THE INTERACTION OF ROOTSTOCKS, WATER AND SOIL HUMECTANTS AND YOUNG APPLE TREE GROWTH

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ABSTRACT

Young apple trees that are planted in areas with limited water resources face challenges in their early growth stages. Insufficient intake of moisture often stunts the growth of the young tree and impacts its subsequent growth. In this study, we observed the interaction of semi-vigorous Marubakaido (Ma) (*Malus prunifolia* 'Ringo') and dwarfing Jm7 ('Marubakaido' × M.9) rootstocks, water treatments (50% and 70% soil water content) and soil treatments (water retention substances) on young 'Miyabi Fuji' apple trees and how this interaction impacts their growth under dry climactic conditions. The development of shoots, stems and roots was analyzed. The results showed that the interaction of rootstock and water and soil treatments had a significant impact on total shoot length ($p < 0.01$), as did the interaction of rootstock and soil treatment on the length of the top three shoots ($p < 0.05$) and trunk fresh weight ($p < 0.05$). In addition, it was found that the interaction of water and soil treatments impacted shoot fresh weight ($p < 0.05$).

This study revealed that the growth of young apple trees in areas with limited water resources can be aided by providing a 70% and 50% saturation of water and soil retention treatments for young trees that have been grafted onto semi-vigorous Ma and dwarfing Jm7 rootstocks. Growers in these areas should think about which rootstock to use, what soil water retention treatments that can be introduced into the soil as well the amount of water that should be applied.

Keywords: 'Miyabi Fuji', rootstock, shoot growth, water treatment, water retention.

INTRODUCTION

In arid and semi-arid regions of the world, access to a stable supply of water is necessary for the successful propagation of apple trees, particularly for young trees shortly after planting. This is because obtaining a sufficient number of shoots on the young tree in the first growing season greatly influences future fruit-bearing capacity. Research (Tromp, 1996 and Bobomirzayev et al., 2022) found that soil temperature affects shoot growth, especially when it rises to where it enables sylleptic shoot growth. It has also been noted that notching techniques increase branching at the top of young apple trees (Greene and Autio, 1994). Arakawa et al (2014) showed that planting season and root mass have an impact on the length of the top two shoots on one-year-old 'Fujis' that where grafted onto 'Marubakaido' (Ma) rootstocks.

Another factor that promotes shoot growth and other physical changes in young trees is the uptake of nutrients from moisture in the soil. The hot and dry conditions during the growing season in some parts of the world, where water resources are scarce, can hinder the growth of young apple trees. To alleviate these problems, the introduction of efficient irrigation practices and water retention substances that could help maintain sufficient water moisture levels in the soil should be adopted.

It has been established that sufficiently high temperatures along with adequate irrigation contribute to the improved growth of young apple trees after they are planted. Ro (2001) found that when water was applied to young apple trees in soil with a water content level of 50%, they showed better average shoot length than those in soil with a water content level of 80%. Zhou et al. (2019) noted that if the soil moisture content was adjusted to 65-75% and an $N\text{-}P_2O_5\text{-}K_2O$ fertilizer mixture controlled at 20-20-10 $g{\cdot}tree^{-1}$ was added, this combination proved to be the most effective for young apple trees planted in semiarid areas. In another study, Hydretain® ES Plus (Hydretain, Inc.), a water retention substance which is a blend of organic hygroscopic and humectants component (sugar alcohols, polysaccharides and neutral salts of alpha-hydroxy propionic acid), was shown to effectively hydrate the soil. On the other hand a further study reported that Hydretain ES Plus and other humectants had no observable effect on soil water retention in drought-tolerant Coleus 'Wasabi' during the plant growth stages (Greenwell et al., 2017).

Rootstocks play an important role in sustaining stable tree growth and controlling tree shape in the early fruit-bearing process of young apple trees. Soejima et al. (1998) reported on the benefits of Marubakaido (*Malus prunifolia* Borkh. v*ar*. *Ringo* Asami), a semi-vigorous rootstock for apple trees that is widely used in Japan. Soejima et al. (2010) also studied the dwarfing rootstock Jm7 ('Marubakaido' × M.9), a rootstock included in the JM series of rootstocks. They found that growth intensity is similar to M.9 and that it is easy to graft by hardwood cutting.

The studies cited above focused on particular elements that promote young apple tree growth. However, the interaction between rootstock, irrigation, and soil treatments (water retention substances) has not yet been tested. The purpose of the present study is to examine the interaction between rootstock (Ma and Jm7) and water and soil treatments and the impact of this interaction on young apple tree growth and the implications it has for farm management practices in areas with limited water resources. The results led to the conclusion that the upper part of young apple trees show more growth when grafted onto Ma than on Jm7 and that the root system is significantly affected by water content levels and soil treatments.

MATERIALS AND METHODS

2.1. Plant materials and soil treatments.

Young 'Miyabi Fuji' (Botirov A., and Arakawa O., 2021) (a bud sport of 'Fuji' having good fruit coloration) apple trees were grafted onto semi-vigorous 'Marubakaido' (*Malus prunifolia* 'Ringo') rootstock and also onto dwarfing Jm7 ('Marubakaido' × M.9) rootstocks and planted on April 24, 2020. 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 volcanic black soil.

Before planting, all apple saplings were scaled to the same size by cutting them to a length of 70 cm; roots were cut back to 10 cm. Two soil humectants (water retention substances) were used. One was a mixture of Glutan (amino acid "γ-PGA" produced→manufactured by *Bacillus* natto) and Kalpak 66 "ROYAL INDUSTRIES" Co, Ltd (Made in Japan). The other was Hydretain ES Plus 11 mL. Irrigation was done by hand-watering.

Sixty young apple trees were used in the experiment. Half of them were grafted onto Ma rootstocks, the other half onto Jm7. Half of the Ma rootstocks were irrigated to a 70% water content level, the other half to a 50% water content level. The same was done for trees grafted onto Jm7. Of the fifteen trees in each of these lots, five were treated with Glutan (11 mL/p) x Kalpak 66 (11 mL/p ^{z}), five were treated with Hydretain ES Plus (11 mL/p) and the remaining five were left untreated as controls. (Table 1). All trees were purchased from "HARADA NURSERY" Co, Ltd. The experiments were conducted on the campus of the Hirosaki University Faculty of Agriculture and Life Science. The experiment design is shown below in Table 1.

Table 1. Experiment materials and used solutions for soil treatment

Rootstocks	Water treatment	Soil treatment
Ma	70%	Control Glutan (11 mL/p) x Kalpak 66 (11 mL/p [z]) Hydretain ES Plus (11 mL/p)
Jm7	50%	

z: mL/p – soil treatments mixed with soil and 11 mL per pot

2.2. Preparing the experiment site

A half-covered greenhouse (5 m wide and 10 m in length) was prepared for the experiment, with a clear plastic film polyethylene cover installed at the top as a shield against unexpected rain. The ground surface inside the greenhouse was layered with a black weed prevention sheet. Concrete bricks were placed on top of these sheets and four boards (1.21 m × 2.44 m) were placed on top of the bricks with a spacing of 0.50 cm between each board. The potted plants were then placed on the boards. Changes in soil water content were measured with a Decagon (pF meter). Insecticide and fungicide sprays were applied during the shoot growth period after planting at the same intervals as they are in area orchards.

2.3. Preparation samples for measuring

On November 24, each tree was carefully dug up and any soil or other matter was washed away with tap water. After that, the shoots, the main trunk (including the rootstock above the roots) and the roots were separated and measured. Root volume was measured in accordance with the Archimedes principle (10) by which a 5-liter plastic cylinder was placed in a large plastic bowl and filled with water, after which each root was carefully immersed in the cylinder. The overflow was poured into a graduated cylinder to measure the root volume.

2.4. Statistical analysis

All of the young apple trees were headed to the same height at the beginning of the experiment, cutting them at a point 70 cm above the graft union. During the growing season, shoot growth was observed from the headed area to the point below the four or more lateral shoots from the top. The same shoot growth was observed on both Ma and Jm7. Before proceeding with a statistical analysis, all shoots were designated as follows: The topmost shoot was called the “top shoot,” the second, third and fourth shoots were named the “top-three shoots” and the remaining shoots were designated as “below shoots;” the combined lengths of all shoots are referred to as “total shoot length”. The results of the observations of soil treatments were analyzed using a three-way ANOVA for the interaction of rootstocks, water treatments, and soil treatments, plus a Tukey test using the R studio version 1.3.1073 (© 2009-2020 RStudio, PBC) software.

RESULTS

3.1. Impact of rootstock, soil and water treatments on shoot growth

A three-way ANOVA revealed that trees grafted onto the two rootstocks showed significant differences in the number of shoots (Table 2), total shoot length and top first and top three shoot length. The number of shoots, total shoot length and the length of the top first and top three shoots were significantly greater for those on Ma than those on Jm7.

Water saturation levels also had a notable impact on the number of shoots and total shoot length, but exerted no significant influence on the length of the top first and top three shoots. The greatest number of shoots were observed on Ma in soil with 70% water content levels, decreasing significantly on Jm7 in soil with 50% water content.

Soil treatments greatly influenced total shoot length, although they had no significant impact on the number of shoots or the length of the top first and top three shoots. The greatest total shoot length was observed on Jm7 in the trees that were taken from the pots with 70% soil water levels and non-treated soil. Total shoot length was significantly diminished on Jm7 trees that were taken from the pots having water content levels of 70% and soils treated with Hydretain ES Plus. As for total shoot length variation, the Hydretain ES Plus soil treatment had the greatest impact on Ma that were grown in pots with 70% soil water levels, followed by Ma in which Glutan and Kalpak 66 soil treatments were combined with 70% soil water levels.

There were significant differences in rootstock and soil treatment interactions on the lengths of the total and the top three shoots, although there were no significant differences in the number of shoots or the top shoot length. A three-way interaction (rootstock, water and soil treatment) was observed on total shoot length. Among the different sections of the trees, the greatest impact of the treatments was observed on the number of shoots on Ma in 70% water-saturated, untreated soil, whereas the longest total shoot lengths were seen on Jm7 in 70% soil water level, untreated soil. The greatest top shoot lengths were observed on Ma in 50% soil water content, untreated soil, whereas the greatest top three shoot lengths were observed on Ma 70% water-saturated, that had also been treated with Glutan and Kalpak 66.

Table 2. Effects of treatments on the number of shoots and total shoot, top first shoot and top three shoot length (Means ± SE) for 'Fuji' on Ma and Jm7.

Rootstock	Water treatment	Soil treatment	Number of shoots[b]	Total shoot length (cm)[a]	Top first shoot length (cm)	Top three shoot length (cm) [a]
Ma	70%	Control	13 ± 0.6b	497 ± 25.4ac	105.9 ± 5.9ac	206 ±15.4ab
		Glutan + Kalpak 66	9 ± 1.5ab	394.2 ± 23.8a	117.7 ± 3.0 c	225.6 ± 10.8b
		Hydretain ES Plus	7.8 ± 0.6ab	630.7 ± 33.6cd	102.7 ± 4.2ac	189.7 ± 9.4ab
	50%	Control	7.2 ± 1.3ab	499.7 ± 17.5ac	124.7 ± 5.56c	189 ± 8.4ab
		Glutan + Kalpak 66	10.6 ± 2.7ab	397.7 ± 18.3a	113.6 ± 3.17bc	198.8 ± 7.1ab
		Hydretain ES Plus	7.8 ± 1.7ab	449.9 ± 10.0ab	118.4 ± 3.5bc	208 ± 17.8ab
Jm7	70%	Control	6.6 ± 0.5ab	715.8 ± 48.0d	93.3 ± 4.8ab	202.9 ± 16.9ab
		Glutan + Kalpak 66	6.2 ± 1.5ab	603.9 ± 44.4cd	111 ± 5.9ac	167.14 ± 5.3a
		Hydretain ES Plus	6.2 ± 1.6ab	540.8 ± 29.0bc	94.1 ± 8.3ab	162.3 ± 8.0a
	50%	Control	5.2 ± 1.4a	558.8 ± 28.2bc	102 ± 6.8ac	192.5 ± 11.1ab
		Glutan + Kalpak 66	5.6 ± 0.7a	541.3 ± 21.4bc	103.3 ± 7.5ac	153.3 ± 10.0a

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	Hydretain ES Plus	6.4 ± 0.9ab	464.2 ± 20.0ab	86.7 ± 3.5a	179.5 ± 15.0ab
		Significance			
Rootstock (R)		***	***	***	***
Water treatment (W)		*	***	ns	ns
Soil treatment (S)		ns	***	ns	ns
R × W		ns	ns	ns	ns
R × S		ns	***	ns	*
W × S		ns	ns	ns	ns
R × W × S		ns	**	ns	ns

Different letters by column indicate statistically significant differences according to a Tukey test and significant levels: (ns) no significance, (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$ (n=5).

[a] From top to below second, third and fourth shoots.

[b] Only those shoots that were longer than 10 cm and shorter than 35 cm were counted.

3.2. Effects of treatments on trunk and shoot diameter

A three-way ANOVA showed that top shoot and trunk diameters and shoot and trunk weight were affected by the rootstock (Ma or Jm7) onto which they had been grafted (Table 3). The weights of the top shoot, trunk diameter and then shoot and trunk were significantly greater on Ma compared with Jm7.

Water treatment significantly affected trunk diameter as well as shoot and trunk weight, although no impact was observed on top shoot diameter. Trunk diameter was greater on Ma with 70% water content, but decreased significantly on Ma with 50% water content and on Jm7 in 50% and 70% water-treated soil. Shoot weight was significantly greater for trees grafted onto Ma in 50% and 70% water-treated soil, whereas no significant differences were observed for Jm7 in 50% and 70% water-treated soil. There were significant differences on Ma in 50% and 70% water when compared with Jm7 in 50% water-treated soil.

Soil treatments had a significant impact on top shoot diameter and trunk fresh weight, although no significant difference was observed on trunk diameter and shoot fresh weight. Rootstock and water treatment interaction affected top shoot diameter, whereas the rootstock and soil treatments impacted trunk fresh weight and water and soil treatments affected shoot fresh weight. There were no observable changes in tree diameters due to the interaction between rootstock, water and soil treatments. Top shoot diameter and shoot fresh weight was significantly altered on Ma in 70% water levels in untreated soil. Trunk diameter and trunk fresh weight were significantly different on Ma in 70% water-treated soil that was followed by a Hydretain ES Plus soil treatment.

Table 3. Effects of different treatments on top shoot diameter, trunk diameter, shoot weight and trunk weight (Means ± SE) of young 'Fuji' apples.

Rootstock	Water treatment	Soil treatment	Top shoot diameter (mm)	Trunk diameter (mm) [a]	Shoot weight (g) [a]	Trunk weight (g)
Ma	70%	Control	11.6 ± 0.3 d	17.7 ± 0.6 de	132.6 ± 11.9c	140.8 ± 6.8bc
		Glutan + Kalpak 66	10.6 ± 0.5 cd	16.1 ± 0.3 be	110.8 ± 5.2ac	117.0 ± 7.7ab
		Hydretain ES Plus	10.6 ± 0.3 cd	18.14 ± 0.8 de	122.0 ± 6.5bc	154.2 ± 6.0c
	50%	Control	11.2 ± 0.3 d	18.2 ± 0.3 e	117.6 ± 3.7bc	141.4 ± 4.3bc
		Glutan + Kalpak 66	11.0 ± 0.3 cd	16.8 ± 0.4 cde	109.0 ± 7.3ac	119.0 ± 5.2ab
		Hydretain ES Plus	11.2 ± 0.3 d	17.2 ± 0.3 de	117.3 ± 6.3bc	130.3 ± 3.7ac
Jm7	70%	Control	8.5 ± 0.6 ab	15.8 ± 0.6 bd	96.7 ± 7.5ac	136.0 ± 9.3ac
		Glutan + Kalpak 66	9.1 ± 0.5 bc	14.7 ± 0.3 abc	92.7 ± 16.5ac	119.4 ± 8.7ab
		Hydretain ES Plus	8.1 ± 0.3 ab	14.8 ± 0.6 abc	96.2 ± 11.3ac	116.9 ± 10.7ab
	50%	Control	8.2 ± 0.6 ab	14.3 ± 0.3 ab	86.7 ± 5.1ab	112.5 ± 3.8ab
		Glutan + Kalpak 66	7.9 ± 0.2 ab	14.4 ± 0.6 ab	81.9 ± 6.9ab	113.5 ± 7.8ab
		Hydretain ES Plus	6.7 ± 0.4 a	13.4 ± 0.4 a	71.8 ± 6.7a	104.3 ± 6.3a
			Significance			
	Rootstock (R)		***	***	***	***

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Water treatment (W)	ns	*	*	*
Soil treatment (S)	*	ns	ns	*
R × W	*	ns	ns	ns
R × S	ns	ns	ns	*
W × S	ns	ns	*	ns
R × W × S	ns	ns	ns	ns

Different letters by column indicate statistically significant differences according to a Tukey test and significant levels: (ns) no significance, (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$ (n=5).

[a] all shoots (top, top three, below and secondary shoots).

3.3. Effects of treatments on root gowth

A three-way ANOVA was utilized to determine the effects of rootstock, water treatments and soil treatments on root fresh weight, root volume and root-to-shoot ratio (Table 4). The two rootstocks had a significant impact on root weight, root volume and root-to-shoot ratio when grafted onto Ma and Jm7. Root weight, root volume and the root-to-shoot ratio increased significantly on Jm7 when compared with Ma.

Water treatments exerted a significant influence on root weight and root volume, but showed no significant difference for the root-to-shoot ratio. Root fresh weight was higher on Jm7 with 70% water content and significantly higher on Ma with 50% water content. Root volume in trees grafted onto Ma in soil with 70% water content was significantly higher than Jm7 in both 50% and 70% water-treated soil.

Soil treatments showed a marked impact on root weight, but no significant difference was observed on root volume and root-to-shoot ratio. Root weight was significantly greater on Ma with 70% water content when the soil was treated with Hydretain ES Plus. Root weight for Jm7 with 70% water content treated with Hydretain ES Plus was substantially lower than the root weight in trees in untreated soil.

The interaction of rootstock, water content treatments and soil treatments showed no significant impact on root weight, root volume or root-to-shoot ratio. Rootstock, water treatment and soil treatment interaction were observed for root weight, root volume and the root-to-shoot ratio. Significant increases in root weight growth and root volume were observed on Ma with 70% water treatment levels in soil treated with Hydreatain ES Plus, as well as on Jm7 with 70% water levels in untreated soil. Root-to-shoot ratio increases were higher on Jm7 in 70% water content in untreated soil.

Table 4. Effects of treatments on root weight, root volume and root to shoot ratio (Means ± SE) for 'Fuji' on Ma and Jm7.

Rootstock	Water treatment	Soil treatment	Root weight (g)	Root volume (ml)	Root: shoot ratio
Ma	70%	Control	115.2 ± 11.6ab	153.5 ± 17.3 ac	0.9 ± 0.1ab
		Glutan + Kalpak 66	74.7 ± 9.6a	97.5 ± 11.5 a	0.7 ± 0.1a
		Hydretain ES Plus	240.4 ± 19.3cd	253.5 ± 21.5 c	2 ± 0.1ac
	50%	Control	121.9 ± 10.1ab	106.5 ± 17.3 a	1.0 ± 0.1ab
		Glutan + Kalpak 66	74.0 ± 7.8a	69.1 ± 7.3 a	0.7 ± 0.1a
		Hydretain ES Plus	104.0 ± 7.1ab	109.5 ± 12.5 a	0.9 ± 0.1ac
Jm7	70%	Control	266.5 ± 34.5d	237.5 ± 28.6 bc	2.8 ± 0.3c
		Glutan + Kalpak 66	181.0 ± 18.9bd	158.1 ± 21.3 ac	2.1 ± 0.3bc
		Hydretain ES Plus	147.9 ± 11.1abc	136.5 ± 22.0 ab	1.7 ± 0.4ac
	50%	Control	165.4 ± 26.2abc	141.5 ± 25.8 ab	2 ± 0.1ac
		Glutan + Kalpak 66	161.3 ± 33.9abc	134.5 ± 38.4 ab	2. 1± 0.6bc
		Hydretain ES Plus	127.6 ± 10.2ab	112.5 ± 13.3 a	1.8 ± 0.2ac
			Significance		
Rootstock (R)			***	***	***
Water treatment (W)			***	**	ns
Soil treatment (S)			**	ns	ns
R × W			ns	ns	ns
R × S			***	***	**
W × S			ns	ns	ns
R × W × S			***	*	*

Different letter by column indicates statistically significant differences according to a Tukey test and significant levels: (ns) no significance, (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$ (n=5).

DISCUSSION

In this study we investigated the impact of rootstock and water and soil treatments on young 'Miyabi Fuji' apple tree growth. Young apple trees are usually planted as unbranched one-year whips. According to Hull (2018), nursery trees are usually headed 70 to 90 cm above the grafted union before planting in order to obtain a sufficient number of side branches when planted in the spring, to promote the growth of new shoots. When this is done, three or four dominant new shoots emerge at the top. It has been observed that when this occurs only very short shoots grow under these top shoots (Kikuchi et al., 2003). This phenomenon has been understood as a physical characteristic of trees having a top predominance. In this experiment, the upper three to four shoots in spring-planted trees were significantly longer than the lower shoots. Similar results have been reported by. Kikuchi et al., (2003) found that in 'Fuji', top shoot weight was the same for both pruned and unpruned shoots. While Kikuchi et al., only compared pruned and unpruned trees, in our study, we found that the rootstock affected top shoot length on pruned trees, and that shoot length was greater on Ma with 70% water content than on Jm7 with 70% water content (Table 2), and that top shoot length differed in soil with a moisture content of 70% depending upon the rootstock.

Our results also suggest that the impact of the rootstock on shoot fresh weight is greater on Ma with 70% water content than on Jm7 (for both 50% and 70% water content). The trunk fresh weight of the young apple trees was higher on Ma with 50% water content than on Jm7 with 70% soil water. These findings extend those of Campbell and Bould (1970), confirming that the number of shoots was closely related to the rootstock. In our experiment it was not only the rootstock but also the water saturation treatments (set at 50% and 70%) that affected the top parts of the young apple trees. Changes in trunk diameter and fresh weight were more pronounced on Ma with 50% water content than on Jm7 (50% water content). Tworkoski and Fazio (2016) have explored the effects of environmental stress (e.g., water and nutrient availability) on the size-controlling capacity of different rootstocks. In our study, trunk growth indicated that semi-vigorous Ma rootstock with 50% soil water content was greater on Jm7 dwarfing rootstocks treated with water content levels of both 50% and 70%.

Changes in the roots showed that some soil treatments had a positive impact on the fresh weight of the root (Table 3). In this experiment, Ma with 70% water content combined with Hydretain ES Plus showed good growth results. Our findings do not, however, support those of Greenwell et al., (2017) on the impact of humectants on plant root parameters. We found that root fresh weight and root volume changes occurred in trees on Ma with 70% water content in Hydretain ES Plus treated soil resulting in increased root biomass and root volume.

According to Botirov et al., (2022) cited fruit tree observation in some experimental orchards and their results of growing nurseries related on different conditions. And other experiment reported that the root growth of young apple trees in winter planted, and their occurring root growth (Botirov and Arakawa, 2021). The healthy growth of new shoots after planting greatly influences future tree shape and initial production. It is therefore important to promote and manage root growth, even after planting, by managing water content and introducing humectants in order to using soil. Even though this study was carried out under artificially constructed conditions, the results can be applied in orchards. Therefore, in the future we plan to implement these findings in field experiments in areas with limited access to water. These results may provide suggestions to growers in such areas as to how as to how they might better manage their orchards and which rootstocks, which soil moisture levels and which soil water retention treatments would work best for their young apple trees.

CONCLUSION

The question of how to promote the growth of young apple trees after they are planted in areas with limited water resources was examined in this paper. We designed an experiment to determine how the choice of rootstock, moisture levels in the soil and water retention treatments can be combined to promote young tree growth. Our findings led us to the conclusion that the interaction of rootstock, water levels and soil treatments affected total shoot length, root weight, root volume and the root-to-shoot ratio of young 'Miyabi Fuji' apple trees.

The fresh weight of the root was greatest for Jm7 with 70% soil water content in untreated soil and for Ma with 70% soil water content treated with Hydretain ES Plus. Root volume on Ma with 70% soil water content in soil treated with Hydretain ES Plus was greater than that on Jm7 with 70% soil water content in untreated soil. The interaction between rootstock, soil water content, and soil treatments was the highest on Jm7 with 70% soil water content in untreated soil and the lowest on Ma with 70% soil water content in Hydretain ES Plus treated soil and on Jm7 with 50% soil water content in untreated soil.

Rootstock, soil water content and soil treatment interaction were more pronounced on the dwarfing Jm7 rootstock, compared with Ma, in terms of total shoot length, root weight and root to shoot ratio. Root volume and top three shoot length (rootstock and soil treatment interaction) was more pronounced on Ma with 70% soil water content in soil treated with Hydretain ES Plus and Glutan and Kalpak 66 soil treatments when compared with Jm7.

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