

Original Research Article

Effect of Low Soil pH on Growth and Tissue Elemental status of MM.111, MM.106, and M.9 Rootstocks

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Abstract

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Acid soils are severe problems in Chencha high land areas of Southern Ethiopia. The coverage of acid soil of the country is estimated to be about 40% of the landmass and from this 15.6% is strongly acidic soil. Considering the adverse effects of low soil pH on soil elemental status and rootstocks growth the research was conducted to assess the effect of different levels of soil acidity on growth and tissue elemental status of selected apple rootstocks in Chencha. The naturally occurring acidic of the study area was 4.9; the pH was adjusted down to pH 3.5 (in H₂SO₄) and higher to pH 6.3 (in lime). The vegetatively propagated apple root stocks: MM.106, MM.111 and M.9 were grown in polythene bags considered as micro-plots in three blocks laid in a factorial design. Each block was treated with one pH level. The experiment was consisted of combinations of three pH levels (3.5, 4.9 and 6.3), three apple rootstocks MM.106, MM.111, and M9 in 5 replications (5 x 3 x 3 = 45). At the end of the study, data on vegetative growth and rootstocks organs (root, shoot, and leaves) nutrient accumulation were analyzed to assess their differences in response to soil acidity. The result showed that, effect of low soil pH on rootstocks growth and elemental status was significant. In soil pH of 3.5, MM.111 showed vigorous growth, least concentration of Al in roots and Mn in leaves and maximum amount of Ca, Mg, P & N considered as the most tolerant followed by M.9. Conversely, least growth and few amount of Ca, Mg, P, N while highest concentration of Al in the roots and Mn in leaves was recorded for MM.106 revealed a worse level of tolerance compared to other two rootstocks. Therefore, under original acidic soil of Chencha (pH 4.9) MM.111 was more productive and recommended for grafting with scion whereas with increasing level of soil pH by adding lime M.9 was recommended as the most productive rootstock for experimental site of Chencha, Ethiopia.

Key words: Chencha, micro plot, nutrient concentrations, rootstocks

INTRODUCTION

Soil occurring in the warm and humid zones of the west and southern part of Ethiopia, particularly those lying on well-drained landscape, are usually highly leached and very acidic due to the high rain fall intensity and continuous crop cultivation for many years (Taye and Hofner, 1993). According to Mesfin (2007) the coverage of acid soil in Ethiopia is close to 40% of the landmass and from this 15.6% is strongly acidic. The fertility status

of these soils is very low due to the removal of nutrients in the harvest products, losses through erosion and leaching of basic cations (Murphy, 1959; Taye and Hofner, 1993). Due to traditional practices, continuous removal of basic cations through crop harvest enhances the depletion of essential nutrients and contributes to increase in soil acidity. In southern Ethiopia, particularly in Chencha high lands, farmers practice this traditional

farming, which includes removal of crops by totally pulling out of the soil without leaving any residues for years. Basic cations responsible for counteracting the acidity are lost with the residues, and hence results in soil degradation, reduced fertility and increased soil acidification. Under low soil pH condition, the major factors limiting the growth of apple rootstocks are aluminium and manganese toxicities, low availability of Ca, Mg, and some of the micronutrients, and low P availability due to high fixation by exchangeable aluminium and/ or oxides of iron and aluminium (Anandan *et al.*, 1984). Both aluminium and Mn under low soil pH condition, affect the growth of apple rootstocks mainly by disrupting the uptake of essential nutrients such as, calcium and magnesium. Although, the influence of these nutrients in acidic soil conditions affect the growth of apple rootstocks, much attention was not given in studying their tolerance to low soil pH of experimental site.

In the study area apple production was practiced for many years under naturally acidic soil (pH 4.9) of Chencha. However, there was no study on the effect of this acidic soil on vegetative growth and elemental concentration in tissues of apple rootstocks under the study area. Besides, the degree of tolerance of apple rootstocks to toxic minerals, uptake and accumulation of essential elements were also not documented. This is why we selected for our experiments the rootstocks MM.111, MM.106 and M.9, all three economically important in Chencha, Ethiopia. Thus, the present study was initiated to determine the degree of tolerance rootstocks to naturally occurring acidic soil and other two pH treatments, with the objective of selecting rootstocks that demonstrate increased tolerance and adaptive abilities to acidic environments of Chencha soil condition.

MATERIALS AND METHODS

Soil acidification in micro plot

The research was set in polythene bags considered as micro-plots (Sas and Mercik, 2004). A total of 45 polythene bags having 85cm height and 40cm in diameter were filled with 40 kg of soil. The polythene bags contained soil with sufficient amounts of nutrients and one of three different pHs: 3.5, 4.9 and 6.3. Each polythene bag had only one pH level. The pH of the experimental soil (4.9) was used as a control, whereas, adjusted pH levels (4.9 +/- 1.4) were used as the other two treatments. The different acidity levels were maintained by using 0.1 M sulfuric acid and lime (CaCO₃) for pH 3.5 and 6.3, respectively. The amounts of sulfuric acid needed to reduce soil pH, and lime to increase soil pH was based on the initial pH (4.9) and the desired pH for the treatments. For both pH 3.5 and 6.3 treatments, the prepared solution was mixed with 40 kg of soil in a

polythene bag to a depth of 50 cm prior to planting the rootstocks. Vegetatively propagated apple rootstocks, MM.106, MM.111 and M.9, were then planted, one per micro-plot. The experiment consisted of 9 treatment combinations, 2 examined factors: three pH levels 3.5, 4.9 and 6.3, three apple rootstocks MM.106, MM.111, and M9 in 5 replications (5 x 3 x 3 = 45) following Sas and Mercik (2004). The rootstocks were allowed to grow for one year.

Soil sample and analysis

The soil used for micro plot was analyzed to assess the suitability of the root environment and identifying nutrient deficiencies and imbalances. The soil samples were collected from the test field for physicochemical analysis. The soil was sampled from surface layer (0 to 15 cm) using an auger from six random spots across the field. Soil samples were air dried and ground to pass a 2mm size sieve. The pH of the soils was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg and K) were analysed using ammonium acetate extraction procedure (Chapman, 1965). Ca and Mg were measured with an atomic absorption spectrophotometer whereas flame photometer was used to measure K contents. The total N was analyzed using the Kjeldahl digestion, distillation and titration method as described by Schuman *et al.* (1973). Available soil P was analysed following the procedure of Olsen *et al.* (1954) extraction method as recommended by Tekalign Mamo *et al.* (2002) for Ethiopian soils. Exchangeable aluminium was determined by 1N KCl extraction and measured with an atomic absorption spectrophotometer. Available Fe and Mn were extracted by DTPA as described by Sahlemedhin and Taye (2000) and measured with an Atomic Absorption Spectrophotometer. The particle size analysis was carried out by the modified sedimentation hydrometer procedure (Bouyoucos, 1962). The soil analysis was conducted in Ecology and Ecophysiological laboratory at Addis Ababa University, and in JiJe pvt.ltd, laboratory.

Plant sample collection and preparation

At the end of the experiment rootstocks organs (root, shoot, and leaf) were collected for nutrient analysis. Samples of ten young leaves that were fully expanded near base of current year's growth were collected. Leaves were air dried under the shade and then dried in an oven at 70°C to constant weight. Completely dried leaves were pooled in to one sample to be analysed in three technical replicates, ground to pass 1 mm sieve

and stored in airtight plastic bottles for nutrient analysis. The available youngest branches of shoots without buds from the middle portion of the stem were randomly removed by sharp stainless steel cutter after removing the leaves one from each replicate a total of five for all replicas. The shoot samples were air dried under the shade and then dried in an oven at 70°C to constant weight. The root branches of all five replicas under three pH treatments were also removed from the wet soil without damaging the main roots and gently dipped in water for removing adhered soil and dried under the shade and finally in an oven at 70°C to constant weight.

Plant sample analysis

For the determinations of P, K, Ca, Mg, Fe, and Mn concentrations, 0.5 g of samples were dry ashed in muffle furnace at 550°C for 8 h, and the ash was dissolved in 4 ml 3N HCl and filled up with distilled water as described in Kucukyumuk and Erdal (2011). Phosphorus contents of samples were determined by vanadate-molybdate colorimetric method. Ca, Mg, Fe, and Mn concentrations were determined using atomic absorption spectrophotometer and K by flame emission spectrophotometers according to procedure described by Kacar and Inal (2008). Aluminium was determined using Wet Ash Extract – Direct Nitrous Oxide Acetylene Flame atomic absorption spectrophotometer method. Nitrogen concentration in samples was determined according to modified Kjeldahl method in which 0.5 g sample digested in concentrated H₂SO₄ and distilled with NaOH (40%). The ammonium N was fixed in H₃BO₃ (2%) and titrated with 0.1N H₂SO₄ following the procedure described by Kucukyumuk and Erdal (2011).

Vegetative growth measurements

A total of 15 leaves/rootstocks were measured by using leaf area meter LA- AM 100, and the average leaf area was recorded. Trunk circumference (cm) of all five replicates was measured at 5 cm above the ground and converted to Trunk Cross Sectional Area (TCSA) following Yahya and Teryl (2004). The circumference was changed to diameter ($D = C / \pi$), and TCSA was calculated using the formula: $TCSA (cm^2) = \pi (D / 2)^2$, where, $\pi = 3.14$. To determine height of the rootstocks, total length above the ground was measured and number of branches was counted following (Esmail *et al.*, 2001) method. The average of one year three round vegetative growth parameters of the rootstocks under pH treatments was analyzed.

Dry weight measurements

Three apple rootstocks were randomly pulled out of the

soil without damaging the roots at the end of the experiment and their root lengths were separately measured and average was recorded. A total of 30 leaves (10 fully developed leaves/ rootstocks) were dried at 70°C to constant weight and their weights were recorded based on Soheil *et al.* (2009) method. The roots were separated from the above ground part (by cutting at soil surface line); both roots and shoots were dried in an oven at 70°C to constant weight. The leaves, roots and shoots were separately weighed and the average was recorded for each rootstock.

Statistical Analysis

The data were subjected to analysis of variance to find out treatment effects and/or interactions between factors. Analysis of variance was carried out using MINITAB statistical package version 14. The mean separation was performed by Duncan's multiple range tests at the level of the significance (LSD at $P < 0.05$) (Duncan, 1955). Sigma plot 10 was used to present the analyzed data in different graphs. The results were elaborated separately for each measurements value. Throughout the text, differences between treatment means is considered significant when $P < 0.05$.

RESULTS AND DISCUSSION

Characterization of Experimental Soil

The experimental soil had a pH of 4.9 before the apple rootstocks were planted. The pH was monitored at the end of the experiments and remained stable for all pH values throughout the experimental period. The soil was silty clay in texture having 14% Sand, 43 %Silt, and 43%Clay. The total nitrogen (0.23 %) content of the soil declined (0.13%) after a year in the treated soil (Table 2). The exchangeable bases were in the order of Ca (9.97) > Mg (3.47) > K (0.78) Cmol(+). And their respective values decreased to 3.70, 1.11 and 0.62 Cmol(+)/kg soil in the treated soil (Table 2). Contrasting results were found for Al and Mn. The exchangeable Al was high in soil pH of 3.5 whereas the total Mn was high in pH 4.9 (Table 2). Previous study showed that, a soil suitable for fruits should have a CEC of 25-35 cmol(+) kg⁻¹; whereas values lower than 20 indicated a soil with low buffering and potentially poor fertility (Webster, 2005). The results of the present study revealed that, under the soil pH of 4.9 in reference with (Webster, 2005; Pam and Brain, 2007) values of Ca, Mg, K and CEC decreased with decreasing the pH to 3.5 and all could be considered low, except K that was under moderate category (Table 2).

According to Kamprath (1970) the available exchangeable Al in soil at pH of 4.9 and 4.5 was 0.60 and 0.91 meq/100g respectively. In our experiment high

Table 1. Soil chemical properties of the experimental site

pH	Total %	mg/kg (Total Available (mg/kg)				Exchangeable bases and CEC(Cmol(+)/kg soil				Exchangeable Cmol(+)/kg soil
		N	Fe	Mn	P	Ca	Mg	K	CEC	
4.9	0.23	7950.0	760.21	23.61	9.97	3.47	0.78	23.59	4.2	
3.5	0.13	834.53	108.60	22.27	3.70	1.11	0.62	17.05	11.4	

exchangeable Al (4.2 meq/100g soil) was recorded under soil pH of 4.9 (Table 2). The exchangeable Al was further increased to 11.4 meq/100 g soil when the soil pH was reduced to 3.5. This could be considered as very high in accordance with Kamprath (1970) (Table 2). The content of Al in soils increases under soil pH < 5.5 whereas Ca, Mg, and K decrease (Pam and Brain, 2007). The decrease in amount of exchangeable bases could be due to the presence of high soluble Al in soil pH of 4.9 and highest in pH 3.5 that displaced the basic cations from the active exchange sites of the soil.

According to Sims and Johnson (1991) the critical levels of available Fe and Mn for crop production are 2.5-5 mg kg⁻¹ and 3.8 mg kg⁻¹ respectively. Therefore, the average means values of available Fe and Mn found in both soil of pH 4.9 qualified above the adequate range for the rootstocks grown in the micro plot (Table 2). Reports on total Mn content in soils are variable showing values from 15 to 17 mg kg⁻¹ (Hue and Mai, 2002), 20 to 10,000 mg kg⁻¹ (Sparks, 1995) and 450 to 4,000 mg kg⁻¹ soil (Adriano, 2001).

According to Landon (1991), available soil P level of < 5 mg kg⁻¹ is rated as low; 5-15 mg kg⁻¹ as medium and > 15 mg kg⁻¹ is rated as high. The available P of the soils of the study site qualified for the high range (Table 2). The high contents of P found in both 4.9 and 3.5 pH level could possibly be due to the farmers' continuous usage of animal manure and compost to promote the soil fertility of the farm land used for our experiment. Low soil pH < 5 was reported to reduce the availability of P in the soil (Pam and Brain, 2007). Even though P decreased in strongly acidic soil of pH 3.5, the amount of available P found was adequate for the uptake of the rootstocks. Following the rating of total N of > 1% as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and < 0.1% as very low N status as indicated by Landon (1991), soil pH of 4.9(0.23%) qualified for the medium range while soil pH of 3.5(0.13%) qualified for the low range indicating that the availability of N decreased with the decrease in soil pH < 5 (Pam and Brain, 2007). (Table 1)

Effect of Low Soil pH on Tissue Elemental Status of Apple rootstocks

Macronutrients (Ca, Mg, N, K and P)

Significant effect ($P < 0.05$) of low soil pH was registered

for rootstocks leaf calcium concentration. The three rootstocks had decreasing Ca content with decreasing pH (Table 3). The differences between rootstocks in leaf calcium content were also significant ($P < 0.001$) with MM.111 having the highest level, and MM 106 the lowest at all pH values. In roots, the Ca content varied between rootstocks. There was no clear tendency for decreasing Ca with decreasing pH, but the content at pH 3.5 was the lowest in all rootstocks (appendix Table 3). Magnesium accumulation in leaves of rootstocks according to the result of two way analysis of variance was not significantly influenced by low soil pH treatments. The differences between rootstocks in leaf Mg content were also statistically not significant ($P > 0.05$). In the roots, Mg content was variable for each rootstock, with no clear tendency for decrease with decreasing pH (Table appendix 3). Tissues' of rootstocks under pH 3.5 were low in P compared to pH 4.9 and 6.3. The differences between rootstocks in leaf P content were statistically significant ($P < 0.01$). Also in the roots, the P content was variable for each of the rootstocks, with no clear tendency for increase with increasing pH. However, roots of MM.106 had a sufficient level of P compared to MM.111 which was least and M.9 intermediate in pH 6.3 (Table appendix 3).

Nitrogen content in leaves of apple rootstocks were not influenced by soil pH and did not differ significantly between rootstocks. The contents of N in roots were however showing a trend for lower values at lower pH in all three rootstocks (appendix Table 3). Comparing the rootstocks organs, more N content was found in leaves, compared to roots and shoots, indicating that N is efficiently transported from roots to leaves of all rootstocks and constitutes a lesser part of the plant structure in roots and shoots than in leaves (appendix Table 3). The effect of low soil pH on rootstocks leaf K accumulation was not significant. However, the differences between rootstocks in leaf K content were statistically significant ($P < 0.001$). M9 had comparatively high levels of K at all three pH values, whereas those of MM106 were low at pH 6.3, and in MM.111 low at both pH 4.9 and pH 6.3. In the roots, K values for M9 were highest under all pH values, followed by MM.106 and the lowest was registered for MM. 111 rootstocks (appendix Table 3).

The nutrient accumulations in the leaves of apple rootstocks under study were evaluated based on standard values established by Joseph (2004). The

Table 2. Effect of low soil pH on concentration of macro nutrients (dw^{-1}) in leaves of rootstocks. Values are the means of 3 repetitions \pm SE.

Rootstocks	Macro nutrients(mg kg^{-1})	pH		
		3.5	4.9	6.3
MM.111	Ca	10955 \pm 2.9c	11880 \pm 5.8b	13150 \pm 2.8a
	Mg	2550 \pm 5.9a	2340 \pm 11.8b	1310 \pm 5.9c
	N%	2.78 \pm 0.05a	2.77 \pm .04a	2.36 \pm .04b
	K	12250 \pm 16.7a	5000 \pm 16.7c	5500 \pm 33.3b
MM.106	Ca	2030 \pm 17.6c	3385 \pm 2.9b	5390 \pm 2.9a
	Mg	1180 \pm 5.9b	2330 \pm 17.6a	1090 \pm 2.9c
	N%	2.27 \pm 0.04a	2.09 \pm .05a	1.39 \pm .05b
	K	12500 \pm 33.3b	16500 \pm 33.3a	7000 \pm 16.7c
M.9	Ca	4015 \pm 2.9c	6510 \pm 5.8b	8735 \pm 2.9a
	Mg	2060 \pm 2.9c	2270 \pm 5.9b	2320 \pm 11.8a
	N%	2.32 \pm .04b	2.36 \pm .04b	2.57 \pm .04a
	K	16500 \pm 16.7a	16000 \pm 16.7b	15500 \pm 16.7c

Means with same letters in rows indicate non-significant differences at $P < 0.05$ by Duncan test. *dw^{-1} = dry weight

author indicates the ranges for N, P, K, Ca, and Mg, 2.00-2.25, 0.20-0.30, 1.25-1.75, 1.20-1.60, 0.25-0.40, and that of Fe and Mn as 100-300 and 40-100 mg kg^{-1} , respectively. The result showed significant differences among the rootstocks (appendix Table 3). In strongly acidic soil of pH 3.5, N, Mg, Fe and Mn concentrations in leaves of MM.111 was not affected by treatment and were in adequate level while P, K and Ca concentrations was below the range (appendix Table 3). Under similar soil pH, P, Ca and Mg concentrations were below the optimum range whereas adequate levels of N, Mg, Fe and Mn were recorded in leaves of both MM.106 and M.9 rootstocks. The Mg values were even lower at pH 6.3, indicating no clear effect of low soil pH on Mg absorption by MM.106 rootstock (appendix Table 3). Among the rootstocks maximum uptake of K was found for M.9 than both MM.111 and MM.106 rootstocks. This could be due to genetic variation in nutrient absorption between these rootstocks (appendix Table 3). The availability of Ca, Mg, K and P were limited at low pH; this is because under low soil pH, the solubility of Al, Mn and Fe increases. The presence of excess Al block the uptake of these largely required nutrients by the roots (Table 5). However, the increase in leaves Ca concentration was observed with an increase in level of soil pH (Table 3). This is in accordance with Sas and Mercik (2004) who reported that, the concentration of Ca in rootstocks was high under high soil pH.

Under the original acidic soil (pH 4.9) there was highest concentration of nutrients in leaves of MM.111 except for P, K and Ca contents, which were below the range. In leaves of MM.106 the concentration of N, P, K, Fe and Mn, were within the sufficiency range established by Joseph (2004) in contrast to Ca and Mg which was below the range. Similarly, in leaves of M.9 the amount of N, K, Fe and Mn respectively was within sufficiency range

while the contents of Ca, P, and Mg were below or approaching the critical values. Nevertheless, there were no symptoms of nutrient deficiency throughout the experimental period. (Table 2)

The highest and lowest amounts of nutrients in leaves of the three rootstocks under pH 4.9 treatment were mainly due to differences in response to the high soluble Al, associated with fewer amounts of exchangeable base cations (Table 2). The accumulation of toxic minerals Al, Fe and Mn increased with decrease in pH in the tissues of apple rootstocks (Table 7). In soil with pH below 5.5 both aluminium and manganese concentrations reach toxic levels (Kamprath, 1970; Vardar *et al.*, 2006). The presence of these excess toxic elements caused adverse effect on essential nutrient absorption by competing with root binding surfaces and caused some nutrient deficiency range under different pH levels. In the leaves of the rootstocks, the excess toxic nutrients also obstruct the utilization by interacting with major nutrients causing reduced growth and weak vigour of the rootstocks (Ducic and Polle, 2005). This study showed that, next to pH 3.5 the naturally acidic soil (pH 4.9) of study area caused the release of toxic mineral elements by increasing their solubility (Table 7).

Under soil pH of 6.3 the P, Mg, K and Mn concentrations in leaves of MM.111 were below the range while, Ca and N were within the range. In leaves of MM.106 the amounts of Ca, Mg, K, and N were below the range while adequate amount of P, Fe and Mn was recorded. Conversely under similar soil pH treatment the concentration of P, N, Mg, K, Mn and Fe in leaves of M.9 were within adequate level while Ca content was below the sufficiency range in reference with standard range established by Joseph (2004) (Table 3 and 7 respectively). This showed that, M.9 was more vigorous in uptake of nutrients under pH level of 6.3 followed by

Table 3. Correlation coefficient of Al concentration in roots and P accumulation in leaves of MM.106 rootstock

	Source	AL	P
AL	Pearson Correlation	1	-.844**
	Sig. (2-tailed)		.004
P	Pearson Correlation	-.844**	1
	Sig. (2-tailed)	.004	

** . Correlation is significant at the 0.01 level (2-tailed).

MM.111 whereas MM.106 was found least. The decrease in uptake below the range was not related with availability of soil nutrients of experimental site (Table 2). Thus, the possible reason might be the genetic variation in uptake of nutrients between the rootstocks under different level of low soil pH. Potassium was highly absorbed by M.9 and qualified for the established range (Table 3). This experiment agrees with Amir and Fallah (2009) who reported M.9 as the most vigorous rootstock in uptake of nutrients than MM.111 and MM.106 under soil pH of 7.3 in Iran.

In our study, apple rootstocks showed differences not only in uptake but also in translocation of phosphorous to the leaves. Under strongly acidic soil of pH 3.5, phosphorous concentrations were relatively low in leaves of MM.106 (1279 mg kg⁻¹) as compared to the concentrations in roots (1904 mg kg⁻¹). Significant negative correlation between leaf P content and root Al accumulation indicated that the transport of phosphorous to the leaves was inhibited by excess Al in the roots of MM.106 rootstocks (Table 4). In accordance with this, previous study revealed that the presence of Al often resulted in precipitation of P in the root cell walls and/or intracellular space (Weiqiangyang and Barbara, 1997; Terence *et al.*, 2002). Other study on inhibition of P also showed that the P transport was limited because of non-metabolic AlPO₄ accumulation in the root cell (Weiqiangyang and Barbara, 1997). In contrast to MM.106, positive significant correlation (appendix Table 1 and 2) between leaves P content and roots Al accumulation for MM.111 and M.9 indicated insignificance effect of Al on leaves P content of both rootstocks. In this micro plot experiment, the result of tissue analysis revealed that among the three apple rootstocks examined, MM.111 accumulated the highest amounts of Ca, Mg, N, and P in leaves and the least concentrations of Al in roots and Mn in leaves, showing MM.111 as the most tolerant to strongly acidic soil of pH 3.5. In contrast, apple rootstocks MM.106 had the lowest contents of Ca, Mg, N, and P in the leaves (Table 3), but highest concentration of Mn in leaves and Al in roots (appendix Table 3) indicating the MM.106 to be the least tolerant, whereas M.9 rootstock was found to be intermediate. However, leaf Fe and K concentrations of M.9 was high in soil pH of 3.5 (appendix Table 3) showing the markedly absorptive capacity of this rootstock for both nutrients

compared to MM.111 and MM.106 rootstocks. (Table 3)

Al, Mn and Fe

The effect of low soil pH on rootstocks Al content was significant ($P < 0.05$) as was the differences between rootstocks in leaf Al content ($P < 0.001$). Roots and leaves from all samples showed a consistent increase of Al content with decreasing pH (appendix Table 3). Comparing the rootstocks, MM106 had the highest Al content in both roots (appendix Table 3) and leaves, followed by M9, whereas MM.111 had the lowest Al contents at all pH values (Table 7).

The amount of soluble Al and Mn accumulation was high in roots and leaves of apple rootstocks respectively (appendix Table 3). It seems that, Al was more accumulated in roots while Mn was transported to the leaves. Our result agrees with finding of Marschner (1995) who reported more Al in roots and Mn in leaves under acidic soil. Mn was rapidly released from the roots into the xylem, reaching photo synthetically active leaves via the transpiration stream (Millaleo *et al.*, 2010). Tolerance differences were observed in Al and Mn toxicity. Among the three rootstocks, under soil pH of 3.5 the concentration of Al in roots (549 mg kg⁻¹) and Mn in leaves (195.2 mg kg⁻¹) of MM.111 were lowest, whereas Ca and Mg, were highest in the leaves indicating highest resistance of MM.111 to the effect of Al on uptake of nutrients followed by M.9 roots, which had 879 mg kg⁻¹ Al, and 238.2 mg kg⁻¹ Mn in the leaves. In contrast, the highest concentrations of Al (1560 mg kg⁻¹) in roots and Mn (318.2 mg kg⁻¹) in leaves were obtained for MM.106 with low amounts of Ca and Mg in leaves under pH 3.5.

The correlation coefficient revealed Al was negatively correlated with Ca, Mg, N and K (Table 5). Thus, the decrease in amount of essential nutrients was caused due to the negative effect of Al on roots to take up these nutrients (appendix Table 3). The accumulation of high Al in roots of MM.106 under pH 3.5 suppress the uptake of essential nutrients, and also inhibited root elongation associated with the observed (appendix Fig.1) severe changes in root morphology, and resulted in curved, stubby and stiff root apices as stated by Vardar *et al.* (2006). Due to its least tolerance to the effect of Al under soil pH of 3.5, the root growth of MM.106 was severely

Table 4. Correlation coefficient of Al concentration in roots and Ca, Mg, N and K accumulation in leaves of apple rootstocks

	Source	Al	Ca	Mg	N	K
Al	Pearson Correlation	1	-.537**	-.224	-.346**	-.285**
	Sig. (2-tailed)		.000	.044	.002	.010
Ca	Pearson Correlation	-.537**	1	.483**	.444**	.158
	Sig. (2-tailed)	.000		.000	.000	.159
Mg	Pearson Correlation	-.224*	.483**	1	.525**	.534**
	Sig. (2-tailed)	.044	.000		.000	.000
N	Pearson Correlation	-.346**	.444**	.525**	1	.684**
	Sig. (2-tailed)	.002	.000	.000		.000
K	Pearson Correlation	-.285**	.158	.534**	.684**	1
	Sig. (2-tailed)	.010	.159	.000	.000	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 5. Correlation coefficient between Mn and Ca concentration in leaves of apple rootstocks

	Source	Mn	Ca
Mn	Pearson Correlation	1	-.237*
	Sig. (2-tailed)		.033
Ca	Pearson Correlation	-.237*	1
	Sig. (2-tailed)	.033	

*. Correlation is significant at the 0.05 level (2-tailed).

reduced. This resulted in minimum uptake of nutrients compared to M.9 rootstock whereas MM.111 with highest root length absorbed more minerals than other two rootstocks (appendix Fig.1). (Table 4)

The effect of low soil pH on rootstocks Mn content was significant ($P \leq 0.05$) as was the differences between rootstocks in leaf Mn content ($P \leq 0.005$). Leaves from all samples showed a consistent increase of Mn content with decreasing pH (appendix Table 3). In this study we observed that excess Mn in leaves was negatively correlated with Ca (Table 6). This showed that Mn interfere the utilization of Ca in leaves of the rootstocks. In accordance with this it has been reported that, excessive Mn concentrations in leaves can alter utilization of other mineral elements (Ca, Mg, Fe and P), causing oxidative stress (Ducic and Polle, 2005; Lei *et al*, 2007). (Table 5)

Comparing the rootstocks, MM106 had the highest Mn content in leaves, followed by M9, whereas MM.111 had the lowest Mn contents at all pH values (Table 7). In shoots of M.9, Mn accumulation was high in pH of 3.5 low in pH 4.9 and least was recorded in pH 6.3 indicated less translocation to the leaves compared to other rootstocks (appendix Table 3). In roots of MM.111, less Mn was found followed by M.9 while highest concentration was recorded in roots of MM.106 under soil pH of 3.5. Unlike

others, shoot Mn content of MM.111 was found less in soil pH of 3.5 and 4.9. High Mn content was found in leaves of M.9 followed by MM.106 and least was recorded for MM.111 in soil pH of 6.3 (appendix Table 3). The interaction effect of rootstocks and low soil pH treatments in terms of Mn content was not significant. Similar to Al, highest Mn accumulation was observed with decreased in soil pH to 3.5 while least was recorded under soil pH of 6.3 (Table 7).

Rootstocks tissue iron content was also not influenced by low soil pH treatments. However, the differences between rootstocks in tissue Fe content were significant ($P < 0.05$). Comparing the three rootstocks differences on the basis of Fe accumulation, roots of M.9 obtained the highest followed by MM.106, and least was found in MM.111 under acidic soil of pH 3.5. The amount of iron in leaves of M.9 was higher, low in MM.111, and least was found in MM.106 under soil pH of 3.5. Among the three rootstocks, the highest concentration of iron was found in root, shoot and leaves of M.9 compared to other two rootstocks (appendix Table 3).

In all three rootstocks, the roots iron content was found high under naturally occurring acidic soil of pH 4.9. On the other hand, except in leaves of M.9, least iron was recorded under soil pH of 6.3. The highest concentration of Fe was found in roots than shoots and leaves

Table 6. Effect of low soil pH on micronutrients and element (dw^{-1}) accumulation in leaves of apple rootstocks. Values are the means of 3 repetitions \pm SE.

Rootstocks	Nutrients (mgkg^{-1})	pH		
		3.5	4.9	6.3
MM.111	Al	135 \pm 5.9a	65 \pm 13.3b	48 \pm 1.8b
	Mn	195.2 \pm 1.2a	48.4 \pm 4.7b	9 \pm 2.4c
	Fe	401 \pm 6.2a	219 \pm 2.4b	159.0 \pm 1.5c
MM.106	Al	756 \pm 3.5a	178 \pm 4.7b	130 \pm 2.9c
	Mn	318.2 \pm 2.9a	137.2 \pm 4.1b	30.1 \pm 2.9c
	Fe	274 \pm 2.4c	453 \pm 5.9a	334 \pm 5.9b
M.9	Al	235 \pm 5.9a	107 \pm 4.1b	96 \pm 6.7b
	Mn	238.2 \pm 4.7a	89.1 \pm 5.2b	56.1 \pm 2.9c
	Fe	705 \pm 8.8c	880 \pm 5.9b	960 \pm 17.6a

Means with same letters in rows indicate non-significant differences at $P < 0.05$ by Duncan test. *dw^{-1} = dry weight

(appendix Table 3). The interaction effect of rootstocks and low soil pH treatments on tissue Fe accumulation was not significant. The increase in Fe concentration with increase in soil pH was not uniformly observed for rootstocks under study. However, the Fe concentration in leaves of M.9 increased with increase in level of soil pH, while the decrease in amount of Fe was found for MM.111. On the other hand, MM.106 rootstock recorded more concentration of Fe in soil pH of 4.9 compared to pH 3.5 and 6.3 (Table 6).

Vegetative Growth of apple rootstocks as influenced by soil pH

Highly significant ($P < 0.001$) differences were recorded between rootstocks in growth of root length. Root growth as a function of total plant growth was higher in rootstocks grown at pH 6.3 than in rootstocks grown at pH 4.9 and 3.5. The amount of Al from soil test indicated that, soil exchangeable aluminium increased from 4.2 meq/100g at a soil pH of 4.9 to 11.4 meq/100g at a soil pH of 3.5 (Table 2). This increase in Al solubility due to decrease of soil pH to 3.5 significantly affected the growth by interfering the absorption of Ca, Mg, K, and N that are largely required by rootstocks (Table 5). Our study supports previous work of Neilsen *et al.* (1994) who reported that, the increased availability and toxicity of Al and Mn elements in acidic soils significantly reduced uptake of essential elements and consequently plant growth and yield. Significant ($P < 0.001$) interaction effect of rootstocks and low soil pH on vegetative growth was recorded. In this experiment, the three apple rootstocks vegetative growth increased with incremental increases in soil pH, from 3.5, to 4.9 and to 6.3 as did final root length and dry weights in nearly all rootstocks (Table 10). The result of our findings in the current study support

previous investigations by Sas and Mercik (2004) who reported that, strongly acidic soil limited the growth of apple rootstocks P.22, M26, and M9 in comparison with soils having higher soil pH in Poland.

Significant differences in the tolerance of the rootstocks to strongly acidic soils were noted in shoot, root and leaf dry weights between those grown in high-pH (6.3), low-pH (4.9) and strongly acidic soil (3.5) (Table 10). Low pH reduced the dry weight of all rootstocks, except for MM.111 rootstock. The highest increase in shoot dry weight for MM.111 occurred in the rootstocks grown in the low-soil pH of 3.5 (Table 10). Low-pH soil significantly reduced root dry weight of M.9.

The toxic effect of high Al and Mn concentrations at soil pH levels below 5.5 have been well documented (Fey *et al.*, 1978). This toxicity would be expected to most greatly affect root growth and development. In this study, a negative trend was obtained in low-pH soils (3.5), as evidenced by the reduced shoot weight and root weight for MM.106 and M.9 respectively (Table 10). Maximum growth of leaf area, total height, number of branches, root length, was registered for MM.111 followed by M.9 while reduced growth was recorded for MM.106 in soil pH of 3.5 (Table 9 and 10). This showed that, MM.111 strongly resisted the negative effect of excess Al and Mn in uptake and transport of adequate nutrients. Conversely, MM.106 which failed to counteract the effect of Al registered reduced growth while M.9 recorded intermediate considered as vigorous rootstocks next to MM.111. Due to the presence of excess Al and Mn under soil pH of 3.5, rootstocks root growth; nutrient uptake and transport were affected. The presence of high Al not only suppresses the absorption and usage of largely required soil nutrients, but also reduced rootstocks growth by inhibiting the development of their roots (Ryan *et al.*, 1993).

It has been reported that trunk diameter was used to

Table 7. Effect of low soil pH on vegetative growth of apple rootstocks.

Rootstocks	Growth	pH		
		3.5	4.9	6.3
MM.111	Root length(cm)	60.3 ± 2.9a	63.7 ± 4.7a	68 ± 1.8a
	Leaf area (cm ²)	28.3± 2.2b	38.22± 4.4b	52.5 ± 5.6a
	Total branches	7 ± 1.5b	9.6 ± .72a	10.6 ± .72a
MM.106	Root length(cm)	21.7± 2.4c	37.3± 1.2b	44.7± 1.2a
	Leaf area (cm ²)	10.8± .33b	18.4± 1.0b	35.6 ± 5.3a
	Total branches	2.2 ± .30b	4 ± .72b	6.6 ± .72a
M.9	Root length(cm)	28.7± 1.2b	38.8± 1.8a	41.3± 2.4a
	Leaf area (cm ²)	23.8 ± 1.7b	28.6 ± 1.6a	33.9 ± 3.2a
	Total branches	5.3 ± .72b	7.6 ± .72a	9 ± .72a

Table 8. Effect of rootstocks, low soil pH and its interaction on vegetative growth

Rootstocks	Growth Parameters	pH		
		3.5	4.9	6.3
MM.111	Total height(cm)	80.8±37.5a	87.2±31.9a	86.3±29.1a
	TCSA (cm ²)	0.95± .02c	1.13 ± .01b	1.29 ± .02a
	LDW(g)	30.6± .72c	52.4 ± 1.6b	74 ± 2.0a
	SDW(g)	111±6.5c	167.2± 4.1b	377.5± 4.1a
	RDW(g)	71.1±3.5c	114.5± 2.4b	168.7± 4.7a
MM.106	Total height(cm)	38.7± 9.0b	52.6± 9.1a	55.4±10.3a
	TCSA (cm ²)	0.54 ± .01c	0.85±.01b	1.2± .01a
	LDW(g)	10 ± .94c	27.3 ± .94b	31.8 ± 1.6a
	SDW(g)	66.7± 3.5c	169.4± 5.3b	293.6± 1.8a
	RDW(g)	50.5± 2.9c	63.9± 1.8b	108± 4.7a
M.9	Total height(cm)	42.6±10.2b	55.2±12.0a	53.7±10.3a
	TCSA (cm ²)	0.64±.01c	1.11±.01b	1.37± .01a
	LDW(g)	14 ± 1.6b	25.9 ± 1.6a	29.2 ± .96a
	SDW(g)	62.6± 1.2b	76.5± 3.5a	78.5± 1.8a
	RDW(g)	29.20 ± 2.4b	41.7 ± 3.5 a	45.3 ± 2.9 a

determine the vigour of apple rootstocks (Webster, 2005). Trunk cross sectional area is often used as a convenient non-destructive estimate of overall rootstock size (Wertheim, 1998; Barden and Marini, 2001). Significant differences in growth of TCSA were found between rootstocks ($p < 0.001$). Highest value of TCSA was recorded for MM.111 followed by M.9 while MM.106 showed least trunk growth under acidic soil of pH 3.5 (Table 10). The thickest and thinnest trunk growth indicated the highest and least tolerance differences between MM.111 and MM.106 respectively to the effect of low soil pH. Although MM.111 showed more growth than others, reduced data of TCSA were recorded for all three rootstocks under soil pH of 3.5. The interaction effect of rootstocks and low soil pH on trunk diameter was also significant ($p < 0.001$). According to the result of

Duncan LSD same type of rootstocks under different levels of soil pH showed differences in trunk growth. The trunk diameter for all rootstocks increased with increase in soil pH (Table 10). This indicated that, with an increase in soil pH the availability of largely required nutrients was more while the amount of toxic minerals was less. (Table 7)

Under naturally occurring acidic soil (pH 4.9) MM.111 recorded highest growth in leaf area, TCSA, total height, number of branches, root length, and dry weight (root, leaf) except for shoot dry weight followed by M.9, except for root, shoot, and leaf dry weight and least was recorded for MM.106 (Table 9 and 10). The root and leaf dry weight of MM.106 was more than M.9 while the shoot dry weight recorded was higher than both rootstocks. This showed that, progress increased in growth was

observed for MM.106 with an increase in low soil pH indicated, the uptake and transport of nutrients by MM.106 was improved due to increase in root growth with the decrease in amount of Al and Mn that severely reduced root growth compared to M.9 rootstock (appendix Fig.1). (Table 8)

In soil pH of 6.3, contrary to soil pH of 4.9, Al and Mn solubility decreased, and effect of toxicity was found insignificant. The increased in growth of all three rootstocks was observed in pH 4.9 and highest in soil pH of 6.3 (Table 7 and 8). Comparing the three rootstocks maximum growth in leaf area, total height, TCSA, number of branches, root length, and dry weight (shoot, root, leaf) was recorded for MM.111 followed by MM.106 except TCSA and number of branches, and least was registered for M.9 (Table 10 and 11). MM.111 does not show difference in total height grown in different level of soil pH. This showed that, the weak performance of MM.106 under soil pH of 3.5 and 4.9 improved due to less or no effect of Al and Mn under soil pH of 6.3. It can be inferred that, the potential uptake and transport of nutrients by MM.106 was high under least amount of Al and Mn in pH 6.3, resulted in increased growth of vegetative parameters. Among the three rootstocks progress increase in growth of TCSA was recorded for M.9 with highest value in soil pH of 6.3 than other rootstocks. This indicated that, the uptake and translocation of nutrients by M.9 was higher under soil pH of 6.3. The vegetative growths of apple rootstocks under study were affected by level of all soil pH. However, effect of severity was more in pH 3.5, low in pH 4.9, and least was found in pH 6.3. According to result of Duncan LSD, same types of rootstocks showed differences in vegetative growth across low soil pH (Table 9 and 10). The strongest performance of MM.106 in soil pH of 6.3 for most parameters except TCSA was contrary to soil pH of 3.5 showed higher growths in leaf area, total height, and root length than M.9 (Table 9 and 10). As low soil pH affected nutrient availability, it is not unpredicted to see changes in vegetative vigour with varying soil pH. In accordance with this many studies have concluded that, strong soil acidification was found to be a limiting factor for growth and yield of apple trees (Neilsen *et al.*, 1994; Vardar *et al.*, 2006).

CONCLUSION

The results showed that low soil pH significantly ($P < 0.001$) reduced the availability of essential nutrients and increase the amount of soluble Al and Mn and thus, affected the rootstocks mineral absorption and transport. Significant ($P < 0.001$) differences between rootstocks were also recorded in uptake of nutrients. Among the rootstocks under strongly acidic soil of pH 3.5, the maximum amount of largely required and least toxic nutrients were recorded for MM.111 whereas the highest

amount of toxic and least essential nutrients were observed for MM.106 while M.9 was found intermediate. On the basis of vegetative growth maximum growth of TCSA, leaf area, total height and dry weight was registered for MM.111 under pH 3.5 followed by M.9 while least was recorded for MM.106 rootstock. The increase in growth was recorded for MM.106 with an increase in level of soil pH with highest in pH 6.3. Thus, under acidic soil condition of experimental site MM.111 was the most tolerant rootstocks followed by M.9 while MM.106 was least. The results of this study would suggest that apple rootstocks vary in their tolerance to different levels of low soil pH treatments. These differences should be considered when choosing rootstocks for grafting with cultivars and adjusting soil pH levels for new cultivars in soil testing and liming schedules for established apple cultivars of study site.

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APPENDIX

Table 1: Correlations coefficient between Al and P for MM.111

		AL	P
AL	Pearson Correlation	1	.861**
	Sig. (2-tailed)		.003
P	Pearson Correlation	.861**	1
	Sig. (2-tailed)	.003	

** . Correlation is significant at the 0.01 level (2-tailed).

Table 2: Correlations coefficient between Al and P for M.9

		AL	P
AL	Pearson Correlation	1	.887**
	Sig. (2-tailed)		.001
P	Pearson Correlation	.887**	1
	Sig. (2-tailed)	.001	

** . Correlation is significant at the 0.01 level (2-tailed).



Figure 1: Root length of apple rootstocks (A, MM.111; B, M.9; C, MM.106) as influenced by low soil pH.

Table 3: Concentration of nutrients and mineral elements in rootstocks organs from three apple rootstocks grown under different levels of low soil pH. Values are the means of 3 repetitions \pm SE.

Nutrients	Soil pH treatm	Apple Rootstocks								
		MM111			M9			MM106		
		leaf	shoot	Root	leaf	shoot	Root	leaf	shoot	Root
Ca	3.5	10955 \pm 2.9a	10180 \pm 5.9a	201 \pm 9.6a	4015 \pm 2.9b	2880 \pm 5.9a	1995 \pm 2.9a	2030 \pm 17.6c	2090 \pm 2.9b	333.9 \pm 5.9b
	4.9	11880 \pm 5.8a	13465 \pm 2.9a	1950 \pm 29.4a	6510 \pm 5.8b	8560 \pm 5.9a	8595 \pm 1.2a	3385 \pm 2.9c	2930 \pm 5.9b	1850 \pm 5.9b
	6.3	13150 \pm 2.8a	4040 \pm 5.9a	1320 \pm 11.8a	8735 \pm 2.9b	3630 \pm 11.8a	2110 \pm 5.9a	5390 \pm 2.9c	4045 \pm 5.9b	1995 \pm 2.9b
Mg	3.5	2550 \pm 5.9a	1460 \pm 5.9a	70 \pm 2.9a	2060 \pm 2.9a	1430 \pm 17.6a	1280 \pm 5.9a	1180 \pm 5.9a	630 \pm 2.9a	1020 \pm 2.9a
	4.9	2340 \pm 11.8a	1680 \pm 5.9a	410 \pm 5.9a	2270 \pm 5.9a	1080 \pm 5.9a	2070 \pm 5.9a	2330 \pm 17.6a	1310 \pm 5.9a	1200 \pm 24.5a
	6.3	1310 \pm 5.9a	1340 \pm 11.8a	490 \pm 2.9a	2320 \pm 11.8a	960 \pm 5.9a	920 \pm 11.8a	1090 \pm 2.9a	3400 \pm 2.9a	1190 \pm 2.9a
Fe	3.5	401 \pm 6.2b	193 \pm 1.8b	775 \pm 2.9b	705 \pm 8.8a	1013 \pm 7.2a	7380 \pm 5.9a	274 \pm 2.4ab	254 \pm 5.9ab	3335 \pm 5.9ab
	4.9	219 \pm 2.4b	206 \pm 3.5b	3635 \pm 2.9b	880 \pm 5.9a	354 \pm 5.9a	7800 \pm 5.9a	453 \pm 5.9ab	222 \pm 5.9ab	7660 \pm 5.9ab
	6.3	15.9 \pm 1.5b	276 \pm 3.5b	2550 \pm 29b	960 \pm 17.6a	375 \pm 5.9a	3170 \pm 5.9a	334 \pm 5.9ab	762 \pm 5.9ab	1333 \pm 1.3ab
K	3.5	12250 \pm 16.7b	2350 \pm 16.7b	690 \pm 5.9b	16500 \pm 16.7a	7000 \pm 16.7a	4500 \pm 6.7a	12500 \pm 33.3b	2710 \pm 5.9b	2000 \pm 16.7b
	4.9	5000 \pm 16.7b	2100 \pm 16.7b	990 \pm 5.9b	16000 \pm 16.7a	4250 \pm 16.7a	5000 \pm 16.7a	16500 \pm 33.3b	3990 \pm 5.9b	3420 \pm 16.7b
	6.3	5500 \pm 33.3b	2800 \pm 16.7b	1140 \pm 1.7b	15500 \pm 16.7a	11500 \pm 5.9a	2390 \pm 5.9a	7000 \pm 16.7b	4000 \pm 16.7b	2820 \pm 6.7b
P	3.5	1933 \pm 4.7b	1145 \pm 4.7b	1162 \pm 3.5b	1636 \pm 1.8a	1636 \pm 3.5a	1784 \pm 3.5a	1279 \pm 5.3a	1220 \pm 5.9a	1904 \pm 2.3a
	4.9	1948 \pm 4.7b	1338 \pm 4.7b	1072 \pm 3.5b	1383 \pm 1.8a	1443 \pm 2.9a	1726 \pm 3.5a	2558 \pm 4.7a	1160 \pm 5.9a	2172 \pm 3.5a
	6.3	1651 \pm 3.5b	1115 \pm 2.9b	624 \pm 2.3b	1889 \pm 5.3a	1591 \pm 2.3a	2498 \pm 5.3a	2454 \pm 2.3a	1487 \pm 4.1a	2618 \pm 4.7a
Mn	3.5	195.2 \pm 1.2b	5.9 \pm .59b	142.1 \pm 5.9b	238.2 \pm 4.7a	153.3 \pm 1.8a	136.9 \pm 3.5a	318.2 \pm 2.9a	74.5 \pm 2.4a	108.3 \pm 4.7a
	4.9	48.4 \pm 4.7b	3.4 \pm .59b	4 \pm .59b	89.1 \pm 5.2a	52.9 \pm 1.2a	71.9 \pm 3.2a	137.2 \pm 4.1a	21.1 \pm 2.9a	36.1 \pm 3.5a
	6.3	9 \pm 2.4b	38.6 \pm 4.7b	7.7 \pm 1.2b	56.1 \pm 2.9a	44.2 \pm 2.4a	24.1 \pm 2.4a	30.1 \pm 2.9a	36.2 \pm 3.5a	59.4 \pm 2.4a

Table 3. Continue

AI	3.5	135± 5.9b	87± 2.9b	549± 2.4b	235± 5.9b	175±2.9b	879± 5.2b	756± 3.5a	235± 2.9a	1560± 11.8a
	4.9	65± 13.3b	127±1.8b	342± 5.9b	107± 4.1b	155± 2.9b	657± 5.9b	178± 4.7a	564± 2.4a	1145± 2.9a
	6.3	48± 1.8b	97± 4.1b	108± 4.7b	96± 6.7b	118± 4.7b	435± 5.9b	130± 2.9a	390± 5.9a	775± 2.9a
N%	3.5	2.78± .05a	1.65± .02a	0.67± .01a	2.32± .04b	1.16±.04b	0.59± .05b	2.27± 0.04c	0.77± .04c	0.51± .04c
	4.9	2.77± .04a	1.69±.05 a	0.700± .01a	2.36± .04b	0.89± .05b	1.3± .02b	2.09± .05c	0.78± .05c	1.38± .05c
	6.3	2.36± .04a	1.59± .05a	1.3± .2a	2.57± .04b	0.93± .20b	1.48± .05b	1.39± .05c	1.01± .001c	1.2± .02c

Means ± SE (n =3) with different letter are significantly different at p<0.05 by LSD test within apple rootstocks