Economic Profitability of Growing Lettuce and Tomato in Western Washington under High Tunnel and Open-field Production Systems

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SUMMARY. Lettuce (*Lactuca sativa*) and tomato (*Solanum lycopersicum*) are popular fresh market vegetable crops. In western Washington, there is interest in growing them in high tunnel production systems because of the region's mild, coastal climate. The objectives of this study were to contrast the economic potential of growing lettuce and tomato under high tunnel and open-field production systems, and identify the main factors affecting profitability within each production system. Economic data for this study were collected by interviewing experienced lettuce and tomato growers in western Washington during focus group sessions. Costs of production varied by crop and production system, and findings indicated that it was five times more costly to grow lettuce and eight times more costly to grow tomato in a high tunnel than in the open field in western Washington. For lettuce, the labor cost per square foot of growing area was found to be 6 times greater in a high tunnel than in the open field; and for tomato, labor costs were 10 times greater in a high tunnel than in the open field. Total labor cost comprised more than 50% of the total production costs of lettuce and tomato in both the high tunnel and open-field systems. The percentage of total labor cost was similar in both the high tunnel and open-field production for lettuce, but was higher in high tunnel tomato production than in the open field. Tunnel-grown lettuce and tomato had three and four times greater marketable yield compared with field-grown, respectively. Given the base crop yield and average price, it was 43% more profitable to grow lettuce in the open field than in the high tunnel, while in contrast, high tunnel-grown tomato was three times more profitable than open-field tomato production.

High tunnels are used worldwide to protect crop quality under adverse weather conditions and to extend the production season of crops through climate enhancement (Lamont, 2009; Zhao and Carey, 2009). Temperature modification under high tunnels can lengthen the growing season from 1 to 4 weeks in the spring, and 2 to 8 weeks in the autumn (Wells and Loy, 1993). High tunnels are generally considered to be temporary structures covered with greenhouse-grade plastic, have no electrical system, and crops in them are planted directly into the soil (Wells and Loy, 1993). The range in engineering

strength and durability of high tunnel technology generally corresponds to the range of purchase price (Giacomelli, 2009). The recent focus on locally grown food combined with low-cost tunnel technology has stimulated interest in crop-specific information relative to high tunnels among specialty crop growers (Reeve and Drost, 2012).

High-value crops including leafy greens, tomato, pepper (*Capsicum annuum*), small fruit, tree fruit, and ornamentals are commonly produced in high tunnels in the United States (Carey et al., 2009). Lettuce (head, leaf, and romaine types combined) ranked first in the United States in total value of production of fresh market vegetables

(U.S. Census Bureau, 2012) and national consumption exceeded 23 lb per capita each year on average between 1980 and 2010 [U.S. Department of Agriculture (USDA), 2012]. Lettuce production peaked in Washington in 1990 with 1700 acres, but by 1999 dropped to 800 acres, and has not been tracked thereafter (USDA, 2011). Washington farmers mostly lost market contracts to farmers in California who can supply large quantities of lettuce year-round (U.S. Census Bureau, 2012).

The optimal temperature for lettuce production is 65 °F (Maynard and Hochmuth, 1997), making this crop well suited for year-round production in regions with mild temperatures such as western Washington (Dufault et al., 2006). Lettuce generally benefits most from high tunnel production during fall, winter, and spring seasons, and is not normally grown in high tunnels during the summer because long daylength and elevated temperatures promote bolting, which reduces lettuce quality and marketability (Mishagi et al., 1992; Wien, 1997). In regions such as western Washington, heavy rainfall in the spring can constrain land preparation for crop establishment, and can negatively impact crop quality (Wallace et al., 2012).

In regions with a moderate climate such as the Pacific northwestern United States, production of warm-season crops such as tomato is limited (Miles et al., 2012; Rader and Karlsson, 2006; Waterer, 2003). In 2007, there were 300 acres of tomatoes produced by 409 farms in Washington, with a total estimated value of \$1 million to \$1.2 million (USDA, 2010; Washington State Commission on Pesticide Registration, 2010). Tomato production occurs on small acreages in essentially every county in Washington, and is predominantly for fresh market. While tomato is a minor crop in terms of overall production and value in

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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
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.8824	lb/ft ²	kg·m ⁻²	0.2048
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Washington, it is considered an essential produce item at every farmers market, community supported agriculture farm, and other direct or local marketing outlet. Tomato benefits from high tunnel production in spring, summer, and fall months in western Washington. In a study by Miles et al. (2012), it was possible to plant tomato 1 to 2 months earlier in the spring in high tunnels than in the open field; during the summer months, plant growth was faster because of elevated temperatures and tomato was ready for harvest earlier; and in the fall, the crop was protected from rainfall and light frost, enabling harvest through October.

Although lettuce and tomato are both grown in high tunnels in western Washington, high tunnel production of both crops is currently low, and was estimated by the authors to be 50 acres for tomato and less than 20 acres for lettuce (Galinato et al., 2012a, 2012b). The adoption rate for high tunnels is low in the region primarily due to a general lack of knowledge about the specific production practices for each crop, the high tunnel structures best suited to each crop, potential returns from high tunnels, and the capital investment needed to initiate and maintain high tunnel production (Miles et al., 2009). In addition, some experienced high tunnel growers in the region claimed that the following factors serve as barriers to more widespread adoption of high tunnels in northwest Washington: high cost of tunnel production in terms of capital investment, time, and effort; lack of experience with tunnel set up and management; lack of horticultural experience with crops requiring high labor input; low knowledge base to manage tunnel operation, maintenance, and repairs; and lack of understanding of the optimal planting dates and varieties for production (M. Finger, personal communication; D. Hedlin and K. Ottenson, personal communication; A. Schwartz, personal communication; T. Thornton, personal communication).

While high tunnels provide growers with the potential to increase production, quality, and sales, little is known about the economic profitability of using these structures. Some studies have looked at the economics of high tunnel crop production (Conner et al., 2010; Jett, 2011; Waldman et al., 2012; Waterer, 2003; Wien et al., 2010)

but none except Rodriguez et al. (2012) have directly examined the profitability of crop production in a high tunnel system as compared with an open-field system. Single crop enterprise budgets have been developed for both field and high tunnel production of lettuce and tomato in western Washington (Galinato and Miles, 2012; Galinato et al., 2012a, 2012b, 2012c). The objectives of this study were to 1) compare the economic potential of growing lettuce and tomato in high tunnel and open-field production systems and 2) identify the main factors that affect the profitability of each crop within each production system.

Materials and methods

Four focus group meetings, each comprised of three to four growers, were convened in western Washington between Apr. and Nov. 2011 to develop crop enterprise budgets. Each focus group addressed one crop (lettuce or tomato) and one production system (open field or high tunnel). Focus group participants were selected based on their experience in growing lettuce or tomato in open field or high tunnel and their management practices. All growers who participated were experienced and knowledgeable in the crop and production system. Each focus group consisted of different growers, except for one grower who grew both lettuce and tomato in high tunnels, and participated in the high tunnel lettuce and tomato focus group meetings. All focus group participants grew several vegetable crops, and lettuce or tomato was one of the primary crops they each produced. Participants had 3 to 15 years of experience growing lettuce or tomato in the open-field or high tunnel system, and their farm area actually planted with tomato or lettuce ranged from less than 1 acre up to 6 acres. These growers were also representative of good and best management practices for the region. Participants sold their produce through direct marketing at a farmers market, food co-operative, and/or community supported agriculture venture. Table 1 summarizes the participants' farming background relevant for the study.

For each crop enterprise budget, a hypothetical farm situation was defined and the types of inputs were itemized based on the production system (i.e., high tunnel or open field)

and vegetable crop selected (i.e., lettuce or tomato). The quantities of various inputs were based on the cultural and management practices of growers who participated in the focus group meetings. The focus groups for open-field production of lettuce and tomato defined a total production area equivalent to 1.5 and 1.25 acres as a baseline, respectively, where 1 acre was the growing area (rows and beds) and the remaining area was not used for direct crop production (alleyway, road, other utility areas). The growing season for field-grown lettuce was defined as April to October, and for field-grown tomato was February to September. Lettuce harvest was June to October, while tomato harvest was August to September.

For lettuce and tomato high tunnel production, the respective focus groups identified the high tunnel as 20 × 96 ft with end walls. Each grower had a different high tunnel model, and some had a three-season structure while others had a four-season structure. Since lettuce is well suited to cool spring temperatures, lettuce can be planted earlier in a four-season structure than in a three-season structure. Three-season structures cannot be erected in western Washington until April due to muddy field conditions. Further, it can be difficult to construct a three-season structure under other adverse weather conditions common during the early spring months in the region (heavy rainfall and wind). To reach consensus regarding costs and returns for high tunnel lettuce, growers participating in focus groups agreed to the following assumptions: 1) a three-season structure high tunnel was set up in mid-April and taken down in November, 2) the growing season (seed through harvest) was February to mid-October, and 3) the harvest season was late April to mid-October. The assumption for high tunnel-grown tomato was that the crop was set out in high tunnels when the minimum nightly temperature was 50 °F, which generally occurs by late April in the region. As three-season and four-season high tunnels are in place at this time of year, tomato was planted at the same time in both types of structures. The growing season (seed through harvest) for tomato was 1 Feb. to 1 Oct. and harvest season was June/July to 1 Oct.

The focus group participants established that the baseline marketable

Table 1. Characteristics of focus group participants in western Washington who grow lettuce or tomato in the open field.

Characteristics by production system	Lettuce			Tomato		
	Grower 1	Grower 2	Grower 3	Grower 1	Grower 2	Grower 3
Open field						
Time farming (years)	15	34	15	11	15	30
Total area farmed (acres) ^z	18	15	12	50	12	20
Primary crops grown ^y	Lettuce, squash, bean	Blueberry, raspberry, mixed vegetables	Salad greens, potato, garlic, dry bean	Mixed vegetables	Mixed vegetables	Berry, mixed vegetables
Time growing crop (years) ^x	10	10	15	6	15	15
Area in production (acres) ^x	6	0.03	0.13	1.5	0.25	>0.25
High tunnel						
Time farming (years)	36	5	42	40	25	42
Total area farmed (acres)	20	1	230	500	7	230
Primary crops grown ^y	Tree fruit, tomato, pepper	Tomato	Nursery stock, mixed vegetables	Vegetable seed, mixed vegetables, small grains, corn/barley silage	Lettuce and mixed greens, tomato, onion, pepper	Nursery stock, mixed vegetables
Time growing in high tunnels (years) ^x	10	5	7	10	3	8
Area in high tunnel (acres) ^x	1	<1	0.01	0.5	0.05	0.02
High tunnels (no.)	2	1	1	1	1–2	2
Size of high tunnels (ft) ^{z,x}	20 × 96 ft	20 × 60 ft	12 × 40 ft	0.5 acre	20 × 96 ft	12 × 40 ft
High tunnel design ^{x,w}	Hybrid	Gable	Quicdan	Haygrove	Quicdan	Quicdan
High tunnel seasons ^x	Three	Three	Four	Three	Four	Four

^x1 acre = 0.4047 ha, 1 ft = 0.3048 m.^ySquash (*Cucurbita maxima*), bean (*Phaseolus vulgaris*), blueberry (*Vaccinium* sp.), raspberry (*Rubus* sp.), potato (*Solanum tuberosum*), corn (*Zea mays*), pumpkin (*Cucurbita* sp.), pepper (*Capiscum* sp.), barley (*Hordeum vulgare*), onion (*Allium cepa*).^zInformation pertains to either lettuce or tomato.^wQuicdan, Salinas, CA; Haygrove, Redbank, Ledbury, UK.

yield per square foot per harvest season was 0.36 head/ft² for field-grown lettuce and 0.56 lb/ft² for tomato (Table 2). These baseline marketable yields were both within the range of previously reported values of 0.29–0.67 head/ft² and 0.43–1.94 lb/ft², respectively (Antonelli et al., 2004; Jeavons, 2006; Veseys, n.d.; Wiswall, 2009). For high tunnel-grown lettuce and tomato, the baseline marketable yield per square foot established by focus group participants was 0.90 head/ft² and 2.25 lb/ft², respectively. These high tunnel yields were much greater than the aforementioned field-grown yield range; specifically up to three times greater than the field-grown lettuce yield and up to five times greater than the field-grown tomato yield. The focus group results for tomato are similar to those reported in a western Washington study where tomato yield was eight times greater in the high tunnel than the open field (Miles et al., 2012). Table 2 shows other production specifications established by focus group participants for the two crops and the two production systems.

To account for variable production costs and returns among different farm operations (crop yield, input prices, commodity price, capital, labor, cultural practices and management skills, among others), baseline budget assumptions were established that served as a discussion guide for each focus group. Each focus group met for 4 h on 1 d at a central location for all participating growers, and the participants discussed the budget assumptions. Main production categories were identified and estimates for the variable and fixed costs of production were provided by participating growers. Variable production costs were soil preparation, fertilizer and chemical application, planting, other labor, harvest and postharvest activities, maintenance and repairs of irrigation system, machinery and/or equipment, overhead, and interest on operating capital. The cost category “overhead” captured variable overhead costs as well as a factor for unforeseeable expenses. Fixed production costs were depreciation and interest on physical capital, interest and tax on land, farm insurance, and farm management. Because growers had different cost estimates for inputs used in production, each focus group achieved a consensus

on the average cost for each production category. Specific crop cultural practices for each grower were also taken into account when discussing and determining the costs and returns of production. For example, participants in the open-field lettuce group were organic growers and participants in the open-field tomato group used plastic mulch. Production costs associated with different types of activities were then tabulated and reviewed by focus group participants and knowledgeable vegetable crop extension specialists in the region.

The values provided by focus group participants did not account for unforeseen production failures. Since crop loss should be anticipated periodically, sensitivity analyses were conducted on potential net returns from crop production (per square foot of total production area) given different crop yield and price scenarios. In particular, the net returns of crop production in a high tunnel or open-field production system were calculated, given a range of crop prices and three scenarios of crop yield: 1) base yield, 2) yield that was 20% less than base yield,

and 3) yield that was 20% greater than base yield.

Results

COST PER UNIT OF TOTAL PRODUCTION AREA. A comparison of the production costs per square foot of total production area for each crop and production system are shown in Tables 3 and 4. The total production costs of high tunnel lettuce and tomato were respectively five and eight times greater than those of open-field lettuce and tomato (Table 3). A breakdown of the production costs by field activity

Table 2. Baseline production values from focus group growers for lettuce and tomato in the open-field and high tunnel systems in western Washington in 2011.

Field specification	Lettuce		Tomato	
	Open field	High tunnel ^z	Open field	High tunnel ^z
Total production area ^{y,x}	1.5 acres	1,920 ft ²	1.25 acres	1,920 ft ²
Growing area ^{y,w}	1 acre	1,597 ft ²	1 acre	480 ft ²
Growing season	April to Oct.	February to mid-Oct.	February to Sept.	1 Feb. to 1 Oct.
Harvest season	June to Oct.	April to mid-Oct.	August to Sept.	June/July to 1 Oct.
In-row spacing (inches) ^y	10	10	24	12
Between-row spacing (inches) ^y	36	10	60	42
Density ^v	26,000 heads/acre	2,300 heads/tunnel	5,500 plants/acre	480 plants/tunnel
Marketable yield ^v	19,500 heads/acre	1,725 heads/tunnel	30,360 lb/acre	4,320 lb/tunnel
Early season (% of total) ^u	NA	30	NA	15
Midseason (% of total)	100	55	100	60
Late season (% of total) ^u	NA	15	NA	25
Marketable yield/ft ^{2t}	0.36 head/ft ²	0.9 head/ft ²	0.56 lb/ft ²	2.25 lb/ft ²

^zHigh tunnel size was 20 × 96 ft (6.1 × 29.3 m). High tunnel was a three-season structure set up in mid-April and taken down in November.

¹1 acre = 0.4047 ha, 1 ft² = 0.0929 m², 1 inch = 2.54 cm.

^yTotal production area included the growing area and area not devoted to direct production of the crop (road, walkpath, etc.).

^wGrowing area was the total crop production area and excluded alleyways, processing station, and other utility areas.

^v1 head/acre = 2.4711 heads/ha, 1000 heads/tunnel = 0.5208 head/ft² = 5.6062 heads/m², 1 plant/acre = 2.4711 plants/ha, 100 plants/tunnel = 0.0521 plants/ft² = 0.5605 plant/m², 1 lb/acre = 1.1209 kg/ha⁻¹, 1000 lb/tunnel = 0.5208 lb/ft² = 2.5429 kg/m².

^uNA = not applicable.

^tMarketable yield per square foot of total production area; 1 head/ft² = 10.7639 heads/m², 1 lb/ft² = 4.8824 kg/m².

Table 3. Estimated annual production costs and net returns from focus group growers for lettuce and tomato in open-field and high tunnel production systems in western Washington in 2011.

Crop	System	Unit ^z	Price per unit	Marketable yields		Production cost		Net returns ^w	
				Total ^y	Per ft ^{2x}	Total ^y	Per ft ^{2y}	Total ^y	Per ft ^{2y}
Lettuce	Open field	head	\$1.75	19,500	0.36	\$16,159	\$0.30	\$17,966	\$0.33
	High tunnel	head		1,725	0.90	\$2,965	\$1.54	\$442	\$0.23
	Early season	head	\$2.50	30% of total					
	Midseason	head	\$1.75	55% of total					
	Late season	head	\$1.75	15% of total					
Tomato	Open field	lb	\$3.00	30,360	0.56	\$25,983	\$0.48	\$65,097	\$1.20
	High tunnel	lb		4,320	2.25	\$7,399	\$3.85	\$6,749	\$3.52
	Early season	lb	\$4.00	15% of total					
	Midseason	lb	\$3.00	60% of total					
	Late season	lb	\$3.50	25% of total					

^z1 lb = 0.4536 kg.

^yNumbers were expressed as total for the given total production area: 1.5 acres (0.61 ha) for open-field lettuce; 1.25 acres (0.506 ha) for open-field tomato; and one tunnel = 1920 ft² (178.4 m²) for high tunnel lettuce and high tunnel tomato; 1 head/acre = 2.4711 heads/ha, 1000 heads/tunnel = 0.5208 head/ft² = 5.6062 heads/m², 1 lb/acre = 1.1209 kg/ha⁻¹, 1000 lb/tunnel = 0.5208 lb/ft² = 2.5429 kg/m², \$1.00/acre = \$2.4711/ha, \$1000/tunnel = \$0.5208/ft² = \$5.6062/m², \$1.00/ft² = \$10.7639/m².

^xMarketable yield per square foot of total production area; 1 head/ft² = 10.7639 heads/m², 1 lb/ft² = 4.8824 kg/m².

^wNet returns = (price per unit × marketable yield) – production cost. For high tunnel lettuce and tomato, net returns were calculated by taking into account the different prices and crop yield during the early, middle and late harvest seasons: net returns_j = Σ_k (price per unit_k × marketable yield_{kj}) – production cost_j, where j = high tunnel-grown lettuce or tomato, and k = early season, midseason, or late season.

further showed the more costly operation of a high tunnel system per square foot (Table 4). The total labor cost for open-field production included field operations, harvest and post-harvest activities, and was \$0.14/ft² for lettuce and \$0.30/ft² for tomato. In contrast, the total labor cost for high tunnel production included the additional cost of tunnel operation and maintenance, and was \$0.89/ft² for lettuce and \$12.87/ft² for tomato.

The cost category of “tunnel operation and maintenance” was \$0.46/ft² for lettuce and \$0.91/ft² for tomato. These results show that the total labor requirement per square foot for high tunnel lettuce and tomato production was 6 and 10 times greater than for open-field production, respectively. High tunnel production also had higher material cost and higher capital investment cost per square foot than open-field production.

RELATIVE COST OF EACH FIELD ACTIVITY WITHIN A PRODUCTION SYSTEM. Total fixed costs and main categories of variable costs as a percentage of total production costs for each crop and production system are summarized in Fig. 1. Harvest and postharvest activities comprised a substantial portion of the total cost of production for both crops in both production systems; this category included labor-intensive harvest, packing,

Table 4. Estimated total production costs for lettuce and tomato, by field activity and by production system.

Field activity	Total production costs ^z			
	Open-field lettuce (\$/ft ²)	High tunnel lettuce (\$/ft ²)	Open-field tomato (\$/ft ²)	High tunnel tomato (\$/ft ²)
Field operations—Labor	0.02	0.09	0.19	0.49
Field operations—Materials and custom ^y	0.01	0.19	0.06	0.27
Harvest and postharvest—Labor	0.12	0.34	0.11	1.48
Harvest and postharvest—Materials	0.03	0.04	0.04	0.05
Maintenance and repairs	0.01	0.02	0.01	0.09
Tunnel operation and maintenance	0.00	0.46	0.00	0.91
Other variable costs	0.02	0.12	0.04	0.28
Total fixed costs	0.04	0.29	0.03	0.30

^zProduction costs were for square foot of total production area: 65,340 ft² [1.5 acres (0.61 ha)] for open-field lettuce; 54,450 ft² [1.25 acres (0.506 ha)] for open-field tomato; and 1920 ft² (178.4 m²) for both high tunnel lettuce and high tunnel tomato; \$1.00/ft² = \$10.7639/m².

^yCustom field work included both the material applied on the field and labor involved. This category was present only in the open-field production of lettuce and tomato.

Fig. 1. Fixed costs and variable costs of high tunnel and open-field production based on grower input during focus group discussions for tomato and lettuce in western Washington in 2011. Four focus groups, each with three to four experienced and knowledgeable commercial farmer participants, met from April through Nov. 2011, and participants reached consensus regarding costs and returns for each crop and cropping system. Field operations included soil preparation, planting, fertilizer and chemical application, and irrigation. Tunnel operation and maintenance included irrigation and fertigation management, temperature management, tunnel system maintenance (labor and some replacement parts), and tunnel setup and removal. Postharvest included packing (labor and materials) and direct marketing. Other variable costs included overhead cost and interest cost on operating capital (also organic certification fee in the case of open-field lettuce production and plastic mulch disposal cost in open-field tomato production). Total fixed costs included depreciation and interest on physical capital, interest and tax on land, farm insurance, and farm management.

and direct marketing activities. For lettuce, harvest and postharvest activities varied by production system, and accounted for $\approx 64\%$ of the total costs in the open-field system and 24% in the high tunnel system. For tomato, harvest and postharvest activities were similar for both production systems, and were 32% of the total costs for the open-field system and 39% for the high tunnel system. The total cost of field operations was similar for lettuce in both production systems, and was 12% of the total costs for open-field production and 18% for the high tunnel. In contrast, for tomato, the field operations category differed for each production system, and was 52% of the total costs for open-field production and 20% for the high tunnel. The category of total fixed costs was similar for each crop regardless of production system, and ranged from 14% to 19% for lettuce and 7% to 8% for tomato. Other variable costs (7% to 8%) and costs for maintenance and repairs (1% to 2%) were similar for both crops and both production systems. Tunnel operation and maintenance comprised the largest and second largest

proportion, respectively, of the total production cost of high tunnel lettuce (30%) and high tunnel tomato (23%). Total labor cost was 58% of the total production costs for both field-grown and high tunnel lettuce. In contrast, total labor cost was 63% of the total production costs for field-grown tomato and 75% for high tunnel tomato.

LETTUCE PROFITABILITY. High tunnel production provides growers an opportunity to produce crops early and beyond the main season, when there is less competition and prices are higher. The average price received for high tunnel grown lettuce was \$2.50/head early into the harvest season, and \$1.75/head late in the season (Table 3). During the main production season, the mean price received was \$1.75/head for lettuce grown in either the high tunnel or open field. Given the marketable yield and prices received during the crop season, it was profitable to produce lettuce in both the high tunnel and the open-field systems. However, the net return for producing lettuce in a high tunnel was 30% less per square foot than the net return for producing lettuce in the open

field. Although there was a 150% yield advantage for high tunnel-grown lettuce as compared with the open field, the higher production costs for high tunnel-grown lettuce offset the yield advantage, which led to profit disadvantage.

Potential profit was sensitive to different combinations of lettuce yield and price within each production system. Assuming all other factors were constant, net returns were positive for open-field lettuce production for all yield and price combinations (Fig. 2). For high tunnel production, the average of the prices received during the early, middle, and late harvest seasons was \$2/head. To breakeven, the average price received during the entire crop season must be \$2.01/head when yield was 20% less than the base yield, \$1.72/head when yield was equal to the base yield, and \$1.53/head when yield was 20% greater than the base yield. When the yield and price were low (20% below base yield and \$1.75/head, respectively), the profit for field-grown lettuce was \$0.20/ft², while the profit for high tunnel production was negative (−\$0.19/ft²). With the same low crop yield but a high price

Fig. 2. Estimated net returns at different prices and yields in western Washington of (A) lettuce produced in open field, (B) lettuce produced in high tunnel, (C) tomato produced in open field, and (D) tomato produced in high tunnel; \$1.00/ft² = \$10.7639/m², \$1.00/lb = \$2.2046/kg.

(\$2.50/head), the profit for open-field production was \$0.38/ft² while the profit for high tunnel production was 7% less (\$0.35/ft²).

TOMATO PROFITABILITY. Tomato production in both high tunnel and open-field systems was profitable. During the main harvest season, the mean price received for field-grown or tunnel-grown tomato was \$3/lb, while mean prices during the early and late seasons were \$4/lb and \$3.50/lb, respectively. Given the higher marketable yield and opportunity of selling tunnel-grown tomatoes beyond the main season at a premium price, the estimated net return was three times greater for high tunnel-grown tomato than for field-grown tomato.

The sensitivity of potential profit to different combinations of tomato yield and price within each production system is illustrated in Fig. 2. Net returns of open-field tomato production were positive for all yield and price combinations, assuming all other factors were constant. The average of the prices received for high tunnel grown tomato during the early, middle, and late seasons was \$3.50/lb. For high tunnel production to breakeven, the average price received during the

entire crop season should be \$2.05/lb when yield was 20% less than the base yield, \$1.71/lb when yield was equal to the base yield, and \$1.49/lb when yield was 20% greater than the base yield. When the yield and price were low (20% below base yield and \$2/lb, respectively), the profit for field-grown tomato was \$0.37/ft², while profit for high tunnel-grown tomato was -\$0.08/ft². Given the same low yield but a high price (\$3.50/lb), the profit for open-field production of tomato was \$1.00/ft², which was 62% less than the profit for high tunnel production (\$2.62/ft²).

Discussion

Lettuce and tomato are among the most popular direct market vegetable crops sold in western Washington. This study provides a comparison of production costs and returns for both crops and shows that it is economically feasible to produce both crops in either a high tunnel or open-field system. However, analyses of the different categories of production costs reveal that it is generally more expensive to grow lettuce and tomato in a high tunnel than in the open field as more labor and physical capital

investment are needed to operate the relatively smaller growing area in a high tunnel. The increased labor in high tunnel operations has also been recognized by others, including Everhart et al. (2009), Giacomelli (2009), Hunter (2010), and Nennich et al. (2004). The total labor cost comprised more than 50% of the total production costs for lettuce and tomato in both production systems, and the cost share for labor was similar for lettuce in both systems while it was greater for tomato in high tunnel than in the open field. Additionally, high tunnel production has negative profitability when crop prices are low, i.e., below \$2.01/head and \$2.05/lb for tunnel-grown lettuce and tomato, respectively, and whenever yield of either crop is 20% below the base yield. In contrast, open-field production is profitable for all price and yield combinations assumed in the study.

The feasibility of tomato production in a high tunnel has been extensively studied in different locations across the country (Table 5). In contrast, to date, there have been very few enterprise budgets calculated for high tunnel lettuce production. Cost estimates of high tunnel production

Table 5. Comparison of variable and fixed production costs from selected high tunnel lettuce and tomato enterprise budgets.

Study	Location	Area of high tunnel (ft ²) ^z	Crop yield ^y	Variable costs ^x			Fixed costs ^x		
				Per tunnel	Per ft ^{2w}	Per unit	Per tunnel	Per ft ^{2w}	Per unit
Lettuce (unit: head)									
Chase (2013) ^v	Iowa	2,160	209	\$146	\$0.81	\$0.70	\$81	\$0.45	\$0.39
This study	Western Washington	1,920	1,725	\$2,411	\$1.26	\$1.40	\$554	\$0.29	\$0.32
Tomato (unit: lb)									
Blomgren and Frisch (2007)	Vermont	2,016	3,500	\$4,937	\$2.45	\$1.41	\$1,094	\$0.54	\$0.31
Bullen (2009)	North Carolina	2,880	5,760	\$4,340	\$1.51	\$0.75	\$1,282	\$0.45	\$0.22
Chase (2013)	Iowa	2,160	5,888	\$1,619	\$0.75	\$0.27	\$966	\$0.45	\$0.16
Cornell University (2009)	New York	2,000	5,780	\$1,905	\$0.95	\$0.33	\$768	\$0.38	\$0.13
Foord (2004) ^u	Minnesota	1,920	4,480	\$2,402	\$1.25	\$0.54	\$1,189	\$0.62	\$0.27
Hunter et al. (2011)	Utah	1,344	1,700	\$1,265	\$0.94	\$0.74	\$416	\$0.31	\$0.24
Jett et al. (2004) ^u	Missouri	2,000	3,400	\$3,041	\$1.52	\$0.89	\$1,011	\$0.51	\$0.30
Upson (2009)	Oklahoma	1,360	3,162	\$1,053	\$0.77	\$0.33	\$903	\$0.66	\$0.29
This study	Western Washington	1,920	4,320	\$6,829	\$3.56	\$1.58	\$570	\$0.30	\$0.13

^z1 ft² = 0.0929 m².

^vTotal marketable crop yield per 1920-ft² tunnel; 1000 heads/tunnel = 0.5208 head/ft² = 5.6062 heads/m², 1000 lb/tunnel = 0.5208 lb/ft² = 2.5429 kg-m⁻².

^xThe production costs of this study for western Washington were as of 2011 prices. To make the figures from other studies comparable, their respective production costs have been adjusted with respect to the year 2011 using the Index for Prices Paid by Farmers for Production Items. The equation used was: cost₂₀₁₁ = cost_t × (Price Paid Index₂₀₁₁/Price Paid Index_t), where *t* refers to the year of the study's publication. The Price Paid Indexes for various years were: 132 (2004); 160 (2007); 182 (2009); 215 (2011); and 220 (2013). Price Paid Index data were obtained from USDA (2013); \$1000/tunnel = \$0.5208/ft² = \$5.6062/m², \$1.00/lb = \$2.2046/kg.

^wVariable and fixed production costs were expressed on per square foot of total production area: 65,340 ft² [1.5 acres (0.61 ha)] for open-field lettuce; 54,450 ft² [1.25 acres (0.506 ha)] for open-field tomato; and 1920 ft² for both high tunnel lettuce and high tunnel tomato. \$1.00/ft² = \$10.7639/m².

^yLettuce was one of the multiple vegetable crops grown in the high tunnel. The production area for lettuce was about 8.38% of the total tunnel area. Based on this, the variable and fixed costs for lettuce was estimated at 8.38% of the total variable and fixed costs for the multiple crop production.

^uFoord (2004) and Jett et al. (2004) examined high tunnel tomato profitability given different yields. The assumed medium yield of 14 lb (6.4 kg) per plant for 320 plants in Foord (2004) and 10 lb (4.5 kg) per plant for 170 plants/1000 ft² (1.83 plants/m²) in Jett et al. (2004) were used in this table.

from different studies vary due to factors such as: the high tunnel model; capital, labor, and natural resources; input prices; cultural practices; and management skills and practices. However, the values presented in Table 5 provide an informative range of the variable and fixed costs associated with tomato production in a high tunnel. The variable costs were \$0.75–\$3.56/ft² or \$0.27–\$1.58/lb; and the fixed costs were \$0.30–\$0.66/ft² or \$0.13–\$0.31/lb. The estimated variable costs of this study were in the high end of the aforementioned range and about two standard deviations away from the mean. On the other hand, this study's fixed cost estimates were in the low end of the range and about one standard deviation away from the mean.

In the summer, price tends to be low for lettuce and tomato as compared with fall, winter, and spring production seasons. In addition, the longer daylength in the region in the summer combined with elevated temperatures in the high tunnel can reduce lettuce marketable yield because of bolting and tip burn (Wallace et al., 2012). These authors found that lettuce yield was similar in high tunnel and open-field production when grown from May through July in western Washington. In contrast, other studies report higher marketable yields of lettuce in a high tunnel as compared with open field (Belasco et al., 2012; Kelly, 2005; Rader and Karlsson, 2006). The variable results may be due to season of production as a high tunnel tends to reduce lettuce yield in the summer whereas yield may be increased during the remainder of the year. Thus high tunnel lettuce production is not likely to be profitable during the summer production period. While it costs two times more to grow tomato than lettuce in a high tunnel, the return from high tunnel-grown tomato is 15 times greater than from high tunnel-grown lettuce. This result is because of greater tomato yield and extended harvest period, both early and late in the season, due to elevated temperature in high tunnels.

A high tunnel offers many benefits to growers in addition to an increase in yield, such as protection from environmental stresses that affect crop quality and marketability, which include hail, frost, excessive rainfall, and high wind. Belasco et al. (2012) and Nennich et al. (2004) have highlighted

the potential of a high tunnel system in minimizing production and financial risks, and suggested high tunnels as a risk management tool for specialty crop producers.

Tomato and lettuce both had higher marketable yields when grown in a high tunnel as compared with the open field. However, the higher crop yield achieved in a high tunnel was not sufficient to offset the increased costs of production for lettuce. Expected crop yield, therefore, should not be the primary driving force in choosing a high tunnel production system over the open-field system. Instead, crop yield in addition to market price of the crop as well as production costs must all be taken into account when examining the profitability for any crop and production system. Furthermore, some limitations to this study are worth noting. The study's data and outcomes regarding profitability were based on information provided by focus groups of tomato and lettuce growers in western Washington. Production costs and returns by individual growers may differ, thus the results of the study cannot be generalized to represent the population of farmers.

Other issues worth mentioning are the possible economies of scale that may be obtained, for example, due to the size of the tunnel, size of the farm operation, and grower's experience. A larger high tunnel will improve the economy of scale to cover fixed capital such as plastic and end walls. Also, operating more than one high tunnel will improve the economy of scale to cover fixed capital that is shared among tunnels, such as machinery (e.g., bed shaper, mulch layer) and irrigation system outlet. High tunnel growers may engage in "trial and error" in their cultural and management practices to investigate what would give them the best crop in terms of quantity and quality. They may make adjustments to the planting method or to temperature management, or they may make changes to their high tunnel structures. When the grower finds the most productive method of growing the crop in a high tunnel, and this method is repeated over time, this experience can lower the average costs of production. In-depth analyses about the sources of economies of scale in a high tunnel operation are worthy of exploration in a future study.

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