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Flowering and Fruiting Characteristics of Eight Pawpaw [*Asimina triloba* (L.) Dunal] Selections in Kentucky

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Abstract

The North American pawpaw [*Asimina triloba* (L.) Dunal] is in the initial stages of commercialization; however, little information has been published concerning flowering and ripening periods of commercially available cultivars. Cultivars with late flowering or extended bloom period could be useful to growers for avoiding crop losses to late spring frosts. The objectives of this study were to determine if mature trees of commercially available pawpaw cultivars display: 1) concentrated bloom periods, 2) late flowering characteristics, 3) high fruit set, and 4) concentrated fruit ripening characteristics that were related to concentrated bloom periods. An orchard was planted in the spring of 1998 in a randomized block experimental design with 8 replicates. In 2004 to 2006, the cultivars 'Middletown', 'Overleese', 'PA-Golden', 'Sunflower','Wells', 'Wilson', 'NC-1' and the advanced selection 2-54 were evaluated for flower number per tree, density, peak, and duration, as well as trunk cross-sectional area, fruit set, days between flower and harvest peak, duration of harvest, fruit weight, yield, and number of fruit per cluster. An extended flowering period or larger flower number did not improve fruit set. Mature trees of commercially available pawpaw cultivars did not display concentrated bloom periods or ripening periods; however, 'Wells' and 'Middletown' did have late flowering peaks (maximum number of flowers) that could allow a partial crop if early spring frosts destroy flowers around or at the flowering peak. However, the average fruit size of 'Wells' and 'Middletown' is small and undesirable for commercial production.

The North American pawpaw [*Asimina triloba* (L.) Dunal] is in the initial stages of commercial production across the United States (6). The pawpaw fruit has both fresh market and processing appeal, with an intense flavor that resembles a combination of banana, mango, and pineapple (1). Little information has been published concerning flowering, bloom period or fruit set in commercially available pawpaw cultivars. This information would be valuable to growers for selection of cultivars for regional suitability and microclimates.

Pawpaw flowers are strongly protogynous and are likely self-incompatible (8), although some cultivars, such as 'Sunflower', may be self-fruitful. Pollination is by flies (Diptera) and beetles (Nitidulidae), and possibly other nocturnal insects (2, 3). Each fruit cluster develops from an individual flower. Seedlings normally flower when trees reach a height of about 1.8 m; cropping is achieved at five to eight years after planting. Grafted trees usually set fruit five to six years after planting, although some cultivars such as 'PA-Golden (#1)' may crop in the fourth year (7). The bloom period for a pawpaw tree usually occurs over 3 to 4 weeks; however, bloom periods for specific cultivars have not been evaluated. Late flowering or extended bloom period could be useful traits to growers for avoiding crop losses due to late spring frosts and microclimates that are frost prone. Harvest from trees is labor-intensive, occurring over several weeks, and has been thought to reflect an extended bloom period for a particular cultivar.

In the wild, pawpaw trees are usually

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found in the understory of hardwood forests and low fruit set has been reported in wild patches (4, 8). Low light levels in the understory may limit flower bud formation during the previous summer. If flowers are formed and successfully pollinated, low light levels may also reduce photosynthate partitioning to fruit and reduce fruit set. Pawpaws in the wild often produce many root suckers, forming large clonal patches, thus leading to poor fruit set within a patch due to flower self-incompatibility. Pollinator limitation may also lead to low fruit set in wild patches (8). Because the pawpaw flowers are protogynous (8), lack of pollen availability from other pawpaw genotypes may also limit pollination. Pollinizer relationships among pawpaw cultivars have not been examined. Fruit set can be enhanced by hand cross-pollination (5).

We tested a number of hypotheses during this study concerning pawpaw fruit production and flowering, including: 1) an extended flowering period on the same tree will lead to greater fruit set, 2) a larger number of flowers on a tree will result in a greater number of fruit on that tree, and 3) fruit set is low in pawpaw. The objectives of this study were to determine if mature trees of commercially available pawpaw cultivars display: 1) concentrated bloom periods, 2) late flowering characteristics, 3) high fruit set, and 4) concentrated fruit ripening characteristics that were related to concentrated bloom periods.

Materials and Methods

In 2004, 2005, and 2006, flowering and fruit set characteristics were evaluated for the commercially available cultivars 'Middletown', 'Overleese', 'PA-Golden', 'Sunflower', 'Wells', and 'Wilson' (Table 1). In 2005 and 2006 the cultivar 'NC-1' and the PawPaw Foundation (PPF) advanced selection 2-54 were also evaluated. The trees used in this study were part of a pawpaw regional variety trial (PRVT) that was planted in late March, 1998 in a Lowell silt loam soil (pH 6.9) at the KSU Research Farm in Frankfort, KY (7). The PRVT planting consists of about 300 trees, with five to eight replications (blocks) of 28 grafted scion varieties per block in a randomized complete block design (10 commercially available cultivars and 18 clones selected in the PPF orchards at the University of Maryland Experiment Stations at Queenstown, Md. and Keedysville, Md.). Seedlings from native Kentucky trees serve as border row trees. Trees were fertigated with Peters 20-20-20 (20 N-8.7 P-16.6 K) water-soluble fertilizer four times each year, in May, June, July, and August, for a total of 12.1 kg N $\cdot ha^{-1}$ (10.8 lbs N/ac). Supplemental irrigation was provided as needed via drip irrigation.

Flowers were counted on individual trees for the selected varieties three times a week during April and May in 2004, 2005, and 2006. Fruit clusters were counted in June and late July. Fruit were harvested from individual trees three times a week as they ripened during the harvest season of mid-August to late September. Trunk diameters were measured at 30 cm from ground level in March of each year prior to bloom. The graft union

Table 1. Genetic background of pawpaw clones examined in this study.

Clone	Genetic background
Middletown	Wild seedling from Middletown, Ohio
NC-1	'Davis' × 'Overleese'
Overleese	Open-pollinated seedling from Rushville, Ind.
PA-Golden	Second-generation seedling from G.A. Zimmerman collection selected by John Gordon in Amherst, NY.
Sunflower	Wild seedling from Chanute, Kans.
Wells	Open-pollinated seedling from Salem, Ind.
Wilson	Wild seedling from Cumberland, Ky.
2-54	Open-pollinated seedling from George A. Zimmerman of Linglestown, Pa.

was at a height of 15 cm from the soil line. Values for trunk diameters were converted to trunk cross-sectional area [TCA (cm^2)]. The number of fruit on each tree was counted in late July each year following the normal fruit drop period. Growing degree days (GDDs) were calculated using a base temperature of 10°C (University of Kentucky Agricultural Weather Center calculator, http://wwwagwx.ca.uky.edu/calculators.html). Temperature data were obtained from the University of Kentucky Agricultural Weather Center's monthly climate summary (http://wwwagwx.ca.uky.edu/cgi-public/climsum2.ehtml), from temperatures recorded at Lexington.

Data on trunk cross-sectional area, flower number per tree, flower density (number of flowers per tree/TCA), flowering peak (date at which the greatest number of flowers were fully open; when flowers are maroon in color), fruit set, days between flower and harvest peak, duration of flowering, duration of harvest, and yield by cultivar or advanced selection were subjected to GLM analysis of variance, LSD mean separation, and regression analysis using the statistical program Costat (CoHort Software, Monterey, Calif.).

Results

In 2004, 2005, and 2006, TCA differed significantly among cultivars, reflecting variation in vigor among the cultivars (Table 2). Flower number per tree varied among cultivars in each of the three years. There was variation among cultivars in flower density, with 'Middletown' tending to produce the most flowers per unit TCA in 2005 and 2006. Significant cultivar differences in fruit set were observed each year. For example, 'Middletown' displayed the highest flower density in 2005 and 2006, but the highest fruit set was not observed in this cultivar in either year (Table 2). Yield varied by cultivar in each year. No crop occurred in 2003 due to an April frost event. This likely resulted in a heavy crop for each cultivar in 2004, lower yields in 2005, and high yields again in 2006. 'PA-Golden' was the highest yielding cultivar in each year of the study.

Peak flowering date, bloom duration period, days between flower peak and harvest peak varied among cultivars during each year of the study (Table 3). Late-flowering cultivars were 'Middletown' and 'Wells', which were about 8 to 10 days later than the early flowering cultivars 'NC-1' and 'Overleese', and the advanced selection 2-54 (Table 3). Bloom duration varied among cultivars in all years ranging from 23-36 days (Table 3 and Fig. 1). Significant differences in harvest duration were only found in 2006, and harvest duration varied from 15 to 31 days across all years (Table 3). 'Middletown', 'Wilson', 'Overleese', 'NC-1' and 'Sunflower', and the advanced selection 2-54 had the longest number of days between flowering peak and harvest peak. 'PA-Golden' (New York), 'Taytwo' (Michigan), and 'Taylor' (Michigan) were selected in the most northern regions and had the fewest days between flowering peak and harvest peak. Fruit weight varied (65 to 189 g) with cultivar and year (Table 3). 'NC-1', 'Overleese' and 'Sunflower' had the largest fruit, averaging over 150 g, and 'Middletown', 'Wilson', 'PA-Golden', 'Wells' and the advanced selection 2-54 had fruit weights that averaged less than 150 g.

Correlation analyses performed on all cultivars combined (Table 4) showed a positive linear relationship between TCA and number of clusters, TCA and number of flowers, flower peak and harvest peak, number of flowers and number of fruit clusters, number of flowers and yield, and a negative linear relationship between number of flowers and fruit set in 2004; TCA and number of clusters, TCA and number of flowers, fruit set and yield, and number of flowers and yield in 2005; and TCA and number of flowers, number of flowers and number of clusters, fruit set and yield, and number of flowers and yield in 2006. Using regression analysis, a positive binomial relationship was also found between flower peak and harvest peak in 2006. When combining all data and using regression analysis on the averages of all years, there was a positive linear relationship between TCA and number of clusters, TCA

Table 2. Trunk diameter, flower number, flower density, and fruit set for 7-9 year old trees of eight pawpaw selections in 2004, 2005 and 2006.

Clone	Trunk cross-sectional area (cm^2)			Number of flowers per tree			Flower density (flowers/cm^2 TCA)			Fruit set (%)			Yield (kg) per tree		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
2-54	28.7 bc[y]	51.2 ab	54.6 ab	NA	938 a	597 bc	NA	20.0 ab	11.0 bc	NA	0.7 c	6.5 b	10.8 abc	3.1 c	12.8 abc
Middletown	24.0 c	31.6 cd	36.6 cd	480 bc	592 d	609 bc	18.8	20.5 a	17.6 a	9.2 b	1.9 b	6.6 b	7.0 c	3.1 c	6.2 de
NC-1	36.3 ab	53.3 ab	60.5 ab	NA	918 a	690 ab	NA	18.4 ab	11.6 bc	NA	1.0 bc	3.0 c	7.9 c	3.7 bc	11.3 bcd
Overleese	32.8 b	44.4 abc	52.0 b	676 ab	662 bcd	460 cd	20.6	15.1 bc	9.0 c	4.4 c	1.5 bc	4.6 bc	9.8 bc	4.9 abc	10.1 cde
PA-Golden	41.1 a	51.3 ab	59.6 ab	758 a	781 abc	817 a	18.6	15.2 bc	13.2 b	8.8 b	3.1 a	9.4 a	13.8 ab	7.7 a	17.2 a
Sunflower	33.0 b	43.1 bc	48.3 bc	545 bc	828 ab	663 ab	16.6	19.6 ab	13.8 b	6.8 bc	1.3 bc	7.0 b	14.0 ab	3.8 bc	16.7 ab
Wells	23.9 c	28.5 d	32.8 d	349 c	660 cd	417 d	13.8	19.1 ab	10.7 bc	13.8 a	3.0 a	6.6 b	9.5 bc	4.9 abc	5.0 e
Wilson	42.9 a	58.9 a	68.1 a	806 a	699 bcd	831 a	19.0	11.9 c	11.8 bc	7.7 bc	3.4 a	5.2 bc	15.7 a	6.0 ab	13.0 abc
Main effect[z]	***	***	***	**	**	***	NS	*	***	***	***	***	**	*	***
Block effect[z]	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
LSD	8.0	14.8	15.3	225	219	187	8.1	5.9	3.8	3.9	1.3	2.6	5.3	3.1	6.3
Mean	32.7	44.9	51.0	601	743	635	17.8	17.5	12.5	8.5	2.1	6.1	11.0	4.6	11.5

[z] NS = not significant, * significant at P=0.05, ** at P=0.01, and *** at P=0.001.

[y] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Fisher's protected LSD mean separation.

Table 3. Peak flowering date, bloom duration and harvest duration periods, and days between flowering peak and harvest peak for mature trees of eight pawpaw selections for 2004, 2005 and 2006.

Clone	Peak flowering date (month/day)			Bloom duration period (days)			Harvest duration period (days)			Days between flower peak and harvest peak			Average fruit weight (g)		
	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
2-54	NA[z]	4/17 d	4/20 d	NA	29 ab	25 f	NA	19	23 ab	NA	139 ab	145 a	134 c	117 c	112 bc
Middletown	4/27 a[y]	4/27 a	4/28 a	23 c	25 c	32 bc	31	18	19 bc	141 ab	135 bc	140 abc	76 e	85 d	65 d
NC-1	NA	4/17 d	4/21 cd	NA	30 a	28 e	NA	18	20 ab	NA	138 abc	144 a	176 a	189 a	171 a
Overleese	4/21 b	4/20 cd	4/21 cd	28 a	29 ab	31 cd	23	18	19 abc	130 c	136 abc	142 abc	145 bc	180 ab	185 a
PA-Golden	4/22 b	4/24 ab	4/23 bc	28 a	28 abc	31 cd	24	27	23 ab	123 d	127 d	136 c	112 d	116 cd	103 c
Sunflower	4/22 b	4/19 cd	4/24 b	27 ab	27 bc	29 de	25	18	25 a	136 abc	140 a	143 ab	169 ab	156 b	140 b
Wells	4/28 a	4/26 ab	4/30 a	26 b	29 ab	34 ab	26	23	15 c	134 bc	133 bc	138 bc	111 d	105 cd	90 cd
Wilson	4/23 b	4/22 bc	4/23 bc	27 ab	28 ab	36 a	28	21	25 a	143 a	132 c	140 abc	98 de	84 d	85 cd
Main effect[z]	***	***	***	***	*	***	NS	NS	**	***	***	*	***	***	***
Block effect[z]	NS	NS	NS	*	NS	**	*	NS	NS	NS	NS	NS	NS	NS	NS
LSD	4	5	3	3	4	3	9	10	6	9	6	6	31	33	33
Mean	4/24	4/22	4/24	26	28	31	26	20	21	134	135	141	128	130	118

[z] NA = not available, NS = not significant, * significant at P=0.05, ** at P=0.01, and *** at P=0.001.

[y] Any two means within a column not followed by the same letter are significantly different at $P \leq 0.05$ using Fisher's protected LSD mean separation

Table 4. Correlation coefficients for trunk cross-sectional area, flowering characteristics, and harvest data for mature trees of eight pawpaw selections in 2004, 2005, and 2006.

Independent variable	Dependent variable	**2004**		**2005**		**2006**		**Average 2004-2006**	
		Significance	r	Significance	r	Significance	r	Significance	r
TCA [z]	Fruit set	0.63 NS[y]		0.23 NS		0.34 NS		0.88 NS	
TCA	Number of clusters	0.0000***	0.60	0.02 *	0.32	0.18 NS		0.0003***	0.52
TCA	Number of flowers	0.0000***	0.72	0.0000***	0.58	0.0000***	0.59	0.0000***	0.76
Flower duration	Harvest duration	0.49 NS		0.46 NS		0.82 NS		0.62 NS	
Flower duration	Fruit set	0.50 NS		0.31 NS		0.61 NS		0.64 NS	
Flower peak	Harvest peak	0.003**	0.44	0.06 NS		0.09 NS		0.001**	0.41
Number of flowers	Fruit set	0.002**	-0.49	0.75 NS		0.74 NS		0.31 NS	
Number of flowers	Number of clusters	0.0002***	0.55	0.08 NS		0.0000***	0.51	0.0000***	0.51
Fruit set	Yield	0.23 NS		0.0000***	0.67	0.0000***	0.51	0.005**	0.36
Number of flowers	Yield	0.004**	0.44	0.01*	0.35	0.0000***	0.56	0.0000***	0.69
Fruit weight	Yield	0.90 NS		0.65 NS		0.09 NS		0.25 NS	

[z] TCA: trunk cross-sectional area in cm^2

[y] NS = not significant, * significant at P=0.05, ** at P=0.01, and *** at P=0.001. r = the sample correlation coefficient and is a measure of extent to which samples of two variables are linearly related.

and number of flowers, flowering peak and harvest peak, number of flowers and number of clusters, fruit set and yield, and number of flowers and yield. Due to year-to-year inconsistencies and variation among cultivars, no definitive conclusions could be reached concerning correlations between flower and fruiting characteristics in individual pawpaw cultivars.

The average temperature in April was similar in 2004 and 2005, and was warmer in April 2006 (Table 5). May 2005 and 2006 temperatures were similar, with May 2004 being warmer than the following years. GDDs from January 1 to first flower and from January 1 to flower peak, were higher each year of the study (Table 6). GDDs from first flower to peak flower were similar in 2004 and 2006, and were lower in 2005. Flowering peak and duration were not correlated with GDD; in 2006, which had the largest GDDs before flowering and by flowering peak, did not display an earlier flowering peak or shorter duration for most cultivars. The GDDs from flower peak to harvest peak were fewer for 2004, than for 2005 and 2006, indicating that these later years had warmer temperatures than 2004. However, the number of days between flowering peak and harvest peak are similar for the tested cultivars.

Table 5. Monthly temperature summary during pawpaw flowering for 2004, 2005 and 2006.

Month/year	Average monthly temperature (°C)
April 2004	13
May 2004	21
April 2005	13
May 2005	17
April 2006	15
May 2006	17

Table 6. Growing degree days (GDDs) during pawpaw flowering across all cultivars calculated using a base temperature of 10°C for 2004, 2005 and 2006.

Growing degree day accumulation	2004	2005	2006
January 1 to first flower	174	216	244
January 1 to flower peak	299	308	366
first flower to peak flower	125	92	122
flower peak to harvest peak	2755	2932	2954

Discussion

This is the first report of combined flowering and ripening characteristics of commercially available pawpaw cultivars. There was significant variation in year to year flowering and ripening characteristics among the cultivars examined. Mature trees of currently available commercial pawpaw cultivars did not display concentrated bloom periods or ripening periods; however, 'Wells' and 'Middletown' did have late flowering peaks that could allow a partial crop if early spring frosts destroy flowers around or at the flowering peak. However, the average fruit size of 'Wells' and 'Middletown' is small (about 100 g; Table 3) and undesirable for commercial production. Based on the data collected in this study, we reject the hypotheses that 1) an extended flowering period on the same tree will lead to greater fruit set and we do not reject hypothesis 2) that a larger number of flowers on a tree will result in a greater number of fruit on that tree. Pollinator limitation has often been suggested as an explanation for low fruit set (<0.5%) in wild patches (8). Fruit set here was greater (5.6%) than that reported in wild pawpaw patches (around 0.5%) (4, 8). Pollinator limitation may reduce fruit set in the wild compared to that in the orchard. Strategies to attract flies to flowering pawpaw orchards could increase fruit set further. Alternatively, pawpaw trees may be able to support a limited number of fruit per tree both in the wild and in orchards and pollinators may not be the limiting factor. Additionally, year to year fruit set may have been influenced by a 2003 frost event that destroyed the pawpaw crop. This likely has resulted in biennial bearing which led to high fruit set in 2004, low fruit set in 2005, and once again high fruit set in 2006. Fruit ripening duration was not related to bloom

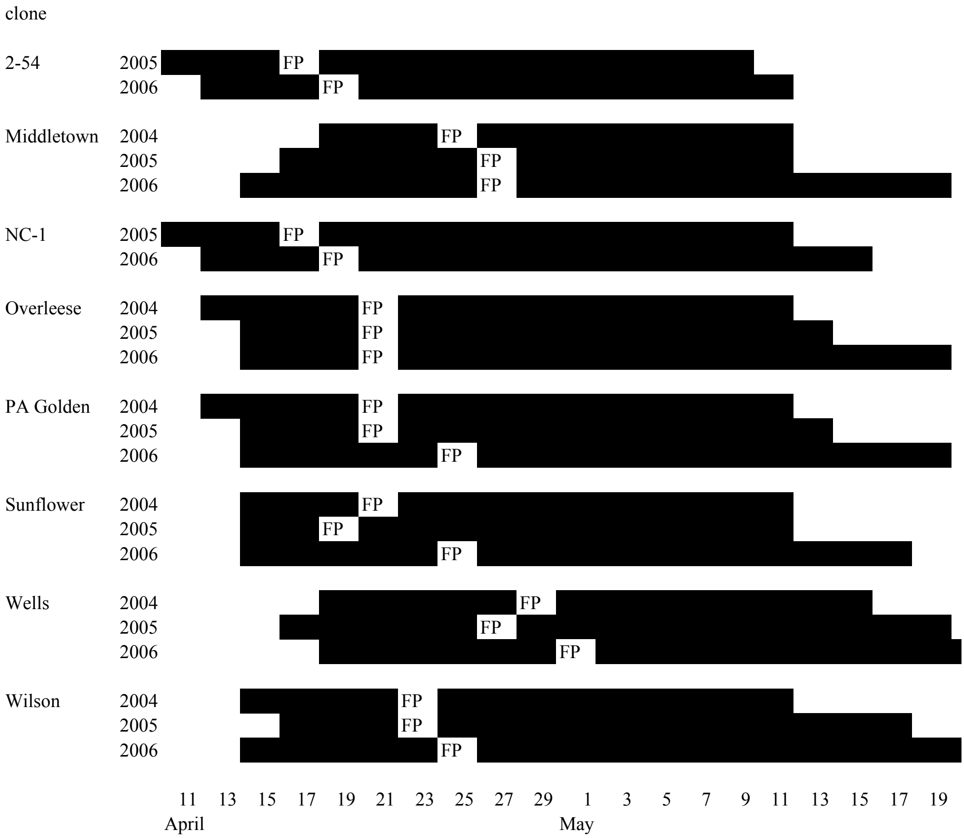

Figure 1. Flowering duration and flowering peak for eight pawpaw selections in 2004, 2005, and 2006. FP = flowering peak

duration. Identification of unique wild germplasm and selective breeding will be required to improve many of the flowering and fruiting characteristics of pawpaw.

Conclusions

Annual variation in flowering and ripening characteristics among the cultivars examined was great. An extended flowering period or larger flower number did not improve fruit set. Mature trees of currently available commercially pawpaw cultivars did not display concentrated bloom periods or ripening periods; however, 'Wells' and 'Middletown' did have late flowering peaks that could allow a partial crop if early spring frosts destroy flowers around or at the flowering peak. Unfortunately, the average fruit size of 'Wells' and 'Middletown' is small and undesirable for commercial production.

Acknowledgments

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Table 1. Average fruit weight of 'Gala' apple on 10 dwarfing rootstocks at five locations for three seasons. Values are least-squares means, adjusted for missing observations and crop density (CD).[z]

	Illinois			Maine			Michigan			New York - Geneva			Virginia		
Stock	2000	2001	2002	2001	2002	2003	2000	2001	2002	2001	2002	2003	2000	2001	2002
M.9 EMLA	185 b	178 ab	145	142 a	121 ab	144 a	178 ab	162 b	149 b	142 a	121 ab	144 a	178 ab	162 b	149 b
M.26 EMLA	187 b	175 b	147	136 ab	121 ab	136 ab	176 bc	159 b	152 ab	136 ab	121 ab	136 ab	176 bc	159 b	152 ab
M.9RN29	192 ab	177 ab	147	135 ab	118 abc	144 a	181 ab	159 b	149 b	135 ab	118 abc	144 a	181 ab	159 b	149 b
M.9 Pajam1	188 b	180 ab	143	138 ab	118 abc	141 a	182 a	164 b	148 b	138 ab	118 abc	141 a	182 a	164 b	148 b
M.9 Pajam2	198 a	186 ab	145	128 bc	116 bc	134 ab	181 ab	163 b	149 b	128 bc	116 bc	134 ab	181 ab	163 b	149 b
B.9	198 a	172 b	164	142 a	124 ab	144 a	171 cd	162 b	150 b	142 a	124 ab	144 a	171 cd	162 b	150 b
O.3	187 b	171 bc	141	142 a	126 a	125 b	181 ab	158 b	156 a	142 a	126 a	125 b	181 ab	158 b	156 a
V.1	183 b	173 b	157	135 a	117 bc	136 ab	174 bc	153 b	154 ab	135 a	117 bc	136 ab	174 bc	153 b	154 ab
Mark	185 b	156 c	137	125 c	108 c	125 b	161 d	148 c	136 c	125 c	108 c	125 b	161 d	148 c	136 c
M.9T337	193 ab	187 a	146	140 a	122 ab	135 ab	179ab	173 a	161 a	140 a	122 ab	135 ab	179ab	173 a	161 a
P-value from ANCOVA															
Stock	0.001	0.001	0.491	0.001	0.001	0.055	0.004	0.001	0.011	0.007	0.024	0.047	0.001	0.001	0.018
CD	0.007	0.003	0.001	0.003	0.019	0.021	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CD*Stock	0.544	0.281	0.347	0.136	0.261	0.313	0.519	0.431	0.304	0.329	0.225	0.873	0.938	0.223	0.169

[z] LSmeans within location and year were compared with PDIFF, P=0.05.

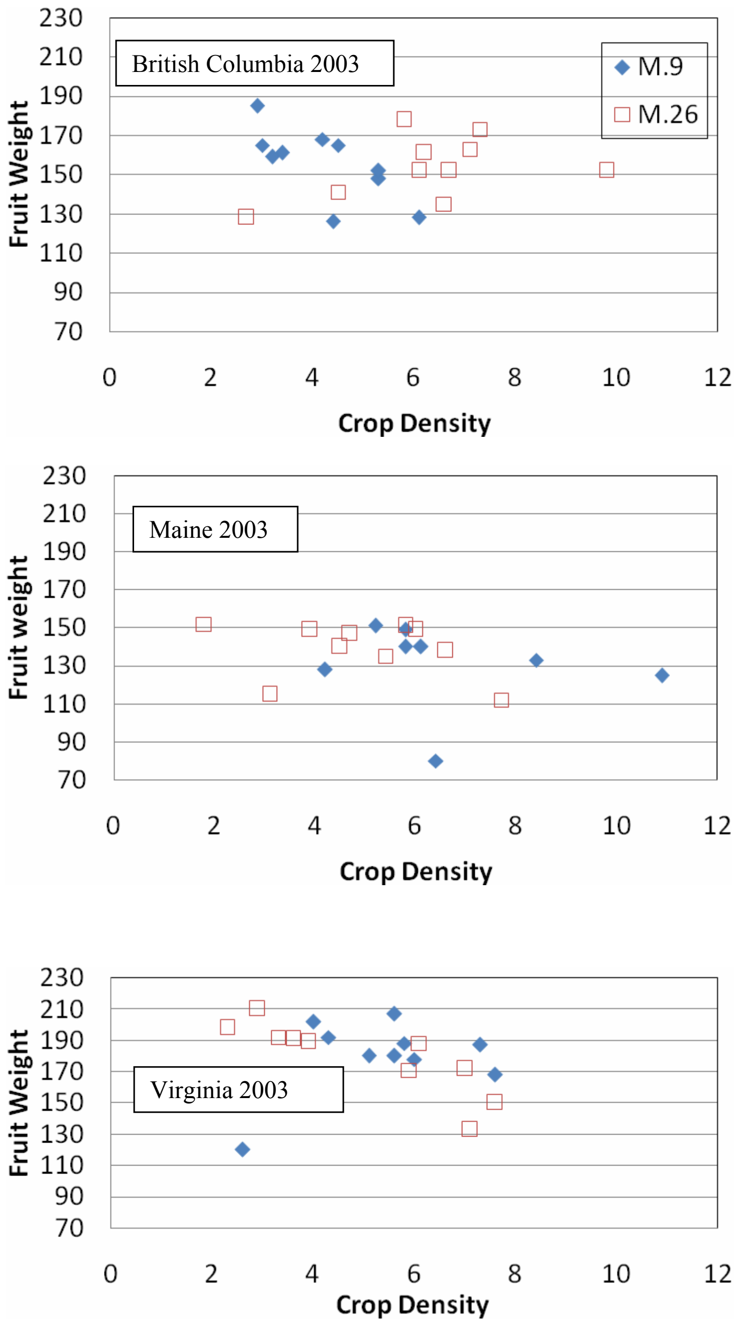

Figure 1. Scatter plots for average fruit weight (g) on crop density (no. of fruit per cm^2 of trunk cross-sectionional area) for two rootstocks at three locations. Scatter plots show the relationship is sometimes poor.

Table 2. Average fruit weight of 'Gala' apple on 10 dwarfing rootstocks at British Columbia for three seasons. Values are least-squares means, adjusted for missing observations and crop density (CD). In 2003 there was a significant rootstock by CD interaction, so least squares means were compared at three CDs (3.0, 5.6, and 7.0 fruit•cm^{-2} TCA).[z]

	2001	2002	2003		
Stock			CD = 3.0	CD = 5.6	CD = 7.0
M.9 EMLA	190 a	177 b	142 b	151 ab	156 a
M.26 EMLA	194 a	180 ab	169 ab	143 b	129 b
M.9RN29	202 a	197 a	156 ab	159 a	161 a
M.9 Pajam1	197 a	187 ab	180 a	161 a	151 a
M.9 Pajam2	195 a	189 ab	166 ab	157 a	153 a
B.9	194 a	185 ab	153 b	154 ab	155 a
O.3	196 a	181 ab	169 ab	162 a	158 a
V.1	196 a	187 ab	165 ab	152 a	144 ab
Mark	161 b	137 c	122 c	129 b	134 b
M.9T337	203 a	197 a	165 ab	161 a	159 a

[z] LSmeans within columns were compared with PDIFF, P=0.05.

designs, scion cultivars, rootstocks and statistical methods may vary. This is the second trial with 'Gala' where trees on B.9 produced relatively large fruit. However, these results also contradict those of the previous trial (14), where trees on Mark produced intermediate sized fruit and trees on M.26 EMLA consistently produced small fruit. The positive relationships between FW and CD, as indicated by the positive slopes, were unexpected because there are many reports of a negative relationship between these two variables (1, 9, 12, 20). There are several possible explanations for these unexpected results. 1) Some cooperators may have thinned trees too late in the season to substantially improve fruit size. 2) The number of replications may have been too low to obtain the true relationship because unusual observations can be highly influential when there are few replicates. 3) The unexpected results most likely resulted from the narrow range of crop loads. In most thinning experiments, treatments are selected that will produce a wide range of crop loads. However in rootstock studies, cooperators use various fruit thinning techniques to obtain crop loads that would encourage good fruit size and adequate return bloom. For these reasons, typical rootstock trials and orchard observations may not be appropriate for evaluating the influence of rootstocks on fruit size. Perhaps the influence of crop load on FW is relatively minor and inconsistent when trees are thinned adequately. Ideally, experiments should be designed specifically to evaluate the influence of rootstock and cultural practices on fruit size. Such experiments would involve wide ranges in CD and overlapping CDs for all rootstocks or treatments. NC-140 cooperators are currently conducting a study to evaluate the effects of rootstock on FW over a wide range of CDs and results from that study may help explain previous inconsistent results.

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Table 3. Slopes of average fruit weight on crop density (CD) for 'Gala' apple on 10 rootstocks at six locations for three seasons. Slopes indicate the change in average fruit weight (g) for an increase of one fruit•cm^{-2} in CD. Slopes were estimated from the solution vector provided by SAS's MIXED procedure.

	IL			ME			MI			NY-G			VA			BC		
Stock	2000	2001	2002	2000	2002	2003	2001	2002	2003	2001	2002	2003	2000	2001	2002	2001	2002	2003
M.9 EMLA	-3.6	-3.5	-3.8	1.4	-4.6	-1.3	-4.4	-4.5	-4.5	-4.0	-3.6	-3.3	-2.9	-2.0	-2.9	1.9	0.1	3.5
M.26 EMLA	-5.4	-9.0	-3.4	2.7	-6.0	0.5	-4.1	-2.1	-3.5	-2.0	-3.2	-6.6	-3.9	-2.9	-13.9	-4.6	-4.9	-10.6
M.9RN29	-6.1	3.2	-9.7	9.1	-6.2	5.3	-2.2	-4.7	-6.6	-3.5	-3.4	-3.1	-2.4	-4.2	-1.9	-4.6	-9.3	1.6
M.9 Pajam1	-4.0	-3.4	-8.3	-0.2	-1.2	-4.2	-1.4	-2.4	-0.5	-6.5	-2.4	-6.2	-3.8	3.4	3.8	-0.4	-3.8	-6.8
M.9 Pajam2	-7.1	-2.5	-7.6	7.6	1.8	-3.7	-2.4	-3.8	-8.4	-4.9	-7.6	-5.3	-2.8	-3.8	-2.6	-1.9	-3.6	-3.4
B.9	-11.2	-2.9	-10.6	8.6	-2.7	-6.6	-1.6	-1.2	-8.4	-0.9	-2.2	-6.2	-7.7	-4.1	-8.1	-2.7	-5.5	0.7
O.3	-6.8	-6.4	-4.5	1.3	-6.3	-5.7	-2.6	-1.4	-3.4	-1.5	-1.8	-5.4	-4.4	-5.2	-0.6	-3.9	-7.4	-3.2
V.1	-3.6	-1.9	-2.9	0.1	-8.4	-0.3	-4.3	-2.7	-10.6	-6.1	-8.3	-8.5	-1.2	-4.0	-3.6	2.6	-5.9	-5.3
Mark	-7.6	-5.6	-6.3	-4.4	-8.6	-1.6	-2.2	-0.9	-5.1	-1.9	-5.0	-8.5	-9.7	-4.0	-21.7	-0.3	12.1	2.7
M.9T337	-1.8	-3.6	-8.6	6.4	6.1	-12.3	0.1	-1.4	-7.7	-2.3	-3.4	-3.6	-4.1	-2.6	-3.9	-6.3	-0.8	-0.8

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