weights of 'Crimson Pixie' associated with fertilizer concentration occurred frequently on plants grown with ebb and flow.

With ebb-and-flow irrigation, the lowest root dry weights were those of plants grown with 150 mg N/liter. In contrast, the increase in root dry weight of 'Crimson Pixie' plants grown with drip irrigation was proportional to the increase in concentration.

Growth, as defined by height and increase in dry matter, and quality of hybrid lilies appears to be controlled or affected by factors other than fertilizer formula or concentration. Plant quality was not affected by the fertilizer treatments. Good-quality, saleable plants were produced with 75 mg N/liter.

Flowering of 'Crimson Pixie' or 'Lemon Pixie' was not affected by any of the fertilizer or irrigation treatments. The results of this experiment show that the number of blasted flower buds of 'Crimson Pixie' and 'Lemon Pixie' were not significantly affected by the amount or concentration of fertilizer. Similarly, the total number of flower buds, flower dry weight, and days to flower were not significantly affected by the fertilizer and irrigation treatments.

Bulbs grown with drip and ebb-and-flow systems were irrigated about once a week. A total of 726 liters of fertilizer solution was applied to a crop of 324 hybrid lily bulbs grown with conventional drip irrigation; whereas, a total of 764 liters was applied to 324 bulbs grown with ebb-and-flow irrigation. When compared to each other, 5% less water was used with drip irrigation in this experiment than with ebb and flow. Drip and ebb-and-flow irrigation appear to be similarly efficient in conserving water and liquid fertilizer.

In summary, ebb-and-flow irrigation reduced water and fertilizer used by ≈40% when compared to overhead hand-watering by hose in the production of *Hedera helix*. However, water and fertilizer use were not significantly different between ebb-and-flow and drip irrigation in the production of Asiatic hybrid lilies.

Literature Cited

Aimone, T. 1986. Culture notes. Grower Talks 50(8):16.

Bakos, S. 1983. Forcing themselves on a willing public. Florists' Rev. 173(4471):26–28, 30.

Beck, R. 1984. The "hows" and "whys" of hybrid lilies. Florists' Rev. 175(4529):22, 24, 27.

Beel, E. and G. Piens. 1987. Water regulation with *Azalea indica*. Verbondsnieuws voor de Belgische Sierteelt 31(11):693, 695. (Abstr.)

Burger, D.W., J.S. Hartin, D.R. Hodel, T.A. Lukaszewski, S.A. Tjosvold, and S.A. Wagner. 1987. Water use in California's ornamental nurseries. Calif. Agr. 41(9–10):7–8.

Conover, C.A. and R.T. Poole. 1984. Light and fertilizer recommendations for the production of acclimatized potted foliage plants. Foliage Dig. 7(8):1–6.

Elliott, G.C. 1990. Reduce water and fertilizer with ebb and flow. Greenhouse Grower 8(6):70–75.

Furuta, T. 1976. Nitrogen fertilization of container grown ornamentals. Amer. Nurseryman 143(12):14, 106–109.

Grower Books. 1983. Foliage pot plant manual. Grower Books, London.

Harbaugh, B.K. and G.J. Wilfret. 1980. Spray carnation production with controlled-release fertilizer and trickle irrigation. J. Amer. Soc. Hort. Sci. 105:367–371.

Hasek, R.F., R.H Sciaroni, and R.L. Branson. 1986. Water conservation and recycling in ornamentals production. HortScience 21:35–38.

Kaniszewski, S. and J. Dysko. 1988. Effect of different irrigation systems on yield of tomatoes grown under plastic greenhouses. Acta Hort. 228:105–107.

Klassen, P. 1987. "We can't produce enough to fill demand!" Greenhouse Grower May:124–127.

Koch, G.M. and E.J. Holcomb. 1983. Utilization of recycled irrigation water on marigolds fertilized with Osmocote and constant liquid fertilization. J. Amer. Soc. Hort. Sci. 108:815–819.

McConnell, D.B., R.W. Henly, and R.L. Biamonte. 1981. Commercial foliage plants, p. 571. In: J.N. Joiner (ed.). Foliage plant production. Prentice Hall, Englewood Cliffs, N.J.

McKenzie, K. 1989. Potted lilies made easy: The new, naturally short Asiatic lily varieties. Grower Talks 52(12):48–58.

Paparozzi, E.T. and H.B. Tukey, Jr. 1979. Foliar uptake of nutrients by selected ornamental plants. J. Amer. Soc. Hort. Sci. 104:843–846.

SAS Institute. 1985. SAS user's guide: Statistics, version 5 ed. SAS Institute Inc., Cary, N.C.

Skimina, C.A. 1986. Recycling irrigation runoff of container ornamentals. HortScience 21:32–34.

Rowcovers Accelerate Fruiting and Increase Productivity in Primocane-fruiting Red Raspberries

Marvin Pritts[1], Eric Hanson[2], Joseph Fiola[3], and Mary Jo Kelly[1]

Additional index words. ***Rubus idaeus*****, polyester, polypropylene**

Summary. **Studies were conducted over eight location–years to evaluate the effects of rowcover material, time of application, and time of removal on 'Heritage' red raspberry cane growth, flowering, and fruiting. We anticipated that rowcovers would accelerate fruit maturity so that more of the crop could be harvested before the onset of cold temperatures in autumn. In seven of the eight experiments, rowcovers either increased yields or accelerated harvest. With a March application, harvest began 3 weeks earlier, and August yields of covered plants were 42 times higher than those of noncovered plants. Responses were observed with spunbonded polypropylene and polyester covers, but not with polyethylene covers. Rowcovers placed over the row before primocane emergence and removed when canes were ≈50 cm tall resulted in the greatest plant response. The use of polyester or polypropylene rowcovers with primocane-fruiting raspberries appears to be economically feasible in most years in northern climates.**

Primocane-fruiting raspberries are widely grown throughout the northern United States and

[1]*Department of Fruit and Vegetable Science, Cornell University, Ithaca, NY 14853.*

[2]*Department of Horticulture, Michigan State University, East Lansing, MI 48824.*

[3]*Rutgers Fruit Research and Development Center, Cream Ridge, NJ 08514.*

southern Canada. In many regions, fruiting begins in September, and harvest often is terminated by frost before a full crop is realized. Although cultivars that fruit earlier than the standard cultivar Heritage have been developed, these cultivars are not as widely adapted and/or often have fruit of inferior quality. Benefits could be realized for northern growers if cultural practices that promote earlier fruiting were identified and used.

Primocanes of 'Heritage' initiate flower buds when canes reach a certain physiological stage. This stage can be promoted by high temperatures, high N, or other factors that accelerate cane elongation in spring (Keep, 1961; Lockshin and Elfving, 1981; Vasilakakis et al., 1979). Rowcovers are used in cropping systems to trap infrared radiation and increase air temperatures under them. When used with primocane-fruiting raspberries, rowcovers, in theory, should promote early growth by increasing temperatures around the growing canes. Early growth, in turn, might lead to earlier flowering and fruiting. Rowcovers have been used for several years by vegetable and strawberry growers to accelerate growth and increase yields (Pritts et al., 1989, Wells and Loy, 1985), but their use on raspberries has not been reported.

The objectives of this research were to: 1) examine the efficacy of rowcover use in promoting earlier fruiting and increasing yields in 'Heritage' red raspberry, 2) evaluate different types of rowcovers, and 3) determine optimum times to apply and remove rowcovers.

Experiments were conducted in New Jersey in 1989 and 1990, Michigan in 1987 through 1989, and New York in 1988 and 1989. Mature plantings of 'Heritage' red raspberry were used, and all canes were mowed annually to ground level in early spring to promote fall fruiting. Raspberries were fertilized in early spring, and standard pest control procedures were used at each location.

The experimental protocol was designed to evaluate the effects of rowcover material, time of application, and time of removal on flowering and fruiting (Table 1). Data collected at each location in each year included date of first fruit, yield per harvest interval, and total yield. Cane heights during the season, fruiting lateral number, node number at flowering, height of the basal fruiting node, date of first flower, and percentage of unharvested fruit also were collected from some experiments.

Table 1. ***Summary of experimental treatments for each of the location–years for which the tests were conducted. Each set of treatments also included a control.***

Location	Cover type	Timing	Year
Cream Ridge, N.J.	Kimberly Farms, 20 $g \cdot m^{-2}$	18 Apr.–12 May	1989
	Kimberly Farms, 40 $g \cdot m^{-2}$	18 Apr.–12 May	1989
	White polyethylene, 0.08 mm	18 Apr.–12 May	1989
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Mar.–12 May	1990
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Apr.–12 May	1990
Colts Neck, N.J.	Kimberly Farms, 20 $g \cdot m^{-2}$	18 Apr.–12 May	1989
Clarksville, Mich.	Slitted polyethylene, 0.03 mm	20 Apr.–30 May	1987
	Reemay, 20 $g \cdot m^{-2}$	20 Apr.–30 May	1987
	Reemay, 20 $g \cdot m^{-2}$	19 Apr.–2 June	1988
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Mar.–1 May	1989
	Kimberly Farms, 50 $g \cdot m^{-2}$	1 Mar.–1 June	1989
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Mar.–1 May	1989
	Kimberly Farms, 50 $g \cdot m^{-2}$	1 Mar.–1 June	1989
Ithaca, N.Y.	Kimberly Farms, 20 $g \cdot m^{-2}$	30 Mar.–19 May	1988
	Kimberly Farms, 50 $g \cdot m^{-2}$	30 Mar.–19 May	1988
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Mar.–1 May	1989
	Kimberly Farms, 50 $g \cdot m^{-2}$	1 Mar.–1 June	1989
	Kimberly Farms, 20 $g \cdot m^{-2}$	1 Mar.–1 May	1989
	Kimberly Farms, 50 $g \cdot m^{-2}$	1 Mar.–1 June	1989

Average daily production was estimated by dividing yield on a particular harvest date by the number of days since the previous harvest. Average daily production then was summed over the appropriate interval so seasonal patterns of production could be expressed in regular intervals. Data were subjected to appropriate analysis of variance procedures.

Description of experiments

New Jersey. Experiments were conducted at an experimental farm in Cream Ridge and a commercial farm in Colts Neck. In 1989 at Cream Ridge, 1-m-wide covers were applied on 18 Apr. and removed on 12 May. Treat-

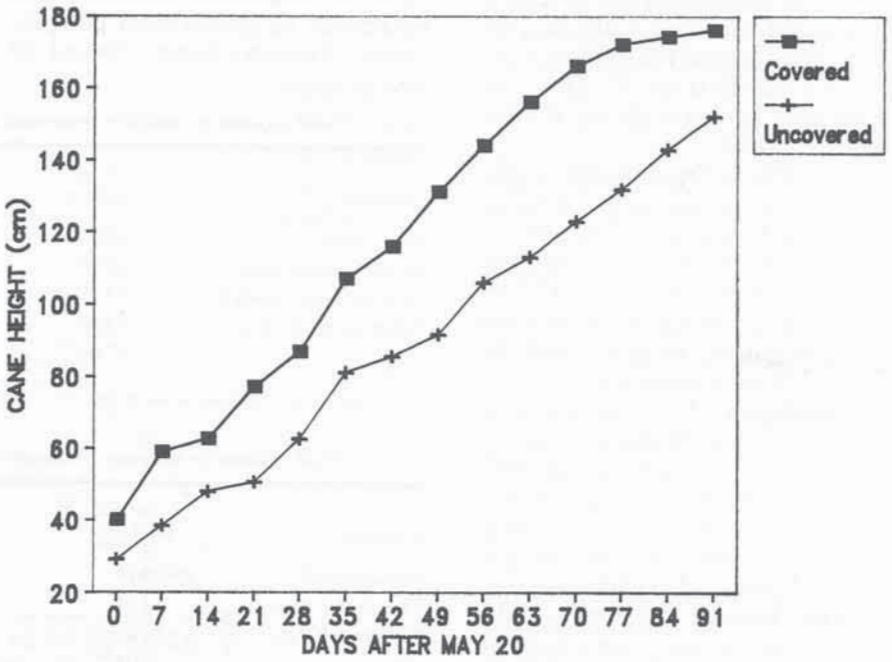

Fig. 1. ***Average cane height over the season measured under covered and noncovered plots at Ithaca, N.Y., in 1988.***

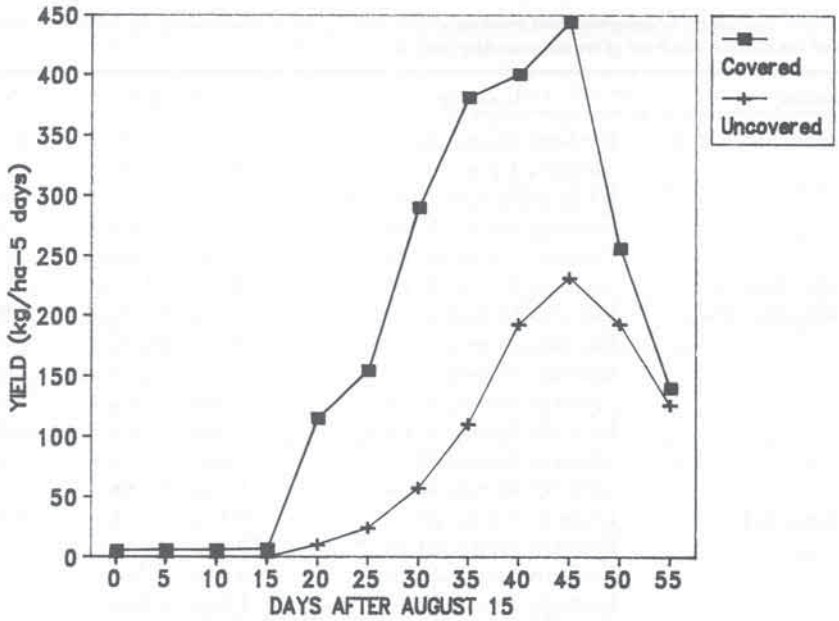

Fig. 2. ***Yield distribution under covered and noncovered plots at Ithaca, N.Y., in 1988.***

ments included a single layer of white polypropylene rowcover (Kimberly Farms floating rowcover, 20 $g \cdot m^{-2}$), a double layer of polypropylene, a single layer of white polyethylene plastic (0.08 mm), and a control with no cover. The experiment was a completely randomized design with four replications. Plots were 2.5 m long.

In Colts Neck in 1989, a single layer of white polypropylene (Kimberly Farms, 20 $g \cdot m^{-2}$) was applied to three 15-m-long plots on 18 Apr., with three additional plots serving as noncovered controls. Treatments were randomized among the six plots. Covers were removed on 12 May, and plants were harvested during the late summer and fall.

In 1990 at Cream Ridge, single-layer polyester covers were applied on 1 Mar. or 1 Apr. to 2.5-m plots. A noncovered control also was included. Rowcovers were removed on 12 May 1990. The treatments were arranged in a randomized complete-block design with four replications.

Michigan. Experiments were conducted at the Michigan State Experiment Station, Clarksville. In 1987, treatments included a clear, slitted, polyethylene rowcover (0.03 mm) suspended above the row on wire hoops, a spunbonded white polyester material (Reemay, 20 $g \cdot m^{-2}$), and a noncovered control. Covers were applied on 20 Apr. and removed on 30 May. Treatments were arranged in a randomized complete-block design with five replications. Plots were 15 m long.

In 1988, the spunbonded polyester material was laid loosely over the row on 19 Apr. and removed on 2 June. Experimental design and plot size were the same as in 1987.

In 1989, a randomized complete-block design with four replications was used to test the effect of rowcover thickness and date of removal. Plots were 3 m long. A factorial arrangement of treatments included two thicknesses of spunbonded polypropylene (Kimberly Farms, 20 and 50 $g \cdot m^{-2}$) and two dates of removal (1 May and 1 June), plus a nontreated control. Covers were applied on 1 Mar.

New York. In 1988, two thicknesses of rowcover (Kimberly Farms, 20 and 50 $g \cdot m^{-2}$) were assigned randomly to each of three 20-m rows. An additional three rows served as controls. Rowcovers were applied on 30 Mar. and removed on 19 May. A 3-m section of each row was harvested, and cane heights were monitored throughout the season.

In 1989, an experiment identical to the one in Michigan was conducted at the Cornell Orchards Research Farm, Ithaca.

Spunbonded rowcovers (Kimberly Farms and Reemay) accelerated growth (Figs. 1 and 4), flowering, and fruiting in most years and locations (Figs. 2, 3, 5, and 6; Tables 2, 3, 4, and 5). Yields generally were increased because a greater portion of the potential yield was harvested before the first severe frost. For example, at Ithaca in 1988, differences in cane height between covered and noncovered plots were maintained for at least 3 months after covers were removed (Fig. 1), and the accelerated development under covered plots resulted in earlier production of fruit (Fig. 2). Cold temperatures began on 1 Oct. and dramatically slowed fruit ripening for both treatments, but cumulative yield was significantly higher for plots with accelerated development.

At Cream Ridge in 1989, the first

Table 2. ***Yield response to rowcover treatment at Cream Ridge, N.J., in 1989.***

Treatment	Total yield (g)	August yield (g)	Date first harvest	Date peak harvest
Noncovered	3049	623	21 Aug.	13 Sept.
Single spunbonded	2256	1207	13 Aug.	1 Sept.
Double spunbonded	2377	999	13 Aug.	3 Sept.
White polyethylene	3250	871	19 Aug.	6 Sept.
$LSD_{0.05}$	1700^{NS}	902^{NS}	12 Days^{NS}	12 Days*

^{NS}, *Nonsignificant or significant treatment effects at $P < 0.05$, respectively.

Table 3. ***Yield response to rowcover treatment at Cream Ridge, N.J., in 1990.***

Treatment	Total yield (g)	August yield (g)	Date first harvest	Date peak harvest
Noncovered	2144	57	29 Aug.	18 Sept.
Covered 1 Mar.	4431	2413	7 Aug.	1 Sept.
Covered 1 Apr.	2588	881	12 Aug.	7 Sept.
$LSD_{0.05}$	2504^{NS}	557*	8 Days**	13 Days*

^{NS}, *, **Nonsignificant or significant treatment effects at $P < 0.05$ or 0.01, respectively.

harvest under the single spunbonded polypropylene rowcover was 8 days earlier than the control, and peak harvest was an average of 12 days earlier (Table 2). August yields were increased an average of 94% compared to the control. However, some of these differences were not statistically significant because of extreme variability among plots for early yield. If plots with the same treatment differ by as much as 2 or 3 days in date of first ripening, then very large differences in early yield can result; hence, statistical significance will be difficult to obtain. With the single layer of spunbonded rowcover, 77% of the total yield was harvested by the end of August, compared with just 48% in noncovered controls. The response of the double layer was not significantly different from that of the single layer, and the white plastic cover did not have a significant effect on harvest date or yield.

At Colts Neck in 1989, yields were 30% higher under the covered treatments compared to the control. At the end of August, 80% of the fruit was harvested from the covered plots, but only 60% from the noncovered plots (data not shown).

The effects of the rowcovers were most dramatic at Cream Ridge in 1990 (Table 3). The March-applied rowcover accelerated first harvest by 3 weeks, and the early August yield was 42 times higher than that of nontreated plants (Fig. 3). The April-applied rowcover accelerated harvest by 17 days, and August yield was 17 times higher than the control. Early yield reflected the accelerated cane growth rate (Fig. 4).

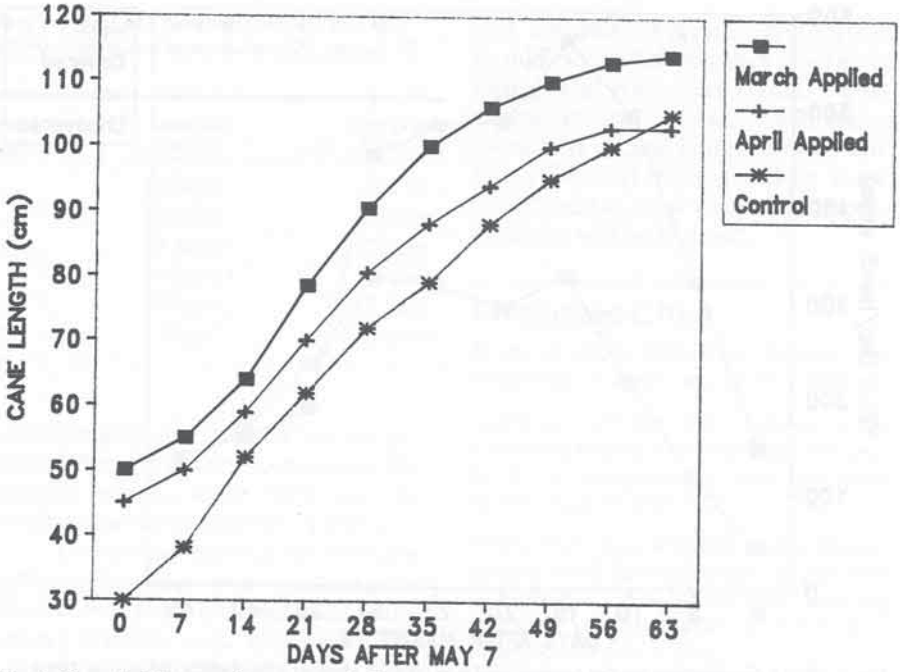

Fig. 4. *Cane height over the season as influenced by application time at Cream Ridge, N.J., in 1990.*

At Clarksville in 1987, in contrast with the New Jersey results in 1990, neither the plastic cover nor the spunbonded polyester had a significant effect on growth or yield. In 1988, however, yields were affected dramatically by the spunbonded cover (Fig. 5). The mean total yield of noncovered plots (2130 g) was significantly less ($P < 0.05$) than that of covered plots (3420 g).

In New York in 1989, date of first flowering and fruiting were significantly accelerated by the rowcover treatments (Table 4). Acceleration of flowering and fruiting also was observed in Michigan with the same set of treatments, but raspberry yield responded more to the weight of the rowcover in New York (Table 4) and more to the date of removal in Michigan (Fig. 6, Table 5). Data suggest that rowcovers influence the rate of plant development and not the individual yield components of the plant (Table 4).

In most years and locations, spunbonded covers accelerated cane growth in spring, resulting in earlier flowering and fruiting. Since the market availability of raspberry fruit is low during mid-August, there is an advantage to producing an earlier crop. Also, when fruiting begins earlier, a greater percentage of the total crop can be harvested before a damaging frost occurs. For these reasons, spunbonded rowcovers appear to be beneficial in locations that experience relatively late summer or early autumn frosts.

A second benefit of rowcovers

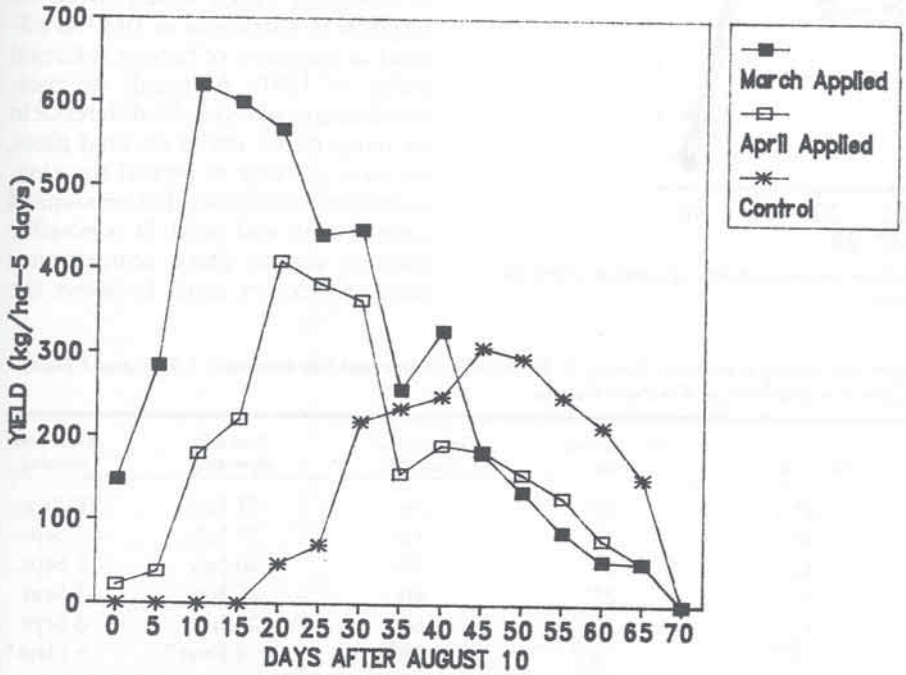

Fig. 3. *Yield distribution with different application times at Cream Ridge, N.J., in 1990.*

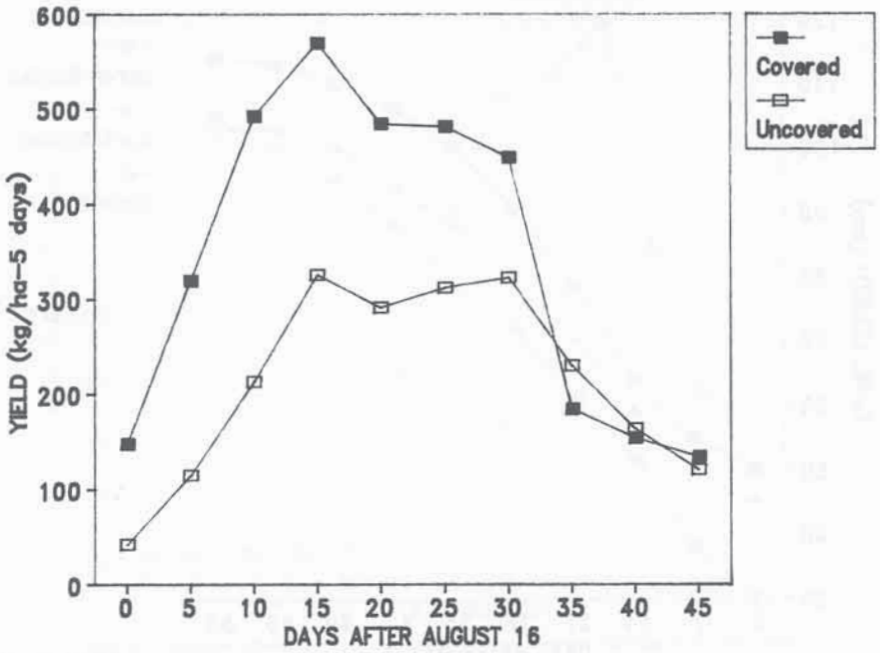

Fig. 5. *Yield distribution under covered and noncovered plots at Clarksville, Mich., in 1988.*

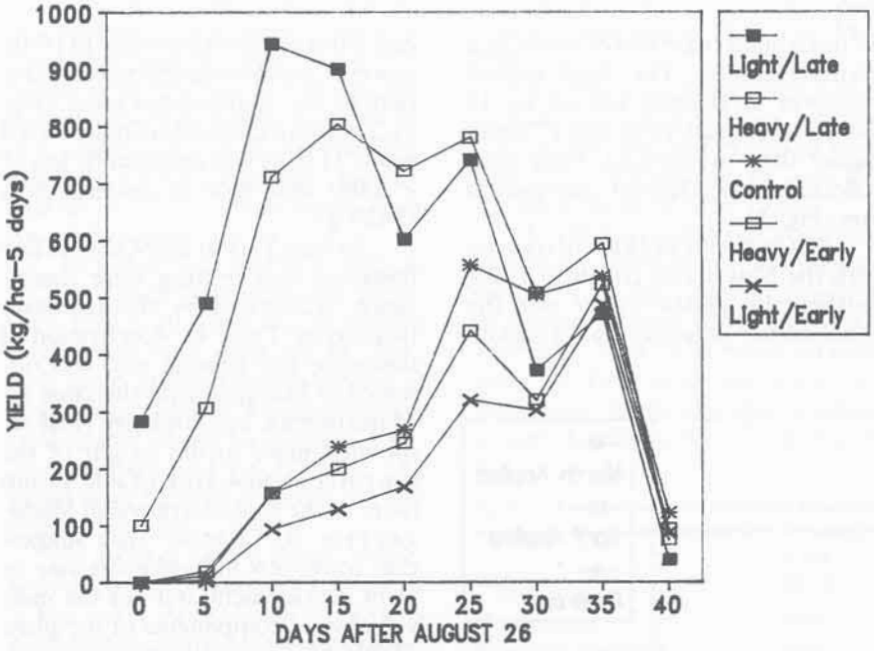

Fig. 6. *Pattern of yield response to cover weight (light or heavy) and date of removal [early (1 May) or late (1 June)] in Clarksville, Mich., in 1989.*

was observed in Michigan and New Jersey in 1989. In Michigan, an early May frost killed many primocanes in noncovered plots, and this also resulted in a yield advantage for covered plots. In New Jersey, snowfall in early April damaged primocanes on noncovered plots, but covered plots were unaffected. In years where late frosts or snows occur, the use of rowcovers on a portion of the planting would help stagger the production peaks.

White or clear polyethylene rowcovers had no effect on cane growth or fruiting. Even though our data were collected at only two locations, a grower trial with clear polyethylene in New York and a university trial in Iowa (Gail Nonnecke, personal communication) also found no significant benefit from using polyethylene tunnels. Apparently the spunbonded materials provide a more optimal environment for cane growth in spring than do polyethylene covers.

The time of cover application had a major effect on fruit production patterns. In New Jersey in 1990, the early March application resulted in higher, earlier yields than the early April application, and both were earlier and more productive than noncovered plots, suggesting that covers must be in place before cane growth begins in spring.

It is important to note that the magnitude of the response of 'Heritage' to rowcover varied widely, from no response in Clarksville in 1987 to a 3-week acceleration of harvest at Cream Ridge in 1990. Although we measured an approximate 3C difference in air temperature under covered plots, we were not able to predict the environmental conditions that maximized cane growth and yield. It is possible that, in certain years, temperatures under rowcovers could be above the

Table 4. *Yield component response to rowcover weight and date of removal at Ithaca, N.Y., in 1989. Early and late removal: 1 May and 1 June, respectively. Light and heavy material: 20 and 50 g·m^{-2}, respectively, of Kimberly Farms.*

Treatment	Total yield (g)	Cane ht (cm)	No. nodes	No. fruiting nodes	Unharvested fruit (%)	Date first flowering	Date first fruiting
Noncovered	3397	150	41	27	54	31 July	28 Aug.
Light, early	3839	151	43	27	46	27 July	2 Sept.
Light, late	3698	146	42	27	46	26 July	5 Sept.
Heavy, early	4919	152	42	27	50	25 July	1 Sept.
Heavy, late	4425	147	42	27	50	27 July	6 Sept.
$LSD_{0.05}$	1180*	16^{NS}	3^{NS}	3^{NS}	29^{NS}	4 Days*	5 Days*

^{NS},*Nonsignificant or significant treatment effects at $P < 0.05$, respectively.

Table 5. *Yield response to rowcover weight and date of removal at Clarksville, Mich., in 1989. Early and late removal: 1 May and 1 June, respectively. Light and heavy material: 20 and 50 g·cm^{-2}, respectively, of Kimberly Farms.*

Treatment	Total yield (g)	August yield (g)	Date first fruiting	Date peak harvest
Noncovered	2466	36	14 Sept.	5 Oct.
Light, early	1645	22	12 Sept.	8 Oct.
Light, late	4988	832	1 Sept.	17 Sept.
Heavy, early	2056	28	10 Sept.	7 Oct.
Heavy, late	4654	375	1 Sept.	18 Sept.
$LSD_{0.05}$	1554**	171**	6 Days**	4 Days**

**Significant treatment effects at $P < 0.01$.

optimum for plant growth; hence, growth of covered plants may be no different than that of noncovered plants in warm springs. In Michigan in 1987, when no effect of rowcover was measured, the spring was early and temperatures averaged 3.4C above normal. Clearly, the effects of environment on 'Heritage' cane growth and development require more extensive study.

Rowcovers influenced the rate of cane growth, but did not appear to influence plant growth habit. At the end of the season, cane heights of covered and noncovered plants were similar. Further, node numbers and the node at which fruiting terminated were nearly identical among treatments. These measurements suggest that rowcovers do not affect yield components directly; the yield increase often observed with rowcover use is attributed to an extended harvest period. When frost does not truncate the harvest season, total yields may be similar among treatments (Table 1).

These experiments provided eight different location–year combinations for observation. In all but one of the years, benefits were observed from using a spunbonded rowcover. The cost of purchasing and installing the lightweight material is about $1200/ha for raspberries, and the material can be used for two seasons if abrasion from cane stubble is not severe. In locations where frosts truncate the harvest season, the use of rowcovers may be economically feasible.

Our data suggest that spunbonded floating rowcovers are superior to plastics for promoting early growth and fruiting in 'Heritage' red raspberry. In the northern United States and southern Canada, application should occur before canes emerge in spring, and rowcovers should be removed around 1 June, which corresponds to a cane height of ≈50 cm. Flowering and fruiting will be accelerated, and in most years, higher productivity will be realized.

Literature Cited

Keep, E. 1961. Primocane fruiting red raspberries. J. Hort. Sci. 36:174–185.

Lockshin, L.S. and D.C. Elfving. 1981. Flowering response of 'Heritage' red raspberry to temperature and nitrogen. HortScience 16:527–528.

Pritts, M.P., K.A. Worden, and M. Eames-Sheavly. 1989. Rowcover material and time of application and removal affect ripening and yield of strawberries. J. Amer. Soc. Hort. Sci. 114:531–536.

Vasilakakis, M.D., B.E. Struckmeyer, and M.N. Dana. 1979. Temperature and development of red raspberry flower buds. J. Amer. Soc. Hort. Sci. 104:61–62.

Wells, O.S. and J.B. Loy. 1985. Intensive vegetable production with rowcovers. HortScience 20:822–826.

Acknowledgements

We acknowledge the technical assistance of Robert Lengyen, Marcia Eames-Sheavly, and Douglas Reichert.