Characterization of the Kentville Stock Clone Apple Rootstocks. III. Quality and Overall Performance

C.G. Embree¹, B.H. Lesser², and A.D. Crowe³

Research Station, Agriculture Canada, Kentville, N.S., B4N 1J5, Canada

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Abstract. The effects of 30 Kentville Stock Clone (KSC) selections on fruit size and color of 'McIntosh' and 'Delicious' apples (*Malus domestica* Borkh.) were monitored over 5 years. Fruit size was influenced by the rootstock and, when averaged over the duration of the study, ranged from 108 to 132 g and 131 to 161 g for 'McIntosh' and 'Delicious', respectively. Variation in fruit size due to crop load (CL) was greater for 'McIntosh' than for 'Delicious'. Fruit color was influenced by the rootstock in all years for 'McIntosh' and in 3 of 5 years for 'Delicious'; it was strongly associated with tree size for 'Delicious' only. An overall performance index, which also included price based on quality, was developed, and the best performers in each size group were: semidwarf KSC 18 and 28; semivigorous KSC 7, 11, and 24; and vigorous KSC 3 and 6.

The quality aspect of apple production is important to the commercial producer. Fruit size and color are major determinants of quality. Apple rootstocks have been found to affect fruit size (Alston, 1991; Autio, 1987; Autio, 1991; Blasco and Jackson, 1974; Jackson 1986; Preston, 1967; Preston et al., 1981), although it is inconsistent over time (Lord et al. 1985) or varies with the cultivar (Wertheim, 1989). Dwarfing rootstocks have also been found to advance maturity and associated coloration in the fruit (Blasco and Jackson, 1974; Hewetson, 1944; Lord et al., 1985; Perry and Dilley, 1984). This result was confirmed by Autio (1987) using spur-type 'Delicious'; however, the dwarfing rootstock Mac 9 (Mark) slowed ripening compared to other rootstocks in this size category. These differences were only a few days in length, and other factors, such as yield and management practices, may also produce an effect of similar magnitude. The purpose of this work is to further characterize the KSC apple rootstocks by determining their influence on 'McIntosh' and 'Delicious' fruit quality. The overall performance of the KSC rootstocks is also reviewed, and superior performers in each size category are identified.

Materials and Methods

A random sample of 54 apples collected from each tree was graded manually for size and color. Size categories were <60 mm, 60 to 63 mm, 64 to 70 mm, and >70 mm. Average weight was determined by dividing sample weight by sample number. Color categories were <1.5% red, 15% to 55% red, and >55% red. Average color was calculated as the midrange of color for each category weighted by the fraction by weight of apples in that category. For each cultivar (separately), regression analysis was performed in which the relationship between average weight or average color and crop load (CL) was estimated in order to derive the percentage of variability explained by CL. Yearly CL was calculated as kilograms of fruit per square centimeter cross sectional area. In addition, the factor rootstock was introduced, and the significance probability of additional rootstock effects beyond that estimated as being due to CL was calculated.

For each sample, a quality index was determined by assigning to each size/color category a value reflecting its return in the marketplace. Top quality fruit suitable for count pack, fruit suitable for poly bags, and culls were assigned relative values of 1.0, 0.7, and -0.34, respectively. One price structure that would correspond to these values would be \$15.00/20 kg for count fruit, \$12.00/20 kg for poly bags, and \$1.60/20 kg for culls, with \$5.00/20 kg deducted for storage and packing expenses. The quality index was calculated as the sum over all size/color categories of the fraction by weight of fruit in each category multiplied by the relative value for that category.

Results and Discussion

Fruit weight. The average fruit weight for each cultivar/rootstock combination for fruit harvested in 1983-87 is shown in Table 1. For 'McIntosh', the 5-year mean fruit weight was highest for KSC 11 and smallest for KSC 28, and rootstock effects on fruit weight were significant ($P < 0.05$) in 4 of 5 years. For 'Delicious', the mean fruit weight for the 5 years was highest on KSC 1 and lowest on KSC 28, and there were rootstock effects on weight in all years. For both cultivars, there was no relationship between fruit weight and tree size.

To assess whether fruit weight differences were related to CL, regression analysis was performed. For 'McIntosh', variability in fruit weight due to CL ranged from 1.1% in 1983 to 17.9% in 1985 and 1986. Rootstock effects on fruit weight, beyond effects due to CL, were still significant ($P < 0.05$) for all years, except 1984 ($P = 0.135$) and 1986 ($P = 0.443$). For 'Delicious', <9% of variability in fruit weight was due to CL differences, and rootstock effects on fruit weight remained significant in all years, except for 1984 ($P = 0.287$) and 1986 ($P = 0.190$). Since 1984 and 1986 were the heavy cropping years of the biennial cycle, rootstock effects may have been masked by the higher CL.

Fruit color. For 'McIntosh', there were rootstock effects on color (Table 2). For 1984, 13.1% of variability in color was related to CL differences, while for other years, the corresponding figure was <5.3%. In 1983 and 1985, rootstock effects on color remained significant ($P < 0.05$) despite CL variability, while in 1986 and 1987, $P = 0.080$ and 0.086 , respectively.

For 'Delicious', there were rootstock effects on color ($P < 0.05$) in 1983, 1984, and 1987; in 1985, $P = 0.079$. Only 4.2% or less of

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¹Research Scientist.

²Research Scientist, term appointment.

³Research Scientist, retired.

Abbreviations: CL, crop load; KSC, Kentville Stock Clone.

Table 1. Average fruit weight for each apple cultivar/KSC rootstock combination in order of increasing average tree size.

KSC (no.)	Wt per fruit (g)											
	McIntosh						Delicious					
	1983	1984	1985	1986	1987	Mean	1983	1984	1985	1986	1987	Mean
28	118	136	134	117	87	108	145	131	164	123	146	131
14	129	127	130	130	121	125	166	190	133	133	144	141
26	129	134	144	112	116	120	144	169	145	128	134	142
18	132	127	146	119	116	127	147	166	124	134	145	143
23	137	129	140	111	130	127	142	168	147	128	151	147
16	142	125	151	123	119	127	159	169	159	139	158	154
4	132	143	131	120	146	129	160	190	142	135	146	143
22	136	130	138	119	122	128	157	172	150	132	146	147
24	144	140	130	117	113	123	155	181	146	141	153	147
7	143	132	141	117	122	127	165	201	143	130	147	145
19	137	132	144	112	100	120	156	178	145	122	147	143
15	143	121	145	115	126	125	159	175	158	136	142	147
9	151	136	147	123	104	124	151	171	138	133	137	140
11	140	143	176	122	133	136	166	174	153	149	154	155
25	138	131	149	113	111	123	151	180	146	136	149	147
8	139	131	147	114	118	124	162	165	145	132	144	141
29	142	126	129	118	121	122	148	170	132	144	143	142
30	138	137	145	126	101	122	151	188	143	134	139	149
12	142	135	152	118	124	129	160	180	146	140	154	152
21	143	133	137	127	120	128	159	169	145	125	144	142
13	142	137	152	119	129	132	159	172	145	135	152	148
27	150	134	142	119	121	128	157	178	138	136	148	144
20	131	130	136	119	108	120	151	176	142	138	137	140
10	133	123	146	113	106	116	159	185	130	122	138	132
17	150	142	153	119	125	132	164	163	143	121	148	139
3	149	141	144	115	121	127	167	193	147	124	156	147
1	134	133	140	119	124	124	168	186	152	150	162	161
6	145	129	124	119	133	126	149	173	154	135	125	141
5	137	141	146	142	120	132	169	184	162	141	146	148
2	144	142	147	128	123	132	171	171	154	123	148	143
Mean	139	133	143	119	119	125	157	176	146	133	146	145
SEM	4.2	5.3	6.0	5.0	7.2	3.0	5.5	10.0	6.4	6.0	5.2	3.2
Pr > F	0.00	0.14	0.00	0.03	0.00	0.00	0.00	0.04	0.05	0.05	0.00	0.00
Percentage of variability due to CL												
	1.1	5.1	17.9	17.9	2.5		1.4	6.5	8.7	3.8	0.9	
Pr > F	0.00	0.14	0.02	0.44	0.00		0.01	0.29	0.00	0.20	0.02	

variability in color was due to CL differences, and rootstock effects on color beyond CL effects were significant ($P < 0.05$) in all years.

For 'Delicious', the Spearman rank correlation coefficient between color and tree size was -0.70, indicating a significant ($P < 0.01$) reduction in color as tree vigor increased. For 'McIntosh', however, there was poor correlation between mean fruit color and tree size (Spearman rank correlation = -0.32; $P > 0.05$). The inconsistency between 'Delicious' and 'McIntosh' may be partly explained by the poor color of the 'Delicious' strain.

Performance index. To assess the overall performance of 30 KSC rootstocks, each factor measured needs to be included and given appropriate weight. Only the first 10 years are included in the quality assessment because of severe fruit drop on 'McIntosh' just before harvest in 1988. Efficiencies for these 10 years were determined (Table 3). For each cultivar/rootstock combination, a mean quality index was calculated representing the mean of each year's quality index weighted by the crop density (apples per tree) in each year relative to the total crop density over the years. Finally,

a performance index combining yield and quality was calculated as the product of efficiency and mean quality index. There were significant rootstock effects ($P < 0.001$) on all parameters. For 'McIntosh', the rootstocks with performance factors significantly higher than the average for all 30 rootstocks (in order of decreasing performance factor) were KSC 7, KSC 6, and KSC 3. For 'Delicious', the corresponding rootstocks were KSC 11, KSC 24, KSC 28, and KSC 7. Rootstocks with performance significantly lower than average (in order of increasing performance factor) were KSC 30 and KSC 19 for 'McIntosh' and KSC 27, KSC 20, and KSC 3 for 'Delicious'.

The performance index (Table 3) shows relative returns from the various cultivar/rootstock combinations. This index can be converted to a dollar value by multiplying by the net return for top quality fruit (e.g., \$0.50/kg) and to returns per hectare by multiplying again by the average square centimeter of trunk cross-section per hectare. If trees of varying sizes were spaced in proportion to their size, then this number would be independent of tree size.

Table 2. Average percent red color for each cultivar/KSC rootstock combination in order of increasing average tree size.

KSC (no.)	Red color (%)											
	McIntosh						Delicious					
	1983	1984	1985	1986	1987	Mean	1983	1984	1985	1986	1987	Mean
28	74	65	55	77	54	62	65	59	39	49	62	53
14	78	72	62	73	56	64	76	63	43	51	67	52
26	76	63	61	74	56	66	71	69	39	46	64	54
18	76	64	61	74	57	65	69	63	31	51	61	53
23	73	57	55	74	52	61	69	67	37	45	63	52
16	71	64	59	74	53	63	52	50	36	44	51	45
4	74	64	51	71	59	63	66	62	38	45	59	50
22	77	66	56	73	55	65	62	60	38	46	59	51
24	67	55	45	65	49	56	59	54	39	44	53	48
7	66	53	50	64	47	58	56	48	36	44	58	47
19	71	55	56	73	58	62	65	62	39	47	58	50
15	68	59	52	72	56	62	71	60	50	55	63	63
9	77	63	65	75	61	63	61	43	36	44	55	46
11	66	55	47	71	56	61	64	56	39	47	56	50
25	73	60	56	74	53	64	67	56	41	45	53	50
8	74	63	62	76	55	64	70	59	46	44	65	53
29	75	54	55	74	49	60	63	56	40	43	57	50
30	72	57	57	76	61	63	66	63	39	50	62	52
12	72	60	55	75	52	62	56	50	36	42	59	46
21	76	60	58	73	57	63	65	53	38	46	60	49
13	70	57	55	68	54	60	60	53	37	44	60	48
27	75	63	55	75	54	64	69	60	37	44	60	50
20	76	63	61	75	62	65	70	64	38	46	62	51
10	69	58	55	76	57	63	66	54	36	40	59	46
17	66	57	55	72	52	61	55	48	35	41	50	44
3	71	61	56	76	56	59	60	49	35	48	57	47
1	76	61	59	74	55	64	63	59	45	46	64	50
6	68	52	56	73	51	61	65	58	43	49	51	45
5	66	59	55	70	50	59	56	52	37	46	60	48
2	68	54	52	73	51	59	58	59	37	46	52	48
Mean	72	60	56	73	55	62	64	57	39	46	59	50
SEM	2.0	3.4	2.9	1.7	2.8	1.4	2.9	4.2	3.0	2.8	2.7	1.7
Pr > F	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.08	0.16	0.00	0.00
Percentage of variability due to CL												
Pr > F	4	13	0	5	5		4	0	2	1	3	
	0.00	0.62	0.02	0.08	0.09		0.00	0.00	0.02	0.03	0.00	

The performance of the two cultivars was not consistent on some rootstocks. For example, 'McIntosh' performed well on KSC 3, while 'Delicious' performed poorly on this rootstock. Since the current study was designed to test rootstock differences and was not randomized by cultivar, this observation warrants further investigation. If it is borne out, it indicates the importance of finding universal criteria for evaluating rootstock performance and the need for finding new ways to predict cultivar/rootstock synergism.

Summary. Tree growth, precocity, yield, and fruit quality are important components of apple tree performance in the field. This study documents field performance of these components for the KSC rootstock candidates with two cultivars and proposes methods that promise to more clearly quantify and reduce the time required to identify superior rootstock.

Differences in final tree size could be projected by the end of the sixth season. There was a substantial range in tree size, and by extrapolation was estimated to be from $\approx 25\%$ smaller to 55%

larger than MM. 106. There was good correlation between three methods of assessing tree size: trunk cross-section area, top weight, and top weight plus accumulated weight of prunings. First fruits were borne in the third season. 'McIntosh' was 60% more efficient in production than 'Delicious' (Embree et al., 1993).

Methods of determining real productivity (independent of tree size and biennial bearing, yet weighing precocity) were developed. Precocity and productivity were not correlated. Therefore, cropping performance ratings for stocks must be delayed until mature production has been achieved. In this trial, the minimum was ≈ 8 years; some stocks required the full 10 years and may not have completely stabilized. There was no correlation between cropping performance and tree size (Lesser et al., 1993).

Fruit size and fruit color were significantly affected by the rootstock even after adjustment for CL, but the magnitude was much less than for tree size and cropping efficiency.

A productivity index, based on efficiency, fruit quality, and a subjective price grade differential, was developed. On this basis

Table 3. Efficiency after 10 years, mean quality index, and performance index for each apple cultivar/KSC rootstock combination in order of increasing average tree size. Means and SE were determined by analysis of variance for each cultivar separately.

KSC (no.)	McIntosh			Delicious		
	Efficiency year 10 (kg·cm ⁻²)	Mean quality index	Performance index	Efficiency year 10 (kg·cm ⁻²)	Mean quality index	Performance index
28	4.08	0.747	3.20	3.12	0.773	2.38
14	3.32	0.873	2.90	1.93	0.802	1.56
26	3.51	0.858	3.01	2.14	0.806	1.83
18	3.92	0.869	3.40	2.73	0.800	2.20
23	3.69	0.845	3.07	2.28	0.802	2.05
16	3.94	0.860	3.37	2.72	0.767	2.18
4	3.93	0.861	3.38	2.35	0.789	1.84
22	3.66	0.866	3.18	2.07	0.794	1.68
24	4.07	0.804	3.25	3.35	0.780	2.54
7	4.89	0.815	4.02	2.80	0.772	2.25
19	3.14	0.822	2.59	1.97	0.785	1.60
15	4.20	0.848	3.53	2.49	0.850	2.15
9	3.40	0.851	2.92	2.14	0.761	1.69
11	3.97	0.852	3.37	3.19	0.797	2.58
25	3.84	0.842	3.22	2.29	0.780	1.79
8	3.32	0.861	2.86	2.12	0.800	1.94
29	3.43	0.819	2.98	1.79	0.789	1.44
30	2.95	0.837	2.37	2.17	0.805	1.58
12	3.77	0.840	3.17	2.54	0.768	1.86
21	3.82	0.866	3.31	2.26	0.783	1.80
13	3.94	0.840	3.26	2.58	0.782	1.95
27	3.45	0.861	2.97	1.78	0.795	1.41
20	3.32	0.849	2.83	1.86	0.793	1.43
10	3.68	0.836	3.10	2.14	0.758	1.61
17	3.86	0.848	3.27	2.48	0.749	1.82
3	4.49	0.837	3.77	2.29	0.777	1.68
1	3.83	0.847	3.24	2.14	0.799	1.77
6	4.56	0.841	3.83	2.79	0.752	2.15
5	3.72	0.845	3.15	2.31	0.779	1.83
2	3.37	0.845	2.85	2.01	0.780	1.57
Mean	3.77	0.843	3.18	2.36	0.786	1.87
SEM	0.195	0.0108	0.164	0.168	0.0090	0.128

there were nine superior and nine inferior stocks. Size classification of the superior ones was: KSC 28 and 18, semidwarf; KSC 7, 11, 15, 16, and 24, semivigorous; KSC 3 and 6 vigorous. (The KSC rootstocks 15 and 16 show high performance values; however, field mortality with 'McIntosh' was high and, therefore, they are not recommended for further study at this time). The methods of evaluating field performance of apple rootstocks illustrated in this series of papers have potential for accelerating the screening process. We recognize that these methods need additional testing over a wider range of conditions.

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