgre, 2023). Even when liquidating an old apple orchard, it is beneficial to grow green manure crops. In this experiment, cereals, white sweet clover (*Melilotus albus* Medik.), and many-leaved lupine (*Lupinus polyphyllus* Lindl.) were grown for four years before planting new apple trees. The experiment showed that white sweet clover positively affected

the growth of young apple trees (Univer, 2022). According to Viil and Võsa (2005), white sweet clover leaves 247 kg ha⁻¹ of nitrogen in the soil already in the first year. It has been found that growing legumes as green manure has a positive effect on earthworm populations (Lauringson *et al.*, 2009). The mass of the green manure crop’s root system is also important for the development of subsequent crops, as it decomposes over several years (Lauringson, Talgre, & Roostalu, 2006). Plant root residues, decomposing leaves, branches, and decaying roots are the main causes of soil fatigue. Among toxins, phenolic compounds are most significant. Phenols strongly inhibit the development of most bacteria but have a lesser effect on fungi. Saprotrophic fungi are very important in the nutrient cycle as they break down dead organic matter into simpler compounds that are accessible to other organisms. In the experimental area of the old apple orchard, the presence of 17 saprotrophic fungal species was identified. The cultivation of green manure crops had an impact on the number of fungal species (Zettur & Univer, 2015).

Various environmental factors affect the accumulation of phenolic compounds in the soil of apple orchards. Factors detrimental to apple tree growth, such as insufficient moisture during a dry summer, increase phenolic compound formation (Miidla, 1970; Sarapuu & Miidla, 1970; Sarapuu, 1971). One of the causes of soil fatigue in apple orchards is the florigidin released during root decomposition (Miidla, 1965). Soil fatigue may be associated not only with florigidin but also with other phenolic acids and flavonoids found in apple tree roots, leaves, bark, and fruits. Roots that die off during tree growth and the root residues of uprooted trees are a source of florigidin in the soil. Florigidin accumulates more in the bark layer of the roots. The smaller the proportion of wood in the root mass, the more growth-inhibiting substances are released during root decay. In thick roots with a diameter of 40–80 mm, there are more than three times fewer growth inhibitors than in fine roots with a diameter of 1–3 mm (Moroz, 1980). The root systems of vigorous and dwarf apple trees are different. Dwarf apple trees have many fibrous roots, and their root system is mostly in the area near the trunk. In contrast, seedling apple trees have thicker roots under the tree’s crown, with thinner roots in the outer crown area. As a result, in this experiment, the growth performance of new apple trees was reduced in the inter-row planting locations compared to the former tree rows. Stump grinding likely added organic matter to the soil, which supported beneficial soil fungi. As a result, the soil had fewer harmful compounds, and young apple trees grew better. Therefore, planting new trees in the rows of old vigorous apple trees does not negatively affect

tree growth and yield. The situation may be different when renewing an orchard where weak-growing apple trees have previously been planted. Lithuanian trials confirm that apple replant disease causes substantial growth and yield penalties in the Baltic region, requiring the selection of resistant rootstocks rather than chemical treatment. Long-term studies show that while specific dwarfing rootstocks like P 2, B.396, G.41, and G.11 offer tolerance, most rootstocks suffer 30–70% performance declines, making genetic selection essential for high-density planting (Kviklys *et al.*, 2008; Kviklys *et al.*, 2023).

Summary and Conclusions

When liquidating an old apple orchard, the stumps can be crushed with stamp grinder. This preserves the organic matter stored in the wood and reintroduces it into the natural nutrient cycle. The decomposition of the roots of old apple trees results in byproducts that may cause soil fatigue.

This study revealed, that to improve soil conditions, it is advisable to grow green manure crops before planting a new apple orchard. Apple tree growth and yield in re-established orchards are primarily determined by the cultivar–rootstock combination, though pre-planting soil management also plays a substantial role.

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