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Horticultural and Economic Considerations in the Sustainability of Three Cold-climate Strawberry Production Systems

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***Abstract*. Three cold-climate strawberry (*Fragaria ×ananassa*) production systems, conventional matted row (CMR), advanced matted row (AMR), and cold-climate plasticulture (CCP), were compared for horticultural and economic aspects of sustainability over a 3-year planting cycle. The systems were tested using a single cultivar, Allstar, to avoid treatment × cultivar interaction. System-specific management operations and materials affected the total production costs of each system. Both CMR and AMR had higher management costs than CCP as a result of labor costs for weed control, but CCP had much higher cost of materials. Overall expenses were lowest for CMR and highest for AMR. Yields in the first fruiting year were highest for CMR at 17.4 Mg·ha^{-1} followed by AMR and CCP at 13.2 Mg·ha^{-1} and 11.8 Mg·ha^{-1}, respectively. In the 2004 harvest season, CMR and AMR were the highest yielding at 10.0 Mg·ha^{-1} and 9.0 Mg·ha^{-1}, respectively, with CCP the lowest yielding at 6.0 Mg·ha^{-1}. Low yield and fruit size in the second year and high material costs for establishment limit the economic viability for CCP when managed as a perennial system.**

Introduction

There is much interest in moving strawberry production systems in a more sustainable direction (Black et al., 2002a; Merwin and Pritts, 1993; Nonnecke and Dewitt, 1996; Pritts, 2002). Sustainable systems have been defined as systems that provide adequate quantity to meet demand, optimize crop output per unit of input, conserve and protect the essential agro–ecosystem resource base, and provide profits that are sufficient to support farmers and viable rural communities (Merwin and Pritts, 1993). For a system to be sustainable to the farmer, it has to be economically viable. Strawberry is a labor-intensive crop in which production of marketable fruit is closely tied to the ability of the grower to minimize weed, insect, and disease pressure through pesticide use and/or cultural practices (Chandler et al., 2001; Hancock et al., 2001; Rhainds et al., 2002), and a large amount of production costs are allocated to managing these pests. Weeds are a major management concern in strawberry and can severely limit the development of runners in matted row systems (Pritts and Kelly, 2001). Controlling weeds is especially vital during the establishment year (planting to first harvest) and between harvests in perennial plantings. Pathogens can cause substantial losses when outbreaks occur. In years when the weather is cool and wet from frequent rainfall, fruit rots can render much of the crop unmarketable. In other instances, virus and soilborne pathogens and pests can lead to plant decline and death.

Growers in the mid-Atlantic and northeast United States have typically relied on the matted row system of strawberry production. The planting is carried over for 3 to 7 years depending on disease pressure and other site-specific considerations. Weed control in the CMR system is accomplished through periodic mechanical cultivation with some hand weeding and possible herbicide application. Growers have long recognized inefficiencies in the matted row system and have explored other production practices to improve efficiency and reduce labor requirements (Hancock and Roueche, 1983; Rotthoff, 1980). One system currently being explored is a cold-climate adaptation of the annual hill or plasticulture system of California and Florida (Poling, 1996). This CCP system may offer some benefits in improved yields and fruit quality (Fiola et al., 1995, 1997; O'Dell and Williams, 2000). However, the tradeoff costs of this system include increased establishment costs and greater risk for crop loss resulting from spring frost. To offset these higher establishment costs and greater risk, the CCP system has relied on methyl bromide fumigation to maximize yields (Larson, 1996; Pritts and Handley, 1998). With the phase out of methyl bromide, the potential yield benefits of the CCP system may be less pronounced (Hancock et al., 2001). The elimination of methyl bromide from strawberry production systems will undoubtedly result in increased need for other means to control weeds and diseases. Although exceptional weed control is achieved by the use of plastic mulch in the CCP system, herbicide application is necessary to control weeds between rows. Because this system is also replanted more frequently than with the CMR system (typically every year, compared with every 3 to 7 years), material costs are much greater over both the short and long term. As a result, there is interest in carrying over CCP plantings for a second bearing year.

The AMR system may be a sustainable alternative for growers in colder regions (Black et al., 2002a, 2002b). AMR uses raised beds and drip irrigation similar to the plasticulture system, but plants are managed like in CMR production and a cover crop residue persists on the raised beds as a mulch. Yield trials for the AMR system have been performed for several years and indicate this system has promise for a number of eastern varieties; however, an economic comparison of this system to the CMR or CCP is necessary to assess economic viability of each system.

The objective of this study was to compare the horticultural labor inputs, material costs, and marketable yields among three cold-climate strawberry production systems and develop crop budgets for each production system to compare relative profitability over a 3-year planting cycle.

Materials and Methods

Production systems. Three replicate plots of each of the three production systems, CMR, AMR, and CCP, were established in 2001–2002 in a randomized complete block design at the U.S. Department of Agriculture,

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Use of trade names does not imply an endorsement of the products named nor criticism of similar ones not named.

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Henry A. Wallace Beltsville Agricultural Research Center in Beltsville, MD. Plots measuring 13.7 m long and 6.1 m wide (four rows) were prepared in a north–south row orientation, planted in 2002, and cropped in the 2003 and 2004 seasons. Each cropping system was managed according to regional best management practices for that system (Black et al., 2002a; Poling and Monks, 1994; Pritts and Handley, 1998). The variety 'Allstar' was used in all systems because of a favorable disease resistance profile and adaptability to different production systems. 'Allstar' was originally selected for CMR production (Galletta et al., 1981) but has shown superior performance in both the CCP and AMR systems (Black et al., 2002b). Although growers would likely choose to grow a different cultivar that is specifically adapted to a particular production system, using 'Allstar' for all treatments in this experiment limited potential treatment × cultivar interactions.

In Sept. 2001, raised beds were formed in the AMR plots with subsurface drip irrigation lines placed at a depth of 6 to 10 cm. A winter cover crop of hairy vetch (*Vicia villosa* Roth), grain rye (*Trifolium incarnatum* L.), and crimson clover (*Secale cereale* L.) was seeded over the beds at seeding rates of 45, 78, and 34 $kg \cdot ha^{-1}$, respectively. The cover crop was killed using glyphosate (Roundup Original; Monsanto) ≈3 weeks before planting and then cut down 1 week later. On 12 May, dormant bare-root plants were hand-planted through the resulting cover crop residue layer. Plants were spaced 30 cm apart in a single row down the center of each raised bed and allowed to runner and form matted rows. The cover crop residue provided some weed suppression during strawberry establishment, and a combination of hand weeding and spot applications of paraquat (Gramoxone Max; Syngenta) was used to control remaining weeds. In the fall, beds were narrowed with directed application of paraquat.

CMR plots were prepared in Mar. 2002 after a winter cover crop of hairy vetch, crimson clover, and grain rye, which was incorporated into the soil before planting. Dormant bare-root plants were set at a spacing of 45 cm within row and 1.5 m between row centers. Overhead irrigation was delivered using gear-driven lawn sprinklers placed along the edges of each plot. Plots were cultivated periodically to control weeds with hand weeding around mother plants and hand placement of runners. In Aug. 2002, CCP plots were prepared with raised beds, subsurface drip irrigation lines placed at a depth 6 to 10 cm, and covered with 1.25-mil black plastic mulch. Plug plants were planted through the plastic mulch in offset double rows at a 30-cm within-row and between-row spacing. Weeds between beds were controlled by directed application of paraquat.

Each plot was irrigated independently using an automated system. Irrigation in each plot was triggered by a switching tensiometer placed at a depth of 30 cm (Irrometer Model RA, Riverside, CA). The CMR system was irrigated by overhead sprinklers, whereas both the AMR and CCP treatments had drip irrigation lines. Fertilizer nitrogen requirements were either broadcast-applied to the CMR system or injected into the drip system for AMR and CCP. Clean wheat straw was spread in December for winter freeze protection for all systems and was removed to the row middles in late March, and overhead irrigation was used to protect flower buds from spring frosts. Fruit was harvested in both 2003 and 2004. Postharvest renovation after the 2003 harvest was accomplished by mowing/trimming to remove leaves in all systems followed by hand removal of excess crowns (more than five per plant) in the CCP system and application of dichlorophenoxyacetic acid (2,4-D) to the CMR and AMR systems. Rows in the AMR and CMR systems were also narrowed mechanically.

Labor requirements. All hand labor processes, including removal of fruit and flowers, crown and runner management, and hand weeding, were timed by stopwatch to determine labor requirements. Machine processes, including land preparation, bed formation, and cultivation, were documented for each treatment. In some cases, processes that would normally be done by machine such as pesticide spraying, fertilizer broadcasting, and planting were performed by hand as a result of the small plot size. The number of pesticide and fertilizer applications and volumes applied was recorded for each treatment.

Fruit harvest. In 2003, fruit harvests were carried out twice weekly from 27 May through 19 June for a total of eight harvests. There were six twice-weekly harvests in 2004, from 17 May through 3 June. Yield data were collected from the two center rows of each four-row plot. Each center row was divided into three 3.7-m-long harvest plots with a minimum of 1 m of row remaining at each end to act as guard plots, resulting in six harvest plots per treatment plot for a total of 54 harvest plots (three treatments × three replications × six plots per replicate). One harvest plot per treatment plot was randomly designated for measuring total biological yield with both marketable and unmarketable fruit harvested and weighed. For the remaining harvest plots, only marketable fruit was harvested with harvests carried out by volunteers to simulate pick-your own (PYO) customers (Stevens et al., 2007).

Pesticides. Each production system was treated with an identical bloom-time fungicide spray regime following the recommendations of the Maryland Commercial Small Fruit Production Guide (Steiner et al., 1999). All fungicides were applied using an experimental plot sprayer equipped with a single-row boom with three nozzles directing spray from above and both sides of the row. In 2003, benomyl (Benlate; DuPont Agricultural Products) was applied on 22 Apr., at ≈10% bloom, to control Botrytis rot (*Botrytis cinerea* Pers.:Fr). Azoxystrobin (Quadris Flowable; Syngenta) was applied 5 May 2003 as a management for anthracnose (*Colletotrichum acutatum* J.H. Simmonds). Thiophanate–methyl (Topsin-M WSB; Cerexagri) and captan (Captan 50-WP; Micro Flo) were applied together as a tank mix on 13 May 2003. Thiophanate–methyl was applied for management of Botrytis rot, and captan was applied to manage common leaf spot [*Mycosphaerella fragariae* (Tul.) Lindau], Phomopsis leaf blight [*Phomopsis obscurans* (Ellis & Everh.) Sutton], and leaf blotch (*Gnomonia comari* P. Karst. and *Gnomonia. fragariae* Kleb.). Captan and thiophanate–methyl were applied together as a tank mix, because thiophanate–methyl has a similar mode of action to benomyl. A second azoxystrobin application was made 19 May 2003. In 2004, benomyl was not applied because it was no longer available for commercial use. Except for the elimination of benomyl, a similar spray regime was used in 2004. Two applications of azoxystrobin were made, 12 Apr. at ≈25% bloom and 26 Apr. at full bloom, with a single application of the captan/thiophanate–methyl tank mix applied on 19 Apr. at ≈50% bloom. A group of insecticides was identified for potential use and plots were scouted on a regular basis, but there was minimal insect infestation and no insecticide applications were necessary during the course of the experiment.

Herbicides were applied to each plot as needed and in concert with other weed management practices appropriate for that system. Although between-row weed control in the CMR system was primarily through mechanical cultivation, row middles in the CCP and AMR systems were treated when necessary with paraquat. On one occasion, the CMR treatment also received an application of paraquat to control a developing perennial weed problem. Additionally, the CMR and AMR treatments each had on application of 2,4-D (2,4-D 6 Amine; NuFarm Turf & Specialty) during renovation after the 2003 harvest season. The AMR had one application of glyphosate to kill the cover crop before planting. Paraquat and 2,4-D were applied using a backpack sprayer. Glyphosate was applied with a boom sprayer.

Data analysis. Results of fruit harvest for 2003 and 2004 and measured labor inputs were analyzed as a completely randomized design using the Proc Mixed routine of the SAS program package (Version 8; SAS Institute, Cary, NC). Crop budgets for each system were constructed based on measured variables and approximations appropriate to the project scale. Costs for machine operations were determined based on those used by O'Dell et al. (2001) with a 2% one-time adjustment for inflation. Because the crop budgets are intended to show relative profitability only among treatments, the cost of land and buildings, PYO harvest costs, and other costs were assumed to be equal among treatments, and were not included in the calculation of net returns. These costs would need to be included in a growers' assessment of the net profit from each system.

Results and Discussion

Hand labor

Herbicide use throughout the experiment was highest in AMR plots followed by CCP and CMR (Table 1). CMR plots were primarily controlled by cultivation, contributing to the low amount of herbicide use. Total hand labor for the duration of the production cycle was greatest for the AMR and CMR systems (Table 2). The AMR system did not reduce need for weed control compared with the CMR and, in fact, weed control costs were significantly higher overall in the AMR system as a result of the increased need for hand weeding. It is important to note that the AMR system was designed in part to reduce weed pressure during the early portion of the establishment season through the use of cover crop residue and a later planting date than CMR. For this experiment, however, significant weed control was not accomplished during this period as evidenced by statistically similar labor requirements for weed control for this period compared with the CMR. Weed control labor was significantly higher in the AMR system for the period of Sept. through Nov. 2003, suggesting that by this point, the cover crop had essentially broken down and become ineffective. Both the CMR and AMR systems had substantially higher labor requirements for weed control than the CCP system. The CMR system had significantly higher labor requirements for runner and crown management as a result of frequent cultivation that tended to cause crowns to be partially covered with soil. This was also a function of the earlier planting date for the CMR compared with the other two systems, resulting in greater runner production during the establishment year. There was no significant difference in labor required for runner and crown management between the AMR and CCP systems. Fruit and flower removal were greatest in the CMR system followed by AMR and CCP. Again, this can be attributed to the planting dates of each system. However, the minimal time requirement for fruit and flower removal compared with other management practices indicates that these differences are not economically significant.

Input and operational costs

Input costs were highest for the CCP system (Table 3), primarily as a result of the higher cost of plug plants, $0.17 per plant (Davoncrest Farms, Hurlock, MD) compared with $0.09 (Nourse Farms, South Deerfield, MA) for bare-root plants, and the higher planting density of the CCP system of 44,000 plants per hectare (based on 1.5-m row spacing) compared with 22,000 for AMR and 14,347 for CMR. The cost of the plastic mulch also contributes to the higher overall cost of materials for the CCP system. Also of importance is the higher pesticide expenditure for AMR compared with the other two systems. The cost of the overhead irrigation system used for CMR was also listed for the other systems, because an identical system would also be necessary for frost protection in the CCP and AMR systems, and the cost to the grower would be the same across all systems.

Hand labor was the primary difference in operational costs among systems (Table 4). Management operations shown in Table 1 were designated as minimum wage operations, whereas operating machinery, mixing, and application of pesticides and fertilizers were considered semiskilled with an appropriately higher hourly wage. Estimates of labor necessary per machine operation were made based on the

Table 1. Total herbicide and fungicide use for the 3-year planting cycle.[z]

	Conventional matted row (CMR)		Advanced matted row (AMR)		Cold-climate plasticulture (CCP)	
Pesticide	Sprays (no.)	Amount (kg ai/acre)	Sprays (no.)	Amount (kg ai/acre)	Sprays (no.)	Amount (kg ai/acre)
Paraquat	1	0.3	4–5	4.1	3–4	2.0
Glyphosate	—	—	1	2.3	—	—
2,4-D	1	3.9	1	3.9	—	—
Azoxystrobin	4	0.5	4	0.5	4	0.5
Benomyl	1	0.1	1	0.1	1	0.1
Thiophanate–methyl	2	0.3	2	0.3	2	0.3
Captan	2	0.9	2	0.9	2	0.9

[z] Glyphosate was used in AMR before planting to kill pre plant cover crop. Spot applications of paraquat were applied as needed to all systems. 2,4-D was applied to CMR and AMR treatments at an equal rate as part of renovation in July 2003. All fungicides were applied equally to all treatments. Benomyl used in 2003 only. Pesticide formulations and toxicity ratings were: Paraquat (Gramoxone Max), Glyphosate (Roundup Original), dichlorophenoxyacetic acid (2,4-D; 2,4-d 6 Amine), Azoxystrobin (Quadris Flowable), Benomyl (Benlate 50WP), Thiophanate–methyl (Topsin M 70WP), and Captan (Captan 50WP).

Table 2. A comparison of hand labor requirements among treatments from establishment through the second harvest.[z]

Management practice	CMR (h·ha^{-1})	AMR (h·ha^{-1})	CCP (h·ha^{-1})
Fruit/flower removal	35.9 a	14.6 b	0.0 c
Runner/crown management	164.5 a	66.1 b	69.8 b
Weed removal	965.8 a	1294.0 b	147.5 c
May to June 2002	295.3 a	370.4 a	0 b
July to Aug. 2002	329.6 a	495.7 a	0 b
Sept. to Nov. 2002	91.0 b	151.5 a	8.6 c
2003	54.5 ab	87.0 a	29.2 b
2004	195.4 a	188.0 ab	109.6 b
Total labor	1166 a	1375 a	217 b

[z] Fruit and flowers were removed from all systems during the establishment year to encourage vegetative growth. Runners in AMR and CMR treatments were placed within rows as they spread and were removed in CCP. Within-row hand weeding was performed as necessary for all systems.

CMR = conventional matted row; AMR = advanced matted row; CCP = cold-climate plasticulture.

Values in a column that are followed by the same letter are not significantly different at $P = 0.05$.

Table 3. A comparison of purchased input costs among three strawberry production systems.

			Unit cost ($US/ha)		
Item	Unit	Price	CMR	AMR	CCP
Cover crop seed					
Hairy vetch[z]	kg	2.76	—	49.18	—
Grain rye[z]	kg	0.49	—	15.14	—
Crimson clover[z]	kg	2.20	—	29.61	—
Strawberry plants					
Allstar bare root[y]	plant	0.09	1,291.23	1,980.00	—
Allstar plugs[x]	plant	0.17	—	—	7,480.00
Irrigation equipment					
Drip tape[w]	m	0.10	—	660.00	660.00
Blue-line poly[w]	m	0.36	—	39.60	39.60
Plastic inserts[w]	ea	1.72	—	113.52	113.52
Overhead irrigation system[v]	m	2.61	1,563.00	1,563.00	1,563.00
Mulch					
1.25-mil embossed plastic[w] mulch	m	0.10	—	—	660.00
Herbicides					
Gramoxone Max[z]	L	10.57	23.89	326.72	159.40
Roundup Original[z]	L	9.77	—	155.93	—
2,4-D 6 Amine[z]	L	3.58	50.51	50.51	—
Fungicides					
Quadris Flowable[u]	L	84.54	419.08	419.08	419.08
Benlate 50WP[t]	kg	36.38	17.98	17.98	17.98
Topsin M 70WP[t]	kg	45.17	47.84	47.84	47.84
Captan 50 WP[z]	kg	6.64	29.53	29.53	29.53
Fertilizer					
Ammonium nitrate[z]	kg	0.41	60.68	53.30	40.30
Total input costs			3,503.74	5,550.94	11,230.25

Price estimates taken from the following sources: [z]Bowens Farm Supply (Annapolis, MD), [y]Nourse Farms (South Deerfield, MA), [x]Davoncrest Farms (Hurlock, MD), [w]Trickle-Eez (Biglerville, PA), [v]Mid-Atlantic Irrigation (Farmville, VA), [u]Talbot Ag Supply (Easton, MD), [t](Parvin and Wadden, 1997).

CMR = conventional matted row; AMR = advanced matted row; CCP = cold-climate plasticulture.

number of operations performed and by the approximate length of each operation as given by O'Dell et al. (2001). Frost protection labor and hand labor were based on measured observations during the course of the experiment. AMR had the highest total cost of hand labor followed by CMR and CCP. As a result, total operational costs were highest in the AMR system followed by CMR and CCP. Custom hire operations were similar among systems, in which the cost for cultivation in the CMR system was offset by the higher cost of pesticide application in the AMR system. CCP had the highest labor cost for planting (Table 4).

Table 4. Operational costs among treatments (US $/ha).

Item	Rate ($/h)	CMR	AMR	CCP
Custom hire[z]				
Fertilizer broadcast	7.95	39.75	—	—
Machine planting	15.40	77.00	96.25	192.50
Pesticide spraying	14.73	29.46	98.25	54.06
Cultivation/discing	7.72	61.76	15.44	7.72
Mowing	7.48	7.48	7.48	7.48
Bed formation	7.50	—	7.50	7.50
Labor				
Minimum wage	5.15	6005.42	7079.71	1119.10
Semi-skilled	7.00	147.00	118.44	134.19
Total operational costs		6367.87	7423.07	1522.55

[z]Custom hire rates based on O'Dell et al. (2001) with 2% one-time adjustment for inflation.
CMR = conventional matted row; AMR = advanced matted row; CCP = cold-climate plasticulture.

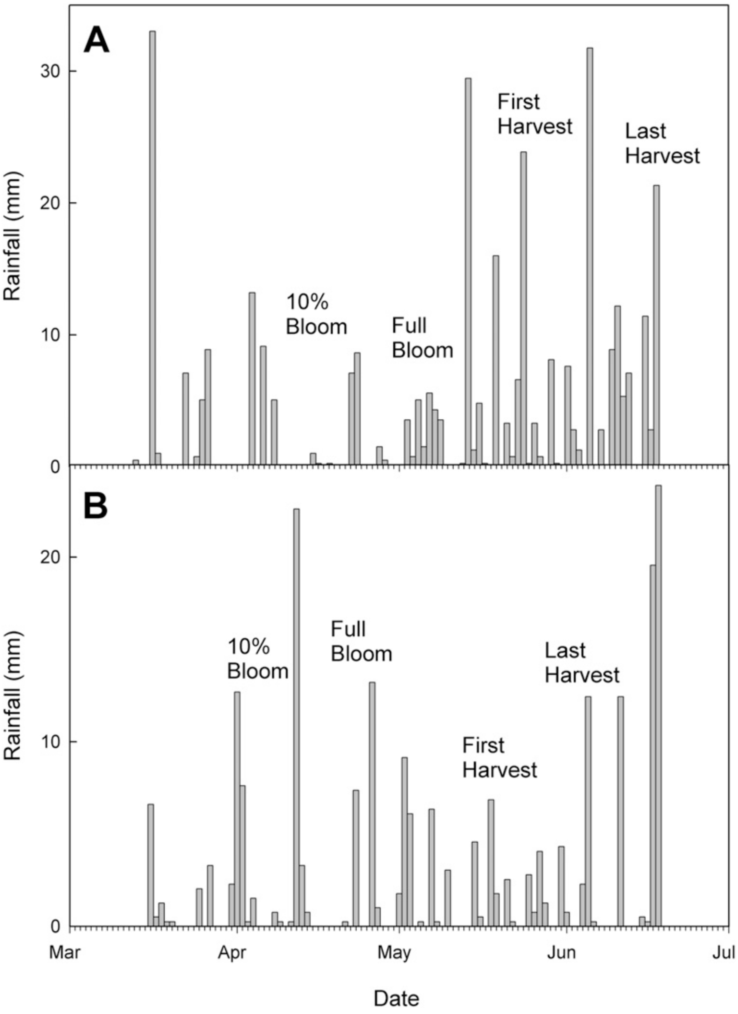

Fig. 1. Total daily rainfall for the period from bloom to harvest for 2003 (**A**) and 2004 (**B**).

Yields

2003. The preharvest and harvest period in 2003 was unseasonably wet and cold. Rainfall was well above average for the months of Apr., May, and June 2003 (Fig. 1) with measurable precipitation occurring 34 of 46 d from full bloom through the final harvest. Temperatures were below the recorded 30-year normal for 29 consecutive days during the harvest period (Fig. 2). As a result, a large amount of the fruit was lost to water damage and fruit rot despite the fungicide applications. The CMR system had the highest yield in 2003 at 17.4 Mg·ha^{-1} with no significant difference between AMR and CCP yields (Table 5). CCP had larger fruit on average than either AMR or CMR treatments with 22.4 g/fruit compared with 18.3 g and 16.8 g, respectively. Treatment differences in fruit size were most pronounced in the early season in which CCP had a peak fruit size of 30 to 35 g compared with 18 g for the AMR and 15 g for CMR (Fig. 3). Yields were much lower than expected for all systems based on prior results for this location. For the same location over a 5-year period, Black et al. (2002b) reported average yields of 21.8 Mg·ha^{-1} and 27.7 Mg·ha^{-1} for 'Allstar' in AMR and CCP systems, respectively.

In addition to the adverse weather conditions in the spring of 2003, the reduced yields in the CCP were partly the result of slow establishment. Typically, a planting date of 20 Aug. is sufficiently early to obtain formation of five to six branch crowns at this location, which is considered ideal crown development for this system (Poling and Monks, 1994). However, we observed less than five crowns per plant on average by the 2003 harvest. As a result of this low number of crowns, crown removal was not performed as part of the renovation process.

2004. In 2004, the AMR and CMR systems were the highest yielding treatments with 10.0 and 9.0 Mg·ha^{-1}, respectively, and were not significantly different from one another. The CCP system had a significantly lower marketable yield at 6.0 Mg·ha^{-1}. AMR had the largest average fruit size. Although AMR fruit was statistically larger than the other systems, the difference was less than 1 g. This size difference was unlikely to have an effect on marketability. The CCP system had a significantly higher percentage of unmarketable fruit than either the CMR or AMR systems at 32.5% compared with 25.9% and 23.9% for AMR and CMR, respectively. In 2004, the weather during the preharvest and harvest period was much hotter than normal (Fig. 2), causing the harvest season to be very short. Much of the fruit ripened quickly and became overripe and unmarketable before it could be harvested. This rapid ripening could have been exacerbated on the black plastic mulch of the CCP system.

Although yields in both years were low, the marketable fruit percentages are likely higher than what would be expected from a typical pre-picked strawberry operation. Marketable yields were based on harvests by volunteers that were allowed to keep the harvested fruit at no charge in exchange for their participation (Stevens et al., 2007). Although the volunteers were recruited to simulate PYO consumers, they tended to harvest and keep fruit that would generally be smaller than commercially acceptable, resulting in an overestimate of fruit marketability for the 2 years of this study.

Net returns

As a result of being the highest yielding system, CMR had the highest gross return of any system in the comparison and was also the most profitable, because total costs were less

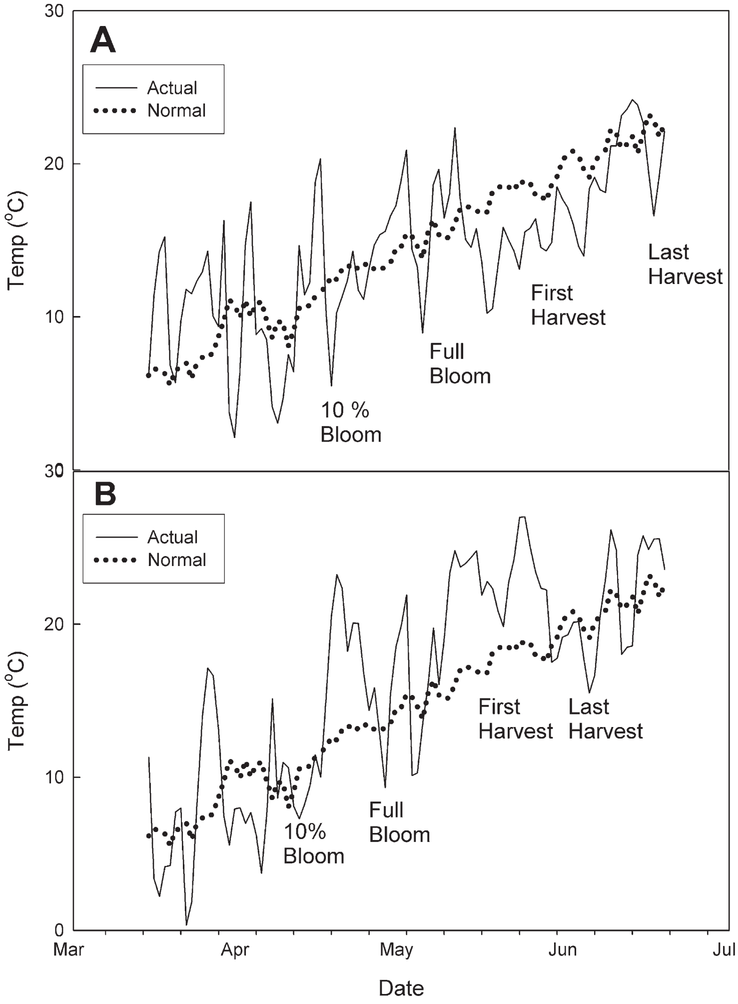

Fig. 2. Average daily temperature and 30-year normal temperature for the period from bloom to harvest in 2003 (**A**) and 2004 (**B**).

Table 5. Comparison of 2003 and 2004 harvest data among treatments.[z]

Treatment	Marketable yield (Mg·ha^{-1})	Mean fruit size (g)	Peak fruit size (g)	Unmarketable fruit (%)
2003				
Conventional matted row	17.4 a[y]	15.6 b	19.0 b	33.1 a
Advanced matted row	13.2 b	16.1 b	19.6 b	32.0 ab
Cold-climate plasticulture	11.8 b	21.9 a	35.6 a	21.4 b
2004				
Conventional matted row	10.0 a	11.0 a	17.3 a	23.9 a
Advanced matted row	9.0 a	11.9 b	16.0 a	25.9 a
Cold-climate plasticulture	6.0 b	11.0 a	16.2 a	32.5 b

[z] Marketable yield represents total amount of marketable fruit harvested in Mg·ha^{-1}. Mean fruit size was calculated as a weighted average from mean fruit weights determined at each harvest. Percentage of unmarketable fruit represents the percentage of fruit not suitable for harvest averaged over harvest dates. There were a total of eight harvests in 2003 and six in 2004.

[y] Means followed by different letters are significantly different at $\alpha = 0.05$.

in this system compared with the other two systems (Table 6). Although CCP fruit in the first harvest season were large enough to likely receive a larger market price, overall yield was low enough to indicate that the CCP system could not earn revenue comparable to the CMR system. Furthermore, the low yields and small fruit size of the CCP system in the second harvest year indicate that the fruit size benefits of the CCP system are limited to the first fruiting year. Although a single cultivar, Allstar, was used to minimize cultivar × treatment interaction, in reality, growers would likely select a cultivar specifically adapted to their location and production system. A number of cultivars are commonly used for the CMR system and would likely be equally adapted to AMR, whereas 'Chandler' or 'Sweet Charlie' is most commonly selected for the CCP system. As such, the differing yields among these cultivars would have an effect on net revenue for each system in a commercial setting.

Although both the CMR and AMR systems were more profitable than the CCP system in this comparison, each system's profits are limited to some degree by the high labor requirement. The AMR system was not able to adequately reduce weeding requirement compared with the CMR system. A more cost-effective method of weed control could improve profits for both of these systems. Straw mulch is moderately effective at controlling weeds between rows, and using living mulches between rows can be effective as well. However, in this study, hand weeding within rows accounted for the majority of the labor expense. Currently, most herbicides are not viable options for control of within-row weeds during active growing periods. 2,4-D is labeled for use on strawberry but is only recommended during renovation. Terbacil may also be effective for within-row weed control. Polter et al. (2004) reported that terbacil was effective in controlling weeds in newly established plantings without lowering yields but that best results occurred when the leaves were rinsed after application. The current label for Sinbar (terbacil) advises rinsing of leaves by rainfall or irrigation immediately after application to prevent unacceptable crop damage. Furthermore, terbacil application can significantly reduce strawberry growth (Black, unpublished data) and frequent use of this pre-emergent herbicide has been correlated with planting decline as a result of black root rot (Wing et al., 1995). Clearly, a more effective chemical weed control program is necessary to improve the economic viability of a "no-till" approach like the AMR system.

Similarly, the high cost of plug plants remains a limitation on the achievable profits for the CCP system. Individual plug plants tend to cost approximately twice as much as freshly dug bare-root plants, and the CCP system is planted at twice the density of the AMR system, making the cost of planting material for CCP essentially four times that of AMR and more than five times that of CMR. For the CCP system, this represented 76% of the total establishment costs compared with 48% for AMR and 37% for CMR. Although some growers may have experimented with using bare-root plants in CCP systems, the use of plug plants remains as the predominant method for CCP establishment. A further limitation to this system is the general availability of clean disease-free plug plants (Hokanson et al., 2004). The availability of lower cost plants would enhance the economic viability of this system.

Estimated gross returns were calculated for each of the treatments using a range of prices ($1.10/kg to $3.30/kg) and yields to illustrate alternative market and production scenarios. The sum of $3.30/kg represents the average price received by PYO strawberry growers in Maryland (Susan Butler, grower, Butler Orchards, Germantown, MD, personal communication), whereas $2.20/kg and $1.10/kg are the high and low end of prices, respectively, received by North Carolina growers (Safley et al., 2004). Because experimental yields often overestimate what is possible in a commercial setting, a conservative estimate of yields (80% of observed) was calculated. However, the yields in this experiment were lower than previously observed at this location, perhaps as a result of the adverse weather conditions in both harvest years. Black et al. (2002b) reported average biological yields of 21.8 Mg·ha^{-1} and 27.7 Mg·ha^{-1} for 'Allstar' in AMR and CCP systems, respectively, for the Beltsville location for 1997–2001. For that reason, an optimistic yield estimate (120% of observed yield) was also calculated for each system. Estimated gross returns were determined for each combination of yield and price and are shown in Table 7. The CMR system had the highest return of the three systems in this comparison under all scenarios. Although the CCP system had the lowest returns of any system, the larger fruit size of the CCP system in early 2003 (Fig. 3) indicates a likelihood that fruit from the CCP plots could be sold at a higher price. In a scenario in which CCP fruit could be sold for $3.30/kg and CMR for $2.20, the returns to each system are comparable. However, there was no size advantage for CCP fruit in 2004 (Fig. 3).

In conclusion, total input costs were lowest for the CMR system. Total input costs were higher in the CCP system, mainly as a result of the high cost of plug plants. Total costs in the AMR system were higher as a result of relatively higher operational costs. The CMR system had the highest estimated net return based on the total fruit yield over the 2-year experiment followed next by AMR with CCP having the lowest yield and lowest net return. Previously, we explored the environmental sustainability (Stevens et al., 2009) and consumer impacts (Stevens et al., 2007) of these strawberry management systems. Here we report that based on the 2003 and 2004 seasons, CMR was the most economically sustainable

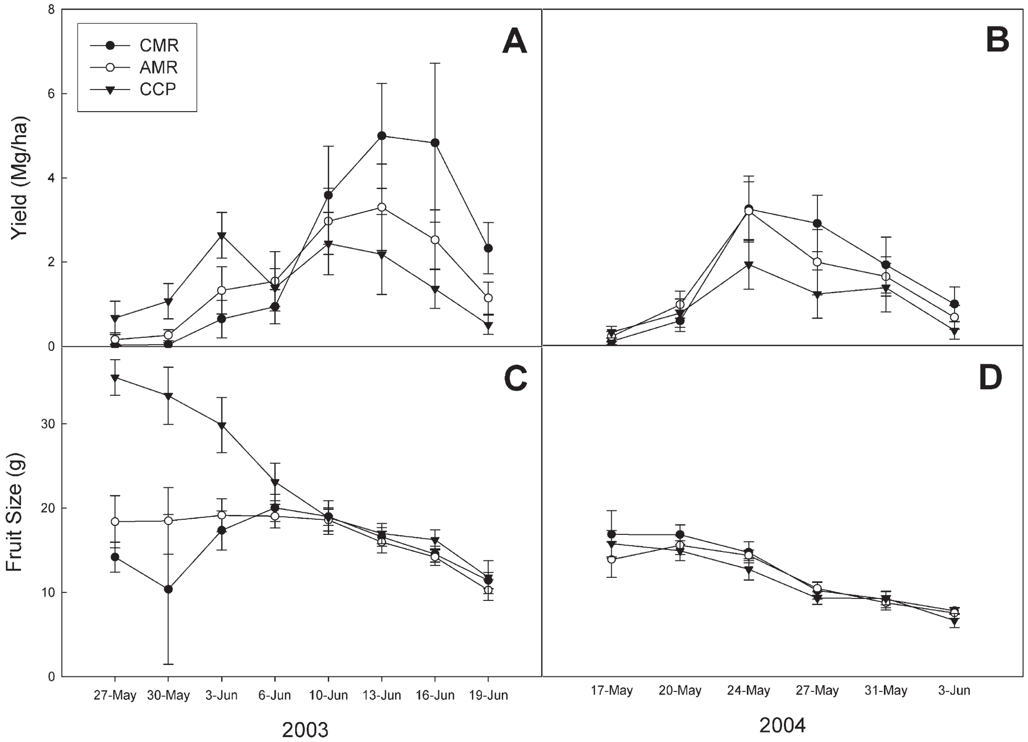

Fig. 3. Yield (**A–B**) and fruit size (**C–D**) for each harvest date in 2003 and 2004.

Table 6. Estimated net returns per hectare for three strawberry production systems based on experiments conducted in 2003 and 2004.

	CMR			AMR			CCP		
	Yield (Mg·ha^{-1})	Price ($/kg)	$/ha	Yield (Mg·ha^{-1})	Price ($/kg)	$/ha	Yield (Mg·ha^{-1})	Price ($/kg)	$/ha
Gross return									
2003	17.4	2.20	$38,280	13.2	2.20	$29,040	11.8	2.20	$25,960
2004	10.0	2.20	22,000	9.0	2.20	19,800	6.0	2.20	13,200
Total returns			$60,280			$48,840			$39,160
Less (2003–2004 costs)									
Purchased inputs			$3,504			$5,551			$11,230
Operational costs			6,368			7,423			1,522
Total costs			$ 9,872			$12,974			$12,752
Net return			$50,408			$35,866			$26,408

CMR = conventional matted row; AMR = advanced matted row; CCP = cold-climate plasticulture.

Table 7. Estimated returns per hectare for three strawberry production systems at varying prices based on experimental results for marketable yield (100%) as well as conservative (80%) and optimistic (120%) projections.^{z}

	CMR			AMR			CCP		
PYO price ($/kg)	80%	100%	120%	80%	100% ($1000/ha)	120%	80%	100%	120%
1.10	24.1	30.1	36.2	19.5	24.4	29.3	15.7	19.6	23.5
2.20	48.2	60.3	72.3	39.1	48.8	58.6	31.4	39.2	47.1
3.30	72.3	90.4	108.5	58.6	73.2	87.9	47.1	58.9	70.6

^{z}Values are expressed as $1000 U.S./ha.

PYO = pick your own; CMR = conventional matted row; AMR = advanced matted row; CCP = cold-climate plasticulture.

of the three systems for the mid-Atlantic region.

Literature Cited

Black, B.L., J.E. Enns, and S.C. Hokanson. 2002a. Advancing the matted-row strawberry production system. 5th North American Strawberry Conference. p. 112–115.

Black, B.L., J.M. Enns, and S.C. Hokanson. 2002b. A comparison of temperate-climate strawberry production systems using eastern genotypes. HortTechnology 12:670–675.

Chandler, C.K., D.E. Legard, and J.W. Noling. 2001. Performance of strawberry cultivars on fumigated and non fumigated soil in Florida. HortTechnology 11:69–71.

Fiola, J.A., R.J. Lengyen, and D.A. Reichert. 1995. Planting density and date affect productivity and profitability of ‘Chandler’, ‘Tribute’, and ‘Tristar’ in strawberry plasticulture. Advances in Strawberry Research. 14:49–52.

Fiola, J.A., C. O’Dell, and J. Williams. 1997. Cool climate strawberries fare well on plasticulture. Fruit Grower. May 41–42.

Galletta, G.J., A.D. Draper, and H.J. Schwartz. 1981. ‘AllStar’ strawberry. HortScience 16: 792–794.

Hancock, J. and J. Roueche. 1983. A comparison of ribbon and matted row strawberry culture. Advances in Strawberry Production. 2:7–8.

Hancock, J.F., P.W. Callow, S. Serce, and A.C. Schilder. 2001. Relative performance of strawberry cultivars and native hybrids on fumigated and nonfumigated soil in Michigan. HortScience 36:136–138.

Hokanson, S.C., F. Takeda, J.M. Enns, and B.L. Black. 2004. Influence of cold storage duration on strawberry runner tip viability and field performance. HortScience 39:1596–1600.

Larson, K.D. 1996. Challenges for annual strawberry production systems. IV North American Strawberry Conference, Orlando, FL, 15–17 Feb. 1995. p. 155–161.

Merwin, I.A. and M.P. Pritts. 1993. Are modern fruit production systems sustainable? HortTechnology 3:128–136.

Nonnecke, G.R. and J.R. Dewitt. 1996. Sustainable strawberry production: A new model for growers and researchers. Proc. of the IV North American Strawberry Conference. University of Florida, Orlando, FL. p. 193–197.

O’Dell, C., H. Snodgrass, C. Conner, and G. Groover. 2001. Selected costs and returns budgets for horticultural food crops production/marketing Publication 438-898, Virginia Cooperative Extension, Virginia Tech, Blacksburg, VA.

O’Dell, C.R. and J. Williams. 2000. Hill system plastic mulched strawberry production guide for colder areas Publication 438-018, Virginia Cooperative Extension, Virginia Tech, Blacksburg, VA.

Parvin, D.W. and W.C. Wadden. 1997. Estimated costs and returns of strawberries in south Mississippi Publication B1081. Mississippi State University Cooperative Extension, Mississippi State, MI.

Poling, E.B. 1996. Challenges for annual production systems in cool climates. IV North American Strawberry Conference, Orlando, FL, 15–17 Feb. 1995. p. 162–170.

Poling, E.B. and D.W. Monks. 1994. Strawberry plasticulture guide for North Carolina. NCCES AG-505:16.

Polter, S.B., D. Doohan, and J.C. Scheerens. 2004. Tolerance of greenhouse-grown strawberries to terbacil as influenced by cultivar, plant growth stage, application rate, application site and simulated postapplication irrigation. HortTechnology 14:223–229.

Pritts, M. 2002. Growing strawberries, healthy communities, strong economies and clean environments: What is the role of the researcher? Acta Hort. 567:411–417.

Pritts, M.P. and D.M. Handley. 1998. Strawberry production guide for the northeast, midwest, and eastern Canada. NRAES 88, Ithaca, NY.

Pritts, M.P. and M.J. Kelly. 2001. Early season weed competition reduces yield of newly planted matted row strawberries. HortScience 36:729–731.

Rhainds, M., J. Kovach, and G.E. Loeb. 2002. Impact of strawberry cultivar and incidence of pests on yield and profitability of strawberries under conventional and organic management systems. Biol. Agr. Hort. 19: 333–353.

Rotthoff, W. 1980. Challenging practices, systems, and thoughts for the ‘80’s, p. 77–82. In: Childers, N.F. (ed.). The strawberry: Cultivars to marketing. Horticultural Publications, Gainesville, FL.

Safley, C.D., E.B. Poling, M.K. Wohlgenant, O. Sydorovych, and R.F. Williams. 2004. Producing and marketing strawberries for direct market operations. HortTechnology 14:124–135.

Steiner, P.W., R. Heflebower, and R. Rouse. 1999. Maryland commercial small fruit production guide. MCES 242, 8 pp. University of Maryland Cooperative Extension, College Park, MD.

Stevens, M.D., B.L. Black, J.D. Lea-Cox, A.M. Sadeghi, J. Harman-Fetcho, E. Pfiel, P. Downey, R. Rowland, and C.J. Hapeman. 2009. A comparison of three cold-climate strawberry production systems: Environmental effects. HortScience 44:298–305.

Stevens, M.D., J.D. Lea-Cox, B.L. Black, and J.A. Abbott. 2007. A comparison of fruit quality and consumer preferences among three cold-climate strawberry production systems. HortTechnology 17:586–591.

Wing, K.B., M.P. Pritts, and W.F. Wilcox. 1995. Biotic, edaphic, and cultural factors associated with strawberry black root rot in New York. HortScience 30:86–90.