Off-Season Organic Blackberry and Raspberry Production to Expand Markets and Sustain Farm Profitability

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Out-of-Season Berry Production in Tunnels to Expand Markets

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Project Final Report

Project Title: Off-Season Organic Blackberry and Raspberry Production to Expand Markets and Sustain Farm Profitability

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Executive Summary

- The potential of high tunnel blackberry and raspberry production for the southeast U.S. was tested in three experiments: 1) advancing spring production of floricane producing berries, 2) extending autumn harvest of primocane producing berries, and 3) double-cropping (spring and autumn) primocane berries.
- High tunnels advanced bloom and harvest of floricane producing berries about two weeks compared to field production. Additional advance will require additional heat conservation and tunnel management.
- Selecting early blooming and maturing cultivars may advance the season more.
- Tunnels resulted in significant yield savings in seasons of poor weather.
- Fruit produced in high tunnels may require additional protection from frost because they bloom earlier and during period of frosts.
- High tunnels extended autumn production of primocane producing berries approximately four weeks after field production ceased due to cold weather.
- Selecting late blooming and maturing cultivars may extend the season more.
- Not all primocane blackberries performed as well or better in high tunnels and cultivar testing will be important for future recommendations.
- Primocane raspberries tended to produced greater yields than primocane blackberries.
- Fruit produced in the tunnels may benefit from frost protection to reduce the risk of severe autumn cold temperatures.
- Both blackberries and raspberries produced in high tunnels tended to be larger berries than those produced in the field.
- There were no specific pest problems or minimization in the high tunnels compared to the field, although primocane fruiting berries had lower incidence of damaging cane borers due to the removal of cane after primocane fruit harvest and prior to pest problem manifestation.
- It has been observed and it is believed by the authors that screening high tunnels may further reduce the incidence of some specific insect pests.
- Yields of the double cropping system were greater than the primocane yield only but showed no specific advantage to separate summer floricane or autumn primocane producing systems.
- Economic analyses indicated that high tunnel production could be profitable but if yields and prices are similar to field production, field production would be more profitable due to the increased capital and management costs of high tunnels.
- Although not tested, the project directors believe that high tunnel blackberry production may be ideal for movable tunnels where a tunnel could be place over plants for either spring or autumn production and then moved for production of other revenue generating crops in the alternate season. Raspberries benefit from year-around enclosure, reduced light, and temperature moderation from the tunnels.
- The authors believe that high tunnel production has specific use for organic production.

Project Objectives

The purpose of this project was to enhance the sustainability of organic farming using protected cultivation for high-value small fruit crops.

High tunnels provide a means of 1) producing crops out-of-season for increased profitability, 2) increasing quality grade of fruit, 3) reducing delays in cultural activities and harvest due to rainfall, 4) reducing disease pressure. By shifting production either earlier or later in the season, workload and cash flow are spread more evenly among seasons. Additionally, by shifting production season, crop value increases due to the inelasticity of supply and demand of the product price and the lack of traditional large scale production of the main season.

The project was established with two primary research objectives:

> ***Objective 1) Determine management practices for out-of-season organic blackberry production in high tunnels in the southeast, and to adapt practices for high tunnel management of organic raspberries to high tunnel production in southeastern conditions.***
>
> ***Objective 2) Perform an economic analysis of both crops to determine the economic feasibility of out-of-season small fruit production as a means of supplementing income of existing organic or transitioning farms.***

Introduction

This project was developed to investigate the production issues for blackberries and raspberries, and the economics of extending the season of those crops with the use of high tunnel technology in order to increase product value and farm income.

Floricane-fruiting blackberry is a traditional southern high-value crop and is well adapted to the summer temperatures of the south. The traditional blackberry produces fruit on a two year-old cane (floricane) for 2-4 week harvest period in mid-summer. The new primocane fruiting (aka fall-bearing) blackberries, which were introduced by the University of Arkansas (UA) in 2004, (Clark et al., 2005) are similar to primocane fruiting raspberry production (Ourecky et al., 1969), in that they form terminal flowers in late summer and fruit during the autumn. Primocane blackberry and raspberry yields are limited by high temperature inhibition of development during flowering and fruit set (Stanton, 2005). As fruits take approximately 45 days from bloom to maturity, the harvest season of the primocane fruiting crops is limited by early frosts in October. Pruning techniques to delay flowering (Oliviera et al., 1998, Thompson et al., 2005) and thereby escape high temperatures during flowering and early fruit development, and the use of minimally structured high tunnels to escape freezing temperatures can be used to protect the crop and extend harvest until November or December (Rom, preliminary results).

Raspberries, both floricane and primocane types (summer and fall bearing, respectively) are not well adapted to the south as raspberries cannot tolerate high temperatures during fruit formation in the summer and flower formation in autumn. However, if the flowering and fruiting periods were shifted either earlier in the spring or later in the autumn, this may become a viable crop for farmers. Further, in preliminary tests, it was observed that raspberries had few insect or disease problems in the south which may provide an opportunity for organic fruit production.

High tunnels have been demonstrated to be practical and economically sustainable by advancing production earlier and/or extending it later into the season (Lamont et al., 2003, Pritts et al., 1999). Preliminary research at UA demonstrated that primocane fruiting blackberries and raspberries in high tunnels were harvested later into the season than field plots. Lamont et al. (2003) indicated that high tunnels extended the production season and improved shelf-life of small fruits such as blackberries and primocane raspberries, and may be an opportunity for improved economic stability for growers. Tunnel production, in combination with field production, would take an average 2-4 week harvest season in mid-summer and add several weeks potential harvest in the spring and several additional weeks harvest in the autumn. The off-season products would likely receive a higher market price.

Protected cultivation offers several significant advantages for blackberry and raspberry production. Tunnels reduce the threat of frost damage, produce the crop outside the normal biological period for insect infestation and disease infection, protect from precipitation to reduce diseases and improve fruit quality, and increase farm income by extending the production season.

<u>Farmer involvement</u>. This project was developed in response to grower, stakeholder groups that encourage us to develop production systems for organic fruit production and to develop additional crops out-of-season, particularly for spring and fall markets where there is a paucity of traditional season fruit available for market (Rom et al., 2005). The development and execution of the study was guided by two grower workshops 1) on blackberry production [Mar 2007] and 2) on organic fruit production [Nov 2007]. With other projects, an Advisory Board has been created upon which growers have membership and provide guidance to the project. As a result, trials were established at two growers in order to understand cropping management first-hand.

* * *

Methodology

A detailed description of the Penn State high tunnel system used is given by Lamont et al. (2002) with the fruit production system described by Olivera et al. (1998), Pritts et al. (1999), Koester and Pritts (2003) and Robbins and Gu (2009). Briefly, tunnel details are as follows:

•High Tunnels were Quonset-shaped tunnels approximately 20’ (w) by 36’ (l), and 12’ center height, ClearSpan™ models (FarmTek, Dyersville, IA).
•Single-layer, 6-mil polyethylene plastic glazing (with UV protection) over galvanized steel pipe frames
• Passive ventilation provided by rolling up plastic on sidewalls, and opening and/or removing endwalls.
• Endwalls constructed of 22-mil rip-stop translucent polyethylene fabric with zipper-door openings. Replaced with a framed endwall (galvanized stud structure), covered with woven polyethylene with swing-open barn doors.
• Drip irrigation

Objective 1. Management practices for out-of-season small fruit production in high tunnels.

High tunnel blackberry and raspberry production was studied in 2 phases. In phase 1, detailed studies were conducted at the Organic Unit at the Horticultural Research Farm in Fayetteville, AR. In phase 2, the best management practices resulting from phase 1 were implemented in two on-farm grower trials by organic producers in Elkins and Greenland, AR.

The blackberry and raspberry production objectives (project sub-objectives) were: 1) to evaluate high tunnel floricane blackberry and raspberry production compared to traditional field production systems with the goal of advancing the harvest season from June to May, 2) to evaluate high tunnel primocane blackberry and raspberry production with harvest continued until December, compared to field production, and 3) to evaluate the opportunity for a double cropping system of primocane blackberry production with a fall primocane harvest season followed by a spring/summer floricane harvest season, prior to pruning and forcing new primocanes, with all production systems being managed in a sustainable permaculture system for USDA organic certification.

<u>Phase 1, Replicated Research Trials - University of Arkansas Experiment Station, Fayetteville AR</u>
A series of three studies were initiated at the University of Arkansas Agriculture and Experiment Station, Fayetteville, AR to accomplish the proposed research sub-objectives. In July 2005, the Department of Horticulture dedicated a research unit of land (1 ha) for organic fruit production research. The soil is an eroded Captina silt-loam and is highly adapted to fruit production. Prior to planting, land was planed and leveled; soil pH was adjusted with agricultural lime; composted manure was applied 5 MT/ha and a perennial ground cover of 'Kentucky-31' fescue with a nurse crop of winter wheat was planted in September, 2005.

All three studies had similar planting and management as follows. Blackberries and raspberries were planted in the field in April 2006 with an in-row spacing of 0.25 m (ca. 1 ft) and between row spacing of 2m (ca. 6 ft) and were maintained at 1.25m (ca. 4 ft) width with a 0.75-1.0m (ca. 3ft) clear work-row for harvest. Cultivars were selected based upon knowledge of chill requirement (Drake and Clark, 2001), physiological adaptability (Stafne, et al., 2000a, 2000b, 2001a, 2001b, Rom and Clark, 1991), and previous performance. Plants were mulched, received supplemental trickle irrigation, received annual nutrient fertilization with an approved NOP nutrient source, and were maintained following an organic system man agement plan following all NOP regulations.

Plots were developed in a completely randomized design with three replications of the two treatments as main plots (unprotected versus protected culture) and three cultivars of each as a sub-plot. The statistical unit is a set of three rows, 8m (26ft) length, divided in half for berry type with a 1.5m (5 ft) guard plot at each end. Main plot treatment effects were determined by analysis of variance, and variable means separated at the 5% level. Measurement variables are described below.

In treatments where protected culture is the treatment dependant variable, high tunnels (as described above) were erected which are 5m width (18ft) x 11m length (36ft) . Tunnels covered three rows of 8m length. Guard plants were used at tunnel ends.

Details of the studies follow.

Study 1) Advancing the summer production

Floricane fruiting blackberries (cvs Navaho, Ouachita, Arapaho) and raspberries (cvs Dormanred, Prelude, and Encore) were assigned to one of two treatments; 1) control – standard field production (FD), or 2) protected high-tunnel production (HT) to advance the season as described below.

Tunnels were closed on 5-February, 2008 and 9-February, 2009, after approximately 1000 chill unit accumulation while field treatments remained in ambient conditions. Tunnels were opened (sides raised and doors opened) on days when ambient temperatures exceeded approximately 55F, and were closed and remained closed when ambient temperatures were below approximately 50F. Tunnels were opened permanently and endwalls/doors removed after all risk of frost had passed (approximately 1-May, annually).

As bloom in tunnels began (ca. 10-April), approximately 75 days after closing the tunnels, bumble bee (*Bombus terrestris*) hives (Kopert Biological Systems, Romulus, MI) were placed in each tunnel to facilitate pollination. Honey bee hives were placed adjacent to all plots to facilitate pollination of field plots as well as tunnels when the sides and ends were opened. Senescent floricanes and other growth were removed after harvest as new primocanes emerged for the crop the following year.

Fruit were harvested one to three times per week as needed. All ripe fruit (based upon color) were harvested and weighed. Average berry size was calculated from a 25 fruit subsample. Fruit were hand graded for color and defects and a marketable grade percentage, those which could be sold as a fresh product, was determined by weight. Fruit that were not of a marketable grade could be used for processing and still have value.

Study 2) Extended autumn harvest season for primocane blackberries and raspberries

Primocane blackberries (cv Prime-Jim®, Prime Jan® and APF 46) and raspberries (cv Dinkum, Caroline, and Autumn Bliss) out-of- season production were based on methods developed by Koester and Pritts (2003) with modifications, as necessary, to adapt to southeastern US climatic conditions. Bare root canes were planted in the field in April, 2006. Annually, plants were pruned by either heading or mowing in mid summer to delay and synchronize bloom and harvest (Drake and Clark, 2000; Vincent, 2008).

High tunnels were closed on any day/night when high temperatures were expected to be below 50^{o}F and opened when temperatures were 55^{o}F or greater. On 28-October 2008, a severe frost of 24^{o}F, 15^{o}F degrees below the average normal temperature for that date, occurred. Plants in tunnels were covered with fabric curtains but no additional heat was added. Overnight tunnel temperatures were only 1^{o} to 2^{o}F above outside temperatures. All ripening fruits and open flowers in both field and tunnels were killed with the frost event, plants ceased to grow and began to express seasonal sensence entering dormancy, and harvest was discontinued in all plots.

Annually, at the end of harvest or after temperatures were too low to sustain growth and productivity, the HT sides were opened and the tunnel endwalls removed to allow plants to go dormant.

Study 3) Evaluation of double cropping (fall and spring) potential of primocane blackberry and raspberry cultivars.

The goal of this study was to determine if the new primocane germplasm can produce two crops annually in either or both field production and in protected, high tunnel cultivation. Thus, this study is a hybrid of objectives 1 and 2 above.

Plots similar to those described Study 2, above, were established. Two treatments were initiated as follows: 1) control, standard field production with primocane fruit harvest in the fall season followed by floricane fruit harvest the following summer, and 2) protected high-tunnel production to extend the fall primocane season and again to advance the spring, floricane season.

High tunnels in the spring were managed as described in Study 1 above and in the fall as described in Study 2 above.

<u>Phase 2, On-farm season-extended production of raspberries and blackberries.</u>

Trials similar to those described in Study 2 above using primocane autumn-bearing blackberries and raspberries were established on two producer sites in Arkansas; Riverbend Garden (Greenland AR) and Hazel Valley Farm (Elkins AR) in the spring 2008. 'Prime Jan' blackberry and 'Heritage' raspberry were planted in April 2008, mulched with wood chips, fertilized with an organic fertilizer and given supplemental irrigation throughout the season. High tunnels were purchased and constructed on site by our research staff in September.

Since the plants were in an establishment year, only a minimal crop was harvested. The systems started production in 2009. Both of the growers stated that even with the limited production in 2008, they were impressed with berry size and quality of the fruit. Bachmann, who markets at the Fayetteville Farmers Market, stated she could garner a premium price since no other growers were offering raspberries in late fall. Both growers were optimistic about the opportunities that high tunnel production may provide. Growers received a $1000 stipend in exchange for producer expertise, management, minimal data collection, and the use of their land. Tunnels, plants and construction labor were part of the project expense.

Objective 2) *an economic analysis of both crops to determine the economic feasibility of out-of-season small fruit production as a means of supplementing income of existing organic or transitioning farms.*

The economic feasibility component of this project was divided into three tasks:

1) The development of berry production budgets (for raspberry and blackberry) of high tunnel production for decision support.
2) A break-even analysis that suggests prices a grower needs to receive to cover new costs of production including return on investment calculations.
3) An economic return comparison be tween protected and unprotected cultivation methods was performed using appropriate statistical, generalized stochastic dominance and sensitivity analyses techniques to make recommendations on the basis of expected profitability as well as respective production risk (crop losses from pathogens/insects or from freezing) and price risk.

Interactive raspberry/blackberry budgets

The interactive budgets were created in Microsoft Excel. Producers can estimate several budgets by using default cost values, by entering their own production values or by combining both. In these interactive budgets, the user selects interest rate, inflation rate, cultivar, planting density, high tunnel dimensions, expected yield, expected prices, marketing plan and production practices; the budget is then calculated automatically. Each budget estimates variable operating costs, fixed costs, total costs and expected total net returns for six different raspberry cultivars (i.e., Autumn bliss, Caroline, Dinkum, Dormanred, Encore and Prelude) and blackberry cultivars (i.e., APF46, Prime-Jan, Prime-Jim, Arapaho, Navaho and Ouachita). Anytime a user modifies an activity, the budget recalculates automatically total cost per year, a break-even analysis for yield and pri ce and sensitivity analyses for total costs, gross revenues and net returns.

In developing both budgets, individual costs were based on early 2009 prices and UA experimental farm conditions. It was assumed berries would be irrigated, and each production system followed the same management procedures. Costs did not include a land charge. Cost estimates were calculated for each year, with year zero as the year before planting (i.e., soil buildup year) and year one as the planting year. Costs in year zero include fertilizing the soil, soil cultivation, and soil establishment. Plants, irrigation, trellis (if any), and weed control are some of the costs in the first year. From year one to year 12, labor, material, and equipment were estimated for each cultivar. Labor costs were hourly. Overhead costs were not included in these budgets.

For all the operations and input prices outlined in this budget, it was assumed that the organic raspberry/blackberry orchard management would be near to optimal and that all recommended practices would be followed. The costs were calculated as if the grower started with a bare field and followed the budgeted pattern.

The assumptions for all berry cultivars grown were:

normal yields
interest rate of 6.5 %,
10 years amortization for high tunnels, irrigation and trellis systems (if any),
direct market price of $4.5/lb for raspberries and $4.0 per blackberries,
processed market price of $1.0 per pound,
High tunnel production - 75 % of production sell in the direct market, 10 % of the production sell in the processed market, 15 % of the production to be culled,
Field production - 60 % of production sell in the direct market and 15 % of the production sell in the processed market, with remainder being disposed.
management $20.0 per hour, labor $9.5 per hour
15 high tunnels per acre (i.e., dimensions 30' x 96').

2) Break-even price and yield analyses by cultivar and production system.
These analyses suggest prices a producer needs to receive (or yields needed to be obtained) to cover total costs of production (i.e., total revenue received equals total costs associated with production). The budgets can make calculations for two production systems (high tunnel and field production). For purposes of illustration here, break-even points were calculated assuming that only 75 % of the raspberry/blackberry production was direct marketed when using high tunnels and 60 % when growing raspberry/blackberry in fields as suggested by UA research trials.

3) Economic return comparisons between field and high tunnel operations.
This task consisted of a sensitivity analysis and a risk analysis. A sensitivity analysis is a technique for systematically changing parameters (i.e., total costs, yields, prices, etc) in a model to determine the effects of such changes. Employing this tool the grower-user can order by importance the strength and relevance of the inputs in determining the variation in the output. A risk analysis helps to estimate

distributions of economic returns for alternative cultivars or production systems so the producer can make better management decisions. Simulation techniques were used to generate possible outcome values.

Sensitivity Analysis The third task called for economic return comparisons between field and high tunnel cultivation methods. Linear sensitivity analyses were done assuming a +/- 25 % variation from the default values among total cost, total revenues and net returns. To measure the deficit or excess of cash flows throughout the life of the project (i.e., 12 years), a net present value (NPV) was estimated for each cultivar. The NPV is defined as the present value of a series of future net cash flows that will result from investing in berry production, minus the amount of the original investment.

Risk Analysis The break-even price and yield analyses presented a single bottom-line result for each cultivar. Since there are many uncertainties surrounding berry production, it was assumed that producers are more interested in an entire distribution of NPV results. Using the interactive budgets a 12-year NPV model for each cultivar was developed to estimate how the NPV varied as the uncertain quantities (in this specific case, yields and prices) vary. Production and market risks were analyzed by creating two random variables, yield and price.

Using random yield and price values and deterministic total cost, an NPV was calculated for each fruiting cultivar. SIMETAR© was used to conduct the risk analysis component of this project. This software produces hundreds or thousands of possible outcomes and their associated probabilities. Five hundred outcomes (i.e., iterations) for each cultivar were generated using this technique. Producers were assumed to be interested in the probability that NPV is less than 0 (i.e., obtaining a negative NPV implies a loss of money over time and therefore rejecting the decision to cultivate berries) or equal to some particular positive target value (i.e., a positive NPV implies accepting the decision to cultivate berries). In this particular case, the target NPV value was $50,000 per acre. Consequently, cumulative distribution functions (CDFs) were estimated for each fruiting cultivar. The CDFs describe the probability that a NPV outcome takes on a value less than or equal to a chosen NPV value (i.e., $50,000 per acre).

* * *

Observations, Results, and Conclusions

Results

Weather Summary 2008 – 2009

2008. Cold temperatures in late/winter and early spring resulted in later than average bloom dates in field and delayed bloom in HT. March had significant precipitation with much of the precipitation as heavy snowfall early followed by heavy rains. A late April freeze of -3 °C (26 °F) resulted in significant bloom damage to field plants. High tunnel plants were protected and did not suffer as much damage, however it was learned that bloom protection in HT is necessary. Fall conditions were not optimal growing conditions with significantly varying temperatures in September and October. September had 2 significant rain events, one with very high winds from the inland remnants of hurricane Ike. However, with the exception of 5 days, the month was very dry and warmer than normal. The months of October and November were very dry. A very hard freeze of -5°C (23°F) in October ended all flowering and fruiting in field and high tunnel plantings even with moderate protection in tunnels. Consequently, both field and tunnel fruit production ended on the same date in 2008.

2009. The 2009 season was a difficult year for both research and commercial fruit growers. In late January, a severe ice storm occurred in the region which caused significant tree damage. Much of the region was without electrical power for 2-12 days. Because of a cool winter and a warm late winter/early spring, bloom progressed more rapidly than average and plants bloomed days earlier than normal. During the full bloom period there was a severe late frost of -3 ^{o}C that caused significant blossom damage to plants growing in the field. Weather during the bloom was unusually cool, cloudy and exceptionally wet and pollination conditions were poor. Fall conditions were acceptable for fruit production. In October, there was adequate precipitation and warm weather. However, a late October freeze ended all fruit production in field plots but high tunnel plots continued producing through mid-November.

Environmental Modification by Tunnels Growing degree days (GDD) and heat units (HU) in both the field and high tunnel (HT) treatments were calculated from hourly meterological data. Seasonal cumulative GDD and HU were significantly greater for tunnels compared to field in both years (Table 1; Figures 1 and 2). On a monthly basis, HT significantly increased cumulative HU and GDD in most months of the spring of both years. This indicates that the tunnels are providing a growing environment conducive to early spring growth and production. However, after tunnels are opened in May, there was no difference between the FD and HT for growing degree day or heat unit accumulation.

Preventing Frost Damage to Blooms No effort was made to manage naturally occurring frosts in the field as would be the traditional management practice. However, in tunnels with growth and flowering occurring earlier, and during a cooler season, precautions were taken to protect plants from frost damage. During frost events, plants were covered with a 4mil thickness geotextile fabric suspended just above the plants, covering the plants with the sides and ends secured to the ground. Temperature measurements both within the covering and outside the covering but within the tunnel indicated that covers provided approximately 2-5^{o} C (5-15 ^{o}F) heat conservation. However, this would not protect against frost damage on nights in March and early April where outside temperatures dropped to -4^{o}C (25 ^{o}F) outside the tunnels and -2^{o} to -4^{o}C (30 to 25 ^{o}F) within the tunnels. Therefore, after preliminary studies, supplemental heat of ethanol burners (chafing dish warmers) were added at a density of 1 burner/50sq ft floor space under the covers. The burners were lit when interior temperatures were approximately 2 ^{o}C (36 ^{o}F) and remained burning for 6-8 hrs. Additional burners were added if the freeze event lasted longer than 6 hrs. During one freeze event, temperatures were measured (Table 2). The combination of ethanol burners and geotextile fabrics resulted in an average HT temperature of 8 ^{o}C (46 ^{o}F) while the average ambient FD temperature during a 15 hr period frost event was -0.2 ^{o}C (31 ^{o}F). Additionally, the HT was protected for 15 hrs of the event, while 9 hours of the event had temperatures below 0 ^{o}C (32 ^{o}F) in the field. As a result, this means of frost protection was used for any night there were predicted frosts or freeze events while the plants in the tunnels had flowers. In 2008, there were four events, and there were three events in 2009 requiring covering the plants and adding supplemental heat.

Table 1. Seasonal summary for growing degree days and heat unit accumulation for high tunnel and field grown blackberries during spring seasons of 2008 and 2009.

	2008[z]		2009[y]	
Trt	Growing Degree Days	Heat Units	Growing Degree Days	Heat Units
HT	1440 a[z]	1556	1318 a	988
Field	769 b	1561	621 b	917

Monthly Cumulative Heat Unit Increase, High Tunnels compared to Field (%)

	February	March	April	May	June
2008	95*	15*	5 ns	-5 ns	-5 ns
2009	30*	4 ns	6*	4*	.

Monthly Cumulative Growing Degree Day Increase, High Tunnels compared to Field (%)

	February	March	April	May	June
2008	175*	133*	94*	62*	25ns
2009	165*	154*	66*	14ns	.

[z] Data were analyzed for the time period of Feb. 22 - June 30, 2008, Feb. 1 - May 18, 2009. using JMP 8® software (SAS Institute) student's t (α = 0.05). Means with different letters within a column are significantly different.

Table 2. Temperature differences between high tunnel (HT) with supplemental heat of alcohol burners (1/50sq ft floor space) and geotextile fabric enclosures, and field conditions and hourly exposure to freezing temperatures during late spring freeze (2008).

Trt	Mean Temp (^{o}C) [z]	Mean Temp (^{o}F)	Hours >0 ^{o}C (32 ^{o}F)
HT + supplemental heat	8 a	46	15 a
Field	- 0.2 b	31	6 b
Prob > F	<0.0001		0.0005

[z] Data were analyzed during a 15 hour time period using JMP 8® software (SAS Institute) student's t (α = 0.05). Means followed by different letters are statistically different

Figure 1. Seasonal heat unit accumulation for first bloom of blackberries for spring of 2008.

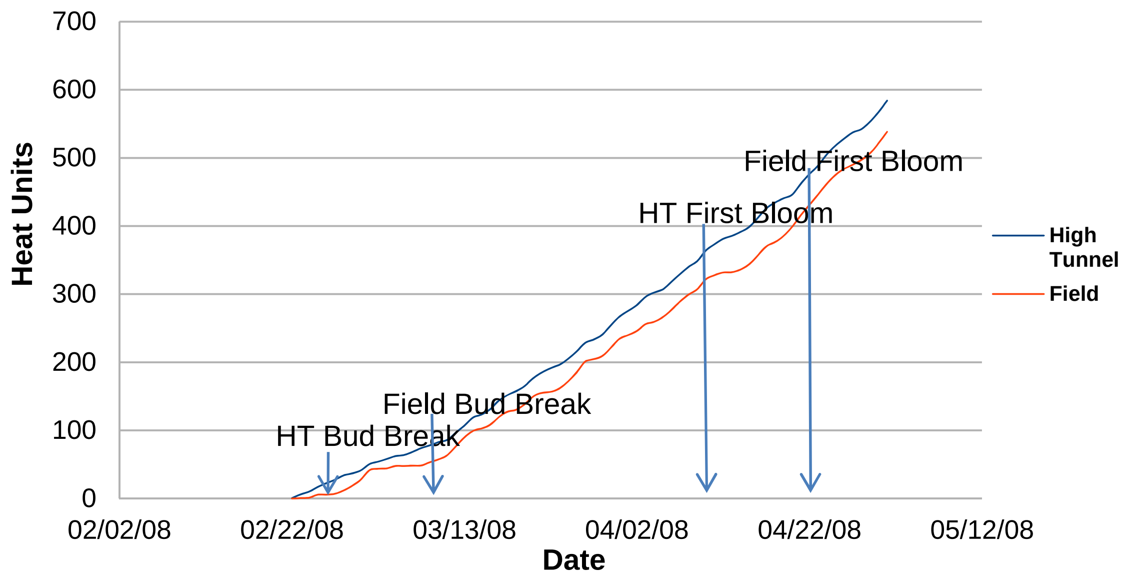
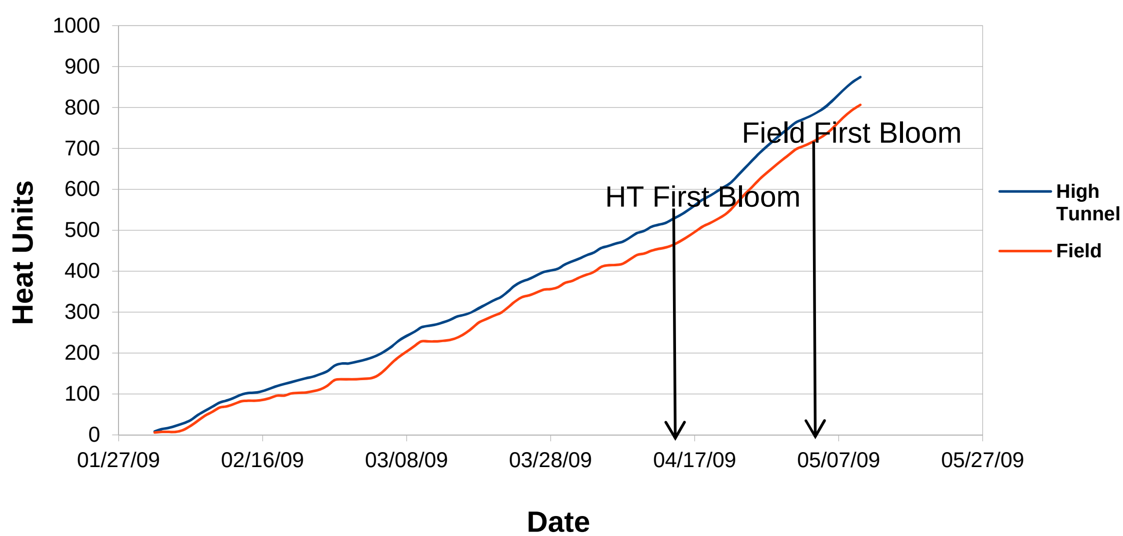


Figure 2. Seasonal heat unit accumulation for first bloom of blackberries for spring of 2009.



Objective 1. Management practices for out-of-season small fruit production in high tunnels.
Sub-objective 1) Advancing the summer production system through spring high tunnels.

Time of Bloom and Harvest Tunnels generally advanced spring bloom of floricane producing blackberry approximately two to three weeks (Figures 1 and 2). It was noticed that the spring bloom period as well as harvest period of blackberries in tunnels was extended approximately seven to 10 days compared to the same cultivars in the field. Harvest was accelerated similarly seven to 10 days or more depending upon the season and the cultivar.

Growth was not advanced to the extent that was hypothesized by this study. Evaluating the meterological data, a new hypothesis was formulated. Although there were fewer hours of temperatures below the growth threshold for blackberry (4^{o}C), the seasonal number of hours of ideal growth temperatures (4-36^{o}C) were similar for both field and tunnel conditions. During the early months of the growing season (February and March), there were only small difference in accumulated growing temperatures between the field and the tunnels and the tunnels had a significant number of hours greater than 36C at which temperature growth would cease. It was observed that during a daily period, only a few hours of optimum growth temperatures occurred. At night there was very little difference between tunnel and field temperatures and temperatures were below the minimum for growth in the tunnels, although not below damaging thresholds. On several days, mid-day temperatures in the tunnels may exceed 36C, and although not damaging temperature, they were above optimum growth temperatures. From these data it is now thought that additional heat conservation is needed to keep tunnels warmer for a longer period of the day and extending into the night period, and additional cooling during mid-day is needed so that temperatures do not exceed those optimum for growth. Additional heat conservation could be provided by tunnels-in-tunnels, heat-sink reservoirs or reconstructing tunnels with inflated bi-walls to conserve daily thermal energy gain. The addition of external heat sources, especially during days or hours when temperatures within the HT would drop below growth minimum of 50^{o} F, would further advance development, bloom and harvest. These ideas will be studied in future research or tried by growers.

The blackberry cultivars selected for this study were popular mid-season ripening cultivars. From the literature and other experiences, it is noted that these cultivars are commonly used because they are not early blooming cultivars and are well adapted to field conditions. It is now thought that to maximize the early season harvest of berries in tunnels, early blooming and ripening cultivars should be selected for HT production while later blooming and ripening cultivars should be planted in the field. Because it is possible to protect early blooming plants in the tunnel as described above, it would make logical sense to capitalize on short chill, early blooming cultivars for tunnel production even though they may not be adapted to general field production in this region.

Harvest Yield There was a signifcant Year X Cultivar interaction and Year x Treatment interaction for both average yield and total seasonal yield of floricane blackberries study (Table 3). However, there were no cultivar by treatment interactions.

Navaho in 2008 had the greatest average and total yield and Arapaho was significantly less. Navaho generally had the largest marketable yield in both years. Ouachita produced the largest berry size. Yields and berry size were greater in 2008 than in 2009. Across both seasons, HT produced 156% larger average harvest and 206% increase in average total yields. Fruit produced in HT were significantly larger than those produced in the field.

For Year x treatment interaction, 2009 HT plots and 2008 field plots produced the greatest average harvest with 563.2 and 479.1 g/plot/harvest respectively. 2009 field plots produced the lowest average harvest and total yield with 113.6 g/plot/harvest and 898.8 g/plot/year. Comparing HT to field within the year indicates a trend for higher production in HT than the field; this was not significant in 2008 but was significant in 2009. The field crop in 2009 was greatly reduced by adverse weather conditions (rain during harvest season), which did not affect HT yields, thereby demonstrating an important advantage of tunnels.

Although cultivar had a significant effect on marketable yield, the main effects of year or treatment were insignificant. There were interactions of year and cultivar for marketable yield although Navaho tended to have the greatest marketable yield in both years. There was no interaction between cultivars and treatments for marketable yield.

There was significant Year x Cultivar interaction and Year x Location interaction for berry size. Ouachita in 2008 produced the largest berries averaging 5.1g/berry while Arapaho in 2009 were the smallest at 2.7g/berry. In 2009, tunnel plots produced the largest berries at 4.5 g/berry while 2009 field plots were the smallest berries at 2.7g/berry. Across both years and all cultivars, berries produced in tunnels were 30% larger than those produced in the field. The increase in berry size in tunnels will account for some of the differences in average harvest and total yield observed in tunnels.

Floricane raspberry plants produced greater average yield in 2009 and a 44% greater yield than in 2008 (Table 4). For total seasonal yield, high tunnel plots produced significantly greater yields than field plots by approximately 480%. Within either year, fruit produced in HT were or tended to have larger harvests, yield, and berry size. The Dormanred cultivar generally had larger average harvests and total yield and produced significantly more marketable fruit and larger fruit size than either Encore and Prelude. There was also a Year X Treatment interaction for berry weight. Berries from 2009 tunnel plots were signficantly larger. Berries for Dormanred and Encore produced in tunnels in either year were larger than those produced in the field while fruit of Prelude in 2008 were similar among the HT and field treatments.

Table 3. Average harvest yield, cumulative yield, marketable yield and mean berry size of three floricane fruiting blackberries, 2008-2009 (Study 1).

Cultivar	Average Harvest (g)/plot[z]			Total Yield (g)/plot[z]			Marketable Yield (%)/plot[z]			Berry Wt (g)/plot[z]		
	Tunnel	**Field**	**Mean**	**Tunnel**	**Field**	**Mean**	**Tunnel**	**Field**	**Mean**	**Tunnel**	**Field**	**Mean**
						2008						
Arapaho	109.1	235.1	172.1 d	1517	2347	1932 c	51.6	63.8	59.5b	3.1	3.3	3.2d
Navaho	588.3	709.1	648.7 a	11746	9105	10425a	75.9	67.5	73.1a	4.0	3.6	3.8c
Ouachita	384.3	493.1	438.7 bc	6916	7172	7044 b	74.4	70.7	72.7a	5.3	4.9	5.1a
						2009						
Arapaho	223.1	53.8	138.4 d	2363	221	1292 c	76.1	63.2	69.6ab	3.2	2.1	2.7e
Navaho	615.2	89.6	352.4 c	8381	699	4540 b	79.3	61.3	70.5a	4.3	2.9	3.6cd
Ouachita	851.3	197.5	524.4 ab	13046	1777	7412 a	82.2	58.3	70.3ab	5.9	3.3	4.6b
YEAR Effects												
2008			419.8a			6467a			67.3			4.0a
2009			338.4b			4414b			70.1ns			3.6b
CULTIVAR Effects												
Arapaho			155.2b			1611b			57.7			2.9c
Navaho			500.5a			7482a			71.7			3.7b
Ouachita			481.5b			7228a			72.6			4.9a
TREATMENT EFFECTS												
High Tunnel			461.9			7328			67.3			4.3a
Field			296.4			3553			67.3			3.3b
% Increase HT/FD			156%			206%			0%			130%
YEAR * TREATMENT												
2008 * field			479.1ab			6207.8 a			67.4 b			3.9 b
2008 * tunnel			360.5 b			6726.7 a			67.3 b			4.1 ab
2009 * field			113.6 c			898.8 b			61.0 b			2.7 c
2009 * tunnel			563.2 a			7929.8 a			79.3 a			4.5 a
P(f)												
Yr			0.0460			0.0025			0.4800			0.0098
Cv			0.0002			0.0020			0.2000			0.0001
Treatment			0.0900			0.0600			0.1000			0.0200
Yr * Cv			0.0033			0.0010			0.0700			0.5400
Yr * Treatment			0.0001			<0.0001			0.0007			0.0001
Treatment * Cv			0.2400			0.1500			0.2500			0.0100

[z] Data were analyzed using JMP 8® software (SAS Institute) student's t ($\alpha = 0.05$).

Table 4. Average harvest yield, cumulative yield, marketable yield and mean berry size of three floricane fruiting raspberries, 2008-2009 (Study 1).

Cultivar	Average Harvest (g)/plot[z]			Total Yield (g)/plot[z]			Marketable Yield (%)/plot[z]			Berry Wt (g)/plot[z]		
	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean
2008												
Dormanred	305.4	51.8	178.6	2951	297	1624	84.0	71.7	77.9	2.9	2.8	2.8
Encore	139.9	156.6	148.2	2149	215	1182	69.7	64.0	66.9	2.7	1.9	2.3
Prelude	210.5	63.7	137.1	2660	628	1644	67.5	62.4	65.0	1.7	1.8	1.8
2009												
Dormanred	487.6	287.5	387.5	4551	1939	3245	92.1	92.3	92.2	3.6	3.0	3.3
Encore	236.6	125.3	181.9	2783	126	1454	74.8	38.1	56.5	3.5	1.5	2.5
Prelude	242.0	68.6	155.3	2904	520	1712	67.8	56.1	61.9	2.8	1.6	2.2
YEAR												
2008			154.6 b			1484			69.8			2.3b
2009			241.3 a			2137			70.2			2.7a
CULTIVAR												
Dormanred			283.1			2434			85.0a			3.1a
Encore			164.6			1318			61.7b			2.4b
Prelude			146.2			1678			63.4b			2.0b
TREATMENT												
High Tunnel			270.3			3000a			64.1			2.9a
Field			125.6			621b			76.0			2.1b
% Increase HT/FD			216%			483%			(84%)			138%
YEAR * TREATMENT												
2008 * field			90.7			381			66.0			2.2 b
2008 * tunnel			218.6			2587			73.7			2.4 b
2009 * field			160.5			862			62.2			2.0 b
2009 * tunnel			322.1			3412			78.2			3.3 a
P(f)												
Yr			0.03			0.054			0.940			0.020
Cv			0.30			0.510			0.010			0.006
Treatment			0.09			0.010			0.054			0.004
Yr * Cv			0.06			0.090			0.070			0.740
Yr * Treatment			0.62			0.580			0.300			0.002
Treatment * Cv			0.64			0.970			0.500			0.17

[z] Data were analyzed using JMP 8® software (SAS Institute) student's t (α = 0.05).

Sub-objective 2) Extended fall harvest season for primocane blackberries and raspberries through autumn high tunnel production.

The Effect of Tunnels on Bloom and Harvest There were no differences in bloom dates of autumn-bearing plants as the tunnels were opened in the summer and therefore plants experienced identical growing conditions. In the fall of 2008, harvest of both tunnel and field berries ended the same day due to a severe freeze on 24-October of -4.5^{o}C. Temperatures in tunnels were below freezing and no measures were made to protect the remaining crop. In the autumn of 2009, berry harvest in tunnels continued for approximately one month (late November) after the field harvest was terminated due to a severe frost. At that late time in the season, a severe freeze occurred and there were insufficient fruit within the HT to justify protecting. In a preliminary year (2007), it was also observed that harvest in HT continued for more than 4 weeks after field harvest was discontinued due to freeze events.

The Effect of Tunnels on Harvest and Yield An interaction between cultivar and treatment occurred. For two year study period, total yield was generally greater in the tunnels than the field, except for Prime-Jan in 2008 when the opposite was observed (Table 5). So, although there was a 168% increase in average total yield in HT, this effect was not significant. There was very little difference in average harvest or total yield across both years although marketable yield and berry size were greater in 2009. Prime-Jan produced the largest average harvest and average total yield. Within HT across both years and all cultivars, there was a 19% increase in average harvest, 68% in total yield, an 8% increase in marketable yield, and a 12% increase in fruit size. There was a significant year by treatment interaction where the difference in yield between the HT and field was greatest during a wet harvest season in 2009. Primocane blackberry harvest in this trial was approximately 30% of the average floricane harvest in study 1.

Primocane fruiting raspberries had larger average harvest and average total yield in HT compared to the field (Table 6). Although there were no differences between years for total yield, there were larger average harvests in 2008. This was due to the shortened season caused by an early frost in that season (see above). There were no difference in harvest or yield among the cultivars used except for berry size where Caroline had significantly larger fruit. There was no interaction of cultivar and treatment. High tunnels resulted in significantly larger average harvest, average total yield, average marketable fruit, and average berry size. Total primocane raspberry harvest was approximately the same as total floricane raspberry harvest (study 1).

Sub-objective 3) Evaluation of double cropping (fall and spring) potential of primocane blackberry and raspberry cultivars.

The yields of primocane blackberries fruiting as floricanes in the spring of 2008 were generally similar between HT and field production systems. However, in spring of 2009, yields in HT were greater in every case than in the field. When primocanes fruiting types were harvested as floricanes in the spring, the following autumnal primocane crop is smaller than observed in study 2 where they were grown as primocane-only crops. Primocane fruiting genotypes fruiting as floricanes in spring seasons produced larger spring than fall crops. Primocane fruiting type fruiting as floricanes in the spring (study 3) produced yields similar to traditional floricane spring crops (study 1) in 2008 but less in 2009. Averaged across three harvest seasons, HT resulted in larger average harvests, total yield, and berry size compared to the field. There was no significant treatment by cultivar interactions observed. It was also noticed that all the primocane fruit types blooming as floricanes in the spring were advanced an additional week or two in the HT compared to the field and compared to traditional floricane fruiting cultivars (study 1).

When primocane-fruiting raspberries were double-cropped there were few statistically significant observations due to great variability in plot-to-plot data. Generally, for all cultivars average HT yields were greater than from the field and when compared across all cultivars and harvest seasons, the HT resulted in a 676% greater yield than the field (Table 8). Similar to double-cropped blackberries, the autumn primocane crop after a spring fruiting season (study 3) was less than if only grown as an autumn primocane crop (study 2). Spring floricane yields in the double cropping study (study 3) were similar to spring yields only (study 1).

On-farm Production. 'Prime Jan' blackberry and 'Heritage' raspberry plants were established at a farm in Elkins and Greenland in April 2008.

2008 Production. Since berries were planted in 2008 there was little to no yield in the establishment year.

2009 Production. Both growers expressed personal interest and bias toward raspberries, both as a fruit and a cropping plant, and neither grower was impressed with the primocane fruiting blackberry. The yields in the first year of production for the blackberry 'Prime Jan' were quite low but not atypical for first year production, as yield increases over the first three years of growth. At the Elkins site, 'Prime Jan' yield was .78lb/ft and .88 lb/ft at the Greenland site. Both growers commented that the abundant, large thorns and vigorous growth habit of 'Prime Jan' made it more cumbersome to harvest and felt that their trellis systems needed modifications to support the vigorous growth of the blackberry.

Both growers were more enthusiastic about raspberry production in the high tunnels. Yields were 1lb/ft in Elkins and 3lbs/ft in Greenland. The Elkins grower commented that berry size began large but as temperatures increased in June and July it was hard to maintain sufficient watering and berry size decreased. The grower felt his trellis system needed to be improved to support the extra vigorous growth of the plants and weight of the berries. Many of the canes became top heavy with the berry weight and partially broke and collapsed onto canes below creating some molding issues and reduction in yield. Even with these issues, the grower felt the plants were manageable and believed improvements could be made to improve the trellis system and boost yield. The last harvest at Elkins was November 18, and at Greenland, November 23, 2009 while field harvest ended in approximately mid-October.

Overall, both growers were optimistic about the opportunities that high tunnel production may provide but felt that growers need to be aware of the extra management required to monitor and open and close sidewalls and endwalls as well as monitoring things like soil moisture.

Table 5. Average harvest yield, cumulative yield, marketable yield and mean berry size of three primocane fruiting blackberries, 2008-2009 (Study 2).

Cultivar	Average Harvest (g)/plot [z]			Total Yield (g)/plot [z]			Marketable Yield (%)/plot [z]			Berry Wt (g)/plot [z]		
	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean
						2008						
APF46	90.2	79.4	84.8	2934	2113	2523	77.7	70.7	74.2	4.0	3.7	3.8 e
Prime-Jan	84.0	108.4	96.2	2311	2790	2551	60.3	66.2	63.25	4.7	4.8	4.8 b
Prime-Jim	75.4	45.6	60.5	2072	1037	1554	58.5	59.9	59.2	4.2	3.6	3.9 de
						2009						
APF46	65.6	50.3	58.0	2531	1057	1794	81.0	76.1	78.6	4.4	4.2	4.3 cd
Prime-Jan	128.8	107.4	118.1	3924	2046	2985	74.2	69.0	71.6	6.3	5.9	6.1 a
Prime-Jim	84.2	55.4	69.8	3121	998	2059	75.0	54.0	64.5	5.2	3.8	4.5 bc
YEAR												
2008			80.5			2209			65.5b			4.2b
2009			82.0			2279			71.6a			5.0a
CULTIVAR												
APF46			71.4a			2158b			76.4a			4.1
Prime-Jan			107.2a			2768a			67.4b			5.4
Prime-Jim			65.1b			1807b			61.9c			4.2
TREATMENT												
High Tunnel			88.0			2815			71.1			4.8
Field			74.4			1673			65.6			4.3
% Increase HT/FD			119%			168%			108%			112%
YEAR * TREATMENT												
2008 * field			77.8			1980 b			65.6 b			4.0
2008 * tunnel			83.2			2439 b			65.5 b			4.3
2009 * field			71.0			1479 b			66.4 b			4.6
2009 * tunnel			92.9			3375 a			76.8 a			5.3
P(f)												
Yr			0.88			0.81			0.010			0.0001
Cv			0.01			0.01			0.001			0.0001
Treatment			0.43			0.16			0.090			0.1200
Yr * Cv			0.15			0.20			0.690			0.0250
Yr * Treatment			0.43			0.03			0.020			0.1400
Treatment * Cv			0.45			0.27			0.120			0.0400

[z] Data were analyzed using JMP 8® software (SAS Institute) student's t (α = 0.05).

Table 6. Average harvest yield, cumulative yield, marketable yield and mean berry size of three primocane fruiting raspberries, 2008-2009 (Study 2).

Cultivar	Average Harvest (g)/plot [z]			Total Yield (g)/plot [z]			Marketable Yield (%)/plot [z]			Berry Wt (g)/plot [z]		
	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean
						2008						
Autumn Bliss	155.6	89.9	122.8	3013	1401	2207	78.5	63.8	71.1	2.4	2.0	2.2
Caroline	174.1	113.9	144.0	3366	1758	2562	74.5	60.3	67.4	2.6	2.4	2.5
Dinkum	147.8	101.5	124.7	2751	1636	2193	72.6	57.0	64.7	2.4	2.0	2.2
						2009						
Autumn Bliss	106.8	47.1	77.0	3419	1013	2216	83.3	72.4	77.9	2.8	2.4	2.6
Caroline	118.6	119.1	118.9	3731	2308	3020	79.9	75.5	77.7	2.9	2.6	2.7
Dinkum	102.7	46.8	74.8	3183	1002	2092	80.3	70.3	75.3	2.8	2.4	2.6

	Average Harvest	Total Yield	Marketable Yield	Berry Wt
YEAR				
2008	130.5 a	2321	67.8 b	2.3 b
2009	90.2 b	2443	77.0 a	2.6 a
CULTIVAR				
Autumn Bliss	99.9	2211.3	74.5	2.4 b
Caroline	131.4	2790.8	72.6	2.6 a
Dinkum	99.7	2142.8	70.0	2.4 b
TREATMENT				
High Tunnel	134.3a	3244a	78.2a	2.6a
Field	86.4b	1520b	66.6b	2.3b
% Increase HT/FD	156%	213%	116%	113%
P(f)				
Yr	0.003	0.70	0.0002	0.005
Cv	0.550	0.15	0.1600	0.010
Treatment	0.040	0.05	0.0007	0.030
Yr * Cv	0.620	0.75	0.6400	0.820
Yr * Treatment	0.400	0.39	0.1000	0.440
Treatment * Cv	0.450	0.74	0.6004	0.810

[z] Data were analyzed using JMP 8® software (SAS Institute) student's t (α = 0.05).

Table 7. Average harvest yield, cumulative yield, marketable yield and mean berry size for spring and fall harvested primocane fruiting blackberries, 2008-2009 (Study 3).

Cultivar	Average Harvest Yield (g)/plot ^{z}			Total Yield (g)/plot ^{z}			Marketable Yield (%)/plot ^{z}			Berry Wt (g)/plot ^{z}		
	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean
2008 Spring												
APF46	351.1	462.8	406.9 b	5064	5719	5392 b	68.1	75.2	71.6a	4.2	4.4	4.3
Prime-Jan	762.1	705.1	733.6 a	10968	7858	9413 a	59.0	59.9	59.4cd	5.7	5.6	5.6
Prime-Jim	660.8	832.5	746.7 a	10134	10114	10124 a	54.8	55.5	55.2d	4.8	5.0	4.9
2008 Fall												
APF46	47.6	30.8	39.2 c	597	189	393 d	74.7	65.9	70.3ab	2.0	1.5	1.7
Prime-Jan	56.5	35.6	46.0 c	802	300	551 d	55.1	66.2	60.6bcd	2.3	1.7	2.0
Prime-Jim	49.4	47.7	48.6 c	500	297	399 d	55.8	63.2	59.5cd	2.0	2.4	2.2
2009 Spring												
APF46	102.0	39.2	70.6 c	1205	274	740 d	60.1	62.8	61.4bcd	4.1	2.9	3.5
Prime-Jan	372.6	253.1	312.8 b	4725	2130	3428 c	65.8	54.4	60.1cd	5.3	3.8	4.6
Prime-Jim	405.5	261.6	333.5 b	5733	2043	3888 bc	60.8	71.7	66.3abc	4.4	3.3	3.9
YEAR												
2008 Spring			629.1a			8310a			62.1			4.9a
2008 Fall			44.6c			448c			63.5			2.0c
2009 Spring			238.9b			2685b			62.6			4.0b
CULTIVAR												
APF46			172.3			2175b			67.8			3.2b
Prime-Jan			364.2			4464ab			60.1			4.1a
Prime-Jim			376.3			4804a			60.3			3.7a
TREATMENT												
High Tunnel			312.0a			4414 a			61.6			3.9
Field			296.5b			3214 b			63.9			3.4
% Increase HT/FD			105%			137%			(96%)			115%
YR * TREATMENT												
2008 Spring, tunnel			591.3			8722			60.6			4.9 a
2008 Spring, field			666.8			7897			63.5			5.0 a
2008 Fall, tunnel			51.2			633			61.8			2.1 c
2008 Fall, field			38.0			262			65.1			1.9 c
2009 Spring, tunnel			293.4			3887			62.2			4.6 a
2009 Spring, field			184.6			1482			62.9			3.3 b
P(f)												
Yr			0.0001			0.0001			0.86			0.001
Cv			0.0001			0.0006			0.07			0.007
Treatment			0.0200			0.0020			0.07			0.120
Yr * Cv			0.0080			0.0200			0.03			0.140
Yr * Treatment			0.0700			0.1800			0.87			0.004
Treatment * Cv			0.3300			0.1700			0.58			0.390

^{z} Data were analyzed using JMP 8® software (SAS Institute) student's t ($\alpha = 0.05$).

Table 8. Average harvest yield, cumulative yield, marketable yield and mean berry size for spring and fall harvested primocane fruiting raspberries 2008-2009 (Study 3).

Cultivar	Average Harvest (g)/plot[z]			Total Yield (g)/plot[z]			Marketable Yield (%)/plot[z]			Berry Wt (g)/plot[z]		
	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean	Tunnel	Field	Mean
2008 Spring												
Autumn Bliss	216.7	37.9	127.3	3500	322	1911	72.1	39.9	56.0	2.3	2.0	2.1
Caroline	148.9	47.6	98.3	1923	361	1142	81.7	73.8	77.7	2.0	2.0	2.0
Dinkum	224.6	54.2	139.4	3617	553	2085	59.7	72.5	66.3	1.9	1.6	1.7
2008 Fall												
Autumn Bliss	110.1	33.1	71.6	1590	373	982	71.0	53.2	62.1	2.5	1.7	2.1
Caroline	60.6	66.8	63.7	732	600	666	66.5	44.6	55.6	2.5	1.6	2.1
Dinkum	51.7	60.1	55.9	510	170	340	68.7	32.9	50.9	2.4	2.1	2.3
2009 Spring												
Autumn Bliss	199.3	48.7	124.0	3706	150	1928	76.0	89.31	82.6	2.7	1.6	2.1
Caroline	141.8	23.1	82.5	1987	102	1045	77.0	97.2	87.8	2.5	1.8	2.1
Dinkum	155.1	125.6	140.3	2157	285	1221	73.7	81.9	77.9	2.4	2.1	2.3
YEAR												
2008 Spring			121.6			1713			66.6 b			1.96
2008 Fall			63.7			663			56.2 b			2.14
2009 Spring			115.6			1400			82.5 a			2.16
CULTIVAR												
Autumn Bliss			107.7			1607			66.9			2.1
Caroline			81.5			951			73.5			2.1
Dinkum			1118			1215			64.9			2.1
TREATMENT												
High Tunnel			145.4			2191			71.8			2.4
Field			55.3			324			65.0			1.8
% Increase HT/FD			264%			676%			110%			133%
YR * TREATMENT												
2008 Spring, tunnel			196.7			3013			71.2abc			2.1
2008 Spring, field			46.5			412			62.2bc			1.8
2008 Fall, tunnel			74.11			944			68.7abc			2.5
2008 Fall, field			53.4			381			43.7c			1.8
2009 Spring, tunnel			165.4			2616			75.4ab			2.5
2009 Spring, field			65.8			179.0			89.5a			1.8
P(f)												
Yr			0.69			0.13			0.006			0.13
Cv			0.25			0.47			0.42			0.99
Treatment			0.77			0.18			0.54			0.17
Yr * Cv			0.96			0.87			0.35			0.25
Yr * Treatment			0.13			0.12			0.04			0.07
Treatment * Cv			0.60			0.40			0.76			0.66

[z] Data were analyzed using JMP 8® software (SAS Institute) student's t (α = 0.05).

Objective 2. *an economic analysis of both crops to determine the economic feasibility of out-of-season small fruit production as a means of supplementing income of existing organic or transitioning farms.*

1) Interactive blackberry/raspberry production budgets. Using a common spreadsheet software, interactive blackberry and raspberry budgets were developed. In general, start-up costs were recovered after five years for raspberry cultivars and six years for blackberry cultivars. Net returns were positive the following years. Accumulative net cash flow after 12 years varied according to cultivar.

2) Break-even price and yield analyses by cultivar and production system.
Blackberry Analysis High tunnels break-even prices for blackberry primocane cultivars differed drastically. For instance, the break-even price for cultivar APF46 was the highest of any cultivar analyzed ($5.18/lb). In fact, this price was higher than the retail price indicating that the operation is not profitable. Primocane yields ranged from 4,293 to 4,951 pounds per acre. Field break-even prices and yields ranged from $2.15 to $3.72 per pound and from 1,850 to 2,406 pounds per acre, respectively. Prices and yields for blackberry floricane cultivars produced using high tunnels ranged from $2.43 to $3.20 per pound and yields from 4,961 to 5,537 pounds per acre, respectively. Field prices ranged from $2.96 to $3.14 and yields from 2,332 to 2,721 pounds per acre.

Overall, break-even prices differed depending on the fruiting cultivar or production system analyzed. Five cultivars had break-even prices lower than the retail price (i.e., $4.00/lb) when high tunnels were used. Those prices indicated that the operation would be profitable. However, the yields needed to offset the initial capital investment (when using high tunnels – calculated at 15, 30'x 96' tunnels per acre) and the total cost of production were roughly double than those for fields. It is important to highlight that these estimations were limited by the cultivar, the production and management practices selected for this report.

Raspberry Analysis High tunnels break-even prices ranged from $2.41 to $3.19 per pound and yields from 4,401 to 4,987 pounds per acre for raspberry primocane cultivars. Field break-even prices ranged from $2.46 to $3.21 per pound and yields from 1,772 to 2,035 pounds per acre. Prices and yields for raspberry floricane cultivars produced using high tunnels ranged from $2.85 to $3.25 per pound and yields from 4,484 to 4,718 pounds per acre, respectively. Field prices ranged from $2.96 to $3.14 and yields from 1,855 to 1,959 pounds per acre, respectively.

Break-even prices were similar regardless of cultivar or production system. In all cases the break-even price was lower than the retail price (i.e., $4.50/lb) indicating that the operation would be profitable. The yields needed to offset high tunnel costs were roughly 60 % higher than those for fields. This could be explained by the additional revenue (in terms of additional production) needed to offset the initial capital investment required when high tunnels are used.

3) Economic return comparisons between field and high tunnel operations.
Sensitivity Analysis
Blackberry Production High tunnel production costs on a per acre basis were more than two times that of field production. Even though the revenues offset the high tunnel costs in the majority of the cases, field production proved to be more profitable in scenarios of production without loss due to weather and equal prices regardless of season. Only one cultivar, APF46, generated negative net returns under both production systems and does not appear profitable (Note: this genotype selection has been removed

from consideration for release due to low productivity). Primocane and floricane cultivars seemed to perform similarly in terms of total costs and net returns.

Raspberry Production As expected, HT production was more expensive due to both capital investment and additional labor required in HT operation. However, the revenues offset the costs in the majority of the cases. Only one cultivar, Dormanred, performed better in terms of net returns in field conditions than the HT. Floricane fruiting cultivars, except Prelude, were outperformed by primocane fruiting cultivars in both high tunnel and field operations.

Risk Analysis

Blackberry Analysis Overall, there were no large differences among NPV mean values in terms of production systems (HT vs FD). The primocane cultivar APF46 performed poorly compared to the other cultivars. This cultivar had the lowest NPV mean value for both field and HT and it was the only cultivar with a negative NPV mean value. It was difficult to identify the best cultivar and production system. However, it was clear that APF46 in HT had high probability of generating negative NPV and only Ouachita generated positive NPVs for both field and high tunnel production.

Raspberry Analysis In general, floricane cultivars have higher probabilities than primocane cultivars of generating more than $50,000 per acre of net present value (NPV). Specifically, Autumn bliss, Caroline, Dormanred and Prelude have higher probabilities of obtaining positive NPVs when produced under high tunnel than under field conditions. Overall, Encore had the greater probability of resulting in negative NPVs in high tunnel production systems followed by Dinkum. The other cultivars presented very low probabilities of producing negative NPV meaning that those projects may be undertaken. In fact the cultivar Caroline presented 0.000 probability of obtaining negative NPVs.

Field production had higher probabilities of resulting in a negative NPVs than high tunnel production. Encore, Dinkum and Prelude had the greatest probabilities of producing negative NPVs in the field. The best field production cultivar was Caroline which had a significant probability of obtaining a NPV greater than $50,000. None of the other cultivars were predicted to generate a NPV greater than $50,000 when produced in the field.

High tunnel production had the highest probability of generating over $50,000 per acre compared to the field. Prime-Jim in HT as an autumn primocane crop and Ouachita in HT as a spring floricane had the highest predicted probabilities of generating more than $50,000 per acre. These two cultivars also present the higher probabilities of generating more than $50,000 per acre under field production.

Summary and Conclusions

Horticulture In these initial studies, it was determined there are opportunities for producing blackberries and raspberries in HT to complement field production. Bloom and harvest of berries was advanced approximately 2 weeks. The HT production of primocane berries in the spring would benefit from additional heat conservation or addition to further advance bloom and harvest and will require additional study. It was observed that the primocane fruiting types when double-cropped for spring floricane production bloomed earlier than traditional floricane types. This has led to the idea that to maximize early bloom and harvest, early blooming and early maturing cultivars should be selected for HT production to complement traditional FD cultivars. The earliness of blooms in tunnels requires frost protection.

The use of HT did not affect the time of bloom of autumn-fruiting primocane berries. Additional horticultural treatments are needed to delay bloom of primocane fruiting berries and therefore further extend the harvest season in tunnels. There was an interaction between cultivars and treatments; some of the new blackberry cultivars performed better in HT conditions while others performed better in the field. This requires additional research to determine which cultivars are suited specifically to HT production systems. Although a very unseasonable autumnal freeze in 2008 ended both FD and HT production, in 2007 and 2009 HT prod uction continued through the month of November, approximately 4-5 weeks after FD production was ended by cold temperatures. This has demonstrated the possibility of autumn season extension with primocane fruiting berries. The season could be prolonged more with horticultural treatments to delay flowering and the use of heat conserving tunnel-in-tunnel structures, heat-sinks, and/or inflated bi-wall tunnel construction, all of which will require additional research.

The opportunity for double cropping primocane producting berries is an option. However, in our work it showed no specific advantage over either HT production of spring floricane fruiting cultivars and autumn primocane fruiting types. Yields from double cropping were larger than from primocane only production but not as large as floricane only production systems.

Berries in tunnels grew 10 to 25% taller in HT than in the field and produced more canes annually although not all canes, especially late emerging canes, produced a crop. To maximize HT production, modifications must be made to trellis systems and additional research on pruning to remove late emerging canes will be needed.

Although pest management was not a study objective of this project, organic pest management was practiced and pest infestations and infections were observed. Production in HT did not result in any unusual or unexpected significant pest problems. However, pest problems were not as reduced in HT as expected. A primary pest of blackberries, rednecked cane borers, is a problem in organic production and occurred in both FD and HT plots of floricane fruiting genotypes and the double-cropping system. It was noted that the incidence of cane boring was not as great in the HT as in the FD. A new pest, broad mite, was observed and occurred in both HT and FD systems (Vincent et al., 2010). To further eliminate insect pests, future trials will have side walls and doors screened in order to exclude the pests. Boring insects were not a significant problem in the primocane fruiting trial as canes were fruited and then removed prior to the borers manifesting cane death in floricanes. Invasive weeds and grass species were a significant problem to the field production of primocane fruiting berries but were generally less of a problem in HT.

Economics Although the demand for raspberries and blackberries is increasing, the cost of producing berries has increased due to increases in labor, equipment, and preferred production system. The initial establishment cost (i.e., first three years) can exceed $30,000 per acre for high tunnel production (5 tunnels) and $10,000 per acre for field production. Producers need to be aware of their expected costs before they make a financial investment. Estimated costs and returns over 12 years were used to determine the price that producers would need to make a profit or positive net return on their investment. For instance, the Dinkum high tunnel production system had the lowest annual cost and could be profitable if sold at more than $3.19 per pound. The Caroline high tunnel production system had the highest annual cost but could be profitable if sold at more than $2.41 per pound. In general, blackberries produced under high tunnel conditions were profitable if sold at more than $3.01 per pound. Producers need to compare different production systems and cultivar options before they make a high investment. Especially, producers should focus on the probabilities of obtaining negative NPVs before making a final investment decision.

The sample budgets generated by this project can help ensure that costs and receipts are included in planning and estimating calculations. While the budgets are calculated for one acre of production, a producer introducing berries to his production system may be advised to start smaller, e.g. fraction of an acre. Costs and returns are often difficult to estimate in budget preparation because they are numerous and variable. Therefore, producers should think of these budgets as an approximation and then make appropriate adjustments in the “Your Values” column to reflect specific production and resource situation. Changing production practices (i.e., quantities and prices) will require a new economic analysis. Contact local extension for technical guidance and expected yield production for your specific area.

Afterthought

Although this project was limited in scale and scope, it proved valuable as a research, outreach and demonstration, and teaching tool. Growers from around the region visited the trials, and it is estimated that several hundred growers and farmers have heard presentations of the research group related to this trial. Although this project ended, additional follow-up projects have been planned for which continued funding is sought. Further, the authors have noted that even with the limitations of this project, the information that was developed and presented has encouraged production of cane berries in high tunnels for organic, sustainable, and conventional systems. Therefore, this project has been noted for the direct impact it has made on farm systems.

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