Manipulating Propagule Type and Interrow Ground Cover to Influence Flowering Time, Yield, Fruit Quality, and Harvest Dates in the Day-neutral Strawberry 'Albion'

Mykala Robertson[1] and Marvin Pritts[1]

Keywords. exclusion netting, *Fragaria ×ananassa*, interrow groundcover, pollinators, tarnished plant bug

Abstract. We examined methods of producing day-neutral strawberries in a north temperate climate using alternatives to standard bare-root propagules and clean cultivation between plant rows. *Fragaria ×ananassa* 'Albion' were planted in plastic-covered raised beds in Ithaca, NY, USA, for each of the 2022 and 2023 growing seasons. Plants were selected from the following four propagule types from different developmental stages: standard bare-root plants set in early May; bare-root plants started in the greenhouse in February and planted in early May; bare-root plants started in the greenhouse in March and planted in early May; and plug plants set in the field in fall (Aug 2021 and Oct 2022) of the previous year. To determine if pollination could be enhanced, each type of plant was grown in plots in the field with one of the following between rows: bare ground; a diverse flowering groundcover; or exclusion netting on hoops over the strawberry plants when they were flowering. Pollinators visiting strawberries were observed weekly and identified to species when possible. Fruits were collected weekly and marketable and unmarketable yields were measured through the harvest season. Fall-planted plugs produced significantly higher marketable yields than those of other propagule types in both years. Bare-root plants set in early May had the lowest yield. Percent marketable yield varied depending on the growing year because of drastically different weather conditions. There was no evidence that flowering groundcover attracted pollinators to the strawberry plants because strawberries had few pollinator visits, regardless of the surrounding vegetation. Exclusion netting had significantly higher percent marketable yield and total yield than the those of other groundcover types despite lower percent fruit set, likely because of the benefits of tarnished plant bug exclusion.

Year-round strawberry availability in the United States relies on production in warmer climates like those in California and Florida. However, producing and delivering this crop to population centers across the country are energy-intensive and require significant time between harvest and consumption. Production closer to markets has advantages in terms of resource use and quality of fruit.

Several different production systems are used to produce strawberries in northeastern North America (Orde and Sideman 2023). Hodgdon et al. (2024) reported that most farms primarily grow June-bearing cultivars (>75% of production) in perennial systems, but day-neutral cultivars in annual systems comprise the majority on 21% of farms in Ontario and Québec and 15% of farms in New York. Day-neutral strawberries allow growers to extend the season beyond the limited short-day season because they flower within 2 to 3 months of planting and continue flowering throughout the summer and early fall. They do not flower continuously, but they exhibit flushes of flowers (Hancock 1999), resulting in an uneven pattern of production. Planting strawberries at various developmental stages and times could possibly even out production peaks by staggering these flushes.

Commercial strawberry nurseries sell dormant bare-root plants for spring planting or plug plants for fall planting. Fall-planted plug plants are produced by removing daughter plants from the stolon of a mother plant in midsummer and rooting them for transplanting (Black et al. 2010). This allows growers "increased flexibility in planting date as well as producing less transplant shock and improving plant establishment as a result of a developed root system" (Weber 2021). However, for optimal productivity in colder climates, row covers must be used in fall to enhance plant establishment, and it may be difficult to source quality plug planting stock for late summer planting (Hancock et al. 1997). As an alternative, "early start" (ES) plants (bare-root plants started in the greenhouse before field planting) have the potential to produce similar performance to that of plug plants because both the roots and vegetative growth are more developed at the time of field planting. One hypothesis of this study is that flowering and fruiting will occur at different times if propagule types are at different stages of development when planted into the field, potentially leading to more continuous fruit production if various propagule types. A corollary hypothesis is that different propagules will vary in seasonal yield potential. A third hypothesis is that a flowering interrow groundcover will attract pollinators that will increase pollination of adjacent strawberry flowers and enhance fruit size and yield.

Materials and methods

Raised beds 10 cm from the ground, 0.8 m wide, and covered with white-on-black plastic 1 mil film (Grower's Solution, Cookeville, TN, USA) with 2.0 m between row centers were established in a Cornell Agricultural Experiment Station field (lat. 42.441775, long. −76.471034) in Ithaca, NY, USA, with an Arkport fine sandy loam (mesic Lamellic Hapludalf) soil. Six replications of three groundcover treatments 4 × 6 m in size (18 whole plots in total) surrounding two raised beds were established in fall, and interrow groundcover treatments were randomly assigned to the whole plots. Interrow treatments were as follows: 1) bare ground that was cultivated regularly to prevent flowering of the natural vegetation; 2) a spring hand-seeded flowering species (*Lobularia maritima* in 2022 and *Trifolium repens*

Received for publication 27 Sep 2024. Accepted for publication 20 Nov 2024.

Published online 13 Jan 2025.

[1]School of Integrative Plant Science, Horticulture section, Cornell University, Ithaca, NY 14850, USA

M.P. is the corresponding author. E-mail: mpp3@cornell.edu.

https://doi.org/10.21273/HORTTECH05553-24

in 2023) complementing the natural vegetation (*Galinsoga quadriradiata*, *Oxalis stricta*, *Matricaria recutita*, *Medicago polymorpha*, and *Veronica chamaedrys*); and 3) plots where pollinators were excluded with a white fine mesh netting (1 mm; Mosquito Curtains, Alpharetta, GA, USA) over the plants. The mesh netting was installed over low tunnel hoops (Dubois Agrinovation, St. Remi, QC, Canada) that were approximately 80 cm above the plastic film and remained closed except during harvest periods.

Lobularia maritima was slow to establish and was a weak competitor with weeds. In 2023, we used *Trifolium repens* as the introduced species because it is more competitive with weeds and is a strong nectar source. Regardless, in both years, there was strong continuous flowering in the designated plots from a combination of the introduced and existing species.

Within each whole plot, four subplot rows were planted to various propagule types of 'Albion' strawberry. Subplots consisted of a raised bed in a staggered double row with 16 plants per 2.5 m. Propagule treatments were randomized within whole plots for a completely randomized split-plot design. Subplots were as follows: 1) plug-type propagules planted in fall (Aug 2021 or Oct 2022); 2) ES bare-root plants from greenhouse trays plugged in late February (ES1) and planted in early May; 3) ES bare-root plants from greenhouse trays plugged in late March (ES2) and planted in early May; and 4) standard dormant bare-root plants set in the field in early May. Each subplot (a 2.5-m-long row of strawberry plants) was located within the whole plot of vegetation management type with at least 1 m of treatment vegetation type adjacent to the strawberry propagation subplot.

Strawberry plants were supplied by Nourse Farms (Whately, MA, USA) except in 2022, when we used a commercial source for plug plants (McNitt Growers, Carbondale, IL, USA) in contrast to 2021, when we made our own plugs. To make plugs, 'Albion' bare-root plants were set in pots in a greenhouse in May 2021 and runner tips were collected in July. Tips were rooted under mist in 5- × 5- × 10-cm plug trays filled with Lambert 111 soil mix (Riviere-Ouelle, QC, Canada).

After planting on 26 Aug 2021, fall-planted plugs were covered with a semi-transparent spunbonded row cover (30 $g \cdot m^{-2}$; Agribon-30, Johnny's Selected Seeds, Winslow, ME, USA), and it remained on the plants over the winter. The ES transplants began as bare-root crowns planted in the aforementioned plug trays on 14 Feb and 21 Mar in 2022 and on 13 Feb and 20 Mar in 2023, and they were maintained in a greenhouse without supplemental light until field planting in early May. Roots were trimmed before setting into the plug trays.

While in the greenhouse, all plants were fertilized with 150 ppm nitrogen (N) (21–2.2–16.6–9.9 N–P–K–Mg; JR Peters, Allentown, PA, USA) on weekdays and with plain water on weekends. Flowers and runners were removed to encourage vegetative growth while in the greenhouse. ES1 plants typically had more than four fully expanded leaves, and ES2 plants typically had four or fewer at the time of planting. Dormant bare-root plants were planted directly in the field in early May. Plants were not acclimated to the field before planting (Table 1).

In 2022, after planting, the plants received water through drip irrigation though a single drip tape in the center of the plastic mulch rows at least once each week and were simultaneously fertilized with 15.5N–0P–0K plus 19% calcium nitrate for a total of 5 $kg \cdot ha^{-1}$ actual N per week early in the season and 20N–4.4P–16.4K (JR Peters, Allentown, PA, USA) at 5 $kg \cdot ha^{-1}$ actual N after fruiting commenced. Plants were less frequently irrigated during the 2023 season because of above-average rainfall. For both years, flowers were removed weekly for the first month in the field in all propagules to allow for establishment and vegetative growth. All runners were removed weekly for the entire season for both years.

Chemical pest management strategies were implemented when pests were severely impacting fruit quality. Tarnished plant bug (TPB; *Lygus lineolaris*) populations exceeding the economic threshold of three nymphs per 15 flower clusters were treated with the bioinsecticide Grandevo (Marrone Bio Innovations, Raleigh, NC, USA) weekly per label instructions from 23 Jun to 13 Aug 2022, and once with

Table 1. Timeline for generating various propagule types for both the 2022 and 2023 growing seasons.

2022 Propagation Schedule		
Propagule	**Date**	**Timeline**
Plug	27 Jul 2021	Runner tips trimmed and planted in plug trays
		Maintained in greenhouse
	26 Aug 2021	In-field planting
	1 Dec 2021	Row covers applied
	13 Apr 2022	Row covers removed
ES1	14 Feb 2022	Dormant crowns planted in plug trays
		Maintained in greenhouse
	6 May 2022	In-field planting
ES2	21 Mar 2022	Dormant crowns planted in plug trays
		Maintained in greenhouse
	6 May 2022	In-field planting
Bare root	6 May 2022	Planted in field following dormant cold storage
2023 Propagation Schedule		
Propagule	**Date**	**Timeline**
Plug	7 Oct 2022	Prepared plants arrived and were planted in the field
	14 Oct 2022	Row covers applied
	10 Apr 2023	Row covers removed
ES1	13 Feb 2023	Dormant crowns planted in plug trays
		Maintained in greenhouse
	5 May 2023	In-field planting
ES2	24 Mar 2023	Dormant crowns planted in plug trays
		Maintained in greenhouse
	5 May 2023	In-field planting
Bare root	5 May 2023	Planted in field following dormant cold storage

ES = early start.

Table 2. Main effects of propagule type and interrow groundcover on fruit characteristics of 'Albion' strawberry grown in Ithaca, NY, USA, in 2022. ES1 and ES2 refer to starting plants in the greenhouse in February and March, respectively. Percent fruit set from open plots (from combined bare ground and flowering cover treatments) is reported as bare ground % fruit set. Different letters within a main effect imply statistical differences at $P < 0.05$.

Main effect	Variables			
Propagule	**Total yield (g)**	**% Marketable**	**Fruit size**	**% Fruit set**
Bare root	1,090 c	34.5	10.7 a	73.5
ES1	2,009 ab	35.4	9.6 b	73.6
ES2	1,667 b	31.7	9.5 b	73.0
Plug	2,418 a	29.8	10.6 a	73.0
P value	0.0001	NS	0.0002	NS
Groundcover				
Bare ground	1,364 b	41.8 a	10.0 ab	77.0 a
Flowering cover	1,304 b	25.4 b	9.4 b	N/A
Exclusion netting	2,718 a	31.4 b	10.9 a	67.6 b
P value	0.0001	0.005	0.008	0.0001
Interaction				
P value	NS	NS	NS	0.0001

ES = early start; N/A = not available; NS = not significant.

malathion (FMC, Philadelphia, PA, USA) on 22 Jul 2022. In 2023, TPB was treated with azadirachtin (Aza-Direct; Gowan, Yuma, AZ, USA) biweekly per the label from 15 Jun 2023 to 14 Jul 2023, and once with malathion on 18 Aug 2023. Weeds were managed primarily through hand-weeding under strawberry plants and periodic mowing in between rows. Herbicide (glufosinate; BASF, Florham, NJ, USA) was spot-applied on 9 May 2022 and 11 Aug 2022 to assist with weed management. The herbicide was applied to all groundcover treatments directly next to the plastic mulch to control weeds that had begun to grow up the sides of the raised beds and could not be managed by hand-weeding alone without disrupting the plastic mulch. Because of a fruit anthracnose outbreak (*Colletotrichum acutatum*) in 2023, cyprodinil and fludioxonil (Switch 62.5WG; Syngenta, Wilmington, DE, USA) were applied on 18 Aug 2023 per the label rate.

Pollinators visiting the strawberries were observed weekly beginning 24 May 2022 through 23 Sep 2022, and from 5 Jun 2023 through 22 Sep 2023. Over both years the main pollinators were *Halictus confusus*, *Lasioglossum* sp., *Augochlorella aurata*, and *Bombus impatiens*. Different pollinators were observed visiting the flowering groundcover compared to those visiting the strawberry plants. Few honeybees (*Apis mellifera*) were observed visiting strawberry flowers in either year.

Harvest occurred once each week from 2 Jun to 30 Sep 2022 and from 22 Jun to 21 Sep 2023. Fruits were weighed, counted, and sorted into marketable and unmarketable classes according to the US Department of Agriculture strawberry grading standards. Unmarketable fruits were smaller than 5 g, misshapen, diseased, physically damaged, or not uniformly ripe. Percent marketable yield was determined by the average percent of marketable fruit by weight divided by the total yield over the entire season. Average fruit size was calculated monthly from the marketable yield divided by the number of fruits per sample and then averaged over the season. Percent fruit set (% of total achenes that were fertilized) was measured on fruits under exclusion tunnels and on fruits from the treatments without exclusion netting by counting both filled and unfilled achenes of the surface of several representative fruits per plot at each harvest date. Data from the latter two treatments were combined because both were open-pollinated.

Analyses were performed using R Statistical Software (version 4.1.1; R Core Team RStudio, Vienna, Austria) (R Core Team 2021). Data were read into software with "readxl" (Wickham and Bryan 2019) and tidied with "dplyr," "tidyr," and "stringr" (Wickham 2019, 2021; Wickham et al. 2022). Data for each year were analyzed separately using linear mixed models using "lmer" (packages "lme4" and "lmerTest") linear mixed models comprising block and cover nested in block as random effects and propagule treatment, interrow cover, and their two-way and three-way interaction terms as fixed effects (Bates et al. 2015; Kuznetsova et al. 2017). The length of the picking season was log-transformed in 2023 to meet linear model assumptions. Post hoc analyses used the emmeans package (Lenth 2023). Tukey's honestly significant difference multiple comparisons procedure was used to elucidate significance. Results were visualized using "emmip" and "ggplot2" (Wickham 2016). Significance letters were added to the visualizations using "cld" (package "multcomp"), and

Table 3. Main effects of propagule type and interrow groundcover on fruit characteristics on 'Albion' strawberry grown in Ithaca, NY, USA, in 2023. ES1 and ES2 refer to starting plants in the greenhouse in February and March, respectively. Percent fruit set from open plots (from combined bare ground and flowering cover treatments) is reported as bare ground % fruit set. Different letters within a main effect imply statistical differences at $P < 0.05$.

Main effect	Variables			
Propagule	**Total yield (g)**	**% Marketable**	**Fruit size**	**% Fruit set**
Bare root	993 b	30.6 ab	10.6 c	65.3 c
ES1	1,115 ab	27.1 b	11.0 bc	62.7 c
ES2	1,363 ab	32.2 ab	12.6 a	70.4 a
Plug	2,331 a	37.1 a	12.3 ab	68.0 b
P value	0.014	0.023	0.0001	0.0001
Groundcover				
Bare ground	864 b	31.5	11.1	72.1 a
Flowering cover	944 b	30.1	11.6	N/A
Exclusion netting	2,573 a	33.6	12.1	54.0 b
P value	0.001	NS	NS	0.0001
Interaction				
P value	NS	NS	NS	0.0001

ES = early start; N/A = not available; NS = not significant.

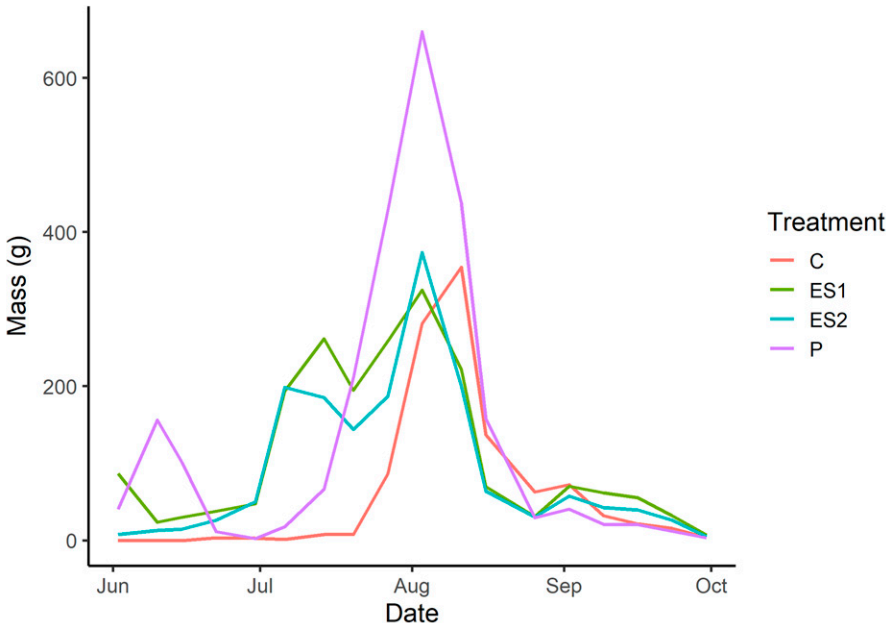

Fig. 1. Average total weekly yields (g/plot) of 'Albion' strawberry by propagule type during the growing season in 2022. C = bare root; ES1 = started in February; ES2 = started in March; P = plug planted in fall.

error bars on graphs represent 95% confidence intervals (Graves et al. 2019). Yield was aggregated on a per-plot basis without accounting for sporadic mortality over the season.

Results

Yields differed among propagule types, with plug plants having the highest yields (Tables 2 and 3) and peaking in early August in both years (Figs. 1 and 2). In 2022, yield in all propagule types peaked in August; however, in 2023, propagule types other than plugs peaked later in the season. Plug propagules produced the greatest mean total yield over the season in both years, followed by the ES propagules, with bare-root plants producing the least amount of fruit. In every case, propagules under the exclusion netting outperformed the same propagules with or without adjacent flowering groundcover in both years (Figs. 3 and 4). The combination of fall-planted plug propagules grown under exclusion netting had the highest yields of any treatment combination in both years.

Plant mortality was negligible during the 2022 growing season; however, in 2023, excessive and continuous rain induced an outbreak of anthracnose (*Colletotrichum acutatum*), resulting in increased plant mortality near the end of the season. Plug propagules experienced 17% plant mortality, followed by bare-root plants at 10.8%, ES2 plants at 6.3% loss, and ES1 plants at 4.2% loss. Despite having the greatest mortality in 2023, plug plants still had the highest yield among propagule types.

In 2022 and 2023, average fruit weight differed among propagule types, but there were no consistent trends except that fruit from plug plants was never the smallest. Fruit set was not statistically different among propagule treatments in 2022, but treatments differed in 2023 (Table 3), with ES2 plants having the highest set (70.4%).

Interrow groundcover and exclusion treatments also affected yield. Yield under exclusion netting was highest in both years ($P < 0.001$), and the bare ground and flowering groundcover treatments were not different from each other (Tables 2 and 3). Fruit size was the same across groundcover treatments in 2023 (average, 11.6 g/fruit), whereas the flowering groundcover treatment had the smallest fruit in 2022 (9.4 g/fruit vs. 10.0 g/fruit and 10.9 g/fruit for bare ground and exclusion netting, respectively). Fruit set was lowest under the exclusion netting in both years.

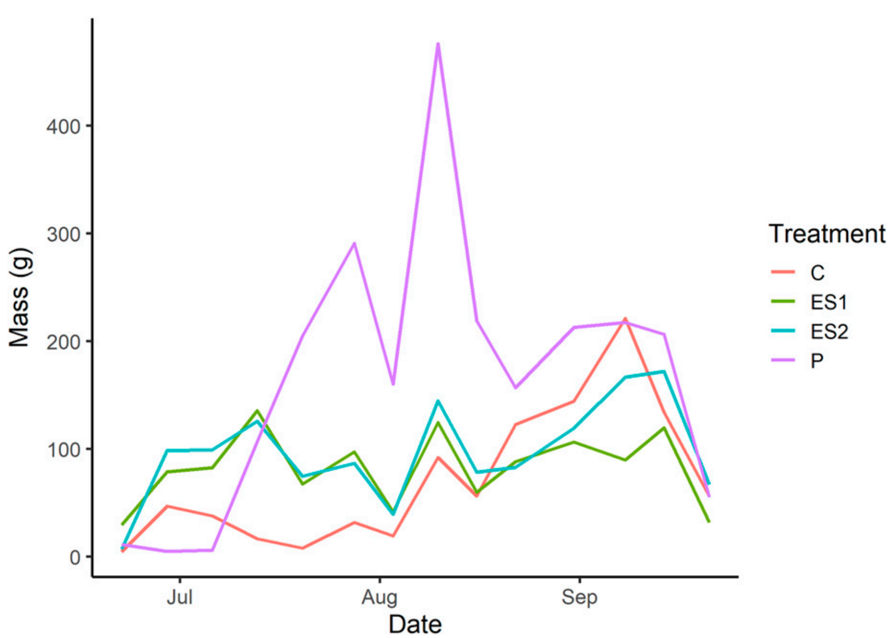

Fig. 2. Average total weekly yields (g/plot) of 'Albion' strawberry by propagule type during the growing season in 2023. C = bare root; ES1 = started in February; ES2 = started in March; P = plug planted in fall.

Discussion

Plug plants produced the greatest average marketable and total yield in both years, likely because of ample time for establishment and acclimation in the field environment. By planting plug propagules in fall, the plants acclimated and established in a cool environment, developed cold hardiness through the winter, and produced far more healthy vegetative growth in spring compared with the other propagules. This was true even when the planting date for plugs was later than recommended, as in 2023 (Orde and Sideman 2023). If

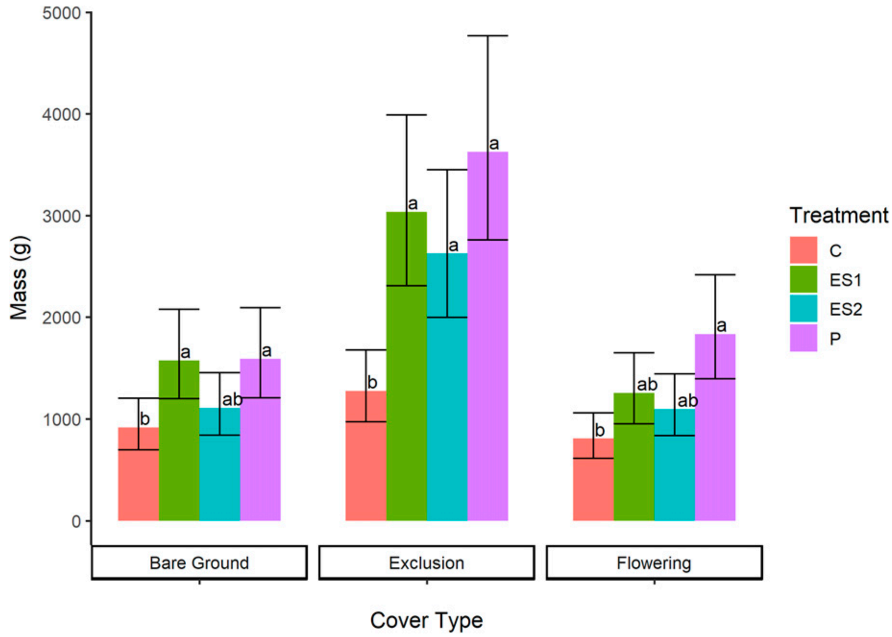

Fig. 3. Modeled estimated marginal means for average total yields (G) separated by interrow cover type for 2022. Comparisons valid within cover types among the propagule types. Tests were performed using the log scale. *P* value adjustment: the Tukey method was used to compare a family of four means.

plugs could be commercially available in late August, then day-neutral growers in north temperature climates would benefit because the plug propagules can also provide an early harvest in late May (Weber et al. 2018).

Yields were related to the time that plants were growing before flowering and fruiting. Plug plants always had the highest yield, followed by ES1, ES2, and bare-root plants set in May. This is not surprising because larger plants would be expected to produce greater yields. Because the growing season is often quite short in the northeastern United States, as evident from the length of harvest dates, bare-root plants started earlier in a protected greenhouse environment have a greater chance of producing an acceptable yield. Gaisser et al. (2024) also found that plants started in the greenhouse before field planting in May yielded at least 30% more yield than that of standard bare-root plants directly planted in May.

Both ES propagules had difficulty with field acclimation after transplanting in 2022 and 2023. Much of the vegetative growth that developed in the greenhouse died back quickly, suggesting that these propagules may be sensitive to environmental conditions, especially wind, when set out in the field in May. An acclimatization protocol likely would have helped these plants adapt to field conditions.

No evidence indicated that establishing flowering plants of other species between rows of strawberry increased fruit set by attracting more pollinators to the adjacent strawberry flowers. In fact, yields were highest when pollinators were excluded from the strawberry flowers. The netting also excluded TPB, which likely enhanced productivity in 'Albion', which can self-pollinate (MacInnis and Forrest 2020). Even though the netting reduced fruit set, the average fruit size and percent marketable fruit were greater because of the absence of TPB damage.

The flowering cover acted as a host plant and breeding grounds for TPB, which were able to cross onto the strawberries and feed aggressively, as also reported by Schloemann and Piñero (2020) and Grab et al. (2018). Limiting attractive pest vegetation near flowering strawberry plants appears to be important for increasing percent marketable fruit, especially for organic growers who may not have as many effective spray options as conventional growers.

Weather impacted the harvest season through drastically different growing conditions in 2022 and 2023. In 2022 and 2023, rain occurred on 38% and 57% of the days during the growing season, respectively (NRCC The Ithaca Climate Page n.d.). Despite plug plants having a high mortality rate because of anthracnose in 2023, yields of plug plant plots were highest.

Even though fruit set was lowest under the exclusion netting, yields were highest because of lower TPB damage. This was consistent in both years. Growers of day-neutral strawberries

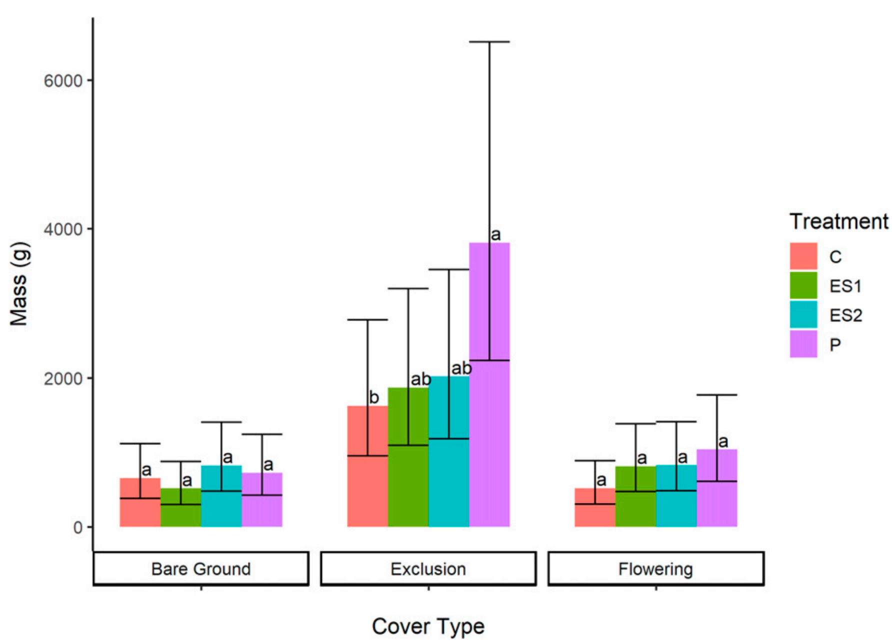

Fig. 4. Modeled estimated marginal means for average total yields (G) separated by interrow cover type for 2023. Comparisons valid within cover types among the propagule types. Tests were performed using the log scale. *P* value adjustment: the Tukey method was used to compare a family of four means.

should control TPB whether by insecticides or exclusion netting because damage from TPB may be greater than the benefit from bee pollination, at least for the cultivar Albion. Other cultivars may have a different response to exclusion or TPB injury.

In summary, our results suggest that the longer plants are in the ground and the sooner that they can be planted, the greater the yields that they will produce. Starting plants early, either through fall-planted plugs or ES, will give them the potential to have higher yields compared with standard bare-root plantings in spring. Plugs planted in late August rather than October should produce more yield, but plugs are typically not available from commercial sources in August. Despite different propagules being planted at different times, peak production was similar in a year without frost. Plug plants had a small early peak, but the largest peak was similar for all propagule types. When a freeze event killed flowers and developing fruit in May, production peaks were shifted later in the season. Planting flowering species between rows to enhance pollination services failed to attract pollinators to strawberry flowers. Rather, these flowering plants attracted TPB, which diminished yields by damaging fruit. Exclusion netting that prevented insect pollination also prevented significant TPB damage; therefore, overall, it was beneficial for this cultivar.

We conclude that day-neutral plants perform best if they are planted as plugs in late summer or started earlier in a protected environment before field planting. The ES propagule types appear to be more susceptible to weather extremes after field planting; therefore, performance could be enhanced with an acclimation protocol. Using multiple types of propagules did not stagger production peaks significantly. Establishing a flowering groundcover between rows of strawberry did not enhance pollination, but it did attract TPB and resulted in more unmarketable fruit. Exclusion netting was beneficial for preventing TPB damage and increasing yield even though it resulted in a lower percent of fertilized achenes.

References cited

Bates D, Mächler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. J Stat Softw. 67(1):1–48. https://doi.org/10.18637/jss.v067.i01.

Black B, Drost D, Rowley D. 2010. Strawberry plug plant production. https://www.sare.org/wp-content/uploads/Strawberry-Plug-Plant-Production.pdf. [accessed 16 Oct 2023].

Gaisser R, Kuehn K, Pritts M. 2024. Novel low tunnel coverings and plant type affect productivity of day-neutral strawberries. HortTechnology. 34(3):381–387. https://doi.org/10.21273/HORTTECH05409-24.

Grab H, Poveda K, Danforth B, Loeb G. 2018. Landscape context shifts the balance of costs and benefits from wildflower borders on multiple ecosystem services. Proc Biol Sci. 285(1884):1102. https://doi.org/10.1098/rspb.2018.1102.

Graves S, Piepho H, Selzer L, Dorai-Raj S. 2019. multcompView: Visualizations of paired comparisons. R package version 0.1-8. https://CRAN.R-project.org/package=multcompView.

Hancock JF. 1999. Strawberries. CAB International, New York, NY, USA.

Hancock JF, Goulart BL, Luby JJ, Pritts MP. 1997. The strawberry matted row: Practical cropping system of dated anachronism? Adv Strawberry Res. 16:1–4.

Hodgdon E, Conner DS, McDermott L, Pritts MP, Handley DT, Orde KM, Grube Sideman R. 2024. A current view on strawberry production practices and trends in the northeastern United States and Canada. HortTechnology. 34(5):574–584. https://doi.org/10.21273/HORTTECH05457-24.

Kuznetsova A, Brockhoff PB, Christensen RHB. 2017. lmerTest package: Tests in linear mixed effects models. J Stat Softw. 82(13):1–26. https://doi.org/10.18637/jss.v082.i13.

Lenth RV. 2023. emmeans: Estimated marginal means, aka least-squares means. R package version 1.8.4-1. https://CRAN.R-project.org/package=emmeans.

MacInnis G, Forrest JRK. 2020. Field design can affect cross-pollination and crop yield in strawberry (*Fragaria x ananassa*). Agric Ecosys Environ. 289:106738. https://doi.org/10.1016/j.agee.2019.106738.

NRCC The Ithaca Climate Page. n.d. https://www.nrcc.cornell.edu/wxstation/ithaca/ithaca.html. [accessed 16 Oct 2023].

Orde K, Sideman R (eds). 2023. Strawberry production guide for the Northeast, Midwest, and eastern Canada. University of New Hampshire Cooperative Extension, Durham, NH, USA. https://extension.unh.edu/resource/strawberry-production-guide-northeast-midwest-eastern-canada-2nd-edition.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Schloemann S, Piñero J. 2020. IPM Fact Sheet Series. UMass Center for Agriculture, Food, and the Environment. https://ag.umass.edu/landscape/fact-sheets.

Weber CA. 2021. Strawberry crown plugs provide flexibility and improved performance in cold climate plasticulture production. Agronomy. 11(8):1635. https://doi.org/10.3390/agronomy11081635.

Weber C, Gassier R, Kuehn K, Pritts MP. 2018. Yield of day-neutral strawberries grown under low tunnels is affected by planting date. HortScience. 53(9):S171. https://doi.org/10.21273/HORTSCI.53.9S.S1.

Wickham H. 2016. ggplot2: Elegant graphics for data analysis. Springer-Verlag, New York, NY, USA. https://ggplot2.tidyverse.org.

Wickham H. 2019. stringr: Simple, consistent wrappers for common string operations. R package version 1.4.0. https://CRAN.R-project.org/package=stringr.

Wickham H. 2021. tidyr: Tidy messy data. R package version 1.1.4. https://CRAN.R-project.org/package=tidyr.

Wickham H, Bryan J. 2019. readxl: Read excel files. R package version 1.3.1. https://CRAN.R-project.org/package=readxl.

Wickham H, François R, Henry L, Müller K. 2022. dplyr: A grammar of data manipulation. R package version 1.0.10. https://CRAN.R-project.org/package=dplyr.