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Economic Analysis of Investing in Open-field or High Tunnel Primocane-fruiting Blackberry Production in Northwestern Arkansas

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SUMMARY. **Extending the production season of blackberry (*Rubus* subgenus *Rubus*) cultivars allows producers the opportunity to potentially receive better prices. Producers could benefit from out-of-season production by sustaining cash flow during more of the year and thereby expanding their market. The objective of this study was to compare the present value (PV) probabilities of being able to cover the total cost (TC) of production (break-even) for open-field and high tunnel production systems for the primocane-fruiting blackberry cultivar Prime-Jan® in northwestern Arkansas. (PVs) of gross revenues (GRs) of each production system were simulated 500 times. Total yields were higher in the open-field system in the first 2 years of production and consistently higher in weeks 33 to 34 and 36 to 37 than high tunnel production. It seems that there are no yield benefits from the high tunnel system early in the harvest season, except in the first year of primocane-fruiting production. The break-even probability was sensitive to the different percentage of yield sold, the percentage of the retail price received by the producer, and the production system analyzed. Even though the potential gross returns obtained with the high tunnel system are high (when compared with open-field production), the PV distributions of the gross returns do not offset the high tunnel TC in half of the simulations. Conversely, open-field production proves to be more profitable both in magnitude and in terms of the likelihood of exceeding the break-even threshold over the productive life of the enterprise.**

Worldwide commercial blackberry (*Rubus* subgenus *Rubus*) production was 140,292 Mg planted in over 20,000 ha in 2005 (Strik et al., 2007). North America represented 42%, Europe 31%, Asia 19%, and other regions 8% of the total world production (Strik et al., 2007). The United States was the leading producer with 23% of the total blackberry production in 2005. Oregon (72%), California (7%), and Arkansas (4%) were the three main producing states; all other states accounted for the remaining 17% of the total blackberry production (Strik et al., 2007). Arkansas produced 1400 Mg in 243 ha (Strik et al., 2007). The release of cultivars with improved fruit quality and a growing consumer demand of blackberries for its associate human health benefits have caused an increase in production in the United States (Clark, 2005; Safley et al., 2006). Although blackberry production is small in Arkansas compared with other regions (e.g., the Pacific northwestern United States), it is growing. The area devoted to blackberry production in Arkansas increased 277% between 1997 and 2007 (U.S. Department of Agriculture, 2011).

The University of Arkansas (UA) has one of the largest blackberry breeding programs in the United States (Rom et al., 2010). In 2004, the UA released 'Prime-Jan®', a primocane-fruiting blackberry (Clark et al., 2005). This thorny, erect cultivar forms terminal flowers in late summer and fruit during the autumn. A detailed description of this genotype is given by Clark et al. (2005). Clark (2008) highlighted the physiological and economic potential of primocane-fruiting blackberries. Although a new primocane-fruiting blackberry cultivar (Prime-Ark® 45) was released by the UA breeding program in 2009 (J.R. Clark, personal communication), this analysis focused on the earlier Prime-Jan® cultivar.

Strik et al. (2008) and Thompson et al. (2009) described management techniques to maximize yield and extend the fruiting season of primocane-fruiting blackberry under a maritime west-coast condition. Researchers at the UA have demonstrated that primocane-fruiting blackberry harvest can be extended with the use of high tunnels (Rom et al., 2010) and by using pruning techniques similar to those described on primocane-fruiting red raspberry (*Rubus idaeus*) by Oliviera et al. (1998) and Pritts et al. (1999). Drake and Clark (2003) indicated that "soft tipping" of the primocane in Arkansas delays flowering. With these methods, flowering can be delayed until there are more suitable temperatures, beginning in September. The harvest season can be maintained through November and possibly December with no or minimal additional heating. Researchers at UA have demonstrated that primocane-fruiting blackberries in high tunnels can be harvested later into the season than from open-fields (Rom et al., 2010). Previous studies indicate fruit quality and yield from out-of-season protected cultivation systems are as good as or of better quality than that produced during the normal harvest season (Koester and Pritts, 2003; Oliviera et al., 1998; Pritts et al., 1999).

Producers could benefit from out-of-season production by sustaining cash flow during more of the year and expanding markets. However, biological factors (e.g., climate, site, soil, plant spacing, disease, etc.) and economic decisions (i.e., allocation of capital, land, and labor) must be taken into consideration before producing blackberries. The objective of this study was to estimate the break-even probabilities of covering the TCs of production for extending the harvest season of the blackberry primocane-fruiting cultivar Prime-Jan® under open-field and high tunnel conditions in northwestern Arkansas. We accomplished this objective by simulating PV outcomes under each production system.

In general, production of blackberries is considered to be risky because of a high initial investment and associated fixed costs, a delay for 2 years or more in returns, and the potential weather extremes. Commercial production with high tunnels offers promise for those producers willing to make the necessary capital investment for early season production, late season production, or both. There are only a few studies documenting U.S. high tunnel research on blackberry crops (Demchak, 2009; Gaskell, 2004; Heidenreich et al., 2009; Lamont, 2009; Thompson et al., 2009). As far as we know, there are no documented studies combining high tunnel and primocane-fruiting blackberry production in the southeastern United States. Consequently, a method that helps producers to estimate break-even probabilities is an important contribution for planning and for the financial management of extending the harvest season of blackberry production in northwestern Arkansas.

In this study, PVs of GRs, defined as yield times price, are computed for both open-field and high tunnel production systems. Because of the aforementioned factors, revenues depend on uncertain yields. For this reason, they can be characterized by a cumulative distribution function (CDF) that can be used to determine whether revenue outcomes fall below the TCs of production (Albright et al., 2006). A break-even point is defined as the point at which the blackberry enterprise makes neither a profit nor a loss, or the point at which TCs are covered. In its simplest form, the break-even probability in this study is defined as a numerical representation of TCs to the GR distribution (Baumol and Blinder, 2006). TCs are the total amount of money spent on producing blackberries including variable and fixed costs.

Sensitivity analyses are used to estimate the effect of a specified change in blackberry price, a yield level, or a combination of both. The sensitivity analysis is more meaningful for decision-making when the level of events (variation on prices and yields) relates to the probabilities for such events.

Materials and methods

Study area

The horticulture study upon which these calculations were based was conducted at the UA Department of Horticulture organic fruit production research unit at the Agricultural Research and Extension Center, Fayetteville, AR (lat. 36°5′4″N, long. 94°10′29″W). The soil was an eroded Captina silt-loam and is adaptable to fruit production. Before planting, land was leveled, soil pH was adjusted with agricultural lime, composted manure was applied 5 $Mg \cdot ha^{-1}$, and a perennial groundcover of 'Kentucky-31' tall fescue (*Festuca arundinacea*) with a nurse crop of winter wheat (*Triticum aestivum*) was planted in Sept. 2005.

Blackberries were planted in Apr. 2006, in experimental plots measuring 6 m wide × 11 m long (external dimensions), with in-row plant spacing of 0.25 m and between row spacing of 2.00 m and maintained at 1.25-m width with a 0.75 to 1.00-m clear work-row for harvest, providing two rows per experimental plot (Rom et al., 2010). In Sept. 2006, high tunnels (6-m wide × 12-m long, 3-m high) were constructed over plots assigned in a completely randomized block design with three replications of the two treatments as main plots (open-field and high tunnel). Data for this experiment were collected from a single 3-m-long subplot within a single row. Additional details of the study have been previously reported (Rom et al., 2010).

Before primocane emergence, plants received annual fertilization with an approved organic nutrient source (2-kg composted poultry litter per row, 2.20% nitrogen w/w), were mulched with wood chips to a depth of ≈10 cm and a row width of 1 m for competitive vegetation management and water conservation, received supplemental trickle irrigation to maintain adequate soil water as measured with soil tensiometers, and were managed for organic certification. Thus, caution should be used when generalizing findings from this study to conventional production systems.

Primocane-fruiting blackberry (cultivar Prime-Jan®) production was based on methods developed by Koester and Pritts (2003) for primocane red raspberry production, with modifications, as necessary, to adapt to southeastern U.S. climatic conditions. Annually, plants were pruned by heading between 1 and 15 July (Drake and Clark, 2000), then soft-tipped 15 to 25 d later to increase lateral shoot formation, and delay flowering until ≈1 Sept. (Rom et al., 2010).

The end-walls and side-walls of high tunnels were closed during expected cool or freezing temperatures (at ≈4.5 °C ambient air temperature),

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
28.3495	oz	g	0.0353
0.9072	ton(s)	Mg	1.1023
2.2417	ton/acre	$Mg \cdot ha^{-1}$	0.4461
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

and ventilated (at ≈12.5 °C ambient air temperature) as needed, to protect plants before the first frost date (22 Oct.) and maintained until ≈15 Dec., or when fruit production had ended. No frost protection was provided for the open-field treatment plants, and harvest ended with seasonal frosts. After harvest was complete, tunnels ends and side-walls were opened. Before normal spring emergence of floricanes, all plots were pruned by mowing to remove all floricanes and force new primocane growth for the coming season. More detailed information regarding the high tunnel operation was previously reported (Rom et al., 2010).

Economic analysis

This analysis was based on the cost of 15 Haygrove multibay high tunnels measuring 26 ft wide × 303 ft long covering ≈1 ha of land (Haygrove, Mount Joy, PA). These tunnels differ from those used in the experimental trial described above, but are indicative of what would be used in an actual commercial situation and so are used in developing the cost estimates used in this study. Probability distributions for GR are defined, parameterized, and simulated using Monte Carlo techniques. Random values from the probability distributions are linked to calculate GR for each production system also making them random. By randomly sampling the probability distributions many times (500 iterations), the model generates estimates of probability distributions for unobservable PVs, so producers can evaluate the probability of being able to cover the full TC of production (i.e., break-even) for each production system. The parts of the model and the order of calculations are described in the following sections.

Total cost

A PV of TCs of production is calculated for 1 ha planted for each production system by using an interactive blackberry budget developed for this project (Haywood, 2009). All production practices and cost data are gathered from trials conducted at the UA Experiment Station, in Fayetteville, AR, from 2005 to 2009 when the study was concluded. Establishment costs, those occurring during the year before and the year of planting, were amortized at a rate of 4% over the remaining 5-year life of the enterprise and were treated as annual fixed costs.

Hired labor includes land preparation, mowing, weeding, spreading applications, constructing the irrigation and trellis systems and tunnels, scouting, leaf analysis, tunnel ventilation, setting out bee hives, watering, high tunnel maintenance (if any), pruning and removal, marketing, and harvesting. More detailed information regarding the cost data are reported in Haywood (2009).

Gross revenues

Yield. The first harvest usually occurs in the year after planting, and maximum annual production is reached in the third year. A blackberry open-field with proper care should remain productive for 5 years or longer (E. Garcia, personal communication). A random yield is created weekly in each production year based on actual replication yield plots (using the lowest, the average, and the highest yield for the first 3 years of production) obtained at the Arkansas Agricultural Research and Extension Center, Fayetteville, from 2007 to 2009. Yields are expected to increase after year 3. However, yield data for years 4 and 5 are not available because the project was concluded after year 3 of production. Consequently, an estimation of yields after year 3 of production assumed that there are no more improvements in average yield and so projected yield from 2010 to 2011 are based on year 2009. Because of the limited availability of yield data (3 years in production), a triangular distribution is assumed to create random weekly yields. The process is explained in more detail below.

Price. Starting in production year 1 (year 2007), blackberries are assumed to be harvested for sale on the fresh market. Retail price data were purchased from the Nielsen Company (Brand and Item Rank Reports; Nielsen Co., Schaumburg, IL). We base our price series on sales through supermarkets in six Nielsen markets that are within 5 h of potential Arkansas production regions. Specifically, these retail markets are Dallas, TX; Kansas City, MO; St. Louis, MO; Little Rock, AR; Memphis, TN; and Oklahoma City/Tulsa, OK. Weekly retail prices from 26 Jan. 2007 through 19 Feb. 2011 were pulled from the reports. The raw prices reflected various retail container sizes and so each was converted to an equivalent dollars per kilogram value. Finally, a weighted average (weighted by volume) across the container sizes and retail markets was then computed for each week of the 52 weeks of the year. Figure 1 shows that retail prices averaged from \$12.50 to \$22.00 per kilogram over the study period. For context, this translates into a price of \$2.13 to \$3.74 per 6-oz retail clamshell.

Random present values

Once the random weekly yields are created, a random GR is estimated by multiplying the average weekly price and the random weekly yield for each year of production. The random GR for year 3 is assumed to be constant for the remaining 2 years of production (years 4 and 5 of production). A PV is calculated for each of the 5 years of production using an interest rate of 4%. Finally, a random PV of GR is estimated for each production system (open-field and high tunnel) using the following three equations:

$$\widetilde{GR}_t = \sum_{w=30}^{46} \left(\widetilde{\Upsilon}_w * P_w \right), \qquad [1]$$

where $\widetilde{GR}$ is stochastic gross revenues in production year t, $\widetilde{\Upsilon}$ is stochastic yield, and P is price. w represents week of the year. The beginning week, week 30, is about 1 Aug. and the ending week, week 46, is about 20 Nov.

$$\widetilde{PV}_{GR} = \sum_{t=3}^{7} \left(\frac{\widetilde{GR}}{(1+i)^t} \right), \qquad [2]$$

where $\widetilde{PV}_{GR}$ is the sum of stochastic present values of gross revenues obtained in each of the 5 years of production (starting in production year 3; $t = 3$) and i is the interest rate.

$$PV_{TC} = \sum_{t=1}^{7} \left(\frac{TC}{(1+i)^t} \right), \qquad [3]$$

where PV_{TC} is the sum of present values of total costs incurred each year and i is the interest rate.

Simulation and assumptions

Simetar© (Simetar Inc., College Station, TX) is used to simulate the random PV of GR for each production system (open-field and high tunnel). A sensitivity analysis of these variables has shown that after 500 iterations the mean and the SD of the distributions changed only marginally.

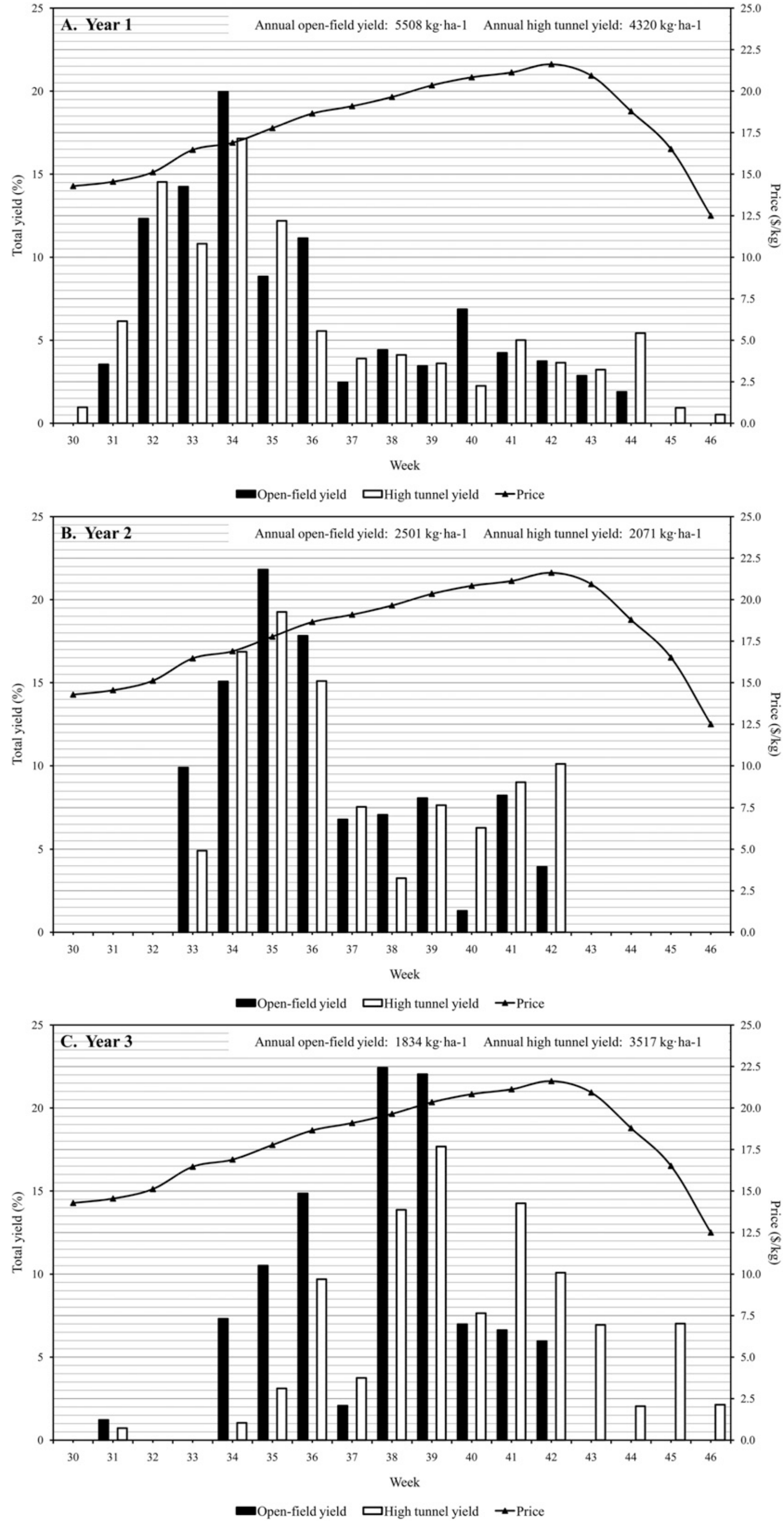

Fig. 1. Price and 'Prime-Jan®' primocane-fruiting blackberry yield by week under open-field and high tunnel production systems for (A) year 1, (B) year 2, and (C) year 3 of production in Fayetteville, AR. Week 30 is ≈1 Aug. and week 46 is ≈20 Nov. Weekly percentages of total yield reported are based on 500 simulated outcomes based on experimental yield outcomes in kilograms per hectare for open-field and high tunnel systems; \$1/kg = \$0.4536/lb = \$0.0283/oz, 1 kg·ha^{-1} = 0.8922 lb/acre.

Consequently, the simulation reported reflects runs for 500 iterations for each PV of GR for both the open-field and high tunnel production systems. For more details regarding this software, please see Simetar (2012).

The iteration of each scenario is used to generate CDFs for each random PV variable. PV distributions of GR were compared with the TC of each system to identify the break-even probability (probabilities of covering the TC of production) for each production system. In this study, the break-even probability was defined as the minimum GR needed to cover fully all of the TC.

Sensitivity analysis

Because of weather, pests, and postharvest management, it is difficult for a producer to be able to sell 100% of the berries produced (some low-quality berries are anticipated) or receive the full retail price for all his production (unless the producer is a retailer himself). Consequently, sensitivity analyses for yields and prices (measured as variations in GR) are conducted for each system. Since it is difficult to sell 100% of the production, sensitivity analyses for yield are undertaken. It is assumed that at least 50% of the production could be sold. Several scenarios were created by increasing sellable production in 10% increments (60%, 70%, 80%, 90%, and 100%). It is also assumed that the producer could receive 50%, 75%, or 100% of the retail price. To better capture the volatility of blackberry prices, the possibility that the price increases by 25% (to 125% of baseline value) is also evaluated.

In total, 24 combinations of price and yields (in terms of GR) for each system (open-field and high tunnel) are evaluated. Break-even probabilities are estimated for each production system and for each combination of GR levels.

Results and discussion

Figure 1 shows yield (percentage) and price by week in the first 3 years of production. Overall, total yields were higher in the open-field systems in years 1 and 2; high tunnel yields were greater in year 3. In general, open-field production is consistently higher in weeks 33 to 34 and 36 to 37 than high tunnel production. It seems that under the scenarios analyzed there were no yield benefits from the high tunnel system early in the harvest season, except in the first year of production (Fig. 1A). Primocane-fruiting blackberry open-field yields from the UA Fayetteville trials are slightly higher than those reported in Clarksville, AR, by Clark et al. (2005).

As mentioned earlier, production begins as early as week 30 or about 1 Aug. (Fig. 1A) and ends as late as week 46 of the year, about 20 Nov. (Fig. 1A–C). However, it is concentrated for both open-field and high tunnel systems around weeks 32 to 42 (≈15 Aug. through 24 Oct.) with a peak in production between weeks 33 (22 Aug.) to 37 (19 Sept.). On average, across the 3 years of production, a greater percentage of the open-field production (≈65%) occurred during this period of time compared with high tunnel production (≈45%). As a result, 55% of the high tunnel production could be sold when fruit is relatively scarce in the local market and prices are higher. This could give a competitive advantage for production using high tunnels for two main reasons: 1) a greater percentage of the total yield is expected to be sold under high tunnel conditions than open-field (increased marketable yield and fruit size, Rom et al., 2010) and 2) high tunnel production may provide additional GR (cash flow) in weeks where there is no open-field production (Fig. 1A and C).

Overall, high tunnels protected the crop, extended production, and increased the expected percentage yield late in the season (Fig. 1A–C). During production year 3, yield from the high tunnel production system was almost double that the one from the open-field production system (Fig. 1C). This was due to several factors including increased competitive vegetation in field plots that did not occur in tunnels, significant periods of rain in September (12 d, 160 mm) and October (19 d, 272 mm), and an early killing frost occurring on 18 Oct. The increase in yield could be attributed to both late season extension and crop protection. These could be determinant factors when choosing between open-field and high tunnel production systems. The next section focuses on analyzing both systems based on their economics.

Economic analysis

The economic analysis is presented first in terms of open-field production and then in terms of high tunnel production. Both production systems are analyzed in terms of CDFs based on PV distributions for GR.

Open-field production system. The PV of TC for open-field production (for 2 years of establishment and 5 years of production) is $107,086 per hectare, whereas the distribution of PVs of GR shown in Table 1 ranges from $49,934 to $300,940 per hectare for the life of the project. If the producer receives 100% or 125% of the retail price, he will be able to cover the full TC of production provided he is able to sell at least 50% of his production. At lower prices received, being able to cover the full TC of production will depend on the percentage of yield that is being sold.

The break-even probability is estimated for each combination of price and yield. The results are sensitive to the different percentage of yield sold and the retail prices received by the producer. Table 2 presents the probability of PV associated GR for open-field production under 24 different yields and prices combinations. There are 14 combinations of yields and prices (in terms of PV of GR) that will always cover the full TC of production. There are also five combinations that will never cover the full TC of production (i.e., the producer will not break-even). In general, the producer needs to receive at least 75% of the retail price and at least sells 70% of his blackberry production to fully cover the TC of production.

High tunnel production system. The PV of TC for high tunnel production is $190,662 per hectare, whereas the distribution of PVs of GR ranges from $55,853 to $394,534 per hectare for the life of the project (Table 3). At lower prices, the producer will not always be able to cover the full TC of production. Table 4 shows the break-even probability when using high tunnels for 'Prime-Jan®' primocane-fruiting blackberry production. As with the previous system, the results are sensitive to the different percentage of yield sold and the retail prices received by the producer. For instance, at 50% or less of the retail price, the producer will not be able to cover the full TC of production regardless of the percentage of yield sold. At 75% of the retail

Table 1. Summary statistics for 500 simulated present values of gross revenues for 'Prime-Jan®' primocane-fruiting blackberries under open-field production at different price and yield percentages over the 5-year productive life of the planting.

Retail price received by the producer (Percentage of total price)[x]		Gross revenues of open-field production ($/ha)[z] Marketable yield (Percentage of total yield)[y]					
		50%	60%	70%	80%	90%	100%
50%	Mean	55,017	66,020	77,023	88,027	99,030	110,033
	SD	1,755	2,106	2,457	2,808	3,160	3,511
	Minimum	49,934	59,921	69,908	79,895	89,882	99,869
	Maximum	60,188	72,226	84,263	96,301	108,338	120,376
75%	Mean	82,525	99,030	115,535	132,040	148,545	165,050
	SD	2,633	3,160	3,686	4,213	4,739	5,266
	Minimum	74,902	89,882	104,862	119,843	134,823	149,803
	Maximum	90,282	108,338	126,395	144,451	162,508	180,564
100%	Mean	110,033	132,040	154,046	176,053	198,060	220,066
	SD	3,511	4,213	4,915	5,617	6,319	7,021
	Minimum	99,869	119,843	139,817	159,790	179,764	199,738
	Maximum	120,376	144,451	168,526	192,602	216,677	240,752
125%	Mean	137,541	165,050	192,558	220,066	247,575	275,083
	SD	4,388	5,266	6,144	7,021	7,899	8,777
	Minimum	124,836	149,803	174,771	199,738	224,705	249,672
	Maximum	150,470	180,564	210,658	240,752	270,846	300,940

[z]$1/ha = $0.4047/acre.

[y]The 100% baseline represents the average stochastic yields from the 500 simulations, which were: production year 1 = 5508 kg·ha^{-1} (4914.1 lb/acre); production year 2 = 2501 kg·ha^{-1} (2231.3 lb/acre); production years 3 to 5 = 1834 kg·ha^{-1} (1636.3 lb/acre). Other yield percentage scenarios reported in the table are relative to this baseline.

[x]The 100% baseline represents the weekly weighted-average annual price from the 500 simulations, which were: production year 1 = $17.88/kg ($8.110/lb or $0.507/oz); production year 2 = $18.57/kg ($8.423/lb or $0.526/oz); production years 3 to 5 = $19.48/kg ($8.836/lb or $0.552/oz). Other price percentage scenarios reported in the table are relative to this baseline.

Table 2. Frequency of break-even in 500 simulations of a 5-year 'Prime-Jan®' primocane-fruiting blackberry planting under open-field production at different price and yield outcomes.

Retail price received by the producer (Percentage of total price)[x]	Frequency of break-even (%)[z] Marketable yield (Percentage of total yield)[y]					
	50%	60%	70%	80%	90%	100%
50%	0.00	0.00	0.00	0.00	0.57	80.08
75%	0.00	0.57	98.59	100.00	100.00	100.00
100%	80.08	100.00	100.00	100.00	100.00	100.00
125%	100.00	100.00	100.00	100.00	100.00	100.00

[z]The break-even probability is estimated for each combination of price and yield. The results are sensitive to the different percentage of yield sold and the retail prices received by the producer. However, to break-even, gross revenues need to be at least \$107,086/ha (\$43,336.2/acre). For instance, if the producer is able to sell at least 70% of his/her production at 75% of the retail price, he/she has a 98.59% chance of being able to cover the total cost of production.
[y]The 100% baseline represents the average stochastic yields from the 500 simulations, which were: production year 1 = 5508 kg·ha^{-1} (4914.1 lb/acre); production year 2 = 2501 kg·ha^{-1} (2231.3 lb/acre); production years 3 to 5 = 1834 kg·ha^{-1} (1636.3 lb/acre). Other yield percentage scenarios reported in the table are relative to this baseline.
[x]The 100% baseline represents the weekly weighted-average annual price from the 500 simulations, which were: production year 1 = \$17.88/kg (\$8.110/lb or \$0.507/oz); production year 2 = \$18.57/kg (\$8.423/lb or \$0.526/oz); production years 3 to 5 = \$19.48/kg (\$8.836/lb or \$0.552/oz). Other price percentage scenarios reported in the table are relative to this baseline.

Table 3. Summary statistics for 500 simulated present values of gross revenues for 'Prime-Jan®' primocane-fruiting blackberries under a 15 high tunnels production system [≈24 × 303 ft (7.3 × 92.4 m) each] at different price and yield percentages of the 5-year productive life of the planting.

Retail price received by the producer (Percentage of total price)[x]		Gross revenues of high tunnels production (\$/ha)[z] Marketable yield (Percentage of total yield)[y]					
		50%	60%	70%	80%	90%	100%
50%	Mean	67,537	81,044	94,551	108,059	121,566	135,073
	SD	3,842	4,610	5,378	6,147	6,915	7,683
	Minimum	55,853	67,024	78,194	89,365	100,535	111,706
	Maximum	78,907	94,688	110,469	126,251	142,032	157,814
75%	Mean	101,305	121,566	141,827	162,088	182,349	202,610
	SD	5,763	6,915	8,068	9,220	10,373	11,525
	Minimum	83,779	100,535	117,291	134,047	150,803	167,559
	Maximum	118,360	142,032	165,704	189,376	213,048	236,720
100%	Mean	135,073	162,088	189,103	216,118	243,132	270,147
	SD	7,683	9,220	10,757	12,293	13,830	15,367
	Minimum	111,706	134,047	156,388	178,730	201,071	223,412
	Maximum	157,814	189,376	220,939	252,502	284,064	315,627
125%	Mean	168,842	202,610	236,379	270,147	303,915	337,684
	SD	9,604	11,525	13,446	15,367	17,288	19,208
	Minimum	139,632	167,559	195,485	223,412	251,338	279,265
	Maximum	197,267	236,720	276,174	315,627	355,080	394,534

[z]\$1/ha = \$0.4047/acre.
[y]The 100% baseline represents the average stochastic yields from the 500 simulations, which were: production year 1 = 4320 kg·ha^{-1} (3854.2 lb/acre); production year 2 = 2071 kg·ha^{-1} (1847.7 lb/acre); production years 3 to 5 = 3517 kg·ha^{-1} (3137.8 lb/acre). Other yield percentage scenarios reported in the table are relative to this baseline.
[x]The 100% baseline represents the weekly weighted-average annual price from the 500 simulations, which were: production year 1 = \$17.41/kg (\$7.897/lb or \$0.494/oz); production year 2 = \$18.93/kg (\$8.587/lb or \$0.537/oz); production years 3 to 5 = \$18.30/kg (\$8.301/lb or \$0.519/oz). Other price percentage scenarios reported in the table are relative to this baseline.

price, more than 90% of production must be sold to come close to covering TC. At the baseline retail price, the producer needs to sell 90% to be assured of break-even. If the producer receives 125% of the retail price, he will be able to cover the full TC of production by selling at least 70% of his production. In fact, there are 12 combinations of yields and prices (in terms of PV of GR) that never cover the full TC of production. Ten of these unprofitable outcomes are associated with receiving only 50% or 75% of the retail price and selling 80% or less of the production. Although high tunnels can generate high GR and higher fruit quality is expected, a percentage of the production is always culled. Consequently, it seems that costs are prohibitive, at least from the results obtained with these specific data.

Conclusions

'Prime-Jan®' yields were higher for the open-field system during the first 2 years of production. Although the high tunnel system produced a higher yield in year 3, our results did not show that high tunnels had any considerable out-of-season benefit in the northwestern Arkansas study region as there was minimal harvest after seasonal frosts. Year 3 increase in 'Prime-Jan®' yield was attributed to season extension to a small degree, but more importantly to crop protection. It was determined that the increased yield due to weather protection may not offset the additional costs of constructing and managing high tunnels.

Yields of primocane blackberries in the conditions of this study were less than has been observed traditionally for floricane-produced berries. These results indicate that 'Prime-Jan®' may not be the best choice for high tunnel primocane-fruiting blackberry production. Rom et al. (2010) reported that there were interactions between blackberry primocane cultivar and production system where some cultivars performed better in high tunnels than open-field conditions while the converse was true for other cultivars. A new primocane-fruiting blackberry cultivar (Prime-Ark® 45) was released by the UA breeding program in 2009, with reported higher yields (J.R. Clark, personal communication), that could perform better in both open-field and high tunnel production systems in other regions. Our results suggest that more work needs to be done evaluating different primocane-fruiting blackberry cultivars and their adaptation to specific locations and production systems.

Overall, break-even probabilities differed depending on the different percentage of yield sold, the percentage of the retail price received by the producer, and the production system analyzed. An increase in the percentage received of the retail price always moved the PV distributions of GR to the right. High tunnel production is almost two times more expensive than open-field production. Even though the potential GR obtained with this system are high (when compared with open-field production), the PV

Table 4. Frequency of break-even in 500 simulations of a 5-year 'Prime-Jan®' primocane-fruiting blackberry planting produced under a 15 high tunnels system [≈24 × 303 ft (7.3 × 92.4 m) each] at different price and yield outcomes.

Retail price received by the producer (Percentage of total price)[x]	Frequency of break-even (%)[z]					
	Marketable yield (Percentage of total yield)[y]					
	50%	60%	70%	80%	90%	100%
50%	0.00	0.00	0.00	0.00	0.00	0.00
75%	0.00	0.00	0.00	0.00	21.78	85.52
100%	0.00	0.00	42.32	97.79	100.00	100.00
125%	1.05	85.52	100.00	100.00	100.00	100.00

[z]The break-even probability is estimated for each combination of price and yield. The results are sensitive to the different percentage of yield sold and the retail prices received by the producer. However, to break-even, gross revenues need to be at least is $190,662/ha ($77,158.2/acre). For instance, if the producer is able to sell at least 90% of his/her production at 75% of the retail price, he/she has a 21.78% chance of being able to cover the total cost of production.

[y]The 100% baseline represents the average stochastic yields from the 500 simulations, which were: production year 1 = 4320 $kg \cdot ha^{-1}$ (3854.2 lb/acre); production year 2 = 2071 $kg \cdot ha^{-1}$ (1847.7 lb/acre); production years 3 to 5 = 3517 $kg \cdot ha^{-1}$ (3137.8 lb/acre). Other yield percentage scenarios reported in the table are relative to this baseline.

[x]The 100% baseline represents the weekly weighted-average annual price from the 500 simulations, which were: production year 1 = $17.41/kg ($7.897/lb or $0.494/oz); production year 2 = $18.93/kg ($8.587/lb or $0.537/oz); production years 3 to 5 = $18.30/kg ($8.301/lb or $0.519/oz). Other price percentage scenarios reported in the table are relative to this baseline.

distributions of GR do not offset the high tunnel TC in 12 simulation cases. Conversely, open-field production proves to be more profitable both in terms of magnitude and in terms of the probability of exceeding the break-even threshold during the life of the blackberry planting. Producers looking to improve their break-even probabilities can look for additional uses for the high tunnel structure or select moveable high tunnels that are over berries only during the harvest season and are over another crop throughout the summer.

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