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Budagovsky, Geneva, Pillnitz, and Malling Apple Rootstocks Affect 'Honeycrisp' Performance Over the First Five Years of the 2010 NC-140 'Honeycrisp' Apple Rootstock Trial

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Abstract

In 2010, an orchard trial of apple rootstocks was established at 13 locations in the United States, Canada, and Mexico using 'Honeycrisp' as the scion cultivar. Rootstocks included two named clones from the Budagovsky series (B.9, B.10), seven unreleased Budagovsky clones (B.7-3-150, B.7-20-21, B.64-194, B.67-5-32, B.70-6-8, B.70-20-20, and B.71-7-22), four named Cornell-Geneva clones [Geneva® 11 (G.11), Geneva® 41 (G.41), Geneva® 202 (G.202), and Geneva® 935 (G.935)], nine unreleased Cornell-Geneva clones (CG.2034, CG. 3001, CG.4003, CG.4004, CG.4013, CG.4214, CG.4814, CG.5087, and CG.5222), one named clone from the Pillnitz series (Supp.3), two unreleased Pillnitz clones (PiAu 9-90 and PiAu 51-11), and three Malling clones as controls (M.9 NAKBT337, M.9 Pajam 2, and M.26 EMLA). All trees were trained as Tall Spindles. After 5 years, the greatest mortality was for trees on CG.4814 (15%), with trees on all other rootstocks averaging 10% or less mortality. Tree size after 5 years allowed for a preliminary partitioning of these rootstocks in to size classes from sub-dwarf to semi-standard. B.70-20-20 was semi-standard, and B.7-20-21 and B.64-194 were large semi-dwarfs. B.7-3-150, B.67-5-32, B.70-6-8, G.202N, CG.4004, and PiAu 9-90 were moderate semi-dwarfs. CG.3001, CG.4814, CG.5087, CG.5222, and PiAu 51-11 were small semi-dwarfs. G.202TC (TC = liners from tissue culture), G.935N (N = liners from stool beds), G.935TC, CG.4013, CG.4214, M.9 Pajam 2, and M.26 EMLA were large dwarfs. B.10, G.11, G.41N, G.41TC, Supp.3, and M.9 NAKBT337 were moderate dwarfs, and B.9, CG.2034, and CG.4003 were small dwarfs. B.71-7-22 was sub-dwarf. B.70-20-20, B.7-20-21, and B.64-194were too vigorous for a high-density system, and conversely, B.71-7-22 was not vigorous enough. Among the six moderate semi-dwarf rootstocks, CG.4004 and G.202N performed best, using cumulative (2011-14) yield efficiency as the primary determinant of performance. Among the five small semi-dwarf rootstocks, CG.5087, CG.4814, and CG.3001 performed best. Of the seven rootstocks characterized as large dwarfs, G.935, CG.4214, and G.202TC resulted in the greatest cumulative yield efficiency. Of the six rootstocks in the moderate dwarf class, G.11, M.9 NAKBT337, and G.41N performed best, and CG.4003 and B.9 resulted in the greatest cumulative yield efficiency among the three small dwarf rootstocks.

One of the most critical elements of any apple orchard is the rootstock, particularly in high-density systems where the economic risks and potential returns are the highest. For more than 40 years, the NC-140 Multi-State Research Project has involved researchers from throughout North America to evaluate fruit-tree performance on different rootstocks, with the principle goal of helping orchardists optimize their rootstock selection. NC-140 greatly enhances the evaluation process with uniform trials at diverse locations including a wide variety of soils and climates.

New apple rootstocks are made available regularly from a number of sources with the potential of providing greater growth control, enhanced precocity, higher yield, improved adaptability to environmental conditions, and enhanced pest resistance. Numerous new rootstocks are available for evaluation from the Budagovsky, Cornell-Geneva, and Pillnitz breeding programs.

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Budagovsky rootstocks are from the Michurinsk State Agrarian University in Michurinsk, Tambov Region, Russia. The breeding program began with I.V. Budagovsky making crosses in 1938, with the principle goal of developing rootstocks with enhanced winter hardiness (Cummins and Aldwinckle, 1983). He released one of the best known Budagovsky Rootstocks, B.9, in 1962. NC-140 first tested Budagovsky rootstocks (B.9 and B.490) in the 1984 NC-140 Apple Rootstock Trial (NC-140, 1996) and has included Budagovsky rootstocks in numerous trials in the ensuing years (Autio et al., 2001; 2013; Marini et al., 2001a; 2001b; 2006; 2014; Robinson et al., 2007).

The Cornell-Geneva Apple Rootstock Breeding Program is managed jointly by Cornell University and the United States Department of Agriculture. Several rootstocks have been released from this program, most with a high degree of disease resistance, particularly to the fire blight bacterium (*Erwinia amylovora*). Many of these rootstocks have been evaluated by NC-140 (Autio et al., 2011a; 2011b, 2013; Marini et al., 2014; Robinson et al., 2007).

The Pillnitz series of rootstocks (PiAu and Supporter) are from the Institut für Obstforschung Dresden-Pillnitz, Germany, (Fischer, 1997). The original material for this program came from discontinued breeding programs in Muncheberg and Naumburg (Cummins and Aldwinckle, 1983). These earlier programs sought better horticultural characteristics and pest resistance. NC-140 has evaluated Supporter 1, 2, 3, and 4 and PiAu 51-4, 51-11, and 56-83 (Autio et al., 2011a; 2011b; 2013; Marini et al., 2014).

The objectives of this trial were to assess and compare the performance of several Budagovsky, Cornell-Geneva, and Pillnitz rootstocks at multiple sites in North America, exposing the rootstocks to diverse climate, soil, and management conditions.

Materials and Methods

In spring, 2010, an orchard trial of 31 apple rootstocks was established at 13 sites in North America (Table 1) under the coordination of the NC-140 Multi-State Research Committee. 'Honeycrisp' was used as the scion cultivar, and trees were propagated by Willow Drive Nursery (Ephrata, WA, USA). Rootstocks included two named clones from the Budagovsky series (B.9, B.10), seven unreleased Budagovsky clones (B.7-3-150, B.7-20-21, B.64-194, B.67-5-32, B.70-6-8, B.70-20-20, and B.71-7-22), four named Cornell-Geneva clones [Geneva® 11 (G.11), Geneva® 41 (G.41), Geneva® 202 (G.202), and Geneva® 935 (G.935)], nine unreleased Cornell-Geneva clones (CG.2034, CG. 3001, CG.4003, CG.4004, CG.4013, CG.4214, CG.4814, CG.5087, and CG.5222), one named clone from the Pillnitz series (Supp. 3), two unreleased Pillnitz clones (PiAu 9-90 and PiAu 51-11), and three Malling series clones to serve as controls (M.9 NAKBT337, M.9 Pajam 2, and M.26 EMLA). Additionally, there were both stool-bed-produced (denoted with an N following the rootstock name) and tissue-culture-produced (denoted with a TC following the rootstock name) liners used for trees on G.41, G.202, and G.935. Please note that this trial is very similar in nature to the 2010 NC-140 'Fuji' Apple Rootstock Trial (Autio et al., 2017), except for the cultivar, planting location, and tree spacing.

The trial was planted in British Columbia (Canada), Chihuahua (Mexico), Colorado, Iowa, Massachusetts, Michigan, Minnesota, New Jersey, Nova Scotia (Canada), New York, Ohio, Utah, and Wisconsin. Cooperators, their contact information, and specific locations for this trial are listed in Table 1. The experiment was arranged as a randomized complete block design at each location, with four replications. Each replication included one plot per rootstock, and each rootstock plot included one to three trees. Trees were spaced 1.2 x 3.6 m and trained as tall spindles (Robinson and Hoying, 2011). Pest management, irrigation, and fertilization followed local recommendations at each site.

Trunk circumference, 25 cm above the

Table 1. Cooperators and sites in the 2010 NC-140 Honeycrisp Apple Rootstock Trail.

Site	Planting location	NC-140 Cooperator	Cooperator affiliation and address
British Columbia (BC)	Summerland	Cheryl Hampson	Summerland Research & Development Centre, Agric. & Agri-Food Canada , P.O. Box 5000, Summerland, BC V0H 1Z0 Canada
Chihuahua (CH)	Cuauhtémoc	Rafael Parra Quezada	Universidad Autonoma de Chihuahua, Facultad de Ciencias Agrotecnologicas, Cuauhtémoc, Chih. 31527, Mexico
Colorado (CO)	Grand Junction	Ioannis Minas	Western Colorado Research Center, Colorado State University, 3168 B 1/2 Road, Grand Junction, CO 81503 USA
Iowa (IA)	Ames	Diana Cochran	Department of Horticulture, 125 Horticulture Hall, Iowa State University, Ames, IA 50011 USA
Massachusetts (MA)	Belchertown	Wesley Autio	Stockbridge School of Agriculture, 205 Paige Laboratory, University of Massachusetts, Amherst, MA 01003 USA
Michigan (MI)	Sparta	Gregory Lang	Department of Horticulture, Michigan State University, East Lansing, MI 48824 USA
Minnesota (MN)	Excelsior	Emily Hoover	Department Horticultural Science, University of Minnesota, 1970 Folwell Ave, St. Paul, MN 55108 USA
New Jersey (NJ)	Pittstown	Winfred Cowgill	Rutgers Cooperative Extension, P.O. Box 2900, Flemington, NJ 08822 USA
New York (NY)	Geneva	Terence Robinson	Department of Horticulture, Cornell University, NYSAES, Geneva, NY 14456 USA
Nova Scotia (NS)	Kentville	Suzanne Blatt	Kentville Research & Development Centre, Agric. & Agri-Food Canada , 32 Main St, Kentville, Nova Scotia, B4N 1J5 Canada
Ohio (OH)	Carroll	Diane Miller	Department of Horticulture & Crop Science, OARDC, Ohio State University, 1680 Madison Ave., Wooster, OH USA
Utah (UT)	Santaquin	Brent Black	Plant, Soil, and Climate Department, Utah State University, Logan, UT 84322 USA
Wisconsin (WI)	Sturgeon Bay	Matt Stasiak	Peninsular Agricultural Research Station, University of Wisconsin, 4312 Hwy 42, Sturgeon Bay, WI 54235 USA

bud union, was measured in Oct., 2014 and used to calculate trunk cross-sectional area (TCA). Also in Oct., 2014, tree height was measured, and canopy spread was assessed by averaging the in-row and across-row canopy widths. Root suckers were counted and removed each year. 'Honeycrisp' zonal chlorosis was assessed as the percent of the canopy affected in 2012, 2013, and 2014.

Yield was assessed in 2011 through 2014; however, very few sites harvested any fruit in 2011. Yield efficiency ($kg \cdot cm^{-2}$ TCA) in 2014 and on a cumulative basis were calculated using 2014 TCA. Fruit weight was assessed on a 50-apple sample (or available crop) in 2012, 2013, and 2014.

Data were subjected to analysis of variance with the MIXED procedure of the SAS statistical analysis software (SAS Institute, Cary, NC). In the analyses, fixed main effects were rootstock and site. Block (within site) was a random, nested effect. In nearly all cases, the interaction of rootstock and site was significant. Rootstock differences within site were assessed (for all sites individually and including all rootstocks, also by the MIXED procedure) for survival (through 2014), TCA (2014), cumulative yield per tree (2011-14), cumulative yield efficiency (2011-14), and average fruit weight (2012-14). Because of the large number of treatments included and the variation in the number of observations per treatment, average Tukey's HSD values ($P = 0.05$) were calculated using the error MS from PROC GLM and the average number of observations per rootstock. Statistically, this approach is inadequate, but it is very conservative in assessing differences and allows for a reasonable look at rootstock effects.

Results

Site and Rootstock Differences at Planting. All trees were produced by one nursery, but some variation in tree size occurred. At planting, largest trees, as assessed by trunk cross-sectional area (TCA), were in New Jersey, and the smallest were in British Columbia (Table 2). Although some variation in nursery branch development existed, cooperators removed different numbers of these branches. At planting and after the initial pruning, the largest number of branches (11.9 per tree) remained on trees in New Jersey, and the smallest number remained (1.1

Table 2. Site means for trunk cross-sectional area, number of branches after pruning, and height of the graft union at planting of Honeycrisp apple trees in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Site	Trunk cross-sectional area at planting (2010, cm^2)	Number of branches at planting	Height of graft union at planting (mm)
BC	1.2	1.1	109
MA	1.6	11.3	147
MI	1.4	4.7	93
MN	1.7	9.8	66
NJ	1.9	11.9	161
NS	1.6	---	82
NY	1.3	9.2	115
OH	---	10.4	63
UT	1.3	6.3	103
WI	1.3	5.6	137
Average HSD	0.6	5.3	13

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

Table 3. Rootstock means for trunk cross-sectional area, number of branches, and height of the graft union at planting of Honeycrisp apple trees in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. Means are based on data from BC, MA, MI, MN, NJ, NS, NY, OH, UT, and WI. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	Trunk cross-sectional area at planting (2010, cm^2)	Number of branches at planting	Height of graft union at planting (mm)
B.9	1.2	5.6	107
B.10	1.4	6.6	106
B.7-3-150	1.3	4.0	116
B.7-20-21	2.0	9.3	125
B.64-194	1.9	8.1	125
B.67-5-32	1.5	5.6	103
B.70-6-8	1.6	6.6	105
B.70-20-20	2.4	11.9	128
B.71-7-22	0.6	0.2	111
G.11	1.4	10.5	118
G.41N	1.3	6.4	106
G.41TC	0.9	3.4	78
G.202N	1.9	12.1	102
G.202TC	1.5	11.1	86
G.935N	1.6	11.5	103
G.935TC	1.2	7.8	85
CG.2034	1.2	6.9	88
CG.3001	1.6	12.6	97
CG.4003	1.1	6.3	111
CG.4004	1.6	15.4	108
CG.4013	1.3	9.6	89
CG.4214	1.3	13.2	108
CG.4814	1.7	13.6	107
CG.5087	1.7	14.6	114
CG.5222	1.8	10.6	87
Supp.3	1.0	4.9	105
PiAu 9-90	2.6	17.4	135
PiAu 51-11	1.9	9.2	127
M.9 NAKBT337	1.3	8.4	121
M.9 Pajam 2	1.5	8.5	119
M.26 EMLA	1.2	5.0	114
Average HSD	0.2	2.2	16

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

per tree) in British Columbia (Table 2). Likewise, planting depth varied with location, with the average graft union height greatest in New Jersey and least in Ohio (Table 2).

Rootstock also resulted in significant differences in the TCA at planting, the number of branches remaining after initial pruning, and the height of the graft union (Table 1). Likely as an expression of tree vigor, the largest trees (in TCA) and those with the great-

Table 4. Site means for survival, trunk cross-sectional area, root suckers, tree height, canopy spread, yield per tree, yield efficiency, fruit size, and zonal chlorosis of Honeycrisp apple trees in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Site	Survival (2014, %)	Trunk cross-sectional area (2014, cm^2)	Cumulative root suckers (2010-14, no./tree)	Tree height (cm)	Canopy spread (cm)	Yield per tree (2014, kg)	Cumulative yield per tree (2011-14, kg)	Yield efficiency (2014, kg/cm^2 TCA)	Cumulative yield efficiency (2011-14, kg/cm^2 TCA)	Fruit weight (2014, g)	Average Fruit weight (2012-14, g)	Zonal chlorosis (%) 2012	Zonal chlorosis (%) 2013	Zonal chlorosis (%) 2014
BC	100	10.1	6.8	277	120	12.9	22.2	1.4	2.4	302	284	---	57	---
MA	98	13.5	7.4	299	188	8.9	24.8	0.8	2.0	230	222	---	54	41
MI	99	12.1	1.2	257	127	6.7	17.2	0.7	1.6	200	200	---	31	69
MN	100	13.7	0.1	292	186	8.3	17.9	0.7	1.5	174	182	14	49	43
NJ	98	18.1	3.6	335	277	9.7	23.7	0.6	1.4	322	280	---	---	16
NS	87	13.0	0.2	273	115	10.7	26.0	0.9	2.2	164	170	19	41	66
NY	99	15.3	5.5	321	170	8.0	33.0	0.6	2.5	259	239	22	20	25
OH	92	12.4	0.8	231	112	11.5	13.9	1.0	1.3	178	178	---	---	---
UT	95	11.9	1.3	208	129	13.2	15.8	1.2	1.4	---	176	---	---	---
WI	99	12.6	2.9	282	176	8.1	30.8	0.7	2.7	173	230	25	24	15
Average HSD	8	3.5	2.9	27	21	4.8	7.2	0.3	0.4	31	21	11	15	12

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

est number of branches were on PiAu 9-90, and the smallest with the fewest branches were on B.71-7-22. Graft-union height at planting was likely affected by the distance between the graft union and lateral roots and the length of the rootstock shank, both of which were very small in a few cases. Most (77% of the rootstock treatments) trees were able to be planted at the recommended level with the graft union between 100 and 150mm above the soil. Trees on PiAu 9-90 were planted such that the average graft union height was 135 mm. Seven combinations (23%) were planted with union heights less than 100 mm, with the lowest for trees on G.41TC.

Site Effects on Tree Performance. Over the first 5 years, site (Table 4) and rootstock (Table 5) affected all aspects of tree performance. Table 4 includes data only from the ten sites with a complete set of rootstocks. Colorado was missing two and Iowa was missing one rootstock treatment at the initiation of the experiment, and tree death resulted in complete loss of one rootstock treatment in Chihuahua. Data from these three sites were excluded from the analyses presented in Tables 4 and 5. Results from Chihuahua, Colorado, and Iowa, however, are included in the tree performance data presented by location in Tables 6-11.

Among the 10 sites included in Table 4, the highest mortality occurred in Nova Scotia (13%, Table 4); however, among all sites greatest mortality was in Chihuahua, with only 77% of the trees surviving for the first 5 years (Table 6). Survival was 100% in British Columbia, Minnesota (Table 4), and Colorado (Table 6).

Site-related tree characteristics are presented in Table 4. After 5 years, the largest TCA was recorded for trees in New Jersey and the smallest for trees in British Columbia. Trees were also tall-

Table 5. Rootstock means for survival, trunk cross-sectional area, root suckers, tree height, canopy spread, yield per tree, yield efficiency, fruit size, and zonal chlorosis of Honeycrisp apple trees in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. Means are based on data from BC, MA, MI, MN, NJ, NS, NY, OH, UT, and WI. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	Survival (2014, %)	Trunk cross-sectional area (2014, cm^2)	Cumulative root suckers (2010-14, no./tree)	Tree height (cm)	Canopy spread (cm)	Yield per tree (2014, kg)	Cumulative yield per tree (2011-14, kg)	Yield efficiency (2014, kg/cm^2 TCA)	Cumulative yield efficiency (2011-14, kg/cm^2 TCA)	Fruit weight (2014, g)	Average fruit weight (2012-14, g)	Zonal chlorosis (%) 2012	2013	2014
B.9	100	6.5	2.5	216	110	5.8	14.6	0.9	2.3	208	201	14	30	30
B.10	96	10.0	0.8	256	143	8.5	21.9	0.9	2.2	237	223	10	26	32
B.7-3-150	100	17.5	0.9	311	171	11.7	23.3	0.7	1.4	241	234	15	25	26
B.7-20-21	100	20.1	1.1	296	170	11.8	25.0	0.6	1.3	227	218	17	30	30
B.64-194	98	21.0	0.2	316	184	10.7	25.4	0.6	1.2	247	230	15	24	25
B.67-5-32	100	18.6	1.0	311	163	7.9	18.3	0.5	1.0	244	234	18	27	29
B.70-6-8	99	17.6	0.5	300	166	11.0	24.1	0.7	1.4	230	221	13	27	29
B.70-20-20	99	33.9	3.3	366	222	12.0	23.8	0.4	0.7	232	234	12	20	23
B.71-7-22	91	2.0	1.9	149	58	1.6	4.1	0.8	2.0	183	189	16	45	42
G.11	99	9.2	2.1	267	155	10.5	23.4	1.2	2.6	228	219	21	45	32
G.41N	95	10.1	0.4	265	152	10.0	24.0	1.0	2.4	238	228	18	35	32
G.41TC	95	9.4	1.4	279	157	8.5	18.4	0.9	2.0	233	224	25	38	42
G.202N	95	17.6	7.0	308	187	13.8	30.2	0.8	1.8	230	228	25	31	38
G.202TC	98	10.8	4.8	279	156	9.8	22.6	1.0	2.1	206	198	29	43	38
G.935N	90	12.2	4.2	285	175	12.9	29.2	1.1	2.4	209	207	26	51	38
G.935TC	96	10.4	4.8	266	162	10.5	24.1	1.1	2.3	213	207	29	57	47
CG.2034	93	7.0	1.3	249	123	6.2	15.1	0.9	2.2	220	214	22	57	47
CG.3001	90	14.5	0.9	288	189	11.2	30.2	0.8	2.1	239	228	25	43	44
CG.4003	98	7.5	1.0	247	128	8.7	19.3	1.2	2.6	203	199	25	41	35
CG.4004	98	17.2	3.9	321	192	15.0	35.4	0.9	2.0	243	235	18	27	36
CG.4013	97	12.5	4.5	284	169	7.9	18.6	0.7	1.6	216	210	27	48	50
CG.4214	99	11.5	8.4	299	171	10.3	26.0	1.0	2.4	221	217	30	45	48
CG.4814	85	13.5	5.9	280	182	13.0	28.6	1.0	2.2	209	211	41	56	50
CG.5087	97	13.0	3.0	292	184	12.2	29.4	0.9	2.2	211	206	30	42	50
CG.5222	94	14.4	7.1	285	171	11.0	24.9	0.8	1.8	216	213	20	40	44
Supp.3	94	8.8	1.7	249	145	8.2	18.9	1.0	2.2	218	211	20	53	55
PiAu 9-90	100	17.3	0.7	287	166	5.6	15.6	0.3	0.9	185	176	60	64	68
PiAu 51-11	100	15.2	1.6	279	162	8.7	20.0	0.6	1.4	242	231	23	39	40
M.9 NAKBT337	100	9.6	4.1	253	145	10.8	22.4	1.2	2.4	224	222	16	41	34
M.9 Pajam 2	100	10.6	8.6	260	148	9.7	21.7	0.9	2.0	212	209	19	42	43
M.26 EMLA	99	11.6	2.6	263	152	8.3	19.7	0.8	1.7	222	218	20	32	38
Average HSD	10	2.2	3.0	22	15	3.2	3.7	0.2	0.3	32	22	13	14	13

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

Table 6. Survival (2014, %) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	BC	CH	CO	IA	MA	MI	MN	NJ	NS	NY	OH	UT	WI
B.9	100	100	100	100	100	100	100	100	100	100	100	100	100
B.10	100	88	100	100	100	100	100	100	88	89	100	85	100
B.7-3-150	100	100	100	100	100	100	100	100	100	100	100	100	100
B.7-20-21	100	92	100	100	100	100	100	100	100	100	100	100	100
B.64-194	100	41	100	100	100	100	100	100	100	100	84	100	100
B.67-5-32	100	79	100	100	100	100	100	100	100	100	100	100	100
B.70-6-8	100	92	100	100	92	100	100	100	100	100	100	100	100
B.70-20-20	100	100	100	100	100	100	100	92	100	100	100	100	100
B.71-7-22	100	100	100	100	100	100	100	80	82	100	68	100	83
G.11	100	58	100	100	100	100	100	100	89	100	100	100	100
G.41N	100	81	100	100	100	100	100	100	69	100	100	91	90
G.41TC	100	100	100	100	100	100	100	100	50	100	100	100	100
G.202N	100	29	100	100	100	100	100	100	82	100	68	100	100
G.202TC	100	45	100	100	100	100	100	100	100	100	84	100	100
G.935N	100	100	---	100	100	100	100	100	66	100	67	78	89
G.935TC	100	100	100	100	100	100	100	100	100	100	100	67	100
CG.2034	100	39	100	100	100	100	100	100	100	100	66	67	100
CG.3001	100	0	100	100	50	100	100	100	45	100	100	100	100
CG.4003	100	59	100	100	100	100	100	100	75	100	100	100	100
CG.4004	100	100	100	100	100	100	100	100	100	100	75	100	100
CG.4013	100	50	---	100	100	100	100	66	100	100	100	100	100
CG.4214	100	70	100	100	100	100	100	100	100	100	100	86	100
CG.4814	100	55	100	100	100	86	100	100	14	100	50	100	100
CG.5087	100	100	100	100	100	100	100	100	100	100	100	67	100
CG.5222	100	76	100	---	100	100	100	100	42	100	100	100	100
Supp.3	100	65	100	33	100	80	100	100	100	83	80	100	100
PiAu 9-90	100	100	100	100	100	100	100	100	100	100	100	100	100
PiAu 51-11	100	100	100	100	100	100	100	100	100	100	100	100	100
M.9 NAKBT337	100	92	100	100	100	100	100	100	100	100	100	100	100
M.9 Pajam 2	100	92	100	100	100	100	100	100	100	100	100	100	100
M.26 EMLA	100	100	100	100	100	100	100	100	100	88	100	100	100
Average HSD	---	10	---	20	18	22	---	27	58	25	53	43	22

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

est with the widest canopy in New Jersey, but were shortest in Utah and with the narrowest canopy in Ohio. Root suckering was greatest in Massachusetts and least in Minnesota. The zonal chlorosis typical of 'Honeycrisp' was not consistent from site to site or year to year, with no discernable patterns.

Site-related fruiting characteristics are presented in Table 4. Yield per tree in 2014 was greatest in Utah and least in Michigan, but on a cumulative basis (2011-14), yield per tree was greatest in New York and least in Utah. Yield efficiency in 2014 was highest in British Columbia and lowest in New Jersey and New York. Cumulative yield efficiency (2011-14) was highest in Wisconsin and lowest in Ohio. Fruit weights in 2014 and on average (2012-14) were highest in New Jersey and lowest in Nova Scotia.

Rootstock Effects on Tree Performance. Survival was affected by rootstock (Tables 5 and 6). Percent survival was lowest for trees on CG.4814 (85%); however, only three out of the ten core sites (or four out of all 13 sites) experienced any loss of trees on CG.4814 (Table 6). Among the 10 core sites, trees on B.9, B.7-3-150, B.7-20-21, B.67-5-32, PiAu 9-90, PiAu 51-11, M.9 NAKBT337, and M.9 Pajam 2 experienced no tree loss in the first 5 years of this trial. Where the reason for tree loss was determined, the most common causes were graft union failure and fireblight. Graft union failure was the reason for 21 trees (B.10, B.71-7-22, G.11, G.41N, G.41TC, G.202N, G.935N, G.935TC, CG.4003, CG.4814, and CG.5222) lost in Nova Scotia, 2 trees (B.10 and M.26 EMLA) in New York, 1 tree (CG.5087) in Utah, and 3 trees (B.71-7-22, G.41N, and G.935N) in Wisconsin. Fireblight resulted in the death of 6 trees (B.64-194, B.70-6-8, CG.4003, CG.4013, and CG.4814) in Chihuahua, 1 tree (Supp.3) in New York, and 1 tree (B.10) in Utah. Winter injury caused the death of 4 out of 6 trees on Supp.3 in Iowa.

TCA, tree height, and canopy spread were affected similarly by rootstock (Table 5). Trees on B.71-7-22 were the smallest, and those on B.70-20-20 were the largest. These two rootstocks produced trees that were well outside of the range of sizes produced by other rootstocks. B.71-7-22 could be considered sub-dwarf in vigor, and B.70-20-20 likely is semi-standard or standard in vigor. At this point in the trial, the other rootstocks can be grouped very roughly by vigor class. Small dwarfs included B.9, CG.2034, and CG.4003. Moderate dwarfs included Supp.3, G.11, M.9 NAKBT337, G.41TC, B.10, and G.41N. Large dwarfs included M.9 Pajam 2, G.935TC, G.202TC, CG.4214, M.26 EMLA, G.935N, and CG.4013. Small semi-dwarfs included CG.5087, CG.4814, CG.5222, CG.3001, and PiAu 51-11, and moderate semi-dwarfs included CG.4004, B.70-6-8, PiAu 9-90, B.7-3-150, G.202N, and B.67-5-32. B.64-194 and B.7-20-21 were large semi-dwarfs.

It is interesting to note the significant difference in tree size between G.202N and G.202TC. G.202TC resulted in trees of the expected vigor, and trees on G.202N were much larger than expected, possibly showing the result of a propagation error. The relative rootstock effects on TCA were similar across sites (Table 7).

Root suckering was affected by rootstock (Table 5), with most resulting in very little suckering. Somewhat greater rootstock suckering was induced by G.202TC, G.935TC, G.935N, M.9 NAKBT337, CG.4013, CG.4004, and B.70-20-20. The greatest amount of root suckering came from M.9 Pajam 2, CG.4214, CG.5222, G.202N, and CG.4814.

In 2014 and cumulatively (2011-14), the greatest yields were harvested from trees on CG.4004, and the smallest yields were from trees on B.71-7-22 (Table 5). Within the small dwarf category, the greatest yields (2014 and cumulatively) were from trees on CG.4003, and lowest were from trees on B.9. Among the moderate dwarfs, the greatest yields in 2014 were from trees on M.9 NAKBT337 and cumulatively from trees on G.41N. The lowest yields (2014 and cumulatively)

Table 7. Trunk cross-sectional area (2014, cm^2) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	BC	CH	CO	IA	MA	MI	MN	NJ	NS	NY	OH	UT	WI
B.9	5.4	5.6	6.9	5.5	6.3	6.9	7.3	5.5	8.1	6.3	6.2	6.5	7.0
B.10	8.1	8.7	13.8	8.9	10.4	9.8	10.1	9.9	9.7	12.2	10.1	10.1	9.5
B.7-3-150	11.5	11.7	22.4	20.6	18.0	14.7	21.2	24.8	13.6	21.5	16.9	17.4	15.9
B.7-20-21	15.1	10.8	27.3	18.7	17.3	16.2	21.5	28.9	22.1	22.4	19.4	18.0	20.0
B.64-194	11.5	12.1	31.0	17.1	21.7	21.4	22.2	26.1	23.2	22.7	20.3	17.4	23.4
B.67-5-32	14.2	10.7	27.1	20.7	19.8	21.7	20.4	23.6	16.6	18.1	18.9	16.0	17.1
B.70-6-8	11.4	11.1	22.7	19.8	19.9	13.6	19.6	23.4	14.3	23.0	18.3	16.6	15.7
B.70-20-20	26.0	16.5	49.4	21.7	34.7	28.4	38.8	46.8	30.3	35.9	31.5	34.0	32.6
B.71-7-22	1.5	3.5	3.6	3.2	1.8	2.6	3.3	2.0	1.2	2.9	2.3	0.0	2.4
G.11	6.6	7.9	12.3	10.9	8.6	9.5	9.9	13.0	7.6	10.1	7.1	10.1	9.9
G.41N	9.3	6.8	15.4	9.4	9.1	9.6	11.6	11.4	10.0	12.1	9.2	7.8	11.1
G.41TC	8.0	6.8	13.7	10.5	8.6	11.0	12.2	12.9	8.9	9.0	3.9	10.3	9.8
G.202N	14.4	9.3	13.6	19.7	20.1	14.0	18.4	23.8	17.5	18.2	16.6	14.7	18.1
G.202TC	7.7	6.8	15.3	10.9	12.4	9.6	11.8	13.2	9.7	15.8	8.9	10.2	9.0
G.935N	10.3	7.0	---	10.9	12.7	10.8	12.2	16.1	10.5	14.8	11.2	10.7	13.2
G.935TC	7.2	5.1	14.9	7.8	9.2	9.7	11.1	15.7	11.5	12.1	9.1	7.1	11.2
CG.2034	7.0	5.8	8.7	7.9	6.7	6.4	6.6	8.6	7.4	6.0	4.8	8.8	7.3
CG.3001	12.1	---	23.0	17.3	20.7	9.5	11.4	21.2	14.6	18.0	13.5	13.3	11.0
CG.4003	5.6	6.5	10.7	7.9	7.5	6.8	8.3	9.4	6.9	8.8	6.3	7.0	8.4
CG.4004	13.5	10.5	18.4	13.8	16.9	15.1	18.7	21.6	22.6	17.6	16.2	12.2	17.6
CG.4013	7.9	11.5	---	15.7	11.8	13.3	10.1	20.4	11.1	17.8	15.0	10.6	6.7
CG.4214	7.0	5.5	11.6	11.1	13.8	12.1	12.1	16.1	12.0	14.0	10.3	8.2	9.4
CG.4814	11.1	8.2	14.3	17.8	12.6	12.0	13.9	21.2	14.6	15.5	11.9	9.4	13.0
CG.5087	12.5	7.2	15.6	12.2	12.4	11.2	13.5	19.8	11.6	15.7	12.1	6.8	14.0
CG.5222	12.2	6.7	19.1	---	15.5	12.8	11.9	18.2	17.3	14.4	17.4	12.7	11.5
Supp.3	7.1	7.6	16.0	10.0	8.1	8.2	7.4	13.3	8.5	11.5	7.7	8.5	7.3
PiAu 9-90	14.5	11.3	23.4	12.0	16.4	13.1	13.2	28.5	15.7	23.3	15.2	20.1	13.2
PiAu 51-11	8.3	10.8	20.3	18.2	15.4	15.8	15.2	25.0	13.6	18.4	13.3	12.8	13.8
M.9 NAKBT337	7.2	7.2	13.3	9.7	10.0	8.8	9.8	13.0	7.8	11.8	9.6	9.0	9.1
M.9 Pajam 2	8.8	7.1	15.3	12.3	9.2	10.4	9.7	13.7	9.5	12.0	10.6	10.3	12.2
M.26 EMLA	9.7	8.0	14.1	13.1	9.7	11.2	11.2	15.7	13.3	12.4	11.1	11.0	10.4
Average HSD	5.2	3.8	11.4	10	7.3	6.2	3.8	5.6	8.2	6.9	5.5	11.0	7.4

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

were from trees on Supp.3. Among the large dwarfs, the greatest yields in 2014 and cumulatively were from trees on G.935N, and the lowest were from trees on CG.4013. Among the small semi-dwarfs, the largest yields in 2014 were from trees on CG.4814 and cumulatively from trees on CG.3001.Lowest yields in 2014 and cumulatively were from trees on PiAu 51.11. Among the moderate semi-dwarfs, greatest yields (2014 and cumulatively) were from trees on CG.4004, and the lowest were from trees on PiAu 9-90. The two large semi-dwarfs (B.64-194 and B.7-20-21) yielded similar in 2014 and cumulatively. Site variations in rootstock effects on cumulative yield are presented in Table 8.

In 2014, the most yield efficient trees were on M.9 NAKBT337, G.11, and CG. 4003, and the least efficient trees were on PiAu 9-90 (Table 5). Cumulatively (2011-14), the most yield efficient trees were on G.11 and CG.4003, and the least efficient were on B.70-20-20 (Table 5). Among the small dwarfs, the most yield efficient trees (2014 and cumulatively) were on CG.4003. Among the moderate dwarfs, the most efficient trees in 2014 were on M.9 NAKBT337 and G.11, and the least efficient were on B.10, and G.41TC. Cumulatively among the moderate dwarfs, the most efficient were on G.11, and the least efficient were on B.10 and Supp.3. For the large dwarfs, the most yield efficient trees in 2014 were on G.935 (N and TC), and cumulatively, the most efficient were on G.935N and CG.4214. The least efficient (2014 and cumulatively) large dwarfs were on CG.4013. The most yield efficient (2014 and cumulatively) small semi-dwarfs were on CG.4814 and CG.5087, and the least efficient (2014 and cumulatively) were on PiAu 51-11. Among the moderate semi-dwarfs in 2014 and cumulatively, the most yield efficient were on CG.4004, and the least efficient were on PiAu 9-90. The two large semi-dwarfs (B.64-194 and B.7-20-21) were similarly yield efficient in 2014 and cumulatively. Site variations in rootstock effects on cumulative (2011-14) yield efficiency are presented in Table 9.

Fruit weight (2014 and averaged 2012-14) was not dramatically affected by rootstock; however, B.71-7-22 and PiAu 9-90 resulted in the smallest fruit in 2014 and averaged over the three fruiting years 2012-14 (Table 5). Similar to the overall differences, very little effect of rootstock on average (2012-14) fruit weight was seen by site, but the relatively small size of fruit from trees on B.71-7-22 and PiAu 9-90 was reasonably consistent from site to site (Table 10).

The percent of the tree canopy expressing zonal chlorosis typical of Honeycrisp was assessed in 2012-14 (Tables 5 and 11). Year-to-year variation, site differences, and most rootstock differences were not consistent. Trees on PiAu 9-90, however, consistently had the highest percent of the canopy affected. Trees on B.70-20-20 and B.64-194 tended to be among the least affected by zonal chlorosis.

Discussion

Seven to 10 years will be required to obtain an adequate evaluation of the rootstocks included in this study; however, after 5 years, rootstocks start separating based on size and tree performance. Table 12 places the rootstocks in this study into eight vigor classes, as described above. Four of those rootstocks (all from the Russian Budagovsky program) likely are unsuitable for a modern high-density system. B.70-20-20 is semi-standard or standard in vigor producing trees much too large. Very likely, the two large semi-dwarfs, B.7-20-21 and B.64-194 are also too vigorous for a high-density system. B.71-7-22, on the other hand, is sub-dwarf and produces trees which are much too low in vigor to be useful in a commercial orchard.

In the moderate semi-dwarf category (Table 12), trees on CG.4004 and G.202N performed the best as measured by cumulative yield efficiency; however, as noted earlier, G.202N may not be identified correctly. Trees on the Budagovsky rootstocks or on PiAu 9-90 were significantly less efficient.

Table 8. Cumulative yield per tree (2011-14, kg) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	BC	CH	CO	IA	MA	MI	MN	NJ	NS	NY	OH	UT	WI
B.9	12.6	0.6	5.5	8.7	13.4	16.2	13.2	9.0	19.7	24.3	7.4	8.3	21.6
B.10	18.3	1.1	7.6	13.8	22.8	18.1	15.6	17.7	25.7	42.9	13.4	15.4	29.0
B.7-3-150	20.0	3.5	9.8	17.9	20.4	12.3	18.3	33.2	24.7	38.6	13.8	18.3	33.4
B.7-20-21	24.4	1.0	8.8	15.7	25.7	20.1	15.5	28.2	40.3	37.1	13.4	16.8	29.0
B.64-194	18.4	2.4	8.0	14.2	22.0	17.5	13.1	33.3	36.0	35.9	10.8	27.2	40.1
B.67-5-32	23.1	1.5	4.1	15.7	18.3	15.4	9.0	20.3	19.0	26.8	12.5	15.7	23.2
B.70-6-8	19.9	2.8	5.8	15.6	25.3	12.8	21.2	30.7	27.8	39.0	12.7	18.3	33.5
B.70-20-20	24.6	2.5	4.5	4.7	23.4	21.6	9.7	25.0	38.3	21.2	19.8	20.5	33.8
B.71-7-22	4.5	0.5	0.7	5.6	2.4	3.8	5.3	4.8	3.0	6.9	2.8	0.5	6.5
G.11	19.1	3.0	8.8	15.8	28.4	22.2	23.0	20.8	22.5	32.0	9.8	19.5	36.9
G.41N	24.8	1.5	9.7	17.1	26.3	18.3	23.3	16.3	31.6	33.9	14.4	14.2	37.3
G.41TC	21.2	1.7	11.0	15.0	18.1	13.8	21.5	14.8	19.0	23.9	6.6	16.1	26.8
G.202N	29.4	3.3	4.7	12.9	50.7	20.0	22.1	28.6	38.1	37.5	18.6	22.1	34.5
G.202TC	20.5	8.0	6.4	18.4	33.6	22.2	20.8	25.3	20.5	38.6	12.9	16.1	15.6
G.935N	31.9	1.6	---	14.8	42.2	23.9	23.8	21.9	25.1	35.9	17.4	17.2	52.8
G.935TC	16.5	1.0	10.0	10.4	18.2	25.1	18.6	28.5	30.3	32.9	14.9	14.7	41.0
CG.2034	18.4	1.1	3.1	11.2	14.0	11.3	14.3	13.9	13.6	17.2	10.1	12.3	25.4
CG.3001	30.9	---	8.3	24.1	52.9	16.9	17.0	23.2	32.9	44.7	21.0	20.3	42.6
CG.4003	16.7	0.6	4.0	14.4	24.7	17.2	14.9	18.9	20.1	34.8	7.5	11.5	26.4
CG.4004	38.0	4.0	11.2	25.3	40.1	20.6	30.0	37.4	55.9	37.5	25.0	13.3	56.3
CG.4013	20.0	1.2	---	12.8	29.3	14.4	18.9	20.5	16.4	23.0	16.3	15.1	11.7
CG.4214	27.1	2.1	11.4	18.3	26.7	23.8	21.9	26.4	31.4	38.4	17.3	9.7	37.0
CG.4814	32.6	1.6	9.9	17.3	30.9	20.5	26.7	29.7	33.5	48.7	14.7	16.2	32.8
CG.5087	32.5	1.7	6.1	15.9	28.9	21.4	25.3	36.7	32.1	41.1	24.4	6.6	45.0
CG.5222	23.3	1.0	7.0	---	22.3	16.7	18.6	31.0	33.7	38.0	15.6	21.5	27.8
Supp.3	21.5	1.8	4.7	6.4	18.3	12.5	15.7	16.9	19.4	33.9	8.0	18.1	24.5
PiAu 9-90	17.5	3.6	5.2	6.5	10.0	8.9	7.4	26.1	9.2	25.6	15.3	21.6	14.3
PiAu 51-11	15.7	1.7	8.6	15.2	19.6	15.3	18.9	23.3	18.0	36.7	15.7	15.9	21.2
M.9 NAKBT337	19.2	2.1	13.2	13.1	24.3	17.4	21.5	25.5	20.0	36.3	15.3	15.9	28.3
M.9 Pajam 2	20.8	1.1	13.6	12.1	17.7	17.7	16.2	28.7	20.0	30.2	11.8	16.8	37.0
M.26 EMLA	23.4	0.5	8.0	17.7	18.3	15.8	14.8	18.5	22.0	29.0	11.8	15.3	28.1
Average HSD	11.2	3.0	10.7	8.9	16.4	12.0	12.8	15.6	13.5	18.1	8.4	11.8	17.1

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

Table 9. Cumulative yield efficiency (2011-14, kg/cm^2 trunk cross-sectional area) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	BC	CH	CO	IA	MA	MI	MN	NJ	NS	NY	OH	UT	WI
B.9	2.3	0.1	0.8	1.6	2.1	2.5	1.8	1.7	2.9	3.9	1.3	1.3	3.1
B.10	2.3	0.1	0.6	1.6	2.2	1.8	1.6	1.8	2.7	3.6	1.3	1.6	3.1
B.7-3-150	1.8	0.3	0.5	1.5	1.2	0.9	0.9	1.4	1.8	1.8	0.8	1.1	2.3
B.7-20-21	1.7	0.1	0.4	0.9	1.5	1.3	0.8	1.0	1.8	1.7	0.7	0.9	1.6
B.64-194	1.7	0.2	0.3	0.9	0.9	0.8	0.6	1.3	1.6	1.6	0.6	1.6	1.7
B.67-5-32	1.7	0.1	0.2	0.8	1.0	0.7	0.5	0.9	1.2	1.5	0.7	1.0	1.4
B.70-6-8	1.8	0.3	0.3	0.8	1.3	0.9	1.1	1.3	2.0	1.7	0.7	1.1	2.3
B.70-20-20	1.0	0.1	0.1	0.3	0.7	0.8	0.3	0.5	1.3	0.6	0.6	0.6	1.1
B.71-7-22	2.6	0.2	0.3	1.8	1.6	1.2	1.7	2.3	2.4	3.1	1.3	1.2	3.0
G.11	2.8	0.4	0.7	1.6	3.3	2.3	2.3	1.6	3.0	3.1	1.4	1.9	3.8
G.41N	2.7	0.2	0.6	1.8	2.8	1.9	2.0	1.5	3.1	2.8	1.6	1.7	3.4
G.41TC	2.6	0.3	0.8	1.4	2.0	1.3	1.8	1.2	2.5	2.6	1.6	1.6	2.8
G.202N	2.1	0.4	0.3	0.9	2.5	1.4	1.3	1.2	2.2	2.6	1.2	1.4	1.9
G.202TC	2.6	1.2	0.4	1.7	2.7	2.4	1.8	1.9	2.0	2.8	1.5	1.6	1.8
G.935N	3.1	0.2	---	1.4	3.3	2.3	2.0	1.4	2.4	2.4	1.6	1.6	4.0
G.935TC	2.3	0.2	0.6	1.4	2.0	2.6	1.7	1.8	2.7	2.8	1.7	1.9	3.9
CG.2034	2.6	0.2	0.4	1.4	2.0	1.7	2.2	1.6	2.0	2.9	2.0	1.4	3.5
CG.3001	2.5	---	0.3	1.5	2.5	1.7	1.6	1.0	2.3	2.4	1.5	1.5	4.1
CG.4003	3.1	0.1	0.4	1.8	3.3	2.5	1.8	2.0	3.0	3.9	1.2	1.6	3.2
CG.4004	2.8	0.4	0.6	1.8	2.3	1.4	1.6	1.8	2.4	2.2	1.6	1.1	3.3
CG.4013	2.5	0.1	---	0.9	2.3	1.2	1.9	0.9	1.5	1.4	1.1	1.4	1.8
CG.4214	3.9	0.4	1.0	1.6	1.9	2.0	1.8	1.7	2.7	2.8	1.7	1.2	4.0
CG.4814	2.9	0.2	0.7	1.0	2.5	1.8	1.9	1.4	2.4	3.2	1.3	1.7	2.6
CG.5087	2.6	0.2	0.4	1.4	2.1	1.9	1.9	1.8	2.8	2.6	2.0	0.9	3.3
CG.5222	1.9	0.2	0.3	---	1.4	1.3	1.6	1.7	2.0	2.7	0.9	1.7	2.4
Supp.3	3.0	0.2	0.4	0.7	2.2	1.7	2.1	1.3	2.1	2.9	1.0	2.1	3.3
PiAu 9-90	1.3	0.3	0.3	0.6	0.6	0.6	0.6	0.9	0.6	1.2	1.0	1.2	1.1
PiAu 51-11	1.9	0.2	0.5	0.9	1.3	1.0	1.2	0.9	1.4	2.0	1.2	1.3	1.6
M.9 NAKBT337	2.6	0.3	1.0	1.4	2.4	2.0	2.2	2.0	2.5	3.3	1.6	1.8	3.2
M.9 Pajam 2	2.4	0.1	0.9	1.1	1.9	1.7	1.7	2.0	2.1	2.4	1.1	1.6	3.1
M.26 EMLA	2.4	0.1	0.6	1.4	1.9	1.5	1.3	1.2	1.6	2.4	1.1	1.4	2.7
Average HSD	0.9	0.3	0.6	1.2	1.0	1.0	0.9	1.1	1.1	1.5	0.8	0.7	1.2

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

Table 10. Average fruit size (2012-14, g) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	BC	CH	CO	IA	MA	MI	MN	NJ	NS	NY	OH	UT	WI
B.9	256	162	131	162	229	180	156	258	163	222	177	155	211
B.10	297	177	186	169	215	233	178	279	173	235	191	193	240
B.7-3-150	302	164	188	212	256	209	203	304	168	266	182	199	256
B.7-20-21	274	175	185	182	224	188	181	280	183	251	183	154	264
B.64-194	279	176	197	204	229	202	228	294	195	258	192	140	282
B.67-5-32	288	177	190	201	234	246	244	273	190	232	183	180	272
B.70-6-8	281	176	187	190	232	196	198	265	177	258	181	171	254
B.70-20-20	305	163	192	210	236	202	210	280	190	263	178	211	267
B.71-7-22	214	198	141	149	179	147	159	294	151	192	187	178	191
G.11	256	164	188	186	247	217	155	282	160	242	197	186	250
G.41N	301	181	199	191	243	226	186	297	170	246	172	211	224
G.41TC	305	174	200	211	241	221	197	286	196	249	181	156	215
G.202N	322	168	217	143	245	204	204	262	158	238	201	214	227
G.202TC	231	148	178	189	203	184	170	282	134	227	191	145	217
G.935N	292	179	---	162	221	190	147	274	168	229	173	178	202
G.935TC	281	189	191	145	199	189	153	270	158	250	160	199	207
CG.2034	294	169	174	185	231	148	182	284	162	254	171	197	215
CG.3001	320	---	167	217	222	176	194	287	203	261	191	200	224
CG.4003	278	193	162	161	207	260	161	276	132	193	148	122	217
CG.4004	317	160	207	208	232	196	205	291	309	228	193	153	224
CG.4013	286	179	---	202	208	170	175	277	187	223	175	195	203
CG.4214	277	172	197	196	238	195	177	287	176	251	160	177	228
CG.4814	307	178	200	221	212	224	176	279	122	247	155	193	200
CG.5087	304	163	181	197	233	208	161	276	156	223	163	143	188
CG.5222	301	171	207	---	205	205	177	264	138	237	182	173	249
Supp.3	294	187	175	185	215	192	165	266	144	235	186	205	202
PiAu 9-90	227	158	158	137	132	162	174	248	121	219	139	155	186
PiAu 51-11	265	179	179	216	238	204	219	279	181	257	168	206	294
M.9 NAKBT337	291	174	192	193	235	216	165	307	174	253	181	164	233
M.9 Pajam 2	277	191	202	175	211	216	164	288	149	228	169	143	244
M.26 EMLA	271	172	180	197	220	185	181	306	171	241	193	161	250
Average HSD	69	52	80	47	54	99	78	59	52	50	52	102	68

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

Table 11. Zonal chlorosis (2014, % of canopy affected) of Honeycrisp apple trees at individual planting locations in the 2010 NC-140 Honeycrisp Apple Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

	BC	IA			MA		MI		MN			NJ	NS			NY			WI		
Rootstock	2013	2012	2013	2014	2013	2014	2013	2014	2012	2013	2014	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
B.9	46	68	2	65	47	24	18	44	17	38	21	20	7	37	69	17	10	29	16	18	7
B.10	32	57	8	11	50	24	25	69	3	14	35	16	8	25	57	14	19	12	17	21	14
B.7-3-150	30	48	4	14	43	20	20	42	20	27	42	13	5	25	43	18	15	14	19	15	6
B.7-20-21	40	54	15	39	59	48	29	57	15	29	37	13	9	17	30	15	16	12	30	21	11
B.64-194	21	64	22	21	42	17	22	43	7	38	33	12	5	9	46	24	15	15	22	18	11
B.67-5-32	36	42	16	24	43	22	25	31	17	23	42	12	10	26	64	22	19	21	22	19	12
B.70-6-8	23	59	8	19	49	20	20	67	10	34	40	11	5	24	38	19	14	15	18	23	11
B.70-20-20	15	58	29	20	31	12	28	25	0	27	47	10	5	7	43	17	14	13	26	19	13
B.71-7-22	100	85	3	27	92	58	15	87	3	25	21	13	13	45	62	17	24	44	31	13	12
G.11	80	68	11	54	40	34	18	66	9	57	22	15	10	76	53	23	16	22	41	26	13
G.41N	68	60	11	29	32	15	18	57	0	49	35	18	23	42	64	21	15	24	27	20	12
G.41TC	65	54	22	32	65	34	28	81	13	44	53	27	10	17	64	28	28	24	50	23	13
G.202N	32	67	34	45	29	26	33	82	8	33	42	17	12	40	73	25	23	15	57	24	14
G.202TC	67	77	32	14	59	38	29	54	8	29	38	20	15	71	84	21	19	16	71	27	20
G.935N	68	79	60	70	43	44	59	80	22	69	33	20	10	64	56	26	23	21	46	31	13
G.935TC	95	79	73	51	71	85	39	66	24	76	65	21	5	65	39	27	19	35	59	32	18
CG.2034	96	78	27	57	79	58	15	71	20	82	42	15	5	83	74	25	28	58	40	19	14
CG.3001	55	59	10	24	64	66	56	76	24	72	52	11	27	7	61	30	24	35	19	22	8
CG.4003	70	73	8	48	42	21	25	84	20	42	20	20	46	66	76	18	29	10	18	11	11
CG.4004	18	70	26	48	33	16	35	70	5	34	42	13	9	19	78	31	16	25	29	33	10
CG.4013	73	46	13	38	58	54	46	80	13	66	53	21	21	31	88	26	23	33	47	38	22
CG.4214	83	66	48	53	54	59	28	86	22	55	39	16	35	44	78	31	21	34	32	33	22
CG.4814	72	55	45	56	66	74	39	91	13	68	44	13	87	87	81	24	22	28	41	36	20
CG.5087	57	59	53	80	55	53	39	91	25	60	66	14	31	36	79	23	17	36	40	30	10
CG.5222	58	---	---	---	68	48	30	77	3	47	51	10	28	23	72	19	30	18	28	25	29
Supp.3	92	89	85	72	54	61	38	92	12	81	82	20	20	53	74	17	18	41	31	32	16
PiAu 9-90	78	90	80	92	72	79	77	85	35	81	92	25	83	85	95	25	21	41	98	32	57
PiAu 51-11	50	52	22	19	61	46	42	74	23	60	43	13	21	18	64	20	24	23	28	21	18
M.9 NAKBT337	58	64	21	60	55	33	27	50	13	63	33	14	6	38	83	23	23	18	23	20	8
M.9 Pajam 2	53	67	36	55	53	39	28	85	17	79	50	14	8	44	76	24	17	21	30	22	13
M.26 EMLA	31	55	7	30	57	32	23	71	25	26	31	16	16	42	79	23	26	32	18	17	9
Average HSD	44	45	29	50	44	42	33	45	25	45	36	12	31	49	43	13	14	28	35	27	25

[z] Mean separation in columns by Tukey's HSD ($P = 0.05$). HSD was calculated based on the average number of observations per mean.

CG.4004, in a New York trial with 'Honeycrisp' as the scion, performed similarly to what is noted in this NC-140 trial (Robinson et al., 2011). After 6 years, trees were similar in size to those on M.7 and were significantly more yield efficient.

In the small semi-dwarf category (Table 12), trees on CG.5087, CG.4814, and CG.3001 were the most yield efficient, and those on PiAu 51-11 were the least efficient. In a New York trial with 'Golden Delicious', 7-year-old trees on CG.5087 were between M.26 and M.7 in size but significantly more yield efficient (Robinson et al, 2011). In the 1999 NC-140 Semi-dwarf Apple Rootstock Trial, after 10 years (Autio et al., 2011b), 'McIntosh' trees on CG.4814 were similar in size to those on M.26 EMLA and smaller than those on M.7 EMLA, but trees on CG.4814 were more yield efficient than trees on either M.26 EMLA or M.7 EMLA. 'Fuji' trees on CG.4814, M.26 EMLA, and M.7 EMLA were similar in size, but those on CG.4814 were the most yield efficient.

In the large dwarf category (Table 12), trees on G.935N, CG.4214, G.935TC, and G.202TC performed the best as assessed by yield efficiency, similar in size but more efficient than trees on M.26 EMLA. After 10 years, 'Fuji' and 'McIntosh' trees in the 1999 NC-140 Dwarf Apple Rootstock Trial on G.935 and G.202 performed similarly to those on M.26 EMLA (Autio et al., 2011a). After 6 years with 'Honeycrisp' as the scion cultivar in New York, G.935 and G.202 were similar in size and yield efficiency to trees on M.7 (Robinson et al., 2011). In the 2002 NC-140 Apple Rootstock Trial after 10 years, 'Gala' trees on G.935 were similar in size to those on M.26 EMLA (Autio et al., 2013). In the 2002 trial, G.935 only occurred at two locations, and at one location (Chihuahua, Mexico), trees on G.935 were similarly yield efficient to those on M.26 EMLA, but at the other location (New York), they were significantly more yield efficient than trees on M.26 EMLA. In the 2003 NC-140 Dwarf Apple Rootstock Trial after 10 years, 'Golden Delicious' trees on G.935 were similar in size to those on M.9 NAKBT337 at four out of eight sites, and similar to trees on M.26 at the other four (Marini et al., 2014). Trees on G.935 were similarly yield efficient to trees on M.9 NAKBT337 at all sites and more efficient than those on M.26 at five of eight sites. After 7 years, 'Golden Delicious' trees on CG.4214 in New York were similar to trees on M.26 in size and yield efficiency (Robinson et al., 2011).

In the moderate dwarf category, G.41N and G.11 performed well and comparably to M.9 NAKBT337. Autio et al. (2011a) and Marini et al. (2014) found after 10 years that 'McIntosh', 'Fuji', and 'Golden Delicious' trees on G.41were similar in size and yield efficiency to those on M.9 NAKBT337. Robinson et al. (2011) found 7-year-old 'Golden Delicious' trees on G.41 to be similar in size to comparable trees on M.26 but significantly more yield efficient. 'Golden Delicious' trees on G.11 were somewhat smaller than those on M.26 and more yield efficient. Robinson et al. (2011) also reported that 6-year-old 'Honeycrisp' trees on G.11 were somewhat smaller than comparable trees on M.9 and similarly yield efficient.

In the small dwarf category, trees on CG.4003 performed well, somewhat greater but statistically similarly to trees on B.9. Among the few reports of CG.4003 performance, a 6-year study with 'Honeycrisp' as the scion cultivar reported that trees on CG.4003 were statistically similar in size and yield efficiency to trees on B.9 (Robinson et al., 2011).

As noted above, these results represent an early assessment of many of the rootstocks in this study. At this point few, if any, of the new Budagovsky rootstocks have shown promise; many are too large and lack efficiency. B.10, however, is a somewhat promising, moderate dwarf rootstock, but it is not yet showing any particularly valuable traits. None of the Pillnitz rootstocks (PiAu 9-90, PiAu 51-11, and Supp.3) have performed well, all three have the lowest yield efficiency in their respec-

Table 12. Rootstocks distributed among eight vigor classes based on trunk cross-sectional area. Within class, rootstocks are ordered highest to lowest based on cumulative (2011-14) yield efficiency. These 2010 NC-140 Honeycrisp Apple Rootstock Trial data are from BC, MA, MI, MN, NJ, NS, NY, OH, UT, and WI. All values are least-squares means, adjusted for missing subclasses.

Vigor category	Rootstock	Trunk cross-sectional area (2014, cm^2)	Cumulative yield efficiency (2011-14, kg/cm^2 TCA)
Semi-standard	B.70-20-20	33.9	0.7
Large semi-dwarf	B.7-20-21	20.1	1.3
	B.64-194	21.0	1.2
Moderate semi-dwarf	CG.4004	17.2	2.0
	G.202N	17.6	1.8
	B.70-6-8	17.6	1.4
	B.7-3-150	17.5	1.4
	B.67-5-32	18.6	1.0
	PiAu 9-90	17.3	0.9
Small semi-dwarf	CG.5087	13.0	2.2
	CG.4814	13.5	2.2
	CG.3001	14.5	2.1
	CG.5222	14.4	1.8
	PiAu 51-11	15.2	1.4
Large dwarf	G.935N	12.2	2.4
	CG.4214	11.5	2.4
	G.935TC	10.4	2.3
	G.202TC	10.8	2.1
	M.9 Pajam 2	10.6	2.0
	M.26 EMLA	11.6	1.7
	CG.4013	12.5	1.6
Moderate dwarf	G.11	9.2	2.6
	M.9 NAKBT337	9.6	2.4
	G.41N	10.1	2.4
	B.10	10.0	2.2
	Supp.3	8.8	2.2
	G.41TC	9.4	2.0
Small dwarf	CG.4003	7.5	2.6
	B.9	6.5	2.3
	CG.2034	7.0	2.2
Sub-dwarf	B.71-7-22	2.0	2.0

tive size class, and trees on PiAu 9-90 have produced the smallest fruit in the trial. The Cornell-Geneva rootstocks (both CG and G), on the other hand, are performing very well, often among the best in their size class.

This trial will continue through the tenth growing season, after which a more thorough evaluation will be presented.

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Literature Cited

Autio, W.R., J.L. Anderson, J.A. Barden, G.R. Brown, R.M. Crassweller, P.A. Domoto, A. Erb, D.C. Ferree, A. Gaus, P.M. Hirst, C.A. Mullins, and J.R. Schupp. 2001. Performance of 'Golden Delicious', 'Jonagold', 'Empire', and 'Rome Beauty' apple trees on five rootstocks over ten years in the 1990 NC-140 Cultivar/Rootstock Trial. J. Amer. Pomol. Soc. 55 (3):131-137.

Autio, W., T. Robinson, D. Archbold, W. Cowgill, C. Hampson, R. Para Quezada, and D. Wolfe. 2013. 'Gala' apple trees on Supporter 4, P.14, and different strains of B.9, M.9 and M.26 rootstocks: Final 10-year report on the 2002 NC-140 Apple Rootstock Trial. J. Amer. Pomol. Soc. 67(2):62-71.

Autio, W.R., T.L. Robinson, B. Black, T. Bradshaw, J.A. Cline, R.M. Crassweller, C.G. Embree, E.E. Hoover, S.A. Hoying, K.A. Iungerman, R.S. Johnson, G. Lang, M.L. Parker, R.L. Perry, G.L. Reighard, J.R. Schupp, M. Stasiak, M. Warmund, and D. Wolfe. 2011a. Performance of 'Fuji' and 'McIntosh' apple trees after 10 years as affected by several dwarf rootstocks in the 1999 NC-140 Apple Rootstock Trial. J. Amer. Pomol. Soc. 65(2):2-20.

Autio, W.R., T.L. Robinson, B. Black, T. Bradshaw, J.A. Cline, R.M. Crassweller, C.G. Embree, E.E. Hoover, S.A. Hoying, K.A. Iungerman, R.S. Johnson, G. Lang, M.L. Parker, R.L. Perry, G.L. Reighard, M. Stasiak, M. Warmund, and D. Wolfe. 2011b. Performance of 'Fuji' and 'McIntosh' apple trees after 10 years as affected by several semidwarf rootstocks in the 1999 NC-140 Apple Rootstock Trial. J. Amer. Pomol. Soc. 65(2):21-38.

Autio, W., T. Robinson, B. Black, R. Crassweller, E. Fallahi, M. Parker, R. Parra Quezada, and D. Wolfe. 2017. Budagovsky, Geneva, Pillnitz, and Malling apple rootstocks affect 'Fuji' performance over the first five years of the 2010 NC-140 Fuji Apple Rootstock Trial. J. Amer. Pomol. Soc. 71(3):167-182.

Cummins, J.N. and H.S. Aldwinckle. 1983. Breeding apple rootstocks. Plant Breeding Rev. 1:294-394.

Fischer, M. 1997. The Pillnitz apple rootstock breeding methods and selection results. Acta Hort. 451:89-97.

Marini, R.P., J.L. Anderson, W.R. Autio, B.H. Barritt, J. Cline, W.P. Cowgill, Jr., R.M. Garner, A. Gauss, R. Godin, G.M. Greene, C. Hampson, P. Hirst, M.M. Kushad, E. Mielke, R. Moran, C.A. Mullins, M. Parker, R.L. Perry, J.P. Privé, G.L. Reighard, T. Robinson, C.R. Rom, T. Roper, J.R. Schupp, E. Stover, and R. Unrath. 2006. Performance of 'Gala' on 18 dwarfing rootstocks: Ten-year summary of the 1994 NC-140 rootstock trial. J. Amer. Pom. Soc. 60(2):69-83.

Marini, R.P., B.H. Barritt, J.A. Barden, J. Cline, R.L. Granger, M.M. Kushad, M. Parker, R.L. Perry, T. Robinson, S. Khanizadeh, and C.R. Unrath. 2001a. Performance of 'Gala' apple on eight dwarf rootstocks: Ten-year summary of the 1990 NC-140 Rootstock Trial. J. Amer. Pomol. Soc. 55(4):197-204.

Marini, R.P., B.H. Barritt, J.A. Barden, J. Cline, E.E. Hoover, R.L. Granger, M.M. Kushad, M. Parker, R.L. Perry, T. Robinson, S. Khanizadeh, and C.R. Unrath. 2001b. Performance of ten apple orchard systems: Ten-year summary of the 1990 NC-140 Systems Trial. J. Amer. Pomol. Soc. 55(4):222-238.

Marini, R.P., B. Black, R.M. Crassweller, P.A. Domoto, C. Hampson, R. Moran, T. Robinson, M. Stasiak, and D. Wolfe. 2014. Performance of 'Golden Delicious' apple on 23 rootstocks at eight locations: A ten-year summary of the 2003 NC-140 Dwarf Rootstock Trial. J. Amer. Pomol. Soc. 68(2)54-68.

NC-140. 1996. Performance of the NC-140 Cooperative Apple Rootstock Planting: I. Survival, tree size, yield and fruit size. Fruit Var. J. 50(1):6-11.

Robinson, T., L. Anderson, W. Autio, B. Barritt, J. Cline, W. Cowgill, R. Crassweller, C. Embree, D. Ferree, E. Garcia, G. Greene, C. Hampson, K. Kosola, M. Parker, R. Perry, T. Roper, and M. Warmund. 2007. A multi-location comparison of 'Geneva® 16', 'Geneva® 41', and 'M.9' apple rootstocks in North America. Acta Hort. 732:59-65.

Robinson, T. and S. Hoying. 2011. The tall spindle planting system: Principles and performance. Acta Hort. 903:571-579.

Robinson, T.L., S.A. Hoying, and G. Fazio. 2011. Performance of Geneva rootstocks in on-farm trials in New York State. Acta Hort. 903:249-255.