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Long-term effects of rootstock and tree type on the economic profitability of 'Gala', 'Fuji' and 'Honeycrisp' orchards performance

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A R T I C L E I N F O

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A B S T R A C T

Planting a new orchard requires a complex management strategy that involves many factors including cultivar, rootstock, planting density, training system, tree type, climate, and economic conditions that affect orchard profitability. To evaluate the relative importance of each factor, data from long-term field studies is required to analyze their impact on lifetime profitability. Here, we conducted two long-term field studies at two locations in New York State (Dressel farm in South-eastern and VandeWalle farm in Western New York State). The trials were planted in 2006 at a planting density of 3,262 tree/ha and the trees were trained as Tall Spindles. The aim of this study was to compare the impact of tree type (newly bench-grafted trees and large 2-year feathered trees) and rootstock (B.9, M.9, G.11, G.16, G.41) on long-term profitability of three apple cultivars ('Fuji', 'Gala', and 'Honeycrisp'). There were important differences in profitability between cultivars, with a higher Net Present Value (NPV) for 'Honeycrisp', followed by 'Gala' and, finally, for 'Fuji'. For all the cultivars, the NPV of the feathered trees was substantially higher compared to bench-grafted trees. Furthermore, the highest cumulative NPV's for 'Honeycrisp' were on B.9, G.11 and G.16, whereas with 'Fuji' the highest NPV's were on G.16, G.11 and M.9 and with 'Gala' the highest NPV's were on G.16, G.41 and M.9. The break-even year of a positive NPV for each rootstock, tree type, and cultivar, showed that the fastest investment pay offs were achieved with 'Honeycrisp', followed by 'Gala' and 'Fuji'. Feathered trees showed a faster break-even year of a positive NPV compared to bench grafted trees in all cultivars. Our results showed that the key variables that influence orchard profitability were, in descending order, fruit price and yield, followed by discount rate, labor cost, and finally tree price and land cost.

1. Introduction

Establishing a new orchard requires a high capital investment which is put at risk by changing markets and global supplies (Auvil et al., 2011). Apples are traded in large quantities in international markets, implying international competition for apple producers (Gallardo and Garming, 2017). Planting a new orchard requires a complex management strategy that involves cultivar, rootstock, training system, tree density, fruit quality, yield and fruit price as the main factors to improve orchard profitability (DeMarree et al., 2003; Goedegebure, 1993; Lordan et al., 2019; Robinson et al., 2007; Sansavini and Musacchi, 2002). Other factors such as successful pest and disease management, and economic ones like land cost, tree cost, labor cost and interest rates also have a high impact on orchard profitability (Robinson et al., 2007).

The decision of the best cultivar or mix of cultivars to be planted in a specific orchard depends on market aspects (market demand nationally

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and internationally) followed by production aspects (yield, tree price, amount of pesticide required, pruning labor, thinning and picking costs) (Gallardo and Garming, 2017). The selection of cultivars and rootstocks and how they adapt to each location will determine if the aforementioned factors will succeed in providing a profitable outcome (Lordan et al., 2018).

High-density systems are mainly based on the highly productive dwarfing rootstock (Russo et al., 2007). This allows trees with less vigor to be planted at a high tree density, resulting in a faster full production and higher mature yields per hectare (Gallardo and Garming, 2017). Trees on dwarfing rootstocks are also easier to prune, thin and harvest (U.S. International Trade Commission, 2010), however, they often require a greater capital investment (like trellis system to help support the canopy) and labor (with more trees to manage per unit of production basis). Rootstocks also affect winter hardiness, fruit size, precocity, productivity, tree vigor, and disease resistance (Cummins and Aldwinckle, 1983; Momol et al., 1998; Russo et al., 2007; Westwood, 1988). The joint apple rootstock breeding and evaluation program of Cornell University and U.S. Department of Agriculture Agricultural Research has developed new rootstock cultivars, designated as Geneva® rootstocks, with an emphasis on productivity, yield efficiency, ease of nursery propagation, fire blight resistance, extreme temperature tolerance, resistance to the soil disease of the sub-temperate regions of the U.S., and tolerance to apple replanting disorder (Fazio and Robinson, 2018; Robinson et al., 2008a).

The Tall Spindle system is a fusion of the Slender Spindle, the Vertical Axis, the Solaxe and the Super Spindle systems (Robinson et al., 2008b). The Tall Spindle planting system maximizes profitability through early yield, improved fruit quality, reduced spraying, pruning, and training costs (Hoying et al., 2016). High density orchards that use the Tall Spindle system, depend on significant 2nd and 3rd year yield, which is made possible by the use of highly feathered nursery trees (Dominguez, 2015; Robinson, 2007). The preferred trees for this systems have a minimum stem diameter of 15 mm and 10–15 feathers (Dominguez, 2015; Reig et al., 2019). The Tall Spindle system is a popular option for replanting orchards. But the investment cost is directly related to the cost of each tree (Reig et al., 2019). Although not mentioned as a main factor for the orchard profitability within previous studies, the tree type should also be considered. An alternative to the use of highly feathered trees is to use less expensive trees, such as bench-grafts, to reduce the investment cost. As a general rule, bench-grafts are more tender and fragile than a standard 2-year-old tree from the nursery (Tvergyak, 2005). With bench-grafted trees, almost all of the infrastructure has to be developed in the orchard after planting and thus, early and maximum production is delayed (Fazio and Robinson, 2008). Moreover, the success of bench-grafted trees dependent highly on their management and the weather conditions, since the graft union on a bench graft is only partially callused at planting time and is physically weak relative to the rootstock and scion (Tvergyak, 2005).

In recent years, 'Honeycrisp' was considered as one of the few cultivars that could change the reference cultivars in the coldest areas (Basedow, 2020). Many of its characteristics have attracted growers and consumers, with a resulting increase in the planted area and production worldwide (Autio et al., 2020b). 'Gala' is widely planted in the USA and its compatibility with older rootstocks is well known; however, less information is available on the performance of 'Gala' with new Geneva® rootstocks (Wallis et al., 2017). 'Fuji' apples are also a popular variety in America. These cultivars are in the top five in the U.S. (1-'Gala', 3-'Honeycrisp' and 5-'Fuji') (2020 USApple Association).

We have conducted a number of long-term studies to analyze the profitability of various cultivars, rootstocks, planting density, training system and tree type (DeMarree et al., 2003; Goedegebure, 1993; Lordan et al., 2019; Robinson et al., 2007; Sansavini and Musacchi, 2002). The horticultural results of this field study have been previously reported as an evaluation of rootstock and tree type (Reig et al., 2019). This previous report concluded that, for all three cultivars, feathered trees were more productive and efficient than the bench-grafted trees. However, to fully evaluate the suitability of using bench grafted trees to reduce initial investment, it is necessary to evaluate long-term economic profitability for both tree types (feathered and bench-grafted). The objective of the present study was to identify and evaluate the economic influence of rootstock and tree type on the profitability of 'Fuji', 'Gala', and 'Honeycrisp' when planted in a high-density Tall Spindle orchard.

2. Material and methods

2.1. Plant material, site description and experimental design

In the spring of 2006, two 0.3 ha orchard trials of two tree types and five apple rootstocks were established at two locations in New York State, USA (Dressel farm (41°42′59.1″N 74°06′50.1″W) and VandeWalle farm (43°12′59.4″N 76°58′15.4″W)). The two types of trees were: fully feathered nursery trees (2 years in the nursery), and bench-grafted trees (no time in the nursery but directly planted to the field after grafting) (Fig. 1). The feathered trees were propagated by Adams County Nursery, Aspers PA, USA, and the bench-graft trees were propagated by Wafler Nursery, Wolcott, NY. Virus free scion wood and rootstocks were used at both nurseries. 'Gala' and 'Fuji' apple cultivars were used at the Dressel farm site, and 'Gala' and 'Honeycrisp' were used as scion cultivars at the VandeWalle farm site.

The rootstocks compared here were B.9, M.9, G.11, G.16, G.41 which are all fully dwarfing rootstocks and suitable for use in a high-density Tall Spindle orchard (Table 1). The trees were spaced 0.91m×3.35 m (3262 trees ha^{-1}) and were trained as a Tall Spindle. The location of the trials, soils descriptions and tree development protocols are described in Reig et al. (2019).

The experimental design at both locations was a randomized block design with a split-split plot, with three replications. Within each block the main plot was cultivar, and the sub plot was tree type, and the sub-sub plot was rootstock. Sub plots consisted of entire rows while rootstock sub-sub plots were composed of a row section 12 m long with thirteen trees. The treatment design was a complete factorial of 2 cultivars, 2 tree types and 5 rootstocks with 20 treatment combinations of cultivar, tree type and rootstock.

2.2. Tree management

In spring 2004, feathered trees were produced by planting the rootstock liner (7 mm diameter) in the nursery and then chip budding a single scion bud in August 2004. The scion bud remained dormant until spring 2005 when it began to grow, and the rootstock stem above the scion bud was removed, as well as all the other competing rootstock shoots. The nursery tree was continuously irrigated and fertilized to achieve very rapid growth in 2005. The trees were planted in the experimental plot in spring 2006. Pruning and thinning management of feathered trees at each site are described in Reig et al. (2019). in February 2006, bench-grafted trees were developed by grafting a 2-bud scion to the rootstock and then callusing the grafted trees for 2 months at 10 °C. In early April, the grafted trees were directly planted into the experimental plot. Pruning and thinning management of bench-grafted trees at each site is described in Reig et al. (2019).

Irrigation, fertilization, foliar micronutrients and phytosanitary treatments are described in Reig et al. (2019). Average annual rainfall for the Dressel site was 1000 mm and for the VandeWalle was 990 mm during the spring and summer months.

2.3. Yield, income, labor and fixed costs

Trees were evaluated for eleven years (2006–2016) after planting. Yield (kg) and the number of fruits were recorded annually from the second year (2007), and then the average fruit size (weight) of the fruits was calculated. For both trials, from year 3 to 11 a sample of 50

Fig. 1. A was bench-grafted tree and B was fully feathered nursery tree.

Table 1
Apple rootstock descriptions.

Rootstock	Vigor Class	Parentage	Tree size class	Origin
B.9	Dwarf	M.8 × Red Standard	M.9	State Research Institute of Horticulture, Mitschurinsk, (Russia)
G.11	Dwarf	M.26 × Robusta 5	M.9	Cornell University-USDA (USA)
G.16	Dwarf	Ottawa 3 × Malus floribunda	M.9	Cornell University-USDA (USA)
G.41	Dwarf	M.27 × Robusta 5	M.9	Cornell University-USDA (USA)
M.9T337	Dwarf	Unknown	M.9	East Malling (UK)

representative fruits randomly hand-picked at commercial maturity stage for each scion-rootstock-tree type combination was classified by color and size as described in Reig et al. (2019). From these data, we calculated a simulated packout for each trial. Table 2 shows the fruit price for each packout category taken from statewide averages of typical New York State apple industry, which were used for the economic and sensitivity analysis.

Labor time for pruning was recorded each year. Average values were used for those years when data was missing. Thus, yield, fruit packout (fruit size and color), and labor input data were based on the trial. Pruning and training costs were calculated as skilled labor at $15/h (Table 3). The cost of management by the owner/manager and an overhead charge for farm wide costs were also included as fixed costs (Table 3). Other costs were taken from statewide averages of New York State apple growers (Tables 3 and 4).

2.4. Economic analysis

In order to assess long-term profitability, NPV analysis was used to compare the present value of accumulated profit for each cultivar, rootstock and tree type over 20 years. We trial data for the first 11 years and average data from the last 4 years (2013 to 2016) to estimate values for 12–20 years after plantation (2017 to 2025). An economic analysis considers the time value of money using discounted annual cash flows (due to inflation effect). NPV is the sum of discounted annual cash flows over 20 years using a fixed discount rate. The discount rate is the interest rate used to determine the present value. This was determined by subtracting the rate of inflation from the current interest rate in order to arrive at a real rate of interest. A discount rate of 5% was used for our basic comparisons, concurring with previous orchard profitability

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 (g)								
Color category	Cultivar	<128	128 <136	136 <153	153 <167	167 <190	190 <215	215 <238	238 <264	≥ 264
XX Fancy	Gala (DrF)	0.09	0.18	0.88	0.88	0.88	1.05	1.10	1.16	1.16
	Fuji (DrF)	0.09	0.17	0.79	0.79	0.79	0.94	1.00	1.05	1.05
	Gala (VW)	0.09	0.18	0.88	0.88	0.88	1.05	1.10	1.16	1.16
	Honeycrisp (VW)	0.10	0.19	1.62	1.62	1.62	1.91	2.20	2.44	2.44
X Fancy	Gala (DrF)	0.09	0.18	0.83	0.83	0.83	0.99	1.05	1.10	1.10
	Fuji (DrF)	0.09	0.17	0.73	0.73	0.73	0.89	0.94	1.00	1.00
	Gala (VW)	0.09	0.18	0.83	0.83	0.83	0.99	1.05	1.10	1.10
	Honeycrisp (VW)	0.10	0.19	1.45	1.45	1.45	1.74	2.03	2.32	2.32
Fancy	Gala (DrF)	0.09	0.18	0.55	0.55	0.55	0.66	0.66	0.66	0.66
	Fuji (DrF)	0.09	0.17	0.47	0.47	0.47	0.58	0.68	0.79	0.89
	Gala (VW)	0.09	0.18	0.55	0.55	0.55	0.66	0.66	0.66	0.66
	Honeycrisp (VW)	0.10	0.19	1.16	1.16	1.16	1.45	1.57	1.68	1.68
No. 1	Gala (DrF)	0.09	0.18	0.18	0.18	0.17	0.18	0.18	0.18	0.18
	Fuji (DrF)	0.09	0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.17
	Gala (VW)	0.09	0.18	0.18	0.18	0.17	0.18	0.18	0.18	0.18
	Honeycrisp (VW)	0.10	0.19	0.19	0.19	0.17	0.19	0.19	0.19	0.19
Utility	Gala (DrF)	0.09	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Fuji (DrF)	0.09	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	Gala (VW)	0.09	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Honeycrisp (VW)	0.10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

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

Pre-Plant Cost			
Land Value ($/ha)			$ 12,000
Land Preparation ($/ha)			$ 1800
Labor: Planting, Training ($/ha)			$ 900
Tree Price ($/Tree)			
	Geneva Rootstocks	Bench-grafted tree	$ 4.50
		Feathered tree	$ 9.50
	B9 & M9 Rootstocks	Bench-grafted tree	$ 4.00
		Feathered tree	$ 9.00
Trellising			
Post Cost ($/post)			$ 20.00
Wire Cost ($/m)			$ 0.03
Wires per Row			5
Post Pounding ($/ha)			$ 200
Labor: Trellis Install ($/ha)			$ 520
Miscellaneous			
Irrigation Material ($/ha)			$ 2500
Irrigation Install Labor ($/ha)			$ 1000
Financials			
Interest rate (Discount rate)			5%
Annual fixed cost			$ 1500/ha
Skilled labor			$ 15/h
Unskilled labor			$ 12/h
Picking			
Base Picking Cost ($/Bin)			
	Gala & Fuji		$ 24.00
	Honeycrisp		$ 35.00
Picking Employer Taxes%			15%
Total Picking Cost ($/Bin)			
	Gala & Fuji		$ 28.00
	Honeycrisp		$ 40.00
Total Picking Cost ($/kg)			
	Gala & Fuji		$ 0.08
	Honeycrisp		$ 0.11

studies conducted in New York State (Lordan et al., 2019, 2018). NPV was obtained every year for each scion-rootstock-tree type combination using 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.

In case the NPV of accumulated profit reaches zero, the investment is sound at the selected discount rate (White and DeMarree, 1992). The year that the NPV of accumulated profit reaches zero is the year that the investment has been recouped with interest. In this case, the orchard can be removed and replanted (Lordan et al., 2019).

2.5. Sensitivity analysis

A sensitivity analysis was used to compare the effect of different economic factors on long-term profitability. We evaluated the effect of tree price, fruit price, yield, discount rate, labor cost and land cost on orchard profitability for each cultivar, rootstock and tree type. We evaluated slopes of linear regression for these factors in order to simulate different scenarios and their influence in the orchard profitability. The criteria to set the base values were based on New York industry standards, then we selected a wide range of scenarios above and below the base values. Therefore, we re-calculated the cumulative 20-year NPV value for each combination of cultivar, rootstock and tree type, changing the values of the aforementioned factors as described in Lordan et al. (2019). Reference tree price (Table 3) was increased by 15%, 25%, and 50%. Reference fruit price (Table 2) was reduced and increased by 15% and 25%. Average yield from the trial was modified to 60%, 80%, 100%, 120%, and 140%. Reference labor cost (Table 3) was increased by 5%, 15%, 25%, and 50%. Land cost was increased from $12,500/ha reference cost to $25,000/ha. Different discount rates (above the reference rate of 5%) of 7%, and 9% were also assessed.

2.6. Statistical analysis

Data was analyzed as a randomized complete block, split-split plot design. Analyses of cumulative 20-year NPV were performed in JMP13 statistical analysis software (SAS institute, 2017). Means were separated using Fisher's LSD tests honestly significant difference (P = 0.05) by one-way or factorial analysis of variance (Proc GLM), considering the rootstock and the type of tree as the main factors.

In addition, the linear relationships between NPV of changes in analysis input parameters were determined. The P values were all significant and the R^2 values were higher than 0.9 in all models. The slopes of the linear regressions were evaluated. Data were analyzed using JMP13 statistical analysis software (SAS institute, 2017).

Table 4
Annual costs ($/ha) for disease, weed, and insect management, nutrition, and thinning. Values were estimated from statewide averages of New York State apple growers. We used average data from 2014 to 2016 to estimate values for years 12– 20.

Year	Nº Year	IPM ($/ha)			Nutrition ($/ha)	Thinning ($/ha)		
		Disease	Weed	Insects		'Gala'	'Fuji'	'Honeycrisp'
2005	0	0	47	0	558	0	0	0
2006	0	0	47	0	558	0	0	0
2007	1	252	79	106	850	0	0	0
2008	2	346	84	105	205	0	0	0
2009	3	591	25	345	432	39	145	39
2010	4	638	86	558	353	213	158	105
2011	5	717	126	661	610	338	316	157
2012	6	600	42	808	413	338	316	157
2013	7	581	86	625	492	338	316	157
2014	8	729	124	463	531	338	316	157
2015	9	729	124	632	492	338	316	157
2016	10	729	124	632	413	338	316	157
2017	11	729	124	632	489	338	316	157
2018	12	729	124	632	489	338	316	157
2019	13	729	124	632	489	338	316	157
2020	14	729	124	632	489	338	316	157
2021	15	729	124	632	489	338	316	157
2022	16	729	124	632	489	338	316	157
2023	17	729	124	632	489	338	316	157
2024	18	729	124	632	489	338	316	157
2025	20	729	124	632	489	338	316	157

3. Results

3.1. Economic analysis

Using actual trial data and New York industry standard prices (Tables 2–4) there were important differences among cultivars in 20-year NPV (Fig. 2 and 3). Among cultivars the 20-year orchard profitability was highest for 'Honeycrisp', followed by 'Gala' (from both sites) and, finally, the lowest for 'Fuji' (Fig. 2 and 3). In general, feathered trees were more profitable than bench-grafted trees. However, only with 'Honeycrisp' the difference was significant (Table 5).

With 'Fuji', G.16 showed the highest cumulative NPV with feathered trees and G.11 with bench-grafted trees. In fact, 'G.16′ had the highest cumulative NPV value, although it did not differ significantly from G.11 and M.9 rootstocks. In contrast, the lowest NPV value was for B.9 with a negative NPV value in both tree types (Fig. 2 and Table 5),

With 'Gala' from Dressel farm, the highest cumulative NPVs was with feathered trees on G.41, G.16 and G.11 (Fig. 2). These rootstocks along with M.9 had lifetime NPV's greater than $120,000/ha while trees on B.9 had the lowest NPV ($84,000). With bench-grafted trees, there were greater differences among rootstocks. G.16 had the highest profits (≈$140,000/ha), followed by B.9 (≈$91,000/ha) and the lowest values were for G.41, M.9 and G.11 (lower than $40,000/ha) (Fig. 2).

With 'Gala' at VandeWalle farm there was lower variability among rootstocks in NPV. They showed similar cumulative NPV values within each tree type. For bench-grafted trees, NPV for each rootstock were similar (≈$220,000/ha) and for feathered trees was ≈$250,000/ha, except for M.9 bench-grafted trees which had a cumulative NPV of

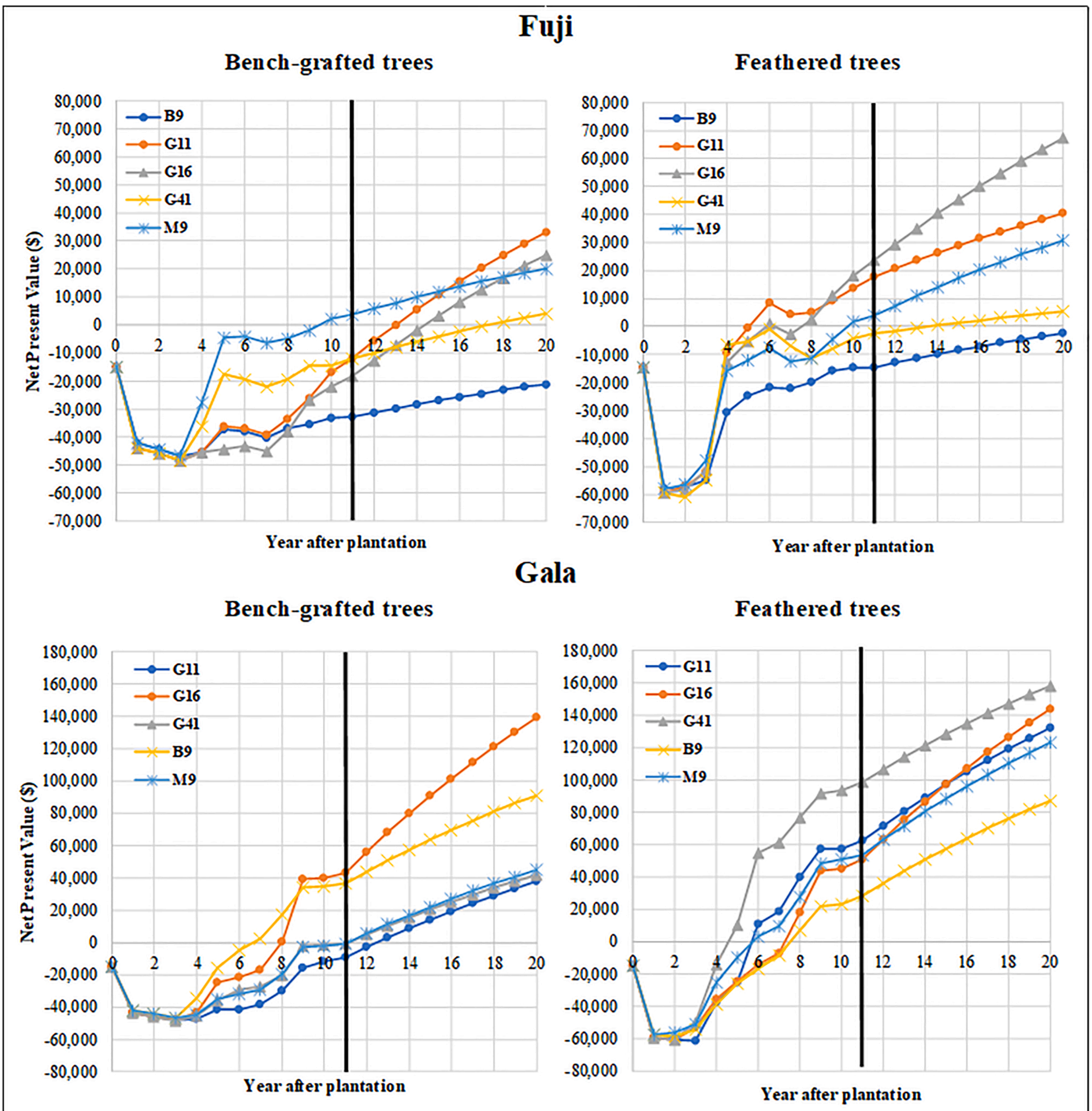

Fig. 2. NPV for 'Gala' and 'Fuji' apple trees on various rootstocks (G.11, G.16, G.41, B.9 and M.9), and of two tree types (bench-grafted and feathered tree) at Dressel farm NY. Estimated values are shown for years after black line.

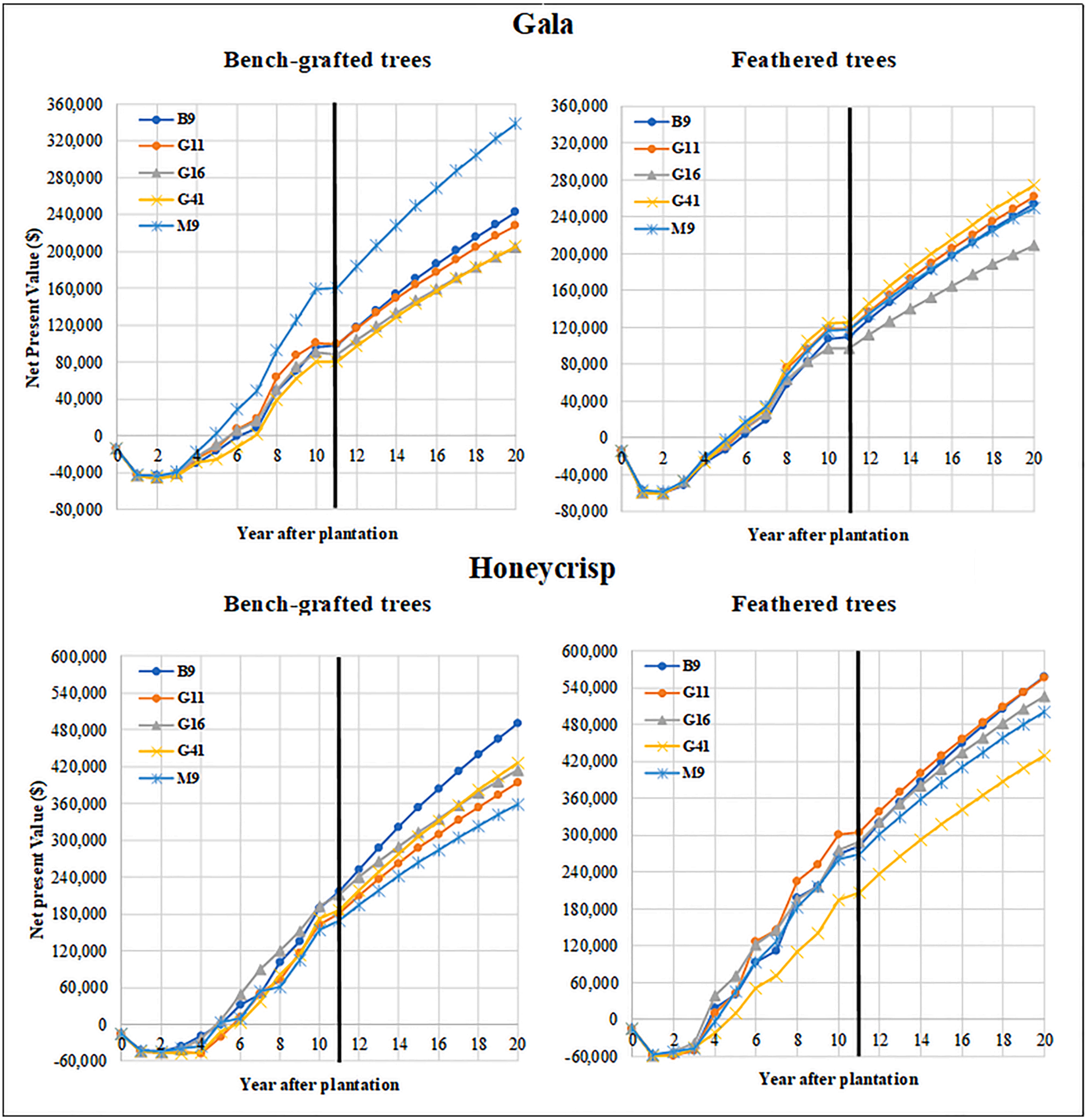

Fig. 3. NPV for 'Gala' and 'Honeycrisp' apple trees on various rootstocks (G.11, G.16, G.41, B.9 and M.9), and of two tree type (bench-grafted and feathered tree), at VandeWalle farm NY. Estimated values are shown for years after black line.

≈$330,000/ha (Fig. 3). This disparity in results with M.9 caused a significant interaction of rootstock and tree type with Gala at VandeWalle farm while with the other cultivars there was no significant interaction of rootstock and tree type. (Table 5).

With 'Honeycrisp', feathered trees showed a significantly higher cumulative NPV after 20 years ($514,527/ha) compared with bench-grafted tree ($416,825/ha) (Fig. 3 and Table 5). Among rootstocks, B.9, G.11 and G.16 had the highest profitability while G.41 and M.9 had lowest profitability (Fig. 3).

In general, feathered trees reached the break-even year for a positive NPV (5–8 years for 'Gala', 6–21 years for 'Fuji' and 4–6 years for 'Honeycrisp') sooner than bench-grafted trees (Table 6). With 'Fuji', B.9 trees were the slowest to reach the break-even year (21 years) in both tree types. The quickest rootstocks to reach the break-even year with 'Fuji' were feathered trees on G.11 and G.16 (6 and 7 years respectively). With 'Gala', bench-grafted trees with G.11 took the longest time to recover the investment (13 years) while feathered G.41 trees took only 5 years. However, 'Gala' in VandeWalle farm, showed a positive NSV between 6 and 7 years in all tree types and rootstocks. With 'Honeycrisp' bench-grafted trees took 5–6 years while feathered trees took only 4–5 years (Table 6).

3.2. Sensitivity analysis

The sensitivity analysis was done to evaluate the weight of different factors that influence orchard profitability. It showed, in descending order, the highest influence were from fruit price and yield, followed by discount rate, labor cost, and finally, tree price and land cost (Fig. 4 and

Table 5
Cumulative NPV for 'Fuji', 'Gala', and 'Honeycrisp' apple trees on various rootstocks (G.11, G.16, G.41, B.9 and M.9) and of two tree types (bench-grafted and feathered tree) at Dressel farm and VandeWalle farm, over 20 years. Means followed by different letters within three shape denotes significant differences (Fisher's LSD tests at P<0.05).

Location	Cultivar	Rootstock & Tree type		Cumulative NPV 20 years ($/ha)	
Dressel	**Fuji'**	**Rootstock (STK)**	B9	-11718	c
			G11	36777	a
			G16	46027	a
			G41	4634	bc
			M9	25514	ab
			LSD *P≤0.05*	28516	
		Tree type (TT)	Bench-grafted tree	12319	
			Feathered tree	28175	
			LSD *P≤0.05*	77721	
		STK x TT	***P***	ns	
	Gala'	**Rootstock**	B9	89101	ab
			G11	84988	b
			G16	141250	a
			G41	99831	ab
			M9	84083	b
			LSD P≤0.05	52530	
		Tree type	Bench-grafted tree	70826	
			Feathered tree	128875	
			LSD *P≤0.05*	107330	
		STK x TT	***P***	ns	
VandeWalle	**Gala'**	**Rootstock**	B9	247925	b
			G11	244737	b
			G16	206602	b
			G41	240094	b
			M9	293992	a
			P	43312	
		Tree type	Bench-grafted tree	243595	
			Feathered tree	249745	
			LSD *P≤0.05*	30023	
		STK x TT	***P***	0.018	
		Bench-grafted tree	B9	242051	b
			G11	227787	b
			G16	204040	b
			G41	205820	b
			M9	338277	a
			LSD *P≤0.05*	40665	
		Feathered tree	B9	253799	
			G11	261686	
			G16	209163	
			G41	274369	
			M9	249706	
			LSD *P≤0.05*	85003	
	Honeycrisp'	**Rootstock**	B9	524207	a
			G11	475172	ab
			G16	470810	ab
			G41	428319	b
			M9	429871	b
			P	94271	
		Tree type	Bench-grafted tree	416825	b
			Feathered tree	514527	a
			LSD *P≤0.05*	38921	
		STK x TT	***P***	ns	

5). For all cultivars, fruit price and yield showed positive linear relationships with cumulative NPV after 20 years. When the fruit price and yield increased, final NPV increased, and the profitability was higher (Fig. 3 and 5). Additionally, discount rate, tree price, land cost and labor cost showed a negative relationship with cumulative NPV after 20 years. When these parameters increased, cumulative NPV decreased and profitably of each cultivar was lower (Fig. 4 and 5).

'Fuji' was more sensitive to fruit price and yield than 'Gala' and 'Honeycrisp'. Indeed, 'Fuji' showed greater slopes of the regression lines between price or yield and NPV compared to 'Gala' and 'Honeycrisp' (Fig. 4 and 5). With 'Fuji' the effect of changing fruit price or yield was especially strong with B.9 and G.41 while with the other rootstocks there was a smaller effect (less sensitivity) (Fig. 4). Among the two tree types there were only small differences in their sensitivity to changes in fruit price or yield (Fig. 5).

Discount rate had a large effect on NPV because affects every year of the final NPV. 'Fuji' was more affected by increasing discount rate compared to 'Gala' and 'Honeycrisp' (Fig. 4 and 5). There were no differences among rootstocks or tree types in their response to changing discount rate (Fig. 4 and 5).

Among the variables we evaluated, labor cost had an intermediate effect on orchard profitability for all cultivars, rootstocks, and tree types

Table 6
Break-even year to positive NPV for 'Fuji', 'Gala', and 'Honeycrisp' apple trees of various rootstocks (G.11, G.16, G.41, B.9 and M.9), and of two tree types (bench-grafted and feathered tree) at Dressel farm and VandeWalle farm, over 20 years. Green color denotes the fastest investment recoup (≤6 years), yellow color denotes intermediate time to recoup investment (7-10 years) while red color denotes slowest investment recoup (≥10years).

		Tree type (Rootstock)									
		Bench-grafted trees					Feathered trees				
Location	Cultivar	G11	G16	G41	B9	M9	G11	G16	G41	B9	M9
Dressel Farm	Fuji	13	15	18	21	10	6	7	14	21	10
	Gala	13	8	12	7	12	6	8	5	8	6
VandeWalle Farm	Gala	6	6	7	7	5	6	6	6	6	6
	Honeycrisp	6	5	6	6	5	4	4	5	4	5

(Fig. 4 and 5). Labor cost showed differences among rootstocks when costs were high and orchard profitability was lower. With 'Fuji', profitability of both G.41 and B.9 was drastically reduced with high discount rates (Fig. 4 and 5).

Tree price and land cost had only a small effect on orchard profitability for all cultivars, rootstocks, and tree types (Fig. 4 and 5). Tree price and land cost showed low slopes as all variables were increased for all cultivars, rootstocks, and tree types. Tree price increases had a flatter slope with bench-grafted tree compared to feathered tree in 'Fuji', with no significant effect on orchard NPV (Fig. 4 and 5). Finally, land cost up to $25,000/ha did not have an important impact on orchard NPV for all cultivars (Fig. 4 and 5).

4. Discussion

With this study there were significant differences in 20-year cumulative NPV among cultivars, which agrees with previous apple economic studies. Our results showed that 'Honeycrisp' had the highest cumulative NPV, followed by 'Gala' and, 'Fuji'. Thus, the most valued cultivar in this study showed the highest NPV after 20 years. Lordan et al. (2019) concluded that orchard profitability varied considerably for each cultivar. Lordan et al. (2018) showed that the high fruit prices for 'Honeycrisp' made it highly profitable, at more than $450,000/ ha for 20 years. This agrees with the observations of the present study since 'Honeycrisp' profitability ranged between $360,000 and $557,000/ha.

Reig et al. (2019) evaluated the agronomic performance of these cultivars, rootstocks and tree types. They concluded that, feathered trees were more productive and efficient than bench-grafted trees for all cultivars. Based on those data, our economic results showed that the cumulative NPV of feathered trees was higher than with bench-grafted trees. This is in agreement with the previous observations of Gąstoł and Poniedziałek (2003) who reported over a shorter time period, compared to our study, that the beneficial effect of using initially branched trees provides higher income in the first years after planting an orchard and greatly shortens the investment period. They concluded that the greater number and length of shoots with feathered trees was important for the formation of fruiting spurs in the year of planting (Radivojevic et al., 2022).

In apple orchard, rootstock selection is a critical element, particularly in high-density systems (Autio et al., 2017a). Rootstock can affect productivity throughout the orchard lifetime (Kosina, 2010), and as a consequence, orchard profitability. Our results with rootstocks showed different outcomes for each cultivar. With 'Honeycrisp', trees on B.9, G.11 and G.16 had the highest NPV's, whereas with 'Fuji', trees on G.11, G.16 and M.9 on both tree types had the highest NPV's and with 'Gala' the highest NPV's were with G.16, G.41 and M.9.

The significant interaction of tree type and rootstock for 'Gala' at the VandeWalle farm, further complicated the rootstock results. At VandeWalle farm, the highest profitability was on M.9 with bench-grafted trees while with feathered trees, the highest profitability was on G.41 and G.11. These differences between location and rootstocks were reported in the previous agronomic study (Reig et al., 2019). In addition other work with 'Gala' showed that rootstock performance may vary greatly from one location to another (Marini et al., 2006). The NC140 group in North America is currently evaluating several rootstocks in many locations in the U.S., in different climate conditions, soils and managements with 'Fuji' and 'Honeycrisp' to clarify this variability (Autio et al., 2017a, 2017b, 2020a; Autio et al., 2020b).

Another objective of our study was to estimate the break-even year to reach a positive NPV for each rootstock, tree type and cultivar. These calculations showed that the minimum orchard life is different for each rootstock, tree type and cultivar, coinciding with previous observations of Lordan et al. (2019). In general, feathered trees had a lower break-even year to positive NPV for all cultivars compared to bench-grafted trees, which agrees with previous studies (Atay and Koyuncu, 2013; Gąstoł and Poniedziałek, 2003). In that regard, Atay and Koyuncu (2013) showed that well-branched nursery trees have a significant impact on early cropping of intensive apple orchards. However, in addition to feather numbers, results obtained by Weber (1998) and Robinson (2003) suggested that the speed with which an orchard achieves its desired tree height is crucial to achieve short-term return of investment costs.

Among cultivars, our results showed that the quickest investment pay off was for 'Honeycrisp', followed by 'Gala' and 'Fuji'. A study done by Lordan et al. (2019) showed longer times to reach the break-even year with 'Gala' and 'Fuji'. However, their results were with different tree shapes and densities. Badiu et al. (2015) observed considerably shorter payback periods for high density plantings, coinciding with the observations of this study. However, it should be noted that our results suggested that the recovery of the investment was related to the price of the fruit and the starting year of the yield.

Our data suggested that the most important economic factors affecting orchard profitability were fruit price and yield, followed by the discount rate, labor cost, and, finally, tree price and land cost which had a small effect on long-term profitability. Fruit price and yield showed a positive linear relationship, while discount rate, tree price, land cost and labor cost showed a negative relationship with NPV. Previous research by Bravin et al. (2009) concluded that fruit price and yield were the decisive starting-points for success. Similar to our study, Lordan et al. (2018) reported that the most important variables that affected orchard NPV were fruit price and yield. However, they showed that the tree price was quite important for higher planting densities. Likewise, Hassan et al. (2020) concluded that yield per ha is one of the most important parameters to assess the performance of crops. In another study Ekinci et al. (2020) also showed that fruit price and yield had the greatest impact on orchard profitability. In our study, the cultivar 'Fuji' (with the lowest fruit price) was more sensitive to fruit price and yield than 'Gala' or 'Honeycrisp'. Our results also suggested that sensitivity to changes in price and yield among rootstocks and tree types were smaller than among cultivars.

The large effect of discount rate is likely due to the fact that it is applied to profits at each year of the 20-year life of an orchard. A lower

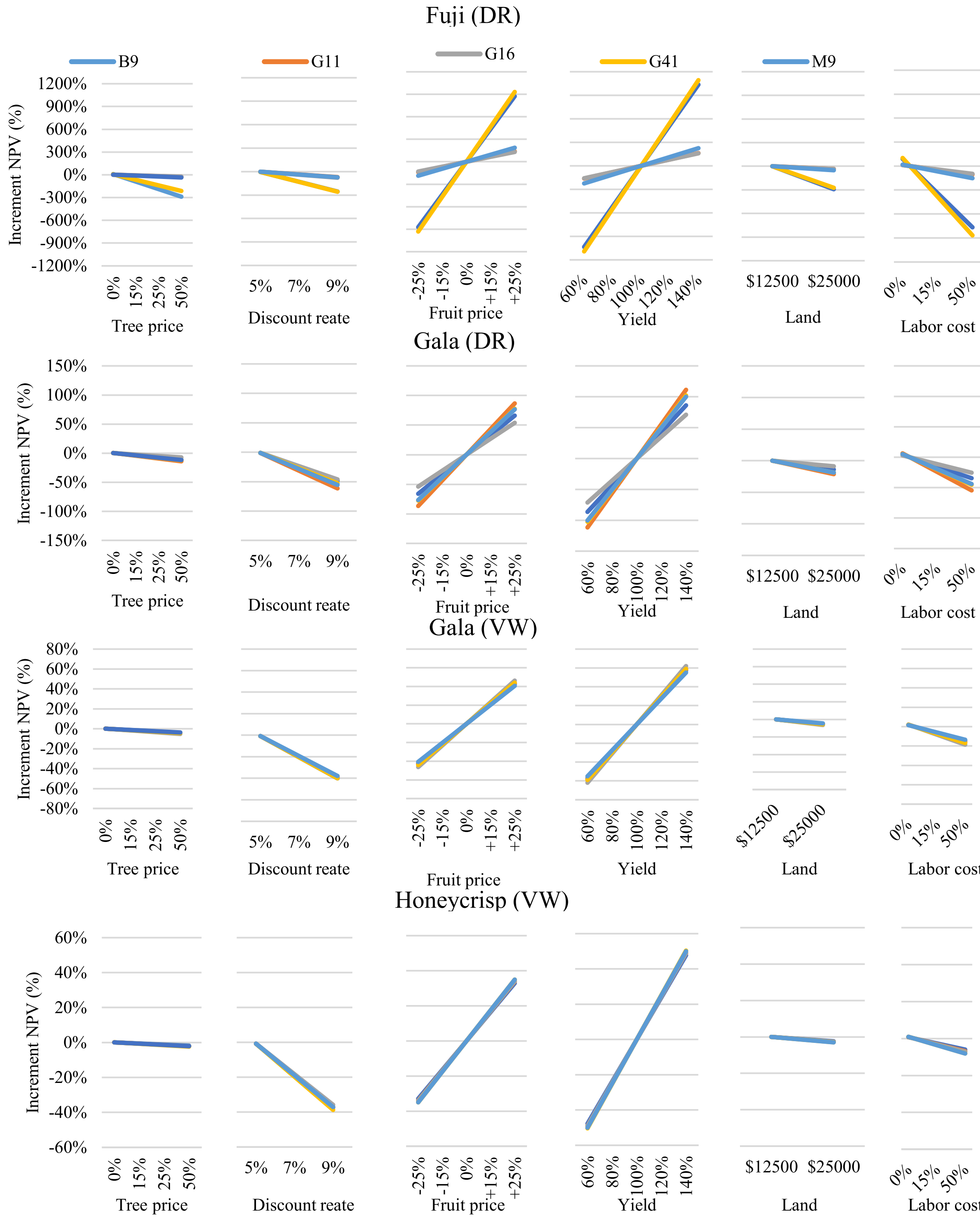

Fig. 4. Linear regression analysis for each rootstock (G.11, G.16, G.41, B.9 and M.9) between NPV (%) after 20 years and tree price (0%, 15%, 25%, and 50% increase relative to reference tree price) (Table 3); discount rate (DR) (5%, 7% and 9%); fruit price (−25%,−15%, 0%, +15%, and +25% relative to reference fruit price) (Table 2); yield variation of 60%, 80%, 100%, 120%, and 140% of average yield obtained from the trial); land cost (100 and 200% relative to the reference land cost; and labor cost variation of 0% +5%, +15%, +25%, and +50% relative to reference labor cost) (Table 2). The slopes of the regressions were evaluated for each cultivar ('Honeycrisp', 'Gala' and 'Fuji') at Dressel farm NY (DR) and VandeWalle Farm NY (VW). Reference NPV was calculated using the trial average yield, 5% DR, and the NY industry standards for the rest of inputs Tables 2, 3, and 4).

percentage of DR....... resulted in a much higher final NPV. Our results suggested that when the discount rate is raised, orchard profitability was significantly lower. 'Fuji' profitability showed a higher dependance on discount rate compared to 'Gala' and 'Honeycrisp'. Robinson et al. (2007) and Galinato and Gallardo (2020) have also shown a large effect of discount rate on profitability.

In the present study, labor cost, land cost and tree price had a smaller effect on orchard profitability in all cultivars. This is counter to the report by Lordan et al. (2019) where they suggested that the factors that lead to reduced investment, such as cheap plant material, land or tree support, can significantly improve profitability when planting at high tree densities. Robinson et al. (2007) also concluded that land and tree price had a large influence on orchard profitability of high-density orchards in New York state. Part of the difference in our result could be due

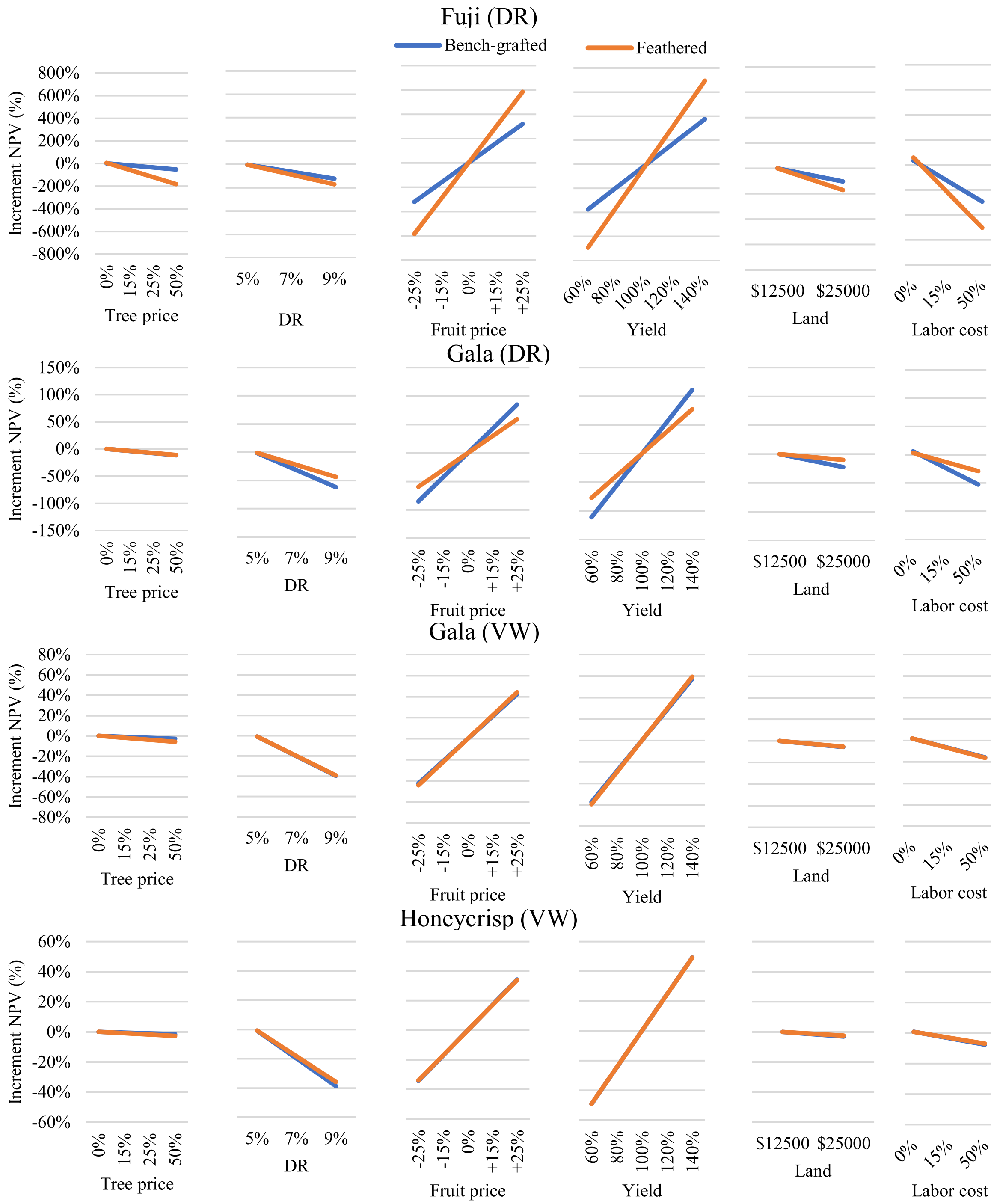

Fig. 5. Linear regression analysis for each tree type (bench-grafted and feathered) between NPV (%) after 20 years and tree price (0%, 15%, 25%, and 50% increase relative to reference tree price) (Table 3); discount rate (DR) (5%, 7% and 9%); fruit price (−25%,−15%, 0%, +15%, and +25% relative to reference fruit price) (Table 2); yield variation of 60%, 80%, 100%, 120%, and 140% of average yield obtained from the trial); land cost (100 and 200% relative to the reference land cost; and labor cost variation of 0% +5%, +15%, +25%, and +50% relative to reference labor cost) (Table 2). The slopes of the regressions were evaluated for each cultivar ('Honeycrisp', 'Gala' and 'Fuji') at Dressel farm NY (DR) and VandeWalle Farm NY (VW). Reference NPV was calculated using the trial average yield, 5% DR, and the NY industry standards for the rest of inputs Tables 2, 3, and 4).

to the single planting density we evaluated with relatively high initial investment for the reference costs.

5. Conclusion

Over the period of this study there were important differences between cultivars, with higher NPV values for 'Honeycrisp', followed by 'Gala' and 'Fuji'. As reported earlier in our horticultural paper by Reig et al. (2019), cumulative yield of the feathered trees was substantially higher compared to bench-grafted trees. In this economic study we found that the highest cumulative NPV's for 'Honeycrisp' were on B.9, G.11 and G.16, whereas with 'Fuji' the highest NPV's were on G.16, G.11 and M.9 and with 'Gala' the highest NPV's were on G.16, G.41 and M.9. The break-even year at a positive NPV for each rootstock, tree type, and cultivar showed considerable variability. However, in general, feathered trees reached the break-even year faster than did bench-graft trees.

Among cultivars, the fastest investment pay offs was achieved with 'Honeycrisp', followed by 'Gala' and 'Fuji'.

Our results showed that the most important factors that influence orchard profitability are fruit price and yield, followed by discount rate, labor cost, and, finally, tree price and land cost. Fruit price and yield showed a positive linear relationship with NPV while discount rate, tree price, land cost and labor cost showed negative relationship.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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