Effects of apple rootstocks on nutrient concentration in 'Honeycrisp' scions in the early orchard life

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Abstract

Rootstocks not only influence tree growth vigor, branch angle, biennial bearing, and productivity but also have a key role when gathering mineral nutrients from the soil and shuttling them into different sinks in the canopy. Determining tree nutrient requirements is urgently needed for effective management of high value cultivars such as 'Honeycrisp', which have high susceptibility to bitter pit. Therefore, identifying rootstocks with better nutrient uptake and more positive effects on fruit quality may represent the most economical long-term solution to many fruit quality problems associated with nutrient imbalances. This study compared the performance of two Malling (M.9T337 and M.26EMLA), one Budagovsky (B.10), eight Geneva® (G.11, G.202, G.214, G.30, G.41, G.890, G.935, G.969), and four Vineland (V.1, V.5, V.6, V.7) rootstocks with 'Honeycrisp' as the scion cultivar. The trial was planted in 2014 as a randomized complete design, with 10 single tree replications. M.9T337 was the most dwarfing rootstock of the trial, followed by G.11 and G.935. G.41 and G.202 were slightly larger, followed by B.10, M.26, G.969, G.214 and V.1. A larger vigorous group comprised V.6 and G.30. V.7, V.5, and G.890 were the most vigorous rootstocks of the trial. The largest fruits (327 g) were on G.11, whereas the smallest were on V.1 (244 g). G.890 had the highest cumulative yield (34 kg tree^{-1}), followed by G.30 (30 kg tree^{-1}), and G.969 (25 kg tree^{-1}). The lowest cumulative yield was observed on G.202 (11 kg tree^{-1}) and G.935 (9 kg tree^{-1}). N, Mg, Mg/Ca, and N/Ca were highly correlated with bitter pit, and the peel seemed to be more sensitive than flesh. With the highest yield efficiency, crop load and Ca concentration in peel, G.969 seemed to be a promising rootstock for 'Honeycrisp' type cultivars. Results from the current study may be used to improve nutrient management for different rootstocks for each nutrient.

Keywords: Ca, N, bitter pit, nutrient management, nutrient uptake, yield efficiency

INTRODUCTION

Apple (*Malus* × *domestica* Borkh.) orchards have experienced a steady increase in tree planting density over the last 50 years. Growers have moved from multiple leader trees on seedling rootstocks to super spindle systems on dwarfing stocks. Dwarfing apple rootstocks, especially M.9 and M.26, have made possible the transition of entire fruit growing sectors to higher tree density and training systems over the last 50 years.

New cultivars such as 'Honeycrisp' require a re-evaluation of promising rootstocks since the scion cultivar has low vigor (Robinson et al., 2011). In addition, 'Honeycrisp' is susceptible to various physiological disorders such as bitter pit (Rosenberger et al., 2001). These disorders are affected by crop load, and fertilization practices (Robinson and Lopez, 2012; Robinson et al., 2009; Telias et al., 2006).

Rootstock can also affect bitter pit and may do so through differential uptake of specific nutrients and the corresponding effects on fruit nutrient status (Fallahi et al., 1984; Fazio et al., 2015). Traditionally, nutrient deficiencies found in soils of fruit orchards have been addressed with the addition of different formulations of fertilizers delivered by multiple means (Fallahi et al., 1984; George et al., 2002). However, most fertilizer recommendations are not tailored to a

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specific rootstock, creating the potential of making such applications less efficient. The rapid adoption of new cultivars during the past 10 years has created an urgent need to identify rootstocks with better nutrient uptake and more positive effects on fruit quality, and to develop associated management practices to control severe fruit quality problems.

The aim of this study was to assess how different rootstocks may affect the vigor, yield, nutrient uptake and fruit quality of the weak scion cultivar 'Honeycrisp'.

MATERIALS AND METHODS

Trees, design and management

A rootstock trial was planted in 2014 at the New York State Agricultural Experiment Station (Geneva, NY, USA), using 'Honeycrisp' as the scion cultivar. Trees were planted in a randomized complete design, with 10 single tree replications. Tree spacing was 1.2×3.6 m. Rootstocks included 2 Malling: M.26 EMLA and M.9T337; 1 Budagovsky: B.10; 4 Vineland: V.1, V.5, V.6 and V.7; and 8 Cornell Geneva: G.11, G.202, G.214, G.30, G.41, G.890, G.935 and G.969. Trees were grown at Willow Drive Nursery and had 5-6 feathers at planting. After planting, trees were managed by removing one to two of the largest feathers and leaving the remaining feathers unpruned in year 1. In years 2 through 4, the leaders were left unheaded. Beginning in year 3, large diameter limbs (>2 cm) were removed back to the trunk with an angled cut to develop replacement limbs. Each year one to two branches larger than 2 cm were removed. Tree height was limited to 3.6 m. Only small lateral branches (<2 cm) were allowed to remain in the tree and they were each kept simple by removing sub-lateral branches to create a single axis for each branch.

The soil was a sandy clay loam with good water holding capacity, well drained and fertile with about 3% organic matter content. Soil pH was 6.8. The trees were trickle irrigated as needed during the growing season using the Cornell apple irrigation model based on a modified Penman-Monteith equation (NEWA.org) (Robinson et al., 2017). The trial was managed with conventional pesticides and fertilizers according to industry standards. Trees received 50 kg ha^{-1} N (calcium ammonium nitrate – CAN 17) and 80 kg ha^{-1} K_2O (KCl) annually in the spring. They also received 3 foliar sprays of urea at pink, petal fall and first cover, 1 spray of boron at pink, and 1 spray of zinc chelate at petal fall. Trees were hand-thinned to 4 fruit cm^{-2} of trunk-cross-sectional area (TCA) when fruits were 25 mm in diameter.

Performance measurements and quality analysis

Trunk circumference (30 cm above the graft union), yield and number of fruits were assessed every year. TCA and fruit size were then calculated. Crop load indicates number of fruits per unit TCA (cm^2). Yield efficiency represents yield (kg) per unit TCA (cm^2).

From seven rootstock replications, a 15-fruit sample was collected at the 1st pick. Fruit color, as a percentage of skin surface colored red (according to USDA color standards) was measured with an electronic weight size/color sorter (MAF Industries, Travers, CA). A 5-fruit sub-sample was then used to assess fruit quality and nutrient analysis, whereas the remaining 10 apples were stored. Flesh firmness (Fruit Texture Analyzer, QA Supplies LLC, Norfolk, Virginia) and soluble solids content (Atago USA Inc., Bellevue, Washington) were assessed as fruit quality parameters. Samples for storage were preconditioned 1 week at 10°C and then stored at 3°C for six months. After storage, all of the apples contained in each sample were individually examined for any external signs of superficial bitter pit. The incidence of biter pit of each sample was calculated as the percentage of fruit with bitter pit symptoms. Net yield was calculated as yield (kg $tree^{-1}$) free of bitter pit.

Nutrient analysis

Each fruit was cut longitudinally twice to produce two opposite, seedless, stemless, wedge-shaped segments which constituted the fruit sample and amounted to approximately 1/16th of the whole fruit mass. The segments from each sample were combined and immediately weighed prior to drying. Samples were oven-dried, ground into powder and shipped to the A&L Great Lakes laboratories in Fort Wayne, IN, for mineral analysis of several macro- and micro-mineral nutrients.

Data analysis

Response variables were modeled using linear mixed effect models. Mixed models including rootstock as fixed factor and rep as a random factor were built to separate treatment effects for the TCA, fruit size, yield, color, firmness, soluble solids, bitter pit, cumulative yield, cumulative crop load, and cumulative yield efficiency. Crop load was included as covariate to adjust fruit size. All mean separations were made by Tukey's HSD (P=0.05). A two-way hierarchical cluster using the Ward method was built in order to classify the rootstocks based on fruit bitter pit and nutrient concentration in fruit peel and flesh. For this purpose, we used the following variables: bitter pit (BP) and nutrient concentration of: B, Ca, K, Mg, Mn, N, P, K/Ca, (K+Mg/Ca), Mg/Ca, N/Ca, and P/Ca. All the data were standardized before analysis. Data were analyzed using the JMP statistical software package (Version 12; SAS Institute Inc., Cary, North Carolina).

RESULTS

M.9T337 was the most dwarfing rootstock of the trial, followed by G.11 and G.935 (Table 1). G.41 and G.202 were slightly larger, followed by B.10, M.26, G.969, G.214 and V.1. A larger vigorous group comprised V.6 and G.30. V.7, V.5, and G.890 were the most vigorous rootstocks of the trial. In general, fruit size was very good for all the rootstocks. The largest fruits (327 g) were on G.11, whereas the smallest were on V.1 (244 g). The highest yields in 2017 were harvested on G.890 (21 kg tree^{-1}) and on G.30 (20 kg tree^{-1}). G.935 and G.202 had the lowest yield (4-5 kg tree^{-1}) in 2017. Few significant differences regarding fruit color were observed among rootstocks. G.202, G.214 and V.5 had the reddest fruits (~64%), whereas the least were on G.11 (29%). No significant differences regarding fruit firmness, soluble solids, and bitter pit were observed among rootstocks. However, there was a trend for more bitter pit on G.11 and M.9T337, and less on G.202. G.890 had the highest cumulative yield (34 kg tree^{-1}), followed by G.30 (30 kg tree^{-1}), G.969 (25 kg tree^{-1}), V.7 (23 kg tree^{-1}), V.5 and V6 (22 kg tree^{-1}), B.10 (18 kg tree^{-1}), G.214 (17 kg tree^{-1}), G.41 and V.1 (16 kg tree^{-1}), M.26 (15 kg tree^{-1}), G.11 (14 kg tree^{-1}), M.9 (12 kg tree^{-1}), G.202 (11 kg tree^{-1}), and G.935 (9 kg tree^{-1}). The lowest cumulative yield was observed on G.202 (11 kg tree^{-1}) and G.935 (9 kg tree^{-1}). In terms of cumulative crop load and yield efficiency, G.969 had the highest values, followed by G.11, and B.10. The lowest values were on V.1, V.5, and G.935.

G.890 was the rootstock with the highest cumulative yield free of bitter pit during the first 4 years (2014-2017), followed by G.30, G.969, V.7, and V.5 (Figure 1). Taking into account bitter pit and fruit nutrient concentration, rootstocks were clustered within six different groups (Figure 2). Cluster 1 comprised B.10 and V.6; cluster 2 (G.41, M.9T337, M.26, and V.1); cluster 3 (G.30, V.5, and V.7); cluster 4 (G.202); cluster 5 (G.214, G.935, and G.969); and cluster 6 (G.11 and G.890). In addition clustering the variable values revealed which variables were connected. N in either peel or flesh, Mg, Mg/Ca, and N/Ca in peel were highly associated (correlated) among them and with bitter pit. Other nutrient ratios that were highly correlated were K/Ca, (K+Mg)/Ca, Mg/Ca, P/Ca, and N/Ca in flesh. The aforementioned nutrients seemed to be more related with bitter pit when in peel rather than in flesh, suggesting peel being more susceptible to bitter pit symptoms. Mn in flesh was highly correlated with B and Ca in either peel or flesh, but these nutrients were much less associated with bitter pit (Figure 2).

Higher bitter pit was observed on G.11, M.9T337, M.26, and V.1 (Figure 2). These rootstocks coincided to have high Mg concentration in peel. G.11 and G.890 were clustered together, both with similar content for the different nutrients, but slightly different in bitter pit and N content in fruit. G.969, G.935 and G.214 were the rootstocks that tended to have lower concentration of P, P/Ca, K, K/Ca, and (K+Mg)/Ca in peel. G.202 was clustered alone, having the lowest content of N, Mg, Mg/Ca, N/Ca, in peel and K/Ca, (K+Mg)/Ca,Mg/Ca, P/Ca and N/Ca in flesh among all rootstocks, which also coincided with the least bitter pit. In addition, high values of Ca in the flesh and B were observed for G.202. G.30, V.5 and V.7 were characterized for having low concentration of N in either peel or flesh. G.41, M.9T337, and M.26 had similar concentration of Mg in peel. B.10 and V.6 were the two rootstocks with the lowest B concentration.

DISCUSSION

Tree size was significantly affected by rootstock. M.9T337 was the most dwarfing rootstock of the trial at the 4th leaf, followed by G.11, G.935, and G.41, all slightly larger. These results are different than what we observed in a previous study at the 6th leaf. In that study, G.11 was significantly smaller than G.41 and M.9T337; and G.935 significantly larger than both G.41 and M.9T337 (Lordan et al., 2017). G.935 is usually reported to have a similar size as M.26 in previous trials once trees have reached maturity (Autio et al., 2011, 2013; Robinson et al., 2011), thus we may expect these results to change during the upcoming years, when trees will reach full mature stage. These differences in tree size affected yield and efficiency as well, with the highest cumulative yield (34 kg tree^{-1}) on the largest tree of the trial, G.890. Nevertheless, G.969 had higher yields than larger rootstocks. In terms of efficiency, G.969 had the highest cumulative crop load (12 fruit cm^{-2}) and yield efficiency (3.4 kg cm^{-2}) of the trial, significantly higher than V.1, V.6, and V.7, which were larger in terms of TCA for instance. These differences in yield and efficiency during tree establishment may have a significant role in the overall orchard profitability, since the effect of precocity on profitability is large at this stage (Lordan et al., 2018).

Regarding bitter pit and nutrient concentration in fruit, rootstocks were clustered within six different groups. Those with high concentration of N in fruit, either peel or flesh had high bitter pit, whereas those with the lowest had lower bitter pit. Also high values for N/Ca, K/Ca, (K+Mg)/Ca, Mg/Ca, P/Ca, P and Mg, had high bitter pit. G.969, which had high N concentration in fruit, was an exception and had low bitter pit. However, it was among the rootstocks with highest Ca concentration in fruit peel. Hence, these results seem to indicate that in situations where Ca in the peel is high, N concentration in fruit is not as important, or gets counterbalanced by the Ca.

Most fertilizer recommendations were not tailored to a specific rootstock, creating the potential of making such applications less efficient (more or less than specifically needed by the rootstock-scion combination) and potentially wasteful. This is evident when looking at the different rootstock clusters that we got in our study, which shows that certain rootstocks have a major influence on the uptake and delivery of certain nutrients while other rootstocks pare better for other types. This suggests that if growers keep using old nutrient recommendations developed for traditional rootstocks (M.9 or M.26) on newer rootstocks like G.969 or G.935, or even on new rootstocks that have critical different nutrient profiles (G.11 vs. G.202), they are probably wasting money and causing unnecessary nutrient imbalances in the orchard. Therefore, as suggested by Fazio et al. (2015), the potential of rootstocks to absorb and translocate nutrients to the scion must be used to match nutrient weaknesses or requirements of fruit.

Neilsen and Hampson (2014) reported a strong effect of year on leaf nutrient concentrations, which suggest that these trends may change once trees reach maturity. However, these results may be taken into account in order to improve yield efficiency and fruit quality during tree establishment. Since bitter pit is described as a Ca deficiency disorder (Rosenberger et al., 2004), several authors suggested Ca sprays to improve bitter pit control by increasing Ca concentration in fruit (Biggs and Peck, 2015; Cline and Gardner, 2005; Peryea et al., 2007; Torres et al., 2017). However, since 'Honeycrisp' is a weak growing cultivar, this may sometimes lead growers to increase N applications to enhance its growth, compromising bitter pit control. Therefore, the use of more vigorous rootstocks that have lower N/Ca ratios may improve 'Honeycrisp' performance. The high levels of N, Mg and K concentration in fruit for G.11, suggest that the current nutrient management that is done for M.9 or B.9 rootstocks may not be the most appropriate for these rootstocks. Other than bitter pit, results from the current study may be used to improve nutrient management for different rootstocks for each nutrient.

Table 1. Trunk cross-sectional area (TCA), adjusted fruit size, yield, fruit color, fruit firmness, soluble solids content (SS) and bitter pit (BP) for 2017, and cumulative yield, cumulative crop load, and cumulative yield efficiency for 2014-2017. Within each response variable means followed by different letters denotes significant differences (Tukey's honestly significant difference, $P \leq 0.05$). Rootstocks are ranked by TCA. Grey bars represent variable value.

Rootstock	TCA (cm2)	Adj. Fruit size (g)	Yield (kg/tree)	Color %	Firmness (kg)	SS (°Brix)	BP %	Cum. yield (kg/tree)	Cum. Crop load (fruit #/cm2)	Cum. Yield eff. (kg/cm2)
M.9T337	6 g	273 bcd	6 ef	38 ab	7.2 a	14.0	31	12 e	8.7 ab	2.5 ab
G.11	7 fg	327 a	7 def	29 b	6.7 a	13.8	35	14 de	9.4 ab	2.8 ab
G.935	7 fg	284 abcd	4 f	44 ab	7.1 a	14.0	18	9 e	6.4 b	1.8 b
G.41	8 efg	294 abc	11 cdef	55 ab	6.9 a	13.5	22	16 cde	7.8 ab	2.4 ab
G.202	8 efg	248 cd	5 f	64 a	7.4 a	13.8	4	11 e	6.7 b	1.9 b
B.10	9 defg	287 abcd	9 cdef	49 ab	7.0 a	13.7	19	17 cde	8.8 ab	2.6 ab
M.26	9 defg	305 ab	7 def	38 ab	6.7 a	13.9	26	15 de	7.7 b	2.3 ab
G.969	9 def	286 abcd	14 bc	49 ab	6.7 a	13.6	19	25 abc	12.0 a	3.4 a
G.214	10 de	276 bcd	10 cdef	62 a	7.0 a	13.8	18	17 cde	7.1 b	2.1 ab
V.1	11 cd	244 d	7 cdef	43 ab	7.0 a	13.6	24	16 cde	5.8 b	1.7 b
V.6	14 bc	285 abcd	13 bcde	48 ab	6.9 a	13.7	14	22 bcd	6.9 b	2.1 ab
G.30	14 b	298 ab	20 ab	55 ab	6.7 a	13.5	16	30 ab	8.3 ab	2.4 ab
V.7	15 ab	265 bcd	14 abcd	45 ab	7.0 a	13.9	13	23 bcd	6.5 b	1.9 b
V.5	16 ab	278 abcd	14 abc	63 a	7.3 a	14.0	9	22 bcd	5.9 b	1.8 b
G.890	18 a	304 ab	21 a	44 ab	6.8 a	13.8	23	34 a	7.7 ab	2.3 ab
P value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0017*	*0.0245*	*NS*	*NS*	*<0.0001*	*0.0002*	*0.0014*

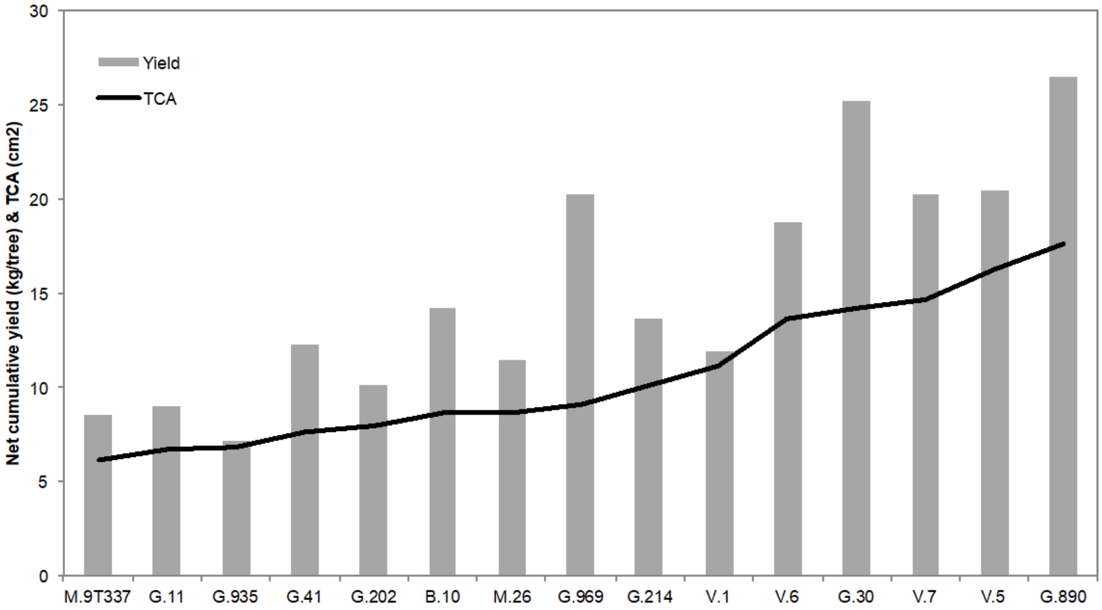

Figure 1. Net (free of bitter pit) cumulative yield (kg tree-1) over 2014-2017 and trunk cross-sectional area (TCA) in 2017 for each different rootstock at Geneva NY.

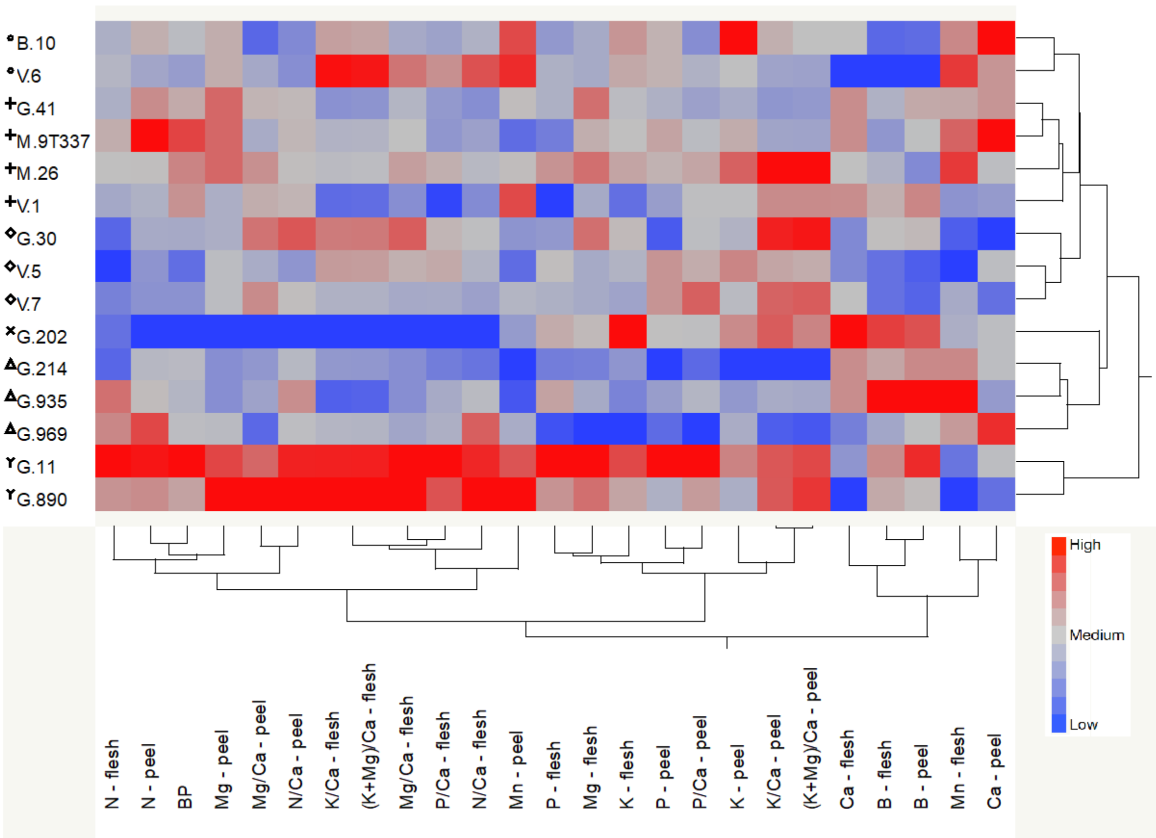

Figure 2. Clustering of the 15 rootstocks based on bitter pit (BP) and nutrient concentration of B, Ca, K, Mg, Mn, N, P, K/Ca, (K+Mg/Ca), Mg/Ca, N/Ca, and P/Ca in fruit flesh and peel.

CONCLUSIONS

The results of the current study provide useful information about how the main Malling, Budagovsky, Vineland, and Geneva rootstocks affect vigor, productivity, yield efficiency, and nutrient balance on a weak growing cultivar such as ‘Honeycrisp’ during establishment. This information should also be combined with the specific scion nutrient requirements to make fertilizer use more efficient. With the highest yield efficiency, crop load and Ca concentration in peel, G.969 seemed to be a promising rootstock for ‘Honeycrisp’ type cultivars.

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