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Root Growth Changes in the Winter Planting of Young 'Miyabi Fuji' Apple Trees

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ABSTRACT

Time of planting is a normal part of any agricultural operation. It has a particularly importance in water-challenged areas where soil moisture is an issue. During the winter months in these areas, there is usually sufficient precipitation to maintain adequate water content levels in freshly planted trees. However, during the summer and early autumn, there is very little precipitation. This can adversely affect young trees. In this study, measurements were taken to determine root growth and variations in the upper parts of apple trees that were planted in the winter, compared to those planted in the spring when planting usually takes place. To do so, one-year-old 'Miyabi Fuji', grafted onto Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and M.9 rootstocks, were examined from January through May. The results showed dramatic changes in root growth from March (average root length less than two cm before March) to May (average root length longer than 10 cm) for both rootstocks. Furthermore, trunk moisture content increased over time (51.8% in January and 56.1% in May on M.9). Although root growth in the young apple trees occurred, it is unknown if root water absorption began before or at the same time of the root growth. Root growth developed favorably because of the soil moisture generated by the winter precipitation. We found satisfactory root growth and tree moisture content changes in the trees used in the study, leading us to recommend winter planting in areas where water resources are limited in the non-winter months.

Introduction

The apple (*Malus domestica* Borkh.) is one of the worlds' most widely cultivated fruits (van Vuuren et al., 2006). Commercial apple production takes place mostly in temperate climate areas where snowfall normally falls during the winter. Young apple trees are usually planted in early spring or late autumn, although planting times differ depending on weather conditions (Arakawa et al., 2014). In recent years, the spring planting of fruit trees has become a normal practice in temperate areas as well as in arid areas with limited water resources (Kikuchi et al., 2003). However, planting in water–challenged areas impacts young plant's root, especially those of young

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apple trees in certain areas of Central Asia. There, apple trees are grown under dry and hot summer conditions. However, in winter, temperatures often fall far below freezing and there is a significant amount of snowfall-generated moisture (Hu et al., 2016). In these areas, water availability and its efficient use after planting are critical factors for favorable tree growth. Therefore, to determine optimal planting time and the best tree management practices, understanding the physical development of newly-planted trees is essential.

Most commercially grown nursery trees have weak root systems and show pruning damage, which affects shoot growth. Previous studies have reported that a healthy root system promotes shoot growth, i.e., the number of shoots and the height of trees in one-year-old apple trees (Arakawa et al., 2014), as well as root growth and shoot growth in citrus trees (Bevington et al., 1985). Budiarto et al. (2019) described the potential benefits of citrus root pruning to manage plant growth. Arakawa et al. (2014) reported the impact of winter and fall planting on root growth and the impact of the roots on shoot growth. In contrast to spring-planted apple trees, whose shoots start to grow less than one month after planting, the buds do not start to grow on winter-planted trees until after shoot growth because of the dormancy that caused by the cold weather conditions. If planted in the spring, root growth is delayed until after shoot growth, which commences one month after planting.

The rootstocks onto which the young trees are grafted are also important for the development of the young trees after they are planted. Soejima et al. (1998) reported that Marubakaido (Ma) (*M. prunifolia* Borkh. *var. Ringo* Asami), a semi-vigorous rootstock for apple trees, is used in most of the apple orchards in Japan. The advantages of semi-vigorous Ma are its perfect anchorage, early and heavy production, resistance to burr root, crown rot, wooly aphids, tolerance to wet soil conditions, and ease of propagation with hardwood cuttings. There is no detailed research or experiments that have been conducted regarding root growth that is related to the physiological changes in apple trees planted in early winter.

Therefore, the aim of this study was to investigate the root growth in one-year-old ‘Miyabi Fuji’ and the impact of the physical growing environment, compare to the semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') with dwarfing M.9 rootstocks under cold winter conditions. The planting season and the environmental conditions after planting affect root growth, shoot growth and tree architecture. The results showed that root growth occurred from March, with significant differences in the two rootstocks.

Materials and Methods

Plant materials and experiment design

One-year-old 'Miyabi Fuji' (a bud sport of 'Fuji' having good fruit coloration) apple trees, grafted onto Ma and M.9 rootstocks, were planted on November 25, 2019. They were then observed over the winter and during the spring growing season. The experiment design was as follows: five measuring dates (January 27, February 27, March 27, April 27, May 28), two rootstocks (Ma and M.9), and 15 young trees planted on each of the two rootstocks. All 30 trees were purchased from "HARADA NURSERY Co., Ltd, Japan and the experiments were conducted on the campus of Hirosaki University. Before planting, all apple saplings were scaled to the same size by cutting them to 70 cm; roots were pruned to 10 cm (Fig. 1A, B).

On November 25, the young apple trees were placed in 11 L black plastic nursery pots that contained a mixture of one-part potting soil used for trees and two parts black volcanic soil. These were then placed in a specially designed hole (Fig. 1C) that would prevent them from freezing during the winter. In mid-April, the potted trees were placed above ground.

Daily temperature alterations are shown for the period of the experiment in Figure 2. The average monthly temperatures and total precipitation for the period during which the experiment was conducted is also shown in Figure 2. In December, the average monthly temperature was 1.7 °C and precipitation was 145.5 mm. In January, the average temperature was 0.3 °C and the precipitation 101 mm. In February, the average temperature was 0.5 °C and precipitation was 144.5 mm. In March, the average temperature was increased to 4.9 °C, while the precipitation was dropped to 84.5 mm. In April, the average monthly temperature was increased to 7.5°C and precipitation was elevated slightly to 98 mm. Finally, in May, the average temperature was 15 °C and total precipitation was 54 mm.

Fig. 1. One-year-old 'Miyabi Fuji' before and after planting; (A) semi-vigorous Ma; (B) dwarfing M.9; (C) specially designed hole to prevent winter freezing

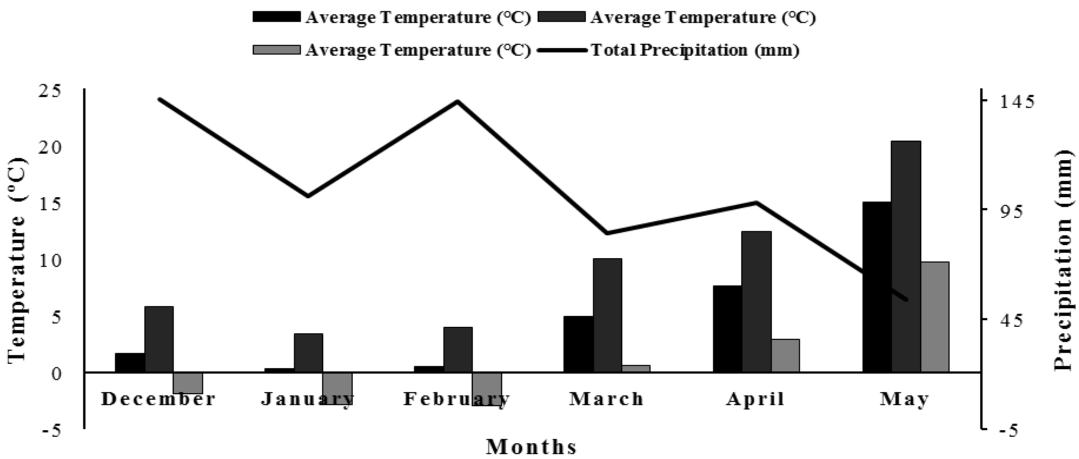

Fig. 2. Daily, maximum, minimum temperatures and total precipitation in Hirosaki, Japan during the experiment period.

Studied traits

On January 27, 2020, the first measurements were done and were repeated on the 27th of each ensuing month until May 28. The young trees were removed from their pots each time before taking the measurements. The roots were separated from the soil and washed, and their average length was measured with a caliper. The tree samples were classified into the following parts: trunks, rootstock stems, and roots. All of the parts were weighed, and then dried in an oven at 80 °C for 48 to 60 hr. After being dried, all samples were again weighed and measured for moisture content (MC). MC was determined using the following equation (1) where FW is the fresh weight of the sample and DW is the dried weight of the sample (Turner, 1981):

$$MC_{(FW_{basis})} = \frac{FW - DW}{FW} \times 100 \quad (1)$$

Data analysis

The observations regarding the effects on MC were analyzed by one-way ANOVA (the difference between dates) and a Tukey test. Moreover, the effect of rootstocks and dates were analyzed by a two-way ANOVA. New shoot length was analyzed using the Student's t-test. All of the above analyses were performed using the R studio version 1.3.1073 (© 2009-2020 RStudio, PBC) software.

Results

Root growth

Root growth change was examined between January and May 2020 for the 'Miyabi Fuji' trees that were grafted onto the Ma and M.9 rootstocks (Table 1). Observations on January 27 and February 27 did not show any root growth for either rootstocks. On March 27, only root hairs and root caps less than or equal to two cm were observed. On April 27, these root hairs and root caps were grown in length to 10 cm or more. Then, on May 28, primary, secondary, and tertiary roots showed vigorous growth.

Table 1. Root growth for 'Miyabi Fuji' on semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing M.9 rootstocks in January through May, 2020

Months	Root growth starting (cm)[a]		Parts of the root [b]
	Ma	M.9	
January 27	NG	NG	All
February 27	NG	NG	All
March 27	≤ 2	≤ 2	Root cap
April 27	≤ 10	≤ 10	Root cap
May 28	≥ 10	≥ 10	All

Note: a-average length of new root growth, b-the new root growth occurred by the root area, NG-not growth. All-primary, secondary, tertiary root and root region.

Moisture content changes in separate parts of the trees

The changes in moisture content in the trunk and the results of the ANOVA are shown in Table 2. The moisture content of the trunks was increased significantly from January to May for the trees on both rootstocks. There was, however, a statistical difference between the two rootstocks; the MC of M.9 was higher than that of Ma ($P \leq 0.01$). The percentage change in MC for Ma in May was higher than that recorded in January, February, and March. The MC for the trunk on dwarfing M.9 increased significantly from January to April and May. There was no significant difference statistically between the interrelation of rootstocks and the months in which they were measured for trunk MC.

Table 2. Changes in trunk moisture content for 'Miyabi Fuji' on semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing M.9 rootstocks in January through May, 2020

Rootstocks	Moisture content (%)				
	January	February	March	April	May
Ma	50.9 ± 0.52a	49.7 ± 0.43a	50.3 ± 0.78a	53.1 ± 0.2ab	55.8 ± 1.4b
M.9	51.8 ± 0.15a	52.1 ± 0.03ab	52.1 ± 0.05ab	53.0 ± 0.3b	56.1 ± 0.4c
	P value	Significance			
Rootstock (R)	0.008026	**			
Date (D)	9.297e-08	***			
R x D	0.239132	ns			

Note: Means ± standard error and different letters indicate statistically significant differences among the months according to the Tukey test; (*) – P ≤ 0.05, (**) – P ≤ 0.01, (***) – P ≤ 0.001, (ns) – not significance, (n = 3).

Rootstock stem MC changes and the results of ANOVA are shown in Table 3. The MC of the rootstock stem increased from January to May on both rootstocks, and changes in rootstock stem MC was markedly in different months during the experiment period. There was a statistically significant difference between the rootstocks; the MC of the M.9 rootstock stems was higher than that of Ma (P ≤ 0.0001). The Ma MC decreased markedly from January to February, then increased dramatically in March and April, and increased even more in May. Alteration of MC for M.9 was notably higher in May when compared to the earlier months. There was no statistically significant difference between the effects of rootstock and the date for rootstock stem MC.

The changes in MC in the root and the results of ANOVA are shown in Table 4. The MC in the roots underwent considerable changes during the experiment period; MC increased from January to May for both rootstock trees. There was statistical significance in the effects of the rootstocks. The root MC of M.9 was higher than that of Ma (P ≤ 0.05). The root MC of M.9 increased significantly from January and February to March and even more in April, then from April to May it decreased greatly. There was no significant difference between the interaction of rootstock and the date for the root MC.

Table 3. Changes in rootstock stem moisture content for 'Miyabi Fuji' on semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing M.9 rootstocks in January through May, 2020

Rootstocks	Moisture content (%)				
	January	**February**	**March**	**April**	**May**
Ma	47.7 ± 0.1b	46.0 ± 0.3a	47.6 ± 0.4b	48.7 ± 0.5b	51.4 ± 0.19c
M.9	48.2 ± 0.6a	48.6 ± 0.4a	48.7 ± 0.6a	50.1 ± 0.7a	52.7 ± 0.34b
	P value	Significance			
Rootstock (R)	0.0001374	***			
Date (D)	1.281e-08	***			
R x D	0.2879832	ns			

Note: Means ± standard error and different letters indicate statistically significant differences among the months according to the Tukey test; (*) – P ≤ 0.05, (**) – P ≤ 0.01, (***) – P ≤ 0.001, (ns) – not significance, (n = 3).

Table 4. Changes in root moisture content for 'Miyabi Fuji' on semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing M.9 rootstocks in January through May, 2020

Rootstocks	Moisture content (%)				
	January	**February**	**March**	**April**	**May**
Ma	55.0 ± 3.3a	54.1 ± 1.4a	60.6 ± 1.1a	61.0 ± 1.6a	56.3 ± 5.4a
M.9	55.3 ± 19.4a	56.8 ± 11.3a	65.8 ± 9.2bc	67.4 ± 7.7c	58.7 ± 7.5ab
	P value	Significance			
Rootstock (R)	0.044436	*			
Date (D)	0.002475	**			
R × D	0.759174	ns			

Note: Means ± standard error and different letters indicate statistically significant differences among the months according to the Tukey test; (*) – P ≤ 0.05, (**) – P ≤ 0.01, (***) – P ≤ 0.001, (ns) – not significance, (n = 3).

New shoot growth for 'Miyabi Fuji' trees on Ma and M.9

New shoot growth in the trees and results of the T-test are shown in Figure 3. The new shoots on the trees were significantly different for the Ma and M.9 rootstocks, and the growth of new shoots commenced in May for both Ma and M.9. There was a statistical difference among the rootstocks; the total number of new shoots for Ma was higher than those for M.9 (P ≤ 0.05).

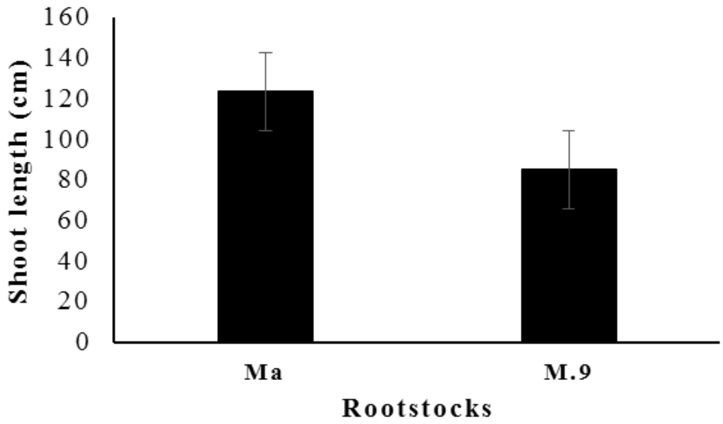

Fig. 3. Total new shoot length for 'Miyabi Fuji' on semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing M.9 on May 28, 2020. Columns shows means ± standard error and different letters indicate statistically significant differences among the rootstocks according to a T-test P ≤ 0.05, (n = 3)

Discussion

In cold weather areas, nursery apple trees are usually planted in the early winter months, just before snowfall. However, there is no detailed research or experiments that have been conducted regarding root growth related to the physiological changes in apple trees planted in early winter. Our findings proved that no root growth occurred in the winter time, January to February. The roots started to grow slowly from March to April, whereas in May vigorous root growth was observed. Van et al. (2011) reported that root growth for dwarfing M.9 occurred from December (early spring time in New Zealand), although they did not check or mention winter time root growth. Temperature change is also vital for root growth. During the experiment period, the average daily temperature in March was 4.9 °C, which impacted root growth. Lopushinsky and Max (1990) found that, for forest trees, root growth occurs when soil temperature is 5 °C or above.

We measured the MC changes in the below and above parts of the trees to determine the relationship between the root condition and growth of different parts of the tree. The MC of the trunk increased slowly from January to May. Root MC increased from January to April when the new roots appeared. These findings suggest that these MC changes are related to root growth and root activity (water absorption by root). Increase of trunk and rootstock stem MC may be related to cold-related damage in young trees during the spring, since it has been suggested that the cold hardiness of woody plants is related to water relations parameters (Anisko and Lindstrom, 1996).

In our study, root MC decreased when shoot growth occurred in May on the young apple trees. Diminishing root MC did not affect root growth in May and the growing process of the root went on vigorously. We found that budburst occurred at the end of April (data not shown), while total new shoot length was observed at the end of May (Fig. 3). This suggests that, in May, the development of shoots on trees grafted onto semi-vigorous rootstock take longer than those on dwarfing M.9. Bevington and Castle (1985) reported that root growth declined during shoot elongation for citrus trees when there is no soil temperature or WC issues.

It is essential to manage soil and water to promote root growth even after planting. It appears that both rootstock selection and winter planting are essential for root growth when young apple trees are planted in areas where moisture is provided by snowfall in the winter but suffer from a shortage of water during the non-winter months.

Conclusion

This research study investigated the effects of winter planting on root growth and certain physical features of one-year old 'Miyabi Fuji' apple trees during the winter and spring. We found that winter planting affected root growth and that the MC of the trees changed from February to March. Accordingly, significant physical changes were observed in the trees.

Hence, winter planting in areas with limited water-resources would ensure that there would be sufficient soil moisture to support root growth and encourage budbreak. Therefore, in the future, we intend to extend the scope of our research to water-challenged areas. The obtained finding of present study provide insights for apple growers in such areas regarding the most effective planting times and the impact of planting time on shoot growth and growth of the upper and lower parts of young trees.

Conflicts of Interest: The authors indicate no conflict of interest for this work.

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