Long-term Effects of Training Systems and Rootstocks on ‘McIntosh’ and ‘Honeycrisp’ Performance, a 20-year Study in a Northern Cold Climate— Part 2: Economic Analysis

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Abstract. Orchard profitability relies on multiple factors such as cultivar, planting density, training system, rootstock, and fruit quality but is also strongly affected by growing climate and soil resources. To evaluate orchard profitability in a northern cold climate, a field trial was planted in Peru, Clinton County, NY, in 2002, with two apple cultivars (Honeycrisp and McIntosh), where we compared the Central Leader (CL) training system on ‘M.M.111’ rootstock; Slender Pyramid (SP) on ‘M.26’ and ‘Geneva® 30’ (‘G.30’); Vertical Axis (VA) on ‘M.9 (Nic® 29)’ (‘M.9’), ‘Budagovsky 9’ (‘B.9’), and ‘G.16’; SolAxe (SA) on ‘M.9’, ‘B.9’, and ‘G.16’; and Tall Spindle (TS) on ‘M.9’, ‘B.9’, and ‘G.16’. CL was planted at 539 trees/ha, SP at 1097 trees/ha, VA and SA at 1794 trees/ha, and TS at 3230 trees/ha. The aim of this study was to evaluate the economic profitability of ‘Honeycrisp’ and ‘McIntosh’ at a wide range of planting densities, training systems, and rootstocks for cold areas such as northern New York state. A secondary goal was to assess the effect of various economic factors on the net present value (NPV) of each combination of training system, rootstock, and density. High NPV was achieved with ‘Honeycrisp’ (≈\$450,000/ha), whereas NPV was significantly lower with ‘McIntosh’ (≈\$80,000/ha). Within ≈5 years, ‘Honeycrisp’ planted in a TS (3230 trees/ha) reached a positive NPV, whereas 9 years were needed when ‘Honeycrisp’ was planted in a CL system at 539 trees/ha. With ‘McIntosh’, break-even year to positive NPV (BYPNPV) was reached at 9 years for TS on ‘M.9’. Most of the other training system and rootstock combinations needed up to 11–13 years to show a positive NPV. The most important variables affecting orchard NPV in our trial were fruit price and yield. The best option for ‘Honeycrisp’ in northern New York State appears to be TS on either ‘B.9’ or ‘M.9’, whereas with ‘McIntosh’, the best option appears to be TS on ‘M.9’.

Orchard profitability is the main goal when planting a new orchard. However, profitability relies on multiple factors such as cultivar, planting density, training system, rootstock, and fruit quality (Bravin et al., 2009; DeMaree, 1995; DeMaree et al., 2003; Elkins et al., 2008; Goedegebure, 1993;

Heijerman et al., 2015; Lordan et al., 2017a; Robinson et al., 2007; Sansavini and Musacchi, 2002; Walsh et al., 2011; White and DeMarree, 1992). How a cultivar adapts to each location will determine how the interaction of the aforementioned factors will succeed in providing a profitable outcome. Therefore, cultivar selection is key for each particular location. New York State is the second largest apple producer in the United States, after Washington State, averaging around 0.6 million tons of production annually (www.nyapplecountry.com). Within New York State, the northern region named the Champlain Valley could be considered as the ‘McIntosh’ apple capital of the world. With an average yearly temperature of 7.5 °C and a mean annual rainfall of 800 mm, the humid and cold climate of the Champlain

Valley requires specific cultivars adapted to such harsh conditions. ‘McIntosh’, because of its cold-hardiness, is one of the main cultivars grown in the northeastern United States and eastern Canada (Ferree and Warrington, 2003). In recent years, ‘Honeycrisp’ was suggested as one of the few cultivars which could challenge ‘McIntosh’ as the most widely grown cultivar in New England (Greene and Weis, 2001). ‘Honeycrisp’ also has a much higher fruit price in the market than ‘McIntosh’, which has a large impact on orchard profitability.

Advances in new training systems and rootstock breeding programs have changed the way apples are grown in modern orchards (Fazio, 2014; Fazio et al., 2015; Robinson, 2008a; Robinson et al., 2011c). Dwarfing apple rootstocks, especially ‘M.9’ and ‘M.26’, have made possible the transition of entire industries to higher tree densities (>1000 trees/ha) and training systems over the last 50 years. The Cornell University apple rootstock breeding project has developed rootstock genotypes which are better adapted than ‘M.9’ and ‘M.26’ to the biotic stresses common in eastern North America (Cummins and Aldwinckle, 1983; Fazio et al., 2015). Among them, ‘G.30’ has been especially useful in northern climates with short growing seasons, whereas ‘G.16’ (Robinson et al., 2003), which has a similar growth and vigor to ‘M.9’ clones, has had only limited evaluation in northern climates. In addition, low-vigor cultivars such as Honeycrisp require a reevaluation of promising rootstocks when the scion cultivar is not vigorous (Robinson et al., 2011b).

Although several studies have reported a positive relationship between yield and planting density (Elkins and DeJong, 2002; Kappel and Brownlee, 2001; Robinson, 2008b; Sansavini and Musacchi, 2002; Vercammen, 1999), it is worth noting that there is a point where increasing planting density can decrease orchard profitability (Robinson, 2008a; Robinson et al., 2007). Therefore, the right selection of cultivar, planting density, training system, and rootstock for each particular location and economic environment needs to be evaluated over the long run.

The aim of this long-term study was to evaluate the economic profitability of ‘Honeycrisp’ and ‘McIntosh’ at a wide range of planting densities, training systems, and rootstocks for cold areas such as northern New York state. A secondary goal was to assess the effect of various economic factors on the profitability of each combination of training system, rootstock, and density.

Materials and Methods

Trial site and design. In 2002, we planted a 1.6-ha on-farm field trial in Peru, Clinton County, NY (lat. 44.597223°, long. -73.545078°), with two apple (*Malus × domestica* Borkh.) cultivars (Honeycrisp and McIntosh). We compared the following (12) production systems: CL on ‘M.M.111’ rootstock; SP on ‘M.26’ and ‘Geneva® 30’ (‘G.30’); VA on ‘M.9 (Nic® 29)’ (‘M.9’),

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‘Budagovsky 9’ (‘B.9’), and ‘G.16’; SA on ‘M.9’, ‘B.9’, and ‘G.16’; and TS on ‘M.9’, ‘B.9’, and ‘G.16’ (Table 1). CL was planted at 539 trees/ha, SP at 1097 trees/ha, VA and SA at 1794 trees/ha, and TS at 3230 trees/ha.

Experimental design was a randomized complete block with a split-split plot and three replications. Training system was the main plot with each main plot consisting of two (CL), four (SP), or six (VA, SA, and TS) 40-m long rows. Cultivar was the subplot, which consisted of one (CL), two (SP), or three (VA, SA, and TS) 40-m long rows. Rootstock was the sub-subplot with each sub-subplot consisting of a single 40-m row. There were 72 rows of 40 m each with 24 rows in each replication containing randomized main plots (system), randomized subplots (cultivar) within the main plots, and randomized sub-subplots (rootstock) within the subplots. The treatment structure was an incomplete factorial of four systems, two cultivars, and six rootstocks with only 24 out of 48 possible combinations of cultivar $\times$ training system $\times$ rootstock. The number of trees in each sub-subplot depended on planting density and varied from 13 trees/row for CL, 18 for SP, 25 for SA and VA, and 38 for TS.

Soil type was a Bombay loam with good water-holding capacity, moderately well drained, and fertile. The site had previously been planted to apple trees on seedling rootstock for 40 years and was not fumigated. The replant disease severity at the trial site was not evaluated before planting, but field fumigation trials in the same county by Merwin et al. (2001) showed low replant

disease pressure for similar soils. The site was prepared by removing the old orchard, tilling the soil to remove old root, liming the soil with 5 t of high mag lime, and then cropping with Sudan grass [*Sorghum $\times$ drummondii* (Steud.) Millsp. & Chas] for 2 years before planting the experiment. The plot was laid out perpendicular to the old orchard rows, thus giving a balanced effect of the location of the old trees on each rootstock and system. The trees were trickle-irrigated as needed during the growing season using the Cornell apple irrigation model based on a modified Penman–Monteith equation (NEWA.org) (Robinson et al., 2017) and received from 200 to 1000 mm of water depending on the year. Average annual precipitation for Peru, NY, is 812 mm. The trial was managed with conventional pesticides and fertilizers according to industry standards (Agnello et al., 2003).

Tree management. All of the trees had three to five feathers at planting. CL system was supported by a steel conduit pipe (3 m with 0.6 m in the ground) at each tree. SP, VA, and SA trees were supported by a single-wire trellis (2.3 m) connected to a steel conduit pipe (3 m with 15 cm in the ground) at each tree (Robinson and Hoying, 1999). TS systems were supported by a 3-wire trellis (2.5 m).

CL trees were developed by initially heading each tree at 70 cm and thereafter annually heading the leader and lower tier scaffolds by one-third each year to produce a strong sturdy trunk and branch framework with permanent branches. Two permanent tiers of scaffold branches were developed,

spaced 1 m apart, with four to five branches per tier. Limb spreading was performed in years 3 and 5 using wooden limb spreaders. Scaffold branches between the first and second tiers were removed between the years 5 and 6. Tree height was limited to 5 m.

SP and VA trees were developed by heading the leader at 120 cm above the graft union at planting and shortening each feather by one-third their length. In years 2 through 6, leaders were not headed. In year 3, four-five lower scaffold branches were tied down to horizontal. Beginning in year 4, large-diameter limbs (>5 cm) were removed back to the trunk with an angled cut to develop replacement limbs. Each year, two to three large branches were removed. Tree height was limited to 4 m. With the VA, lateral branches were kept simple by removing sub-lateral branches to create a single axis for each branch. With the SP, sublateral branches were allowed to remain but were removed if they became as large as the main axis of the lateral branch.

SA trees were developed by heading the leader at 120 cm above the graft union at planting, removing one to three of the largest feathers, and leaving the remaining feathers unpruned. In years 2 through 4, the leaders were not headed. Beginning in year 4 and continuing in years 6 and 8, scaffold branches longer than 1 m and originating above 120 cm height on the trunk were tied down below horizontal ($\approx 120^\circ$ from vertical), and one to two scaffold branches originating below 120 cm on the trunk were removed each year until no branches were left below 120 cm. Tree height was limited to 4 m by bending the top of the tree horizontal at 4 m height in year 8. Sublateral branches on the lateral branches were allowed to develop producing a highly branched scaffold with “fingers.”

TS trees were developed by heading the leader at 150 cm above the graft union at planting, removing one to two of the largest feathers and leaving the remaining feathers unpruned. In years 2 through 4, the leaders were left unheaded. Beginning in year 3, large-diameter limbs (>2 cm) were removed back to the trunk with an angled cut to develop replacement limbs. Each year, one to two branches larger than 2 cm were removed. Tree height was limited to 3.5 m. Only small lateral branches (<2 cm) were

Table 1. Spacing, tree planting density, training system, and rootstock evaluated at Peru, Clinton County, NY, 2002–16.

Spacing (m)	Planting density (trees/ha)	Training system	Rootstock
3.05 $\times$ 6.08	539	Central Leader	M.M.111
2.13 $\times$ 4.28	1,097	Slender Pyramid	G.30
			M.26
1.52 $\times$ 3.67	1,794	SolAxe	B.9
			G.16
		Vertical Axis	M.9 (Nic® 29)
			B.9
			G.16
1.01 $\times$ 3.06	3,230	Tall Spindle	M.9 (Nic® 29)
			B.9
			G.16
			M.9 (Nic® 29)

Table 2. Grower returns (\$/kg) for each cultivar, color category, and fruit size category after subtracting storage and packing charges. These included packing charge, MCP (1-methylcyclopropene) treatment, and average cost between regular and CA storage. Values were taken from statewide averages of New York State apple industry.

Grower returns (\$/kg)		Fruit size								
Color category	Cultivar	<115 g	115 < 133 g	133 < 153 g	153 < 175 g	175 < 199 g	199 < 225 g	225 < 253 g	253 < 283 g	≥ 283 g
XX fancy	Honeycrisp	-0.01	0.18	2.00	2.00	2.61	2.66	2.88	2.99	2.99
	McIntosh	-0.01	0.19	0.94	0.94	1.00	1.06	1.18	0.89	1.23
X fancy	Honeycrisp	-0.01	0.18	1.89	1.89	2.50	2.55	2.77	2.88	2.88
	McIntosh	-0.01	0.19	0.83	0.83	0.89	0.94	1.06	1.12	1.12
Fancy	Honeycrisp	-0.01	0.18	1.72	1.72	2.33	2.39	2.61	2.72	2.72
	McIntosh	-0.01	0.19	0.65	0.65	0.71	0.77	0.89	0.94	0.94
No. 1	Honeycrisp	-0.01	0.18	1.56	1.56	2.17	2.22	2.44	2.55	2.55
	McIntosh	-0.01	0.19	0.19	0.19	0.60	0.65	0.71	0.77	0.77
Utility	Honeycrisp	-0.01	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	McIntosh	-0.01	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

allowed to remain in the tree and they were each kept simple by removing sublateral branches to create a single axis for each branch.

Yield, income, labor, and fixed costs. For each tree, we recorded yield (kg) and fruit number annually. From 2007 onward, we collected an 18-kg fruit sample from each subplot and assessed flesh firmness (Fruit Texture Analyzer; QA Supplies LLC, Norfolk, VA) and sugar content (Atago USA, Inc.,

Bellevue, WA) (Torres et al., 2017). The sample was graded for color and size by an electronic color and weight sizer machine (MAF Industries, Inc., Traver, CA). Fruit color was assessed as a percentage of skin surface colored red (according to USDA color standards). From these data, we calculated a simulated packout for our trials. Packout returns were taken from statewide averages of typical New York State apple industry (Table 2) and were used for both economic and sensitivity analysis. We also recorded annual labor time for tree training and pruning (2006–09, 2011, and 2014). The fruit growers labor crew was used to perform all pruning and training tasks where we recorded labor time to give realistic labor costs. Yield, fruit packout (fruit size and color), and labor input data were based on the trial. Average values were used for those years when fruit quality and pruning time were not assessed. Pruning and training costs were calculated as skilled labor at \$15/h (Table 3).

Fixed costs were calculated at \$1500/ha (Table 3) and included the cost of management by the owner/manager and an overhead charge for farm-wide costs (real estate taxes, insurance, utilities, equipment replacement/investment cost, and charge for miscellaneous farm-wide expenses). The fixed costs were based on the average fruit farm in New York State of 100 ha in a manner similar to White and DeMarree (1992). Total fixed costs per farm were divided by 100 to calculate the fixed costs per ha. Other costs were taken from statewide averages of New York State apple growers (Tables 3–5).

Economic calculations. We performed economic calculations of long-term orchard system profitability using NPV of accumulated and discounted annual cash flows for each cultivar, system, and planting density over 20 years (Casler et al., 1993; White and DeMarree, 1992). We used average data from 2014 to 2016 to estimate values for years 16–20. The analysis model we used to compare the 12 different combinations of training

system and rootstock using NPV. This analysis considered the time value of money using discounted annual cash flows (a dollar received today is worth more than a dollar received in 10 years). NPV is the sum of discounted annual cash flows over 20 years using a fixed discount rate (DR). The DR was determined by subtracting the rate of inflation from the current interest rate to arrive at a real rate of interest. We used a 5% rate DR for our basic comparisons. NPV was obtained for each treatment and year by applying the following formula:

$$NPV = \sum_{t=1}^T \frac{C_t}{(1+r)^t} - C_0$$

where C_t = net cash inflow during period t ; C_0 = total investment costs; r = discount rate; and t = number of time periods.

With NPV analysis, if the NPV of accumulated profit reaches zero, the investment is sound at the selected DR (White and DeMarree, 1992). The year that the NPV of accumulated profit reaches zero is the year in which the investment has been recouped with interest, and in the case of an orchard, is the year in which the orchard can be removed and replanted.

Sensitivity analysis. We performed a sensitivity analysis to study the effect of tree price, fruit price, yield, DR, labor, and land cost on orchard profitability for the optimum planting density and tree shape of each cultivar. In the calculation of NPV, we used different values for these factors to simulate different scenarios that can affect orchard profitability. Therefore, following the same methodology used for the economic analysis (Tables 2–17), we re-calculated the NPV value for each combination of cultivar, training system, and rootstock over a 20-year period, changing the values of the aforementioned factors. The criteria to set these different values were based on our experience and New York industry standards to provide a wide range of scenarios. Trial data and average statewide apple industry costs (Tables 2–5) were used. Reference tree price used for the economic analysis (Table 4) was increased by 15%, 25%, and 50%. Reference fruit price (Table 2) was reduced and increased by 15% and 25%. Average yield obtained from the trial (100%) was modified to 60%, 80%, 120%, and 140%. Land cost was assessed at \$6000/ha, which is typical of land value in northern New York state where the study was carried out and at \$15,000/ha, which is typical of Washington State, which is the largest apple-growing area in the United States. Different DRs (5%, 7%, and 9%) were also assessed. Reference labor cost (Tables 3 and 4) was increased by 5%, 15%, 25%, and 50% to simulate expected increases in labor cost into the future.

Statistical analysis. We analyzed the effect of treatment variables (cultivar, system, and rootstock) on response variables (NPVs) by analysis of variance using linear mixed effect models. Mixed models including cultivar and the 12 combinations of training system $\times$ rootstock as a fixed factor, and

Table 3. Costs used in the economic analysis. Values were estimated from statewide averages of New York State apple growers.

Pre plant costs	
Land value	\$6,000/ha
Land preparation	\$1,800/ha
Labor: planting and training	\$900/ha
Trellising	
Post cost	\$10/post
Conduit/stake cost	\$1.6/stake
Wire cost	\$0.03/m
Post pounding	\$200/ha
Labor: trellis install	\$520/ha
Miscellaneous	
Irrigation material	\$2,500/ha
Irrigation install labor	\$1,000/ha
Financials	
Interest rate (discount rate)	5%
Annual fixed cost	\$1,500/ha
Skilled labor	\$15/h
Unskilled labor	\$12/h

Table 4. Costs used in the economic analysis. Values were estimated from statewide averages of New York State apple growers.

	Honeycrisp	McIntosh
Base picking cost	\$35/bin	\$24/bin
Picking employer taxes	15%	15%
Total picking cost per bin	\$40/bin	\$28/bin
Total picking cost per kg	\$0.11/kg	\$0.08/kg
Feathered tree ^z	\$10.0/tree	\$9.0/tree

^z\$0.5/tree are discounted when buying more than 1,000 trees/ha.

Table 5. Annual costs (\$/ha) for disease, weed, and insect management; nutrition; and thinning. Values were estimated from statewide averages of New York State apple growers.

Yr	IPM (\$/ha)			Nutrition (\$/ha)	Thinning (\$/ha)	
	Disease	Weed	Insects		Honeycrisp	McIntosh
0	0	54	0	642	0	0
1	290	91	122	978	0	0
2	398	97	121	236	0	0
3	679	28	396	497	45	30
4	733	99	642	406	121	45
5	824	145	760	702	181	60
6	691	48	929	475	181	80
7	668	99	719	565	181	80
8	838	142	533	611	181	80
9	838	142	727	565	181	80
10	838	142	727	475	181	80
11	838	142	727	563	181	80
12	838	142	727	563	181	80
13	838	142	727	563	181	80
14	838	142	727	563	181	80
15	838	142	727	563	181	80
16	838	142	727	563	181	80
17	838	142	727	563	181	80
18	838	142	727	563	181	80
19	838	142	727	563	181	80
20	838	142	727	563	181	80

Table 6. Gross income (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data represent packout returns using Table 2 and the trial data (yield, fruit size, and fruit quality).

Honeycrisp		Gross income (\$/ha)												
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9	
Trial data	0	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	
	2002	1	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	
	2003	2	\$—	\$—	\$—	\$47	\$—	\$62	\$22	\$90	\$14	\$1,815	\$117	\$226
	2004	3	\$111	\$1,961	\$3,360	\$7,224	\$2,439	\$8,894	\$7,832	\$4,271	\$11,352	\$23,568	\$3,495	\$13,877
	2005	4	\$2,655	\$7,816	\$10,741	\$19,201	\$16,341	\$30,530	\$17,180	\$17,250	\$25,066	\$39,276	\$38,835	\$43,877
	2006	5	\$1,659	\$24,197	\$11,222	\$34,392	\$31,093	\$20,859	\$34,167	\$18,788	\$26,344	\$46,472	\$13,281	\$15,740
	2007	6	\$10,170	\$50,659	\$37,803	\$43,553	\$51,849	\$53,878	\$51,005	\$63,818	\$64,017	\$61,979	\$77,276	\$77,294
	2008	7	\$7,917	\$54,895	\$25,578	\$52,776	\$56,075	\$28,879	\$63,232	\$49,057	\$53,568	\$67,038	\$46,546	\$37,147
	2009	8	\$35,566	\$108,290	\$57,847	\$80,899	\$81,568	\$92,927	\$83,028	\$80,101	\$98,905	\$126,031	\$124,791	\$122,906
	2010	9	\$47,771	\$76,908	\$28,370	\$47,124	\$42,998	\$48,239	\$49,116	\$43,280	\$54,125	\$60,516	\$77,301	\$67,160
	2011	10	\$21,504	\$33,818	\$19,119	\$35,711	\$9,189	\$37,779	\$20,632	\$4,885	\$45,984	\$54,215	\$40,476	\$80,712
	2012	11	\$67,059	\$114,929	\$55,368	\$82,559	\$68,813	\$61,060	\$81,514	\$55,517	\$63,178	\$73,307	\$72,601	\$75,522
	2013	12	\$38,736	\$78,337	\$54,850	\$70,032	\$54,884	\$49,660	\$84,961	\$59,905	\$70,015	\$60,516	\$55,631	\$48,961
	2014	13	\$66,163	\$101,765	\$49,248	\$42,282	\$54,282	\$45,579	\$66,857	\$54,626	\$72,380	\$53,060	\$69,572	\$57,378
	2015	14	\$29,859	\$61,243	\$28,627	\$51,687	\$41,129	\$44,160	\$71,802	\$48,826	\$51,646	\$47,959	\$47,375	\$44,393
	2016	15	\$95,675	\$86,962	\$53,289	\$43,135	\$63,985	\$52,556	\$44,790	\$52,049	\$84,819	\$69,269	\$51,437	\$55,446

Table 7. Fixed, variable, and establishment costs (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data are calculated using Tables 3–5 and the trial data (planting density).

Honeycrisp		Fixed cost (\$/ha)	Variable cost (\$/ha)	Establishment cost (\$/ha)									
	Yr			CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9
Trial data	0	\$—	\$696	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800
	1	\$1,500	\$1,481	\$11,348	\$20,138	\$20,138	\$28,305	\$28,305	\$28,305	\$28,305	\$28,305	\$28,305	\$40,030

Table 8. Pruning cost (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data are calculated using Table 3 (skilled labor \$15/ha) and the trial data (pruning/training time).

Honeycrisp		Pruning cost (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	1	\$200	\$409	\$293	\$335	\$598	\$562	\$275	\$526	\$466	\$906	\$1,069	\$641
	2	\$80	\$163	\$117	\$134	\$239	\$225	\$110	\$210	\$186	\$363	\$428	\$256
	3	\$120	\$245	\$176	\$201	\$359	\$337	\$165	\$316	\$280	\$544	\$641	\$385
	4	\$1,104	\$327	\$234	\$2,968	\$3,178	\$3,149	\$220	\$421	\$373	\$725	\$855	\$513
	5	\$200	\$409	\$293	\$335	\$598	\$562	\$275	\$526	\$466	\$906	\$1,069	\$641
	6	\$283	\$531	\$479	\$2,578	\$2,662	\$2,709	\$693	\$741	\$657	\$1,190	\$1,037	\$1,327
	7	\$283	\$495	\$311	\$406	\$406	\$514	\$406	\$442	\$430	\$736	\$750	\$757
	8	\$1,296	\$640	\$321	\$2,038	\$2,062	\$2,050	\$382	\$526	\$657	\$892	\$793	\$1,146
	9	\$445	\$702	\$456	\$669	\$766	\$744	\$578	\$641	\$650	\$729	\$689	\$772
	10	\$532	\$767	\$488	\$1,350	\$1,548	\$1,398	\$514	\$669	\$609	\$793	\$850	\$615
	11	\$445	\$702	\$456	\$669	\$766	\$744	\$578	\$641	\$650	\$729	\$689	\$772
	12	\$460	\$702	\$456	\$669	\$766	\$744	\$578	\$641	\$650	\$729	\$689	\$772
	13	\$774	\$1,075	\$683	\$580	\$753	\$645	\$896	\$825	\$896	\$28	\$18	\$18
	14	\$438	\$702	\$456	\$670	\$766	\$743	\$578	\$641	\$650	\$728	\$690	\$773
	15	\$445	\$702	\$456	\$670	\$766	\$743	\$578	\$641	\$650	\$728	\$690	\$773

Table 9. Harvest cost (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data are calculated using Table 4 (harvest cost) and the trial data (yield).

Honeycrisp		Harvest cost (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	1	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	2	\$—	\$—	\$—	\$2	\$—	\$5	\$1	\$4	\$1	\$98	\$6	\$13
	3	\$5	\$86	\$156	\$338	\$108	\$418	\$362	\$191	\$530	\$1,092	\$149	\$632
	4	\$131	\$372	\$561	\$1,053	\$821	\$1,766	\$889	\$854	\$1,326	\$2,217	\$2,141	\$2,765
	5	\$105	\$1,163	\$550	\$1,769	\$1,553	\$1,057	\$1,813	\$959	\$1,352	\$2,342	\$652	\$804
	6	\$443	\$2,308	\$1,798	\$2,012	\$2,314	\$2,502	\$2,386	\$2,921	\$2,996	\$2,823	\$3,589	\$3,563
	7	\$372	\$2,680	\$1,423	\$2,629	\$2,782	\$1,397	\$3,253	\$2,640	\$2,709	\$3,210	\$2,341	\$1,840
	8	\$1,557	\$5,203	\$2,825	\$3,903	\$3,805	\$4,468	\$4,080	\$3,744	\$4,811	\$6,025	\$5,728	\$5,940
	9	\$2,415	\$5,023	\$2,281	\$3,577	\$3,689	\$3,145	\$3,810	\$2,862	\$3,471	\$4,483	\$5,023	\$3,641
	10	\$1,020	\$1,659	\$948	\$1,596	\$481	\$1,785	\$1,004	\$288	\$2,241	\$2,698	\$2,108	\$4,009
	11	\$3,491	\$5,717	\$2,985	\$4,028	\$3,364	\$3,593	\$4,604	\$3,032	\$4,869	\$3,684	\$3,484	\$4,132
	12	\$1,998	\$4,173	\$3,381	\$4,071	\$3,096	\$2,886	\$5,084	\$3,425	\$4,359	\$3,522	\$2,885	\$2,698
	13	\$2,913	\$4,707	\$2,471	\$3,038	\$2,738	\$2,513	\$3,245	\$2,841	\$3,481	\$3,260	\$3,458	\$3,284
	14	\$1,258	\$2,637	\$1,289	\$2,193	\$1,772	\$2,010	\$3,193	\$2,064	\$2,281	\$2,062	\$1,998	\$1,961
	15	\$4,110	\$3,834	\$2,526	\$2,037	\$2,851	\$2,637	\$2,140	\$2,318	\$4,096	\$3,353	\$2,219	\$2,542

Table 10. Net cash (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data are calculated using Tables 6–9. Average trial data from 2014 to 2016 (years 13–15) were used to estimate values for years 16–20.

Honeycrisp		Net cash (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)
	1	\$(14,529)	\$(23,527)	\$(23,411)	\$(31,620)	\$(31,883)	\$(31,847)	\$(31,560)	\$(31,811)	\$(31,752)	\$(43,917)	\$(44,079)	\$(43,651)
	2	\$(2,431)	\$(2,515)	\$(2,468)	\$(2,440)	\$(2,590)	\$(2,518)	\$(2,441)	\$(2,476)	\$(2,524)	\$(997)	\$(2,668)	\$(2,395)
	3	\$(3,160)	\$(1,517)	\$(118)	\$3,539	\$(1,174)	\$4,993	\$4,159	\$618	\$7,395	\$18,786	\$7,442	\$9,714
	4	\$(2,081)	\$3,615	\$6,444	\$11,678	\$8,841	\$22,113	\$12,569	\$12,474	\$19,865	\$32,832	\$32,337	\$37,098
	5	\$(2,758)	\$18,513	\$6,266	\$28,175	\$24,830	\$15,128	\$27,967	\$13,191	\$20,414	\$39,112	\$7,449	\$10,183
	6	\$5,620	\$43,996	\$31,703	\$35,139	\$43,049	\$44,843	\$44,103	\$56,332	\$56,541	\$54,143	\$68,826	\$68,581
	7	\$3,529	\$47,988	\$20,111	\$46,007	\$49,154	\$23,236	\$55,839	\$42,242	\$46,697	\$59,358	\$39,723	\$30,817
	8	\$28,907	\$98,641	\$50,895	\$71,153	\$71,896	\$82,604	\$74,760	\$72,026	\$89,631	\$115,309	\$114,464	\$112,015
	9	\$40,957	\$67,229	\$21,679	\$38,923	\$34,589	\$40,397	\$40,774	\$35,824	\$46,050	\$51,349	\$67,636	\$58,793
	10	\$16,089	\$27,529	\$13,819	\$28,902	\$3,298	\$30,733	\$15,251	\$65	\$39,271	\$46,861	\$33,655	\$72,225
	11	\$59,172	\$104,559	\$47,975	\$73,910	\$60,732	\$52,772	\$72,381	\$47,893	\$53,708	\$64,943	\$64,477	\$66,667
	12	\$32,327	\$69,511	\$47,062	\$61,341	\$47,071	\$42,078	\$75,348	\$51,888	\$61,056	\$52,313	\$48,106	\$41,540
	13	\$58,525	\$92,032	\$42,142	\$34,713	\$46,840	\$38,470	\$58,765	\$47,009	\$64,051	\$45,820	\$62,146	\$50,125
	14	\$24,213	\$53,953	\$22,931	\$44,873	\$34,640	\$37,456	\$64,079	\$42,170	\$44,764	\$41,218	\$40,736	\$37,708
Estimated data	15	\$87,169	\$78,475	\$46,356	\$36,476	\$56,417	\$45,224	\$38,120	\$45,139	\$76,121	\$61,236	\$44,577	\$48,181
	16	\$56,635	\$74,820	\$37,143	\$38,687	\$45,966	\$40,383	\$53,655	\$44,773	\$61,645	\$49,425	\$49,153	\$45,338
	17	\$56,635	\$74,820	\$37,143	\$38,687	\$45,966	\$40,383	\$53,655	\$44,773	\$61,645	\$49,425	\$49,153	\$45,338
	18	\$56,635	\$74,820	\$37,143	\$38,687	\$45,966	\$40,383	\$53,655	\$44,773	\$61,645	\$49,425	\$49,153	\$45,338
	19	\$56,635	\$74,820	\$37,143	\$38,687	\$45,966	\$40,383	\$53,655	\$44,773	\$61,645	\$49,425	\$49,153	\$45,338
	20	\$56,635	\$74,820	\$37,143	\$38,687	\$45,966	\$40,383	\$53,655	\$44,773	\$61,645	\$49,425	\$49,153	\$45,338

Table 11. Annual net present value (NPV, \$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' at Peru, Clinton County, NY, over 15 years. These data are calculated using a discount rate of 5% (Table 3).

Honeycrisp		Annual NPV											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)
	1	\$(13,838)	\$(22,406)	\$(22,296)	\$(30,115)	\$(30,365)	\$(30,331)	\$(30,058)	\$(30,297)	\$(30,240)	\$(41,825)	\$(41,980)	\$(41,573)
	2	\$(2,205)	\$(2,281)	\$(2,239)	\$(2,213)	\$(2,349)	\$(2,284)	\$(2,214)	\$(2,246)	\$(2,290)	\$(904)	\$(2,420)	\$(2,173)
	3	\$(2,730)	\$(1,310)	\$(102)	\$3,057	\$(1,015)	\$4,313	\$3,593	\$534	\$6,388	\$16,228	\$(382)	\$8,391
	4	\$(1,712)	\$2,974	\$5,302	\$9,608	\$7,273	\$18,192	\$10,341	\$10,263	\$16,343	\$27,011	\$26,604	\$30,521
	5	\$(2,161)	\$14,506	\$4,910	\$22,076	\$19,455	\$11,854	\$21,913	\$10,336	\$15,995	\$30,645	\$5,836	\$7,979
	6	\$4,194	\$32,831	\$23,657	\$26,222	\$32,124	\$33,463	\$32,910	\$42,036	\$42,192	\$40,402	\$51,359	\$51,176
	7	\$2,508	\$34,104	\$14,292	\$32,696	\$34,933	\$16,513	\$39,684	\$30,020	\$33,186	\$42,185	\$28,230	\$21,901
	8	\$19,565	\$66,764	\$34,448	\$48,159	\$48,662	\$55,910	\$50,601	\$48,750	\$60,666	\$78,045	\$77,474	\$75,816
	9	\$26,401	\$43,336	\$13,975	\$25,090	\$22,296	\$26,040	\$26,283	\$23,092	\$29,684	\$33,100	\$43,599	\$37,899
	10	\$9,877	\$16,900	\$8,484	\$17,743	\$2,025	\$18,868	\$9,363	\$40	\$24,109	\$28,769	\$20,661	\$44,340
	11	\$34,597	\$61,134	\$28,050	\$43,214	\$35,509	\$30,855	\$42,320	\$28,002	\$31,402	\$37,971	\$37,698	\$38,979
	12	\$18,001	\$38,706	\$26,206	\$34,157	\$26,211	\$23,431	\$41,957	\$28,893	\$33,998	\$29,130	\$26,787	\$23,131
	13	\$31,037	\$48,806	\$22,349	\$18,409	\$24,840	\$20,401	\$31,164	\$24,930	\$33,968	\$24,299	\$23,957	\$26,582
	14	\$12,229	\$27,250	\$11,582	\$22,664	\$17,496	\$18,918	\$32,364	\$21,299	\$22,609	\$20,818	\$20,574	\$19,045
Estimated data	15	\$41,930	\$37,748	\$22,298	\$17,546	\$27,138	\$21,754	\$18,336	\$21,713	\$36,616	\$29,456	\$21,443	\$23,176
	16	\$25,945	\$34,276	\$17,016	\$17,723	\$21,057	\$18,500	\$24,580	\$20,511	\$28,240	\$22,642	\$22,518	\$20,770
	17	\$24,710	\$32,644	\$16,205	\$16,879	\$20,055	\$17,619	\$23,409	\$19,534	\$26,896	\$21,564	\$21,445	\$19,781
	18	\$23,533	\$31,089	\$15,434	\$16,075	\$19,100	\$16,780	\$22,295	\$18,604	\$25,615	\$20,537	\$20,424	\$18,839
	19	\$22,413	\$29,609	\$14,699	\$15,310	\$18,190	\$15,981	\$21,233	\$17,718	\$24,395	\$19,559	\$19,451	\$17,942
	20	\$21,345	\$28,199	\$13,999	\$14,581	\$17,324	\$15,220	\$20,222	\$16,874	\$23,233	\$18,628	\$18,525	\$17,087

Table 12. Gross income (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data represent packout returns using Table 2 and the trial data (yield, fruit size, and fruit quality).

McIntosh		Gross income, (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	2002 1	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	2003 2	\$—	\$46	\$—	\$68	\$44	\$30	\$43	\$56	\$34	\$295	\$193	\$220
	2004 3	\$12	\$2,884	\$1,146	\$4,461	\$2,158	\$7,192	\$4,042	\$3,298	\$6,970	\$9,285	\$8,252	\$10,812
	2005 4	\$673	\$5,541	\$2,995	\$5,640	\$7,240	\$10,193	\$4,200	\$8,498	\$7,207	\$11,260	\$11,164	\$13,210
	2006 5	\$144	\$2,136	\$765	\$2,554	\$2,340	\$5,344	\$1,893	\$2,425	\$3,479	\$4,545	\$5,836	\$4,787
	2007 6	\$4,611	\$15,784	\$10,522	\$19,159	\$17,178	\$23,316	\$17,416	\$16,159	\$25,319	\$26,044	\$19,290	\$31,100
	2008 7	\$3,744	\$10,066	\$7,821	\$12,377	\$11,624	\$15,372	\$12,856	\$12,819	\$16,892	\$17,560	\$13,435	\$18,485
	2009 8	\$12,237	\$15,051	\$14,284	\$23,326	\$15,613	\$23,353	\$14,252	\$17,195	\$19,764	\$28,928	\$27,430	\$32,075
	2010 9	\$19,588	\$9,050	\$8,921	\$13,507	\$13,791	\$12,422	\$17,395	\$11,587	\$14,691	\$20,887	\$21,864	\$19,451
	2011 10	\$3,729	\$2,234	\$3,846	\$12,070	\$6,680	\$5,525	\$7,995	\$2,745	\$6,697	\$15,626	\$10,408	\$14,592
	2012 11	\$18,787	\$17,185	\$16,794	\$22,936	\$17,968	\$21,841	\$21,929	\$26,223	\$24,477	\$21,928	\$23,669	\$22,881
	2013 12	\$9,296	\$12,905	\$15,092	\$19,511	\$15,592	\$22,382	\$16,990	\$18,803	\$22,705	\$17,149	\$15,356	\$18,869
	2014 13	\$34,530	\$39,275	\$37,340	\$22,546	\$21,112	\$25,400	\$24,003	\$24,208	\$24,845	\$20,328	\$16,504	\$24,989
	2015 14	\$26,337	\$29,783	\$29,364	\$37,710	\$37,697	\$42,424	\$32,439	\$38,094	\$42,713	\$37,905	\$33,004	\$48,933
	2016 15	\$21,021	\$16,947	\$12,586	\$20,028	\$16,758	\$18,805	\$15,450	\$18,207	\$19,436	\$16,239	\$14,327	\$22,610

Table 13. Fixed, variable, and establishment costs (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data are calculated using Tables 3–5 and the trial data (planting density).

McIntosh	Yr	Fixed cost (\$/ha)	Variable cost (\$/ha)	Establishment cost (\$/ha)											
				CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$696	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800	\$7,800
	1	\$1,500	\$1,481	\$10,809	\$19,041	\$19,041	\$26,512	\$26,512	\$26,512	\$26,512	\$26,512	\$26,512	\$36,800	\$36,800	\$36,800

Table 14. Pruning cost (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data are calculated using Table 3 (skilled labor \$15/ha) and the trial data (pruning/training time).

McIntosh		Pruning cost (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
	1	\$235	\$355	\$264	\$598	\$574	\$609	\$442	\$693	\$586	\$722	\$878	\$921
	2	\$94	\$142	\$106	\$239	\$229	\$244	\$177	\$277	\$234	\$289	\$351	\$368
	3	\$141	\$213	\$158	\$359	\$344	\$366	\$265	\$416	\$351	\$433	\$527	\$552
	4	\$1,132	\$284	\$211	\$3,178	\$3,159	\$3,188	\$354	\$555	\$468	\$578	\$702	\$736
	5	\$235	\$355	\$264	\$598	\$574	\$609	\$442	\$693	\$586	\$722	\$878	\$921
	6	\$318	\$477	\$345	\$2,685	\$2,686	\$2,626	\$645	\$681	\$825	\$1,303	\$1,459	\$1,360
	7	\$394	\$376	\$376	\$468	\$454	\$430	\$382	\$538	\$621	\$779	\$850	\$1,048
	8	\$1,379	\$488	\$437	\$2,020	\$1,978	\$2,062	\$609	\$741	\$657	\$1,289	\$1,416	\$1,331
	9	\$704	\$654	\$522	\$844	\$853	\$796	\$615	\$807	\$748	\$872	\$982	\$934
	10	\$1,051	\$833	\$660	\$1,637	\$1,709	\$1,566	\$562	\$837	\$693	\$963	\$1,119	\$906
	11	\$704	\$654	\$522	\$844	\$853	\$796	\$615	\$807	\$748	\$872	\$982	\$934
	12	\$704	\$654	\$522	\$844	\$853	\$796	\$615	\$807	\$748	\$872	\$982	\$934
	13	\$1,320	\$1,097	\$792	\$1,013	\$1,040	\$896	\$884	\$1,237	\$944	\$39	\$74	\$28
	14	\$704	\$654	\$522	\$844	\$853	\$796	\$617	\$807	\$748	\$875	\$984	\$935
	15	\$704	\$654	\$522	\$844	\$853	\$796	\$617	\$807	\$748	\$875	\$984	\$935

Table 15. Harvest cost (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data are calculated using Table 4 (harvest cost) and the trial data (yield).

McIntosh		Harvest cost (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	1	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—	\$—
	2	\$—	\$8	\$—	\$12	\$7	\$5	\$8	\$7	\$6	\$66	\$47	\$44
	3	\$2	\$317	\$121	\$491	\$269	\$782	\$430	\$401	\$778	\$1,122	\$915	\$1,149
	4	\$80	\$773	\$370	\$964	\$1,101	\$1,555	\$806	\$1,091	\$1,070	\$1,836	\$1,821	\$2,526
	5	\$24	\$348	\$166	\$373	\$506	\$715	\$325	\$513	\$499	\$635	\$1,096	\$729
	6	\$509	\$1,878	\$1,243	\$2,302	\$2,176	\$2,789	\$2,299	\$1,944	\$3,762	\$3,717	\$2,593	\$4,900
	7	\$466	\$1,729	\$1,285	\$1,779	\$2,023	\$2,265	\$2,197	\$2,133	\$3,076	\$3,079	\$2,347	\$3,243
	8	\$1,558	\$2,278	\$1,977	\$3,697	\$2,355	\$3,748	\$2,602	\$2,585	\$3,327	\$5,252	\$3,517	\$5,307
	9	\$2,542	\$1,818	\$1,881	\$2,786	\$3,336	\$3,143	\$2,826	\$2,274	\$3,041	\$3,962	\$3,714	\$4,094
	10	\$573	\$447	\$640	\$1,788	\$1,154	\$977	\$1,305	\$439	\$1,174	\$2,747	\$1,712	\$2,449
	11	\$4,689	\$6,589	\$6,051	\$7,905	\$6,641	\$8,389	\$7,668	\$7,993	\$8,534	\$9,256	\$7,526	\$9,780
	12	\$1,258	\$1,950	\$2,082	\$2,888	\$2,315	\$3,288	\$2,496	\$2,537	\$3,561	\$2,725	\$2,324	\$3,010
	13	\$3,501	\$4,652	\$4,174	\$3,435	\$3,346	\$4,246	\$3,449	\$3,326	\$3,980	\$4,177	\$3,433	\$4,572
	14	\$3,132	\$3,673	\$3,424	\$4,743	\$4,453	\$4,796	\$4,102	\$4,359	\$5,223	\$4,947	\$3,968	\$6,078
	15	\$3,477	\$3,237	\$2,737	\$3,895	\$3,370	\$3,618	\$3,404	\$3,382	\$4,309	\$3,074	\$2,619	\$4,241

block as a random factor were built to analyze the effect of cultivar and treatment effects (training system and rootstock) on NPV. There was a strong interaction of cultivar and treatment; thus, a second analysis was performed for each cultivar and results are presented separately for each cultivar. Crop load was included as a covariate to adjust for fruit size. Separate analyses were performed to compare the systems (SA, VA, and TS) that had the same common rootstocks ('B.9', 'G.16', and 'M.9') and to compare those three rootstocks across the three systems. Therefore, mixed models including system or rootstock as fixed factor, and block nested to system or rootstock as random factor were

built to separate treatment effects on NPV of each cultivar. All mean separations were carried out using Tukey's honestly significant difference ($P = 0.05$). Residual analysis was performed to insure that model assumptions were met. Multivariate projection methods principal component analysis (PCA) were applied to simultaneously analyze how different variables interact among them and with NPV. For this purpose, we used the following variables: NPV, reference tree price used for the economic analysis (Table 4) increased by 15%, 25%, and 50%; reference fruit price (Table 2) reduced and increased by 15% and 25%; average yield obtained from the trial modified to 60%,

80%, 120%, and 140%; land cost at \$15,000/ha; DR at 7% and 9%; and reference labor cost (Tables 3 and 4) increased by 5%, 15%, 25%, and 50%. For each cultivar, all the variables were analyzed in the same matrix. Data were analyzed using the JMP statistical software package (Version 12; SAS Institute, Inc., Cary, NC).

Results

Economic analysis. Over 20 years, there was a great difference of orchard NPV depending on the cultivar (Table 18; Fig. 1) when using actual trial data and New York industry standard prices (Tables 2–5).

Table 16. Net cash (\$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data are calculated using Tables 12–15. Average trial data from 2014 to 2016 (years 13–15) were used to estimate values for years 16–20.

McIntosh		Net cash (\$/ha)											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)
	1	\$(14,025)	\$(22,377)	\$(22,285)	\$(30,091)	\$(30,067)	\$(30,102)	\$(29,935)	\$(30,186)	\$(30,079)	\$(40,503)	\$(40,659)	\$(40,702)
	2	\$(2,445)	\$(2,456)	\$(2,457)	\$(2,534)	\$(2,544)	\$(2,569)	\$(2,493)	\$(2,580)	\$(2,557)	\$(2,411)	\$(2,556)	\$(2,544)
	3	\$(3,262)	\$(777)	\$(2,264)	\$481	\$(1,586)	\$2,913	\$215	\$(650)	\$2,710	\$4,598	\$3,679	\$5,980
	4	\$(3,964)	\$1,057	\$(1,012)	\$(1,929)	\$(446)	\$2,023	\$(386)	\$3,425	\$2,242	\$5,420	\$5,214	\$6,522
	5	\$(4,106)	\$(2,559)	\$(3,656)	\$(2,408)	\$(2,731)	\$28	\$(2,866)	\$(2,772)	\$(1,597)	\$(804)	\$(129)	\$(854)
	6	\$61	\$9,706	\$5,210	\$10,450	\$8,593	\$14,178	\$10,748	\$9,811	\$17,010	\$17,301	\$11,515	\$21,117
	7	\$(748)	\$4,329	\$2,528	\$6,498	\$5,515	\$9,045	\$6,645	\$6,516	\$9,562	\$10,069	\$6,607	\$10,561
	8	\$5,595	\$8,581	\$8,166	\$13,905	\$7,575	\$13,838	\$7,336	\$10,164	\$12,076	\$18,683	\$18,793	\$21,733
	9	\$12,488	\$2,723	\$2,665	\$6,023	\$5,749	\$4,629	\$10,100	\$4,653	\$7,048	\$12,200	\$13,315	\$10,570
	10	\$(1,657)	\$(2,808)	\$(1,217)	\$4,882	\$54	\$(781)	\$2,367	\$(2,293)	\$1,068	\$8,154	\$3,816	\$7,474
	11	\$9,543	\$6,091	\$6,371	\$10,337	\$6,624	\$8,805	\$9,794	\$13,573	\$11,345	\$7,950	\$11,310	\$8,317
	12	\$3,485	\$6,450	\$8,638	\$11,928	\$8,573	\$14,447	\$10,028	\$11,609	\$14,545	\$9,702	\$8,199	\$11,075
	13	\$25,858	\$29,676	\$28,523	\$14,247	\$12,876	\$16,407	\$15,819	\$15,795	\$16,070	\$12,262	\$9,146	\$16,538
	14	\$18,651	\$21,605	\$21,567	\$28,273	\$28,540	\$32,981	\$23,870	\$29,078	\$32,892	\$28,233	\$24,202	\$38,069
Estimated data	15	\$12,990	\$9,206	\$5,477	\$11,438	\$8,684	\$10,540	\$7,579	\$10,169	\$10,529	\$8,440	\$6,873	\$13,584
	16	\$19,166	\$20,163	\$18,523	\$17,986	\$16,700	\$19,976	\$15,756	\$18,347	\$19,830	\$16,311	\$13,407	\$22,730
	17	\$19,166	\$20,163	\$18,523	\$17,986	\$16,700	\$19,976	\$15,756	\$18,347	\$19,830	\$16,311	\$13,407	\$22,730
	18	\$19,166	\$20,163	\$18,523	\$17,986	\$16,700	\$19,976	\$15,756	\$18,347	\$19,830	\$16,311	\$13,407	\$22,730
	19	\$19,166	\$20,163	\$18,523	\$17,986	\$16,700	\$19,976	\$15,756	\$18,347	\$19,830	\$16,311	\$13,407	\$22,730
	20	\$19,166	\$20,163	\$18,523	\$17,986	\$16,700	\$19,976	\$15,756	\$18,347	\$19,830	\$16,311	\$13,407	\$22,730

Table 17. Annual net present value (NPV, \$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'McIntosh' at Peru, Clinton County, NY, over 15 years. These data are calculated using a discount rate of 5% (Table 3).

McIntosh		Annual NPV											
	Yr	CL M.M.111	SP G.30	SP M.26	SA B.9	SA G.16	SA M.9	VA B.9	VA G.16	VA M.9	TS B.9	TS G.16	TS M.9
Trial data	0	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)	\$(8,496)
	1	\$(13,357)	\$(21,311)	\$(21,224)	\$(28,658)	\$(28,635)	\$(28,669)	\$(28,510)	\$(28,749)	\$(28,646)	\$(38,575)	\$(38,723)	\$(38,763)
	2	\$(2,218)	\$(2,227)	\$(2,228)	\$(2,298)	\$(2,307)	\$(2,331)	\$(2,261)	\$(2,340)	\$(2,319)	\$(2,187)	\$(2,319)	\$(2,307)
	3	\$(2,818)	\$(671)	\$(1,956)	\$415	\$(1,370)	\$2,517	\$186	\$(561)	\$2,341	\$3,972	\$3,178	\$5,165
	4	\$(3,261)	\$870	\$(833)	\$(1,587)	\$(367)	\$1,665	\$(318)	\$2,818	\$1,845	\$4,459	\$4,290	\$5,365
	5	\$(3,217)	\$(2,005)	\$(2,865)	\$(1,886)	\$(2,140)	\$22	\$(2,245)	\$(2,172)	\$(1,252)	\$(630)	\$(101)	\$(669)
	6	\$46	\$7,243	\$3,888	\$7,798	\$6,413	\$10,580	\$8,021	\$7,321	\$12,693	\$12,910	\$8,593	\$15,758
	7	\$(532)	\$3,076	\$1,797	\$4,618	\$3,919	\$6,428	\$4,722	\$4,631	\$6,796	\$7,156	\$4,695	\$7,506
	8	\$3,787	\$5,808	\$5,527	\$9,411	\$5,127	\$9,366	\$4,966	\$6,879	\$8,173	\$12,645	\$12,720	\$14,710
	9	\$8,050	\$1,756	\$1,718	\$3,883	\$3,706	\$2,984	\$6,511	\$3,000	\$4,543	\$7,864	\$8,583	\$6,813
	10	\$(1,017)	\$(1,724)	\$(747)	\$2,997	\$33	\$(479)	\$1,453	\$(1,408)	\$655	\$5,006	\$2,342	\$4,588
	11	\$5,580	\$3,561	\$3,725	\$6,044	\$3,873	\$5,148	\$5,727	\$7,936	\$6,633	\$4,648	\$6,612	\$4,863
	12	\$1,940	\$3,591	\$4,810	\$6,642	\$4,774	\$8,045	\$5,584	\$6,464	\$8,099	\$5,402	\$4,566	\$6,167
	13	\$13,713	\$15,738	\$15,127	\$7,556	\$6,828	\$8,701	\$8,389	\$8,376	\$8,522	\$6,503	\$4,850	\$8,770
	14	\$9,420	\$10,912	\$10,893	\$14,280	\$14,415	\$16,658	\$12,056	\$14,686	\$16,613	\$14,260	\$12,224	\$19,228
Estimated data	15	\$6,248	\$4,428	\$2,635	\$5,502	\$4,177	\$5,070	\$3,646	\$4,891	\$5,064	\$4,060	\$3,306	\$6,534
	16	\$8,780	\$9,237	\$8,485	\$8,240	\$7,650	\$9,151	\$7,218	\$8,405	\$9,085	\$7,472	\$6,142	\$10,413
	17	\$8,362	\$8,797	\$8,081	\$7,847	\$7,286	\$8,715	\$6,874	\$8,005	\$8,652	\$7,117	\$5,850	\$9,917
	18	\$7,964	\$8,378	\$7,697	\$7,474	\$6,939	\$8,300	\$6,547	\$7,624	\$8,240	\$6,778	\$5,571	\$9,445
	19	\$7,585	\$7,979	\$7,330	\$7,118	\$6,609	\$7,905	\$6,235	\$7,261	\$7,848	\$6,455	\$5,306	\$8,995
	20	\$7,224	\$7,599	\$6,981	\$6,779	\$6,294	\$7,529	\$5,938	\$6,915	\$7,474	\$6,148	\$5,053	\$8,567

Although high NPV was achieved with 'Honeycrisp' ($\approx \$450,000/\text{ha}$), for 'McIntosh', the highest values were \$100,000/ha with TS on 'M.9', whereas the rest of the treatments were between \$40,000 and \$80,000/ha after 20 years.

With 'Honeycrisp', the highest cumulative NPVs were attained with TS with 'M.9', 'B.9', and 'G.16'; VA with 'M.9' and 'B.9'; and SP with 'G.30'. The lowest NPV was for CL with 'M.M.111' and SP with 'M.26' (Fig. 1; Table 18). There were no significant differences among TS, VA, and SA or among rootstocks ('B.9', 'G.16', and 'M.9') when comparing within systems that had the same common rootstocks or within rootstock that had the same common systems, respectively.

With 'McIntosh', the highest NPV after 20 years was for TS with 'M.9', followed by VA and SA both with 'M.9', and TS with

'B.9'. On the other hand, SA with 'G.16' and SP with 'M.26' had the lowest NPV (Fig. 1; Table 18). There were no significant differences among TS, VA, and SA. On the other hand, 'M.9' had significantly higher NPV than 'G.16'.

Higher establishment costs were associated with the highest planting densities; therefore, the TS had the highest establishment costs ($\approx \$45,000/\text{ha}$) (Fig. 1; Tables 7 and 13). VA and SA had similar establishment costs (\$35,000/ha), followed by SP (\$27,000/ha), and CL had the lowest establishment costs at planting (\$19,000/ha). However, the low establishment cost of CL did not give a positive NPV (\$7000) until after 14 years with 'McIntosh'.

The quickest time to a positive NPV was 5 years for 'Honeycrisp' with TS on 'B.9', whereas CL with 'M.M.111' had the latest

BYPNPV, 9 years (Fig. 1). With 'McIntosh', BYPNPV was reached at 9 years for TS with 'M.9', 10 years with 'B.9', and 11 years on either TS with 'G.16' or VA with 'M.9'. More time was needed for SA with 'M.9' (12 years), followed by VA on either 'B.9' or 'G.16', SA with 'B.9', and SP with 'G.30', all with a BYPNPV at 13 years. SA with 'G.16', SP with 'M.26', and CL with 'M.M.111' needed 14 years.

There was a different behavior for each cultivar and training system when studying the relationship of NPV to tree density after 1, 5, 10, 15, and 20 years (Fig. 2). Higher negative NPV values were observed when increasing tree density after 1 year. For 'Honeycrisp' at year 1, cumulative NPV was $-\$20,000/\text{ha}$ for 500 trees/ha, whereas it was $-\$50,000/\text{ha}$ when planting 3230 trees/ha. At year 5, cumulative NPV of

Table 18. Cumulative net present value (NPV, \$/ha) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY, over 20 years. Means followed by different letters denote significant differences (Tukey's honestly significant difference, $P \leq 0.05$).

Cultivar	System and rootstock	Cumulative NPV 20 Years (\$/ha)
Honeycrisp	CL MM111	287,143 AB
	SP G30	546,383 A
	SP M26	259,771 B
	SA B9	360,384 AB
	SA G16	351,463 AB
	SA M9	343,499 AB
	VA B9	431,800 AB
	VA G16	342,111 AB
	VA M9	474,510 AB
	TS B9	489,763 AB
	TS G16	442,307 AB
	TS M9	451,113 AB
	<i>P</i>	0.0300
	System SA	351,782
	VA	416,140
	TS	461,061
	<i>P</i>	NS
	Rootstock B9	427,316
	G16	378,627
	M9	423,040
	<i>P</i>	NS
	System x rootstock	NS
McIntosh	CL MM111	53,783
	SP G30	62,538
	SP M26	50,344
	SA B9	63,678
	SA G16	44,728
	SA M9	78,809
	VA B9	52,241
	VA G16	61,486
	VA M9	82,562
	TS B9	72,967
	TS G16	54,240
	TS M9	102,570
	<i>P</i>	NS
	System SA	62,405
	VA	65,430
	TS	76,592
	<i>P</i>	NS
	Rootstock B9	62,962 AB
	G16	53,485 B
	M9	87,980 A
	<i>P</i>	0.0087
	System x rootstock	NS

'Honeycrisp' almost reached a positive value for high-density plantings (>2500 trees/ha), and the advantage of high-density plantings in NPV compared with low-density plantings became even greater after 10–20 years (\$450,000/ha vs. \$330,000/ha).

Similarly, 'McIntosh' had higher negative NPV values for high-density plantings after year 1 and were still significantly more negative than low-density plantings after year 5, but the differences among planting densities were not great at that time (Fig. 2). After 10 years, differences among planting densities became more apparent, where negative NPV values were still observed for

medium and low planting densities (less than 3000 trees/ha), whereas some NPV was already reached for the highest planting densities. All the planting densities were profitable at year 15 and differences became greater at year 20, with the highest NPV values for the highest planting densities (\$80,000/ha vs. \$50,000/ha).

Sensitivity analysis. Tree price had a large impact on orchard NPV, but the impact was different depending on the cultivar (Fig. 3). With 'Honeycrisp', differences in NPV were mainly observed when tree price increased up to 50% (\$21.6/tree), especially for VA and the highest density plantings, TS. With

'McIntosh', tree price had a greater effect. However, positive NPV values were still observed, even when tree price increased by 50% (\$19.4). Price increase tended to have a greater effect on high planting densities similar to what we observed for 'Honeycrisp', but at high tree prices, some 'McIntosh' high-density systems (e.g., TS with 'G.16' and 'B.9') were less profitable than the lowest density system (CL with 'M.M.111').

Changing the DR did not change how the ranking of the NPV of the different systems for either cultivar; however, there was a different response depending on the cultivar (Fig. 4). With 'Honeycrisp', a DR of 9% gave a similar NPV for SP with 'G.30' as 5% DR for SA. With 'McIntosh', the lowest NPV was observed for SA with 'G.16' when DR was 9%. At 7% of DR, TS with 'M.9' had higher NPV than most of the other treatments at 5% DR.

Yield fluctuation had a big impact on NPV (Fig. 5). 'Honeycrisp' was still profitable with all systems when yield decreased to 60%. When yield was increased by 40%, the highest NPV (\$800,000/ha) was for TS with 'B.9' and for SP with 'G.30'. At 140% yield, CL with 'M.M.111' gave similar NPV as TS with 'B.9' with the reference (trial) yield (100%). For 'McIntosh', almost all the treatments were not profitable when yield decreased to 60%, with the exception of SA, VA, and TS, all with 'M.9'. For systems with less than 1100 trees/ha, yield would have to be 140% of trial reference yield for the NPV of these low-density systems to equal or exceed the NPV of the high-density TS on 'M.9' with reference (trial) yield.

Similarly to yield fluctuation, fruit price had a huge impact on orchard NPV. A fruit price increase of 15% had a similar effect on NPV as 120% yield increase (Figs. 5 and 6). All the different training systems were profitable when fruit price decreased by 25%, even 'McIntosh'. However, almost no profit was observed for SA and TS, both with 'G.16'. TS with 'M.9' had the highest NPV, with ≈\$140,000/ha when fruit price increased by 15% and increased to \$160,000/ha when price increased by 25%. For 'Honeycrisp', NPV increased to \$700,000 for SP with 'G.30' and \$600,000 for TS with 'B.9' when price increased by 25%. All 'Honeycrisp' treatments were profitable even when fruit price dropped by 25%.

Land cost did not have an important impact on orchard NPV for 'Honeycrisp', with all of the systems remaining profitable, even when land cost was \$15,000/ha (Fig. 7). For 'McIntosh', all the systems were still profitable when land cost increased; yet, it was more affected than 'Honeycrisp'. For instance, with 'McIntosh', the lowest planting densities experienced the greatest reduction in NPV when land cost increased.

Labor cost had only a slight impact on orchard NPV with 'Honeycrisp', with the largest effect at the highest planting densities (Fig. 8). With 'McIntosh', labor cost affected more uniformly across different planting

Fig. 1. Net present value (NPV) for each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Average data from 2014 to 2016 was used to estimate values for years 16–20.

densities, with higher affects for the lowest planting densities (<1100 trees/ha).

We performed two PCA analyses to study the relation among the different variables that can affect NPV (Fig. 9). The first two principal components (PCs) were able to explain 92% (62% PC1 and 30% PC2) and 96% (78% PC1 and 18% PC2) of the overall variance for 'Honeycrisp' and 'McIntosh', respectively. For both cultivars, yield and fruit price were the most important variables for the definition of the first PC, which were also positively correlated with NPV. Labor cost was the third variable in importance affecting NPV but negatively correlated in this case. Discount rate had different affection depending on the cultivar, with higher effect on 'McIntosh' than on 'Honeycrisp'. For both cultivars, DRs at 7% to 9% were highly positively correlated among them, being highly negatively correlated with DR at 3%, which had a totally opposed effect on NPV in this case, especially for 'McIntosh'. Tree price also had higher negative effect on 'McIntosh' than on 'Honeycrisp', whereas

the land cost had a similar negative correlation with NPV for both cultivars. Land cost and DR were extremely correlated for 'McIntosh'.

Discussion

Economic and sensitivity analyses. Our economic analysis showed that there was a very large difference (5×) in NPV between the two cultivars with 'Honeycrisp' much more profitable than 'McIntosh'. Although 'Honeycrisp' had lower yields in this trial in northern New York (Lordan et al., 2018b), the high fruit prices for this cultivar made it highly profitable, with more than \$450,000/ha over 20 years. This value is much higher than that estimated by Bradshaw et al. (2016) in Vermont, of \$75,000/ha after 20 years. However, in that case, only 725 trees/ha were used. In our study, NPV for 'Honeycrisp' was highly positively correlated with planting density. Thus, the highest NPV was estimated when training as TS (3230 trees/ha), followed by VA (1794 trees/ha), whereas SP (1097 trees/ha) with 'M.26', and CL (539 trees/ha)

with 'M.M.111' were the systems with lowest NPV values. An exception to this relationship was SP with 'G.30'. This rootstock was released in 1994 and was described as a very productive and cold hardy semidwarf rootstock (Robinson et al., 2003). The present study shows that it has excellent yield potential in cold climates and even when planted at medium densities can be very profitable. Previous studies performed in Europe (Balkhoven-Baart et al., 2000; Weber, 2001) with other cultivars and other rootstocks, have all suggested much higher densities (3000–6000 trees/ha) as the most profitable option. However, it appears NPV for a given training system and planting density is also a function of rootstock and how well it is adapted to the climate. For instance, whereas SP with 'M.26' had the lowest cumulative NPV, SP with 'G.30' had the highest NPV and numerically higher than TS with 'M.9', although not statistically different. This was largely due to the advantages in yield with 'G.30' compared with 'M.26'. Most of the efforts during the last decade have been focused on dwarfing rootstocks for high-density plantings rather than semidwarf for mid-densities (Autio et al., 2011; Fazio, 2014; Fazio et al., 2014; Marini et al., 2014). However, the use of semidwarfing rootstocks for mid-density plantings could still be an option with certain conditions. One of the limiting factors with other semidwarfing rootstocks is precocity. However, 'G.30', which is a semidwarfing rootstock, has similar precocity (earliness to bear fruit in the life of the orchard) to 'M.9'. The effect of precocity on NPV is large. After ≈5 years, 'Honeycrisp' with TS (3230 trees/ha) on 'B.9' had a positive NPV in our study, whereas 9 years were needed when planting 539 trees/ha on 'M.M.111'. Similarly, in a study of Badiu et al. (2015) in Romania, 4 years were reported to payback with high-density plantings (3175 trees/ha), whereas up to 10 years were needed for low densities (333 trees/ha); however, payback is not perfectly comparable with NPV because the former does not consider an investment recoup with interest.

Comparing our study with previous studies made in Switzerland, Germany, The Netherlands, and France (Bravin et al., 2009; Weber, 2001), two of the most important variables affecting orchard NPV in our trial were fruit price and yield. Tree price was important, especially for highest densities, mainly because of the higher investment risk that is required in these cases. However, the higher returns that growers are getting for 'Honeycrisp' make this cultivar profitable despite tree price increases. In another study that we performed with other cultivars such as McIntosh, Fuji, and Empire, mid- to high densities (>2200 trees/ha) were highly affected when tree price increased, most likely because of the low fruit price of those cultivars (Lordan et al., 2018a). Greater planting density increases establishment costs and makes a risky investment, but this

Fig. 2. Regressions for yearly cumulative net present value to tree density (trees/ha) for each cultivar (Honeycrisp and McIntosh) at Peru, Clinton County, NY.

can be accepted if a cultivar such as ‘Honeycrisp’, with high fruit price, is planted. Even a reduction of 25% in fruit price or a yield decrease to 60% was still profitable for this cultivar. Thus, if higher yields could be achieved by using new rootstocks (Lordan et al., 2016, 2017b; Reig et al., 2018; Robinson et al., 2011a, 2016), a possible future fruit price reduction could be offset.

Coinciding with ‘Honeycrisp’, the optimum planting density for ‘McIntosh’ was 3230 trees/ha; however, NPV was considerably lower for this cultivar (\$100,000/ha vs. \$500,000/ha, after 20 years). In a previous study, we estimated an NPV of \$40,000/ha after 20 years, but optimum planting density was slightly lower in that case (2500 trees/ha),

mainly because of higher yields in WNY conditions (Lordan et al., 2018a). In the present study, NPV was higher (2×), considering the premium price in the Champlain Valley of New York compared with western New York (\$1.23/kg vs. \$0.84/kg because of higher fruit quality with Champlain ‘McIntosh’ compared with WNY ‘McIntosh’).

In our study, 11–13 years were needed for most of the training system and rootstock combinations to reach a positive NPV value. Release of new cultivars such as Snap-Dragon®, RubyFrost®, and Cosmic Crisp® will likely imply a ‘McIntosh’ price reduction instead of increasing it. Therefore, planting ‘McIntosh’ in the future does not look like the best option, unless significant

higher yields could be achieved while keeping high fruit quality. In addition, labor cost increases will be more detrimental for cultivars such as McIntosh than Honeycrisp. The great effect on NPV that we observed with ‘McIntosh’ when increasing either the land cost or the DR, suggest that this cultivar would be only profitable in the future when high productivity can be attained. Thus, we suggest that the TS plantings (3230 trees/ha) is the best option with dwarfing rootstocks such as ‘M.9’ or newer Geneva® rootstocks other than ‘G.16’. This differs from the optimum density observed in WNY (2500 trees/ha) (Lordan et al., 2018a), where lower planting densities were more suitable to reduce the investment cost because of the lower fruit quality that can be produced in those areas. In addition, the great impact of labor cost could be reduced through mechanization or robotic technology (Bulanon et al., 2002; Markman, 2017; Zhang and Karkee, 2016).

Conclusions

Yield and fruit price were the main variables that affected NPV, followed by labor cost. Therefore, the best approach for growers is to increase orchard yield at the same time reducing labor input and increasing fruit quality to obtain higher fruit prices. It is difficult to quantify the level of risk associated with the different planting options. Yet, when two options have the same NPV, the one with the lower initial investment is preferred (White and DeMarree, 1992). However, with cultivars like Honeycrisp that have high grower returns, more risky investments can be adopted because of their quicker BYPNPV. In these cases, high-density plantings in TS on dwarfing rootstocks seemed to be the best option. Differences between low- and high-density plantings could get even greater if orchard life is increased, for instance from 15 to 20 years. Low number of years to recoup the investment gives growers flexibility to respond to changes in varietal demand. Taking into account NPV and BYPNPV from our trial, the best option would be to plant ‘Honeycrisp’ trained as a TS (3230 trees/ha) with either ‘B.9’ or ‘M.9’. We estimate that planting ‘McIntosh’ is a higher risk decision because time spans of 12 years are required to recover the investment. However, planting low densities (<1000 trees/ha) that require less initial input may even be riskier because lower yields are achieved and this cultivar has much lower market price. Nonetheless, the premium fruit quality of ‘McIntosh’ grown in cold areas such as Champlain Valley leaves this cultivar as still a good alternative. Therefore, because high-density plantings have quicker payoffs, despite being more affected by tree and labor price increases and fruit price decreases; they seem to be the best option for cultivars such as ‘McIntosh’ in Champlain Valley. According to our study, the most profitable option for ‘McIntosh’ was TS with ‘M.9’, at 3230 trees/ha.

Fig. 3. Effect of tree price on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales and tree prices depending on cultivar. Tree prices reflect 15%, 25%, and 50% increase to reference tree price (Table 4). *\$0.5/tree is discounted when more than 1000 trees/ha.

Fig. 4. Effect of discount rate (5%, 7%, and 9%) on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales depending on cultivar.

Fig. 5. Effect of yield level on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales depending on cultivar. Yield levels reflect 60%, 80%, 120%, and 140% variation to average yield obtained from the trial.

Fig. 6. Effect of fruit price on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales and tree prices depending on cultivar. Tree prices reflect -25%, -15%, +15%, and +25% variations to reference fruit price (Table 2).

Fig. 7. Effect of land cost on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales depending on cultivar.

Fig. 8. Effect of labor cost price on net present value after 20 years of each combination of training system (Central Leader—CL, SolAxe—SA, Slender Pyramid—SP, Tall Spindle—TS, and Vertical Axis—VA) and rootstock ('M.M.111', 'B.9', 'G.16', 'M.9', 'G.30', and 'M.26') for 'Honeycrisp' and 'McIntosh' at Peru, Clinton County, NY. Note different y-axis scales depending on cultivar. Labor cost reflects +5%, +15%, +25%, and +50% variations to reference labor cost (Tables 3 and 4).

Fig. 9. Variable loadings represented in the plane defined by the first two principal components analysis for 'Honeycrisp' and 'McIntosh' sensitivity analyses. Variables are net present value; reference tree price (Table 4) (TreeP) increased by 15%, 25%, and 50%; reference fruit price (Table 2) (FruitP) reduced and increased by 15% and 25%; average yield obtained from the trial modified to 60%, 80%, 120%, and 140%; land cost (LandC) at \$15,000/ha, discount rates (IR) at 7% and 9%; and labor cost (LaborC) increased by 5%, 15%, 25%, and 50%.

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