Fall-applied Rowcovers Enhance Yield in Plasticulture Strawberries

Gina E. Fernandez

Additional index words. *Fragaria ×ananassa*, floating rowcover, synthetic spun-bonded cover

Summary. The environmental conditions necessary for floral initiation and development in North Carolina can be arrested by the onset of an early drop in temperatures in the fall soon after planting. Floating rowcovers were placed on plots of three cultivars of strawberry (*Fragaria ×ananassa*), 'Chandler', 'Camarosa' and 'Sweet Charlie,' for 2 weeks in the fall to determine if fruit yield could be increased by enhancing additional plant growth. Yields were taken on plots with and without rowcovers the following spring. Temperatures and photosynthetic photon flux were monitored under the rowcovers, as well in adjacent plots that were not covered throughout the year. Daily, minimum, maximum and mean temperatures were generally higher under the rowcovers when ambient temperatures were above 10 °C (50 °F). Rowcovers had no effect on leaf area, root, crown, leaf, flower and fruit dry weight in the first year and a minimal affect in the second year. The application of rowcovers increased total yield and marketable yield by 80 to 100 g/plant (0.18 to 0.22 lb/plant) but did not affect fruit weight. This study suggests that rowcovers can improve yield. However further studies are needed to assess effects of time of initial placement and duration of rowcovers on strawberry yield, growth and development.

Assistant professor, North Carolina State University, Department of Horticultural Science, Vernon G. James Research and Extension Center, Plymouth, NC 27962.

I gratefully acknowledge Melanie Halsey for her technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Strawberry production in North Carolina is based primarily on an annual plasticulture system where yields can exceed 15,785 kg·ha^{-1} (34,800 lb/acre) in the southeastern part of the state. However, yields in cooler winter regions of the state average only 19,054 to 20,174 kg·ha^{-1} (17,000 to 18,000 lb/acre) using this plasticulture system (Poling, 1993). The primary strawberry cultivars used in our plasticulture system have specific environmental requirements for floral development. These type of strawberries are called June-bearers. Floral induction for these plants occurs in the fall in response to changes in photoperiod (Durner and Poling, 1988). Once the initial trigger from short days is perceived by the plant, suitable temperatures are needed for flower bud initiation and differentiation. Crown growth and development occurs when the temperatures are above 10 °C. Flower buds are formed when days are less than 14 h and temperatures are above 15 °C (59 °F) (Strand, 1994). In North Carolina, daylengths are near 12 h and temperatures are between 15 to 25 °C (59 to 77 °F) for about 1 month following planting. However, in November temperatures often drop below the optimal range for flower bud development. For example, the average maximum, minimum and mean temperatures in October and November are for Plymouth, NC are 23.6, 15.6, and 17.0 °C (74, 60, and 63 °F) and 18.8, 6.1, and 12.5 °C (66, 43, and 54 °F), respectively.

Rowcovers have been used in small fruit production to accelerate ripening (Pritts and Handley, 1998; Pritts et al., 1992), extend the growing season (Pollard, 1990), serve as an overwintering mulch (Pollard and Cundari, 1988), provide frost protection during flowering (Hochmuth et al., 1993) and to increase productivity (Pritts et al., 1992; Gast and Pollard, 1991). Others have found that rowcovers applied in the fall and left on until the following spring enhanced yield by increasing development of tertiary flowers (Pollard, 1990; Gast and Pollard, 1991). However, in the latter studies it was not determined whether the increase in flower number was due to presence of rowcovers in the fall, spring or combination of the two. The use of rowcovers in the fall could increase yields in areas where temperatures drop too early. The objective of this study was to determine if rowcovers applied for 2 weeks in the fall could enhance yield in plasticulture strawberries in northeastern North Carolina.

Materials and methods

The study was conducted at the Vernon G. James Research and Extension Center, Plymouth N.C. (USDA hardiness Zone 7b, Latitude –76.65, longitude 35.87). The soil was a Megget fine sandy loam. The planting consisted of three strawberry cultivars, 'Chandler', 'Camarosa' and 'Sweet Charlie'. Plants were spaced at 30.45 cm in double rows of diagonally staggered plants. The plants were set on 6 Oct. 1996 (Year 1) and, due to wet field conditions plants were set on 17 Oct. 1997 (Year 2). The strawberries received standard recommended cultural practices for plasticulture excluding spring application of water and fertilizer via a drip system (Poling and Monks, 1994). Spring frost protection was successfully administered as needed both years to protect blossoms. Fruit was harvested from 31 Mar. 1997 to 2 June 1997 (Year 1) and from 2 Apr. 1998 to 2 June 1998 (Year 2).

The experiment was a split plot design with cultivar as the main plot and presence or absence of rowcover (±RC) the split plot. The plots were arranged in a randomized block design, with treatments replicated four times. Plots were 15.2 m (50 ft) long, each subplot was 6.1 m (20 ft). A section of row 1.5 m (5 ft) was left between subplots to separate treatments. Typar rowcovers (spunbound polypropylene) 35.4 $g \cdot m^{-2}$ (1.25 $oz/yard^2$), (Reemay, Inc., Old Hickory, Tenn.) were placed on the half of the designated split plots in the first week of November of each year and remained on the plots for 14 d.

Whole plants were harvested at monthly intervals in both years from the ends of the plot allotted to whole plant harvest. Four plants of each treatment combination and replication were carefully dug from the ground along with the adjacent soil to insure that as many roots as possible were harvested. Soil was washed from the roots over a sieve to collect root pieces severed from the plant. Plant were divided into roots, crown, leaves, flowers and fruit. Leaf areas were taken using a leaf area meter (LI-3200; LI-COR Inc., Lincoln, Neb.). The separated plant parts were placed in paper bags and dried in an oven at 70 °C (21 °F) for 10 d.

Temperatures were monitored under the rowcovers and control plots using a data logger and thermocouples (CR10X; Campbell Scientific, Logan, Utah) for the duration of the study. Thermocouples were placed on sticks within the plant canopies. Minimum, maximum and mean air temperatures were recorded for each hour and averaged for each day. Photosynthetic photon flux (PPF) was measured when rowcovers were in place in Fall 1996 (LI-250 equipped with a LI-190SA quantum sensor; LI-COR). Measurements were taken between 1100 to 12:00 HR on 10 Nov. 1996 in all plots and presented as averages of ±RC.

Harvested fruit from each plot was separated into marketable and nonmarketable berries. Marketable berries were blemish free, weighed 15 grams (0.5 oz) or greater and did not have any visible deformities. Fruit size was determined using a random sample of 25 fruit from the marketable fruit.

Determination of the effects of cultivar and rowcover on yield parameters were analyzed statistically as a split plot design with four replications using SuperANOVA (Abacus Concepts Inc., Berkeley, Calif.). Yield data was combined and analyzed jointly for 2 years, plant growth data was analyzed separately each year. Means were separated using Fishers protected LSD.

Results and discussion

The placement of rowcovers significantly increased marketable and total yield but not fruit weight of strawberries in this study (Table 1). Marketable yields in plots with rowcovers were about 80 and 100 g/plant (0.18 to 0.22 lb/plant) higher than in plots without rowcovers respectively (Table 2). This difference was realized in both years despite differences in planting date, indicating rowcovers can not only increase yield when plants are set on time but also compensate for a late planting date.

The increase in yield due to +RC occurred midseason to late-season, commencing about 4 weeks after the first berries were harvested as illustrated with the cultivars 'Camarosa' and 'Chandler' in Year 2 (Fig. 1). This increase in yield was likely due to an increase in the number and not size of berries because berry size was not affected by rowcover treatment in either year (Tables 1 and 2). Therefore yield enhancement was likely due to increased number of secondary or tertiary buds that were initiated during the treatment period. A previous study has shown that rowcovers applied in the fall and removed the following spring increase yield by producing more tertiary fruit (Gast and Pollard, 1991). Anatomical studies would be needed to assess the exact impact of rowcovers on timing of floral initiation and extent of differentiation.

Rowcovers did affect fruit quality. The percent of total yield which was marketable for +RC and –RC was

Table 1. Probability values from analysis of variance for year, cultivar, with and without row covers (+RC and –RC) and interactions of total yield, marketable yield and fruit size of three strawberry cultivars grown in 2 consecutive years.

	P		
Source	**Total yield**	**Marketable yield**	**Fruit wt**
Year	0.0001	0.0001	0.0001
Replication (year)	0.1256	0.1427	0.0955
Cultivar	0.0001	0.0001	0.0163
Cultivar × year	0.0010	0.0014	0.2647
Replication × cultivar (year)	0.4830	0.2205	0.7301
Row cover	0.0144	0.0172	0.9001
Row cover × cultivar	0.4803	0.5944	0.5008
Row cover × year	0.4383	0.5743	0.4549
Row cover × cultivar × year	0.6393	0.6241	0.3335

Table 2. Total yield, marketable yield, and individual fruit weight of three strawberry cultivars with and without row covers (+RC and –RC) means combined over 2 years; 28.35 g = 1.0 oz.

Cultivar	Total yield (g/plant)			Marketable yield (g/plant)			Fruit wt (g/fruit)		
	Treatment × cultivar mean		Cultivar mean	Treatment × cultivar mean		Cultivar mean	Treatment × cultivar mean		Cultivar mean
	+RC	–RC		+RC	–RC		+RC	–RC	
Chandler	890	774	833 a[z]	698	615	656 a	15.7	15.7	15.7 a
Camarosa	850	682	766 a	681	565	622 a	17.4	18.1	17.8 b
Sweet Charlie	378	332	355 a	324	284	304 b	17.1	16.2	16.6 a
Treatment mean	706 a[z]	597 b		567 a	488 b		16.7[NS]	16.7[NS]	

[z]Mean separation within columns and rows by Fishers LSD, $P \leq 0.05$.

73% and 92% respectfully. The primary reason for the classification of unmarketable fruit was attributed to blemishes caused by the fungal disease gray mold (Botrytis cinerea). Observations noted at harvest indicated that more fruit harvested from plots +RC had gray mold than fruit from plots –RC. The elevated yields in +RC plots may have resulted in a more crowded plant microclimate, thus enabling the disease to spread readily from fruit to fruit. No fungicides were used at any time during these studies as a means to control gray mold. A strict spray program would need to be implemented in order to minimize losses due to this disease if rowcovers were to be used.

Analysis of the data combined over the 2 years revealed there were significant effects due to year on all yield components as well as the cultivar × year interaction (Table 1). Yields in Year 2 were about 320 and 480 g/plant (0.7 and 1.05 lb/plant) lower for 'Camarosa' and 'Chandler' respectively than in Year 1. In North Carolina, the correct planting date is considered very important for optimal yield. Planting date has a significant effect on yield and even a slight delay in planting can reduce yields (E.B. Poling, personal communication). In this study adverse weather conditions resulted in a delayed planting date in Year 2 of 11 d. The yield differences we observed due to year was therefore likely due to differences in planting date.

We also observed total and marketable yields varied due to cultivar (Table 1). 'Sweet Charlie' had lower total and marketable yields than the other cultivars (Table 2). 'Chandler' and 'Camarosa' had statistically similar total and marketable yields (Table 2). 'Camarosa' fruit weight was greater than 'Chandler' and 'Sweet Charlie' (Table 2). This is consistent with growers on farm assessments in North Carolina, where 'Chandler' and 'Camarosa' are the cultivars favored by growers based on their yield potential.

Temperature, photoperiod and light levels are important factors in plant growth and development. Daily maximum, minimum and mean temperatures under the rowcovers were in general slightly higher both years, especially when the temperatures were above 10 °C (50 °F) (Table 3). In Year 1, once temperatures dropped below 10 °C (50 °F), plots with rowcovers had lower temperatures than plots without rowcovers. However, these low temperatures would not likely influence floral initiation, as several previous studies indicated that optimal daytime temperatures are closer to 15 to 25 °C (59 to 77 °F) (Arney, 1956, Darrow, 1966; Durner et al., 1984). Determination of the number of hours in a defined range of temperatures and daylength may be a better means of determining optimal conditions for floral initiation and differentiation.

Dry weights and leaf area were not affected by treatment in Year 1 (Table 4). In Year 2, treatment effects were significant in January and May. At these dates average leaf area [112 cm^2 (17.3 $inch^2$)] and dry weight [1.37 g (0.05 oz)] and crown dry weight [1.82 g (0.06 oz)] were higher under the +RC versus –RC treatments respectively. In all instances the cultivar 'Camarosa' +RC had the highest dry weight, or leaf area of all three cultivars. There were no differences in number of crowns due to treatment at any time in the second year (data not shown). Although the response to treatment was not displayed consistently in the whole plant on the same dates, various plant parts did display response to the rowcover treatment. In other studies that depict the growth and development of three cultivars, Butler (1999) has shown that there are

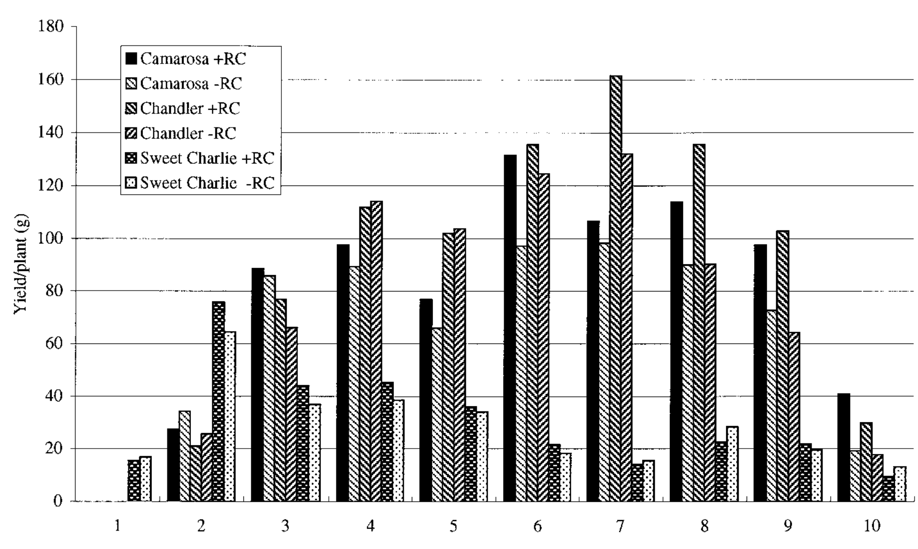

Fig. 1. Weekly marketable yield/plant (g) of the cultivars 'Camarosa,' 'Chandler,' and 'Sweet Charlie' in Year 2 (1997), with and without rowcovers (+RC and –RC); 28.35 g = 1.0 oz.

Table 3. Average maximum (max), minimum (min) and mean temperatures (°C) for Plymouth, N.C., from 1996 and 1997, in plots with and without rowcovers (+RC and –RC).

	Year 1 (1996)						Year 2 (1997)					
	+RC			–RC			+RC			–RC		
Day	Max[z]	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
1	18.3	17.0	17.4	18.0	16.7	17.2	21.4	21.4	21.2	21.5	21.1	21.3
2	25.0	20.9	22.6	23.6	20.1	21.7	19.9	18.6	19.8	17.9	20.2	18.3
3	23.6	20.8	21.9	23.2	20.6	21.6	16.3	14.2	15.1	14.9	14.2	13.6
4	14.9	11.2	12.9	14.9	11.0	12.9	14.3	12.1	13.4	12.6	12.7	11.6
5	11.4	7.9	9.7	11.0	7.6	9.4	12.4	10.1	11.5	10.7	10.7	9.7
6	9.0	5.9	7.4	11.6	7.4	9.4	16.2	12.7	14.1	14.1	12.6	11.8
7	6.9	3.7	5.2	10.5	6.4	8.6	16.1	13.1	14.1	14.4	12.3	12.0
8	7.5	4.3	5.9	11.1	7.4	9.4	15.3	12.6	13.3	13.8	11.4	11.6
9	7.2	5.7	6.4	8.1	6.7	7.4	14.1	11.8	12.9	12.6	11.7	11.2
10	7.4	4.8	5.9	10.1	6.1	7.7	11.5	11.1	11.2	11.3	10.9	10.9
11	7.8	5.6	6.6	11.6	7.8	9.5	12.8	11.8	12.0	12.1	11.4	11.5
12	9.1	6.1	7.5	12.4	8.8	10.7	14.5	11.3	12.4	12.4	10.4	10.4
13	13.1	10.2	11.4	13.0	10.3	11.6	10.7	8.0	8.5	9.3	6.5	6.9
14	12.0	11.7	11.8	11.8	11.6	11.7	9.3	5.2	6.8	6.5	4.5	4.1
AVG	12.4	9.7	10.9	13.6	10.6	12.0	14.6	12.4	13.3	13.2	12.2	11.8

[z]°F = 1.8(°C) + 32.

periods of time in which the plants allocates resources preferentially. In her studies Butler (1999) found that in January and March, there was an upward shift in the percent of whole plant biomass or total dry weight allocated to leaf tissue. While in May, crown dry weight increases dramatically as well. May is the peak month of fruit production so a increased dry weight of crowns may be due to additional floral initiation that took place but went undetected by our assessment of crown number and dry weight in the previous fall. Increased leaf dry weight and leaf area in the winter months may have been a response to increased leaf initiation during the rowcover treatment.

Midday levels of photosynthetic photon flux (PPF) were 689 and 1171 $\mu mol\cdot m^{-2}\cdot s^{-1}$ ±RC respectively. The lower levels of PPF under the rowcovers may be approaching suboptimal levels for maximum photosynthesis. Lower photosynthetic rates could result in lower carbohydrate accumulation in plants in plots + RC. Saturation light intensities for strawberry photosynthesis have not been documented. However, previous studies have shown that strawberries grown under intensities greater than 650 $\mu mol\cdot m^{-2}\cdot s^{-1}$ have increased leaf area, petiole length and root, leaf and crown dry weights over plants grown under lower intensities (Ceulemans et al., 1986; Feree and Stang, 1988).

In our study, an 80 to 100 g/plant (0.18 to 0.22 lb/plant) marketable yield increase was realized. This can translate into significant profit and will help to offset the cost of the rowcovers. For example, in this production system there are about 43,000 plants/ha, (17,400 plants/acre). Growers in North Carolina typically charge \$0.38/kg (\$0.85/lb) for their pick-your-own berries. An additional 80 g/plant (0.17 lb/plant) would translate into a \$6606/ha (\$2456/acre) increase in revenues. Most rowcovers cost \$1111 to 2964/ha (\$450 to 1200/acre), therefore they would more than pay for themselves in a year under the right environmental conditions. Alternatively, yields of 'Sweet Charlie' were only increased by 40 g/plant (0.09 lb/plant) resulting in a potential \$3025/ha (\$1225/acre) increase in revenues. However, this net increase in yield +RC is still not as high as those achieved by 'Chandler' or 'Camarosa' –RC. Therefore the use of rowcovers with the cultivar 'Sweet Charlie' would not be economically viable with the higher priced rowcovers.

Growers also need to consider tow cover quality and price. Lighter weight rowcovers are less expensive but usually cannot be used for more than one year, so new rowcovers would have to be bought each year. The heavier rowcovers used in this study were more expensive, however with good care they could easily last 4 years, thus decreasing the cost of using rowcovers over time.

However, plants could be damaged if rowcovers were used improperly. For example, if unseasonably warm temperatures during rowcover treatment were followed by unseasonably cold temperatures, plants may not acclimate and tissues could have a reduced cold tolerance. This could result in damage to the crown and developing flower buds and yields the following spring could be reduced. Growers should consult seasonal climate data and predicted long range forecasts before they install rowcovers.

Cultural systems that alter the plant microclimate can enhance yield. In this study we found a positive yield response in strawberry yield to the application of rowcovers in the fall shortly after planting. However, many questions remain to fine tune this practice. Additional studies are needed to determine when rowcovers should be placed in the field and how long they should remain on the crop. We need to determine at what point in a strawberry plants development rowcovers would enhance further development and at what temperatures this could be best achieved. These studies would include analysis of crown and root zone temperatures as previous reports have shown that below ground temperatures are very important in strawberry flower initiation (Geater et al., 1997). In addition, morphological studies are needed to determine if the elevated temperatures we measured increased flower initiation and devel-

Table 4. Probability values from analysis of variance for treatment with and without rowcovers (+RC and -RC) on leaf area, root, crown, leaf, flower and fruit dry weights (DW) on nine whole plant harvest dates from planting (October) until afterharvest (June) in Year 1 (1996) and Year 2 (1997).

	P					
Month	**Leaf Area**	**Root DW**	**Crown DW**	**Leaf DW**	**Flower DW**	**Fruit DW**
			Year 1			
October	N/A[z]	N/A	N/A	N/A	N/A	N/A
November	N/A	N/A	N/A	N/A	N/A	N/A
December	0.9822	0.0690	0.7553	0.5190	N/A	N/A
January	0.6313	0.8691	0.3533	0.6904	0.6229	N/A
February	0.6928	0.7217	0.8660	0.6832	0.6544	0.9485
March	0.7079	0.3571	0.2219	0.7738	0.3212	0.6652
April	0.4288	0.9084	0.9309	0.5762	0.4466	0.1306
May	0.4497	0.1315	0.0565	0.9494	0.2518	0.6375
June	0.3074	0.2626	0.4913	0.3885	N/A	0.0758
			Year 2			
October	N/A	N/A	N/A	N/A	N/A	N/A
November	0.2921	0.9297	0.9169	0.2487	N/A	N/A
December	0.0820	0.0716	0.3906	0.1194	0.4351	N/A
January	0.0285	0.7488	0.1298	0.0176	0.1725	N/A
February	0.3297	0.7773	0.9597	0.4880	0.5080	N/A
March	0.0573	0.4584	0.5630	0.0694	0.2794	0.5539
April	0.7439	0.6312	0.3192	0.8824	0.1882	0.0971
May	0.5162	0.1103	0.0254	0.5873	0.7069	0.1417
June	0.3554	0.5303	0.5131	0.3593	0.5317	0.6243

[z]N/A not applicable due to treatment applied after whole plant harvest at this date or to absence of flowers in the fall.

opment. Ultimately we need to determine the number of hours that would be needed within a critical range of temperatures to increase flowers produced and ultimately yield. Using such data a grower could then monitor plant growth and temperatures to determine how long a rowcover should remain in place.

Literature cited

Arney, S.E. 1956. Studies on the growth and development in the genus *Fragaria*. IX. An investigation to floral initiation under natural conditions. Phyton 7:89–102.

Butler, L.M. 1999. The biology of Botrytis cinerea and strawberry plant development in southeastern production systems. MS thesis, N.C. State Univ., Raleigh.

Ceulemans, R, W. Baets, M. Vandergrugen, and I. Impens. 1986. Effects of supplemental irradiation with HID lamps and NFT gutter size on gas exchange, plant morphology and yield of strawberry plants. Sci. Hort. 28:71–83.

Darrow, G.M. 1966. The strawberry. Holt, Rinehart and Winston, New York.

Durner, E.F., J.A. Barden, D.G. Himelrick, and E.B. Poling. 1984. Photoperiod and temperature effects on flower and runner development in day-neutral, junebearing, and everbearing strawberries. J. Amer Soc. Hort. Sci. 109(3):396–400.

Durner, E.F. and E.B. Poling. 1988. Strawberry developmental responses to photoperiod and temperature: A review. Advances in Strawberry Prod. 7:6–15

Feree, D.C. and E.J. Stang. 1988. Seasonal plant shading, growth and fruiting in 'Earliglow' strawberry. J. Amer. Soc. Hort. Sci. 110:322–327.

Gast, K.L.B. and J.E. Pollard. 1991. Rowcovers enhance reproductive and vegetative yield components in strawberries. HortScience. 26:1467–1469

Geater, C.A., G.R. Nonnecke, W.R. Graves, A.S. Aiello, and C.A. Dilley. 1997. High root-zone temperatures inhibit growth and development of *Fragaria* species. Fruit Var. J. 51:94–101.

Hochmuth, G.J., S.J. Locascio, S.R. Kostewicz, and F.G. Martin. 1993. Irrigation method and row cover use for strawberry freeze protection. J. Amer. Soc. Hort. Sci. 11:575–579.

Poling, E.B. 1993. Strawberry plasticulture in North Carolina: II. Preplant, planting and postplant considerations for growing 'Chandler' strawberry on black plastic mulch. HortTechnology 3:383–393.

Poling E.B. and D.W. Monks. 1994. Strawberry plasticulture guide for North Carolina. AG-505. N.C. State Univ. Coop. Ext. Serv., Raleigh.

Pollard, J.E. 1990. The use of rowcovers to extend the strawberry growing season. Proc. 3rd N. Amer. Strawberry Conf. 153–157.

Pollard, J.E. and C.M. Cundari. 1988. Over-wintering strawberry plants under rowcovers increases fruit production. HortScience. 23(2):332–333.

Pritts, M. and D. Handley. 1998. Strawberry production guide. N.E. Reg. Agr. Serv., Ithaca, N.Y.

Pritts, M., E. Hanson, J. Fiola., and M. Kelly. 1992. Rowcovers accelerate fruiting and increase productivity in primocane-fruiting red raspberries. HortTechnology 2(1):46–51.

Strand, L. 1994. Integrated pest management for strawberries. Univ. Calif., Davis, Statewide IPM Proj. Publ. 3351