Biodegradable Plastic Mulches in Tissue Culture Red Raspberry

Lisa DeVetter (PI), Carol Miles, Inga Zasada, Chris Benedict, and Shuresh Ghimire
WSU-Mount Vernon Northwestern Washington Research and Extension Center

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Application of Biodegradable Plastic Mulches in Tissue Culture Red Raspberry: Impacts on Weed Control, Parasitic Nematodes, and Crop Growth

The overall goal of this project is to develop knowledge and practical strategies to manage weeds while improving establishment and yield in commercial red raspberry planted as tissue culture (TC) plugs. TC raspberry plantings are increasing in Washington, largely due to the new cultivar ‘Wakefield’ (exclusively produced through TC), but also due to traditional cultivars such as ‘Meeker’ being offered as TC plugs for disease control. We are comparing four biodegradable plastic mulch (BDM) treatments to one non-degradable polyethylene (PE) mulch and a bare ground control (herbicide plus hand weeding; growers’ standard practice) in both spring- and fall-planted raspberry grown on commercial farms in northwest Washington. The spring-planted trial was established in May 2017 and the fall-planted trial was established Aug. 2017; prior to plot establishment, growers each fumigated the trial area following common practices in the region (the spring-planted trial was broadcast fumigated with Telone C-35 at 35 gallons per acre, the fall-planted trial was bed fumigated with Telone C-35 at 16 gallons per acre). Both trials will continue through 2019. Preliminary results indicate weed incidence was reduced in mulched plots compared to the bare ground control in both trials; no post-plant herbicides or hand-weeding were applied to mulched plots. In the spring-planted trial, BDM degradation started on 15 Aug., but was minimal by early fall. Primocane height was greater in mulched treatments relative to the bare ground control within one month of establishment in both trials. Primocane number was also greater in mulched treatments compared to bare ground from Aug. onwards in the spring-planted trial; it is too soon after plant establishment to measure differences in primocane number in the fall-planted trial. Soil temperature under mulches was higher than bare ground from mulch application onwards in both trials. The average soil volumetric water content in the spring-planted trial from 26 May to 30 Aug. was greatest for soil covered with PE mulch followed by BDMs and the bare ground control. There was essentially no root lesion nematode (*Pratylenchus penetrans*; RLN) populations prior to treatment application and samples collected in fall 2017 are being processed. Information from this study will contribute to the discovery of new and economically viable methods that improve TC raspberry establishment by controlling weeds, understanding how mulches influence RLN populations, and promote on-farm profitability for raspberry growers.

Procedures:

1. **Experimental design.** The project was established as two separate field trials (spring-planted and fall-planted TC raspberry) on commercial farms in Whatcom

County, WA, and included six treatments: four BDMs, one PE mulch, and a bare ground control (herbicide plus hand weeding) (Table 1).

2. **Soil fumigation.** Different soil fumigation methods were used in each trial. The spring-planted trial was broadcast fumigated on 23 Sept. 2016 with Telone C-35 at 35 gallons per acre and the fall-planted trial was bed fumigated on 6 June 2017 with Telone C-35 at 16 gallons per acre. A commercial application (Trident Agriculture Products, Woodland, WA) provided fumigation services at both trial sites.
3. **Mulch laying, hole punching and planting.** Mulches were applied in both trials with a custom-built flatbed mulch layer (Corvallis, OR). Planting holes were punched by hand using a custom-made dibble. 'WakeField' was hand planted on 18 May in the spring-planted trial and 'WakeHaven' was hand planted on 29 Aug. 2017 in the fall-planted trial; planting materials were TC plugs (Northwest Plant Co.; Lynden, WA) in both trials.
4. **Mulch deterioration.** Mulch deterioration on the surface of the bed was visually assessed as percent soil exposure (PSE) in the center 11 ft^2 area in each plot; assessments were made on the same area twice per month (approximately the 15th and 30th of each month) from May to Oct. in the spring-planted trial and from Aug. to Oct. in the fall-planted trial. Assessments will continue to Apr./May 2018 in the spring-planted trial and Aug. 2018 in the fall-planted trial.
5. **Weed incidence.** Total weed number as well as fresh and dry above-ground biomass present within a permanent 11 ft^2 area adjacent to the south side of the PSE region was recorded monthly on the same day that raspberry plant growth measurements were collected. Weeds were clipped at the soil level and immediately weighed to determine fresh weights. After fresh weights were recorded, weeds were dried at 100 °F for 5 days (or until constant weight) and weighed to determine dry shoot biomass.
6. ***Pratylechus penetrans* (RLN) population density determination.** Pre-fumigation RLN soil densities for both field sites were provided by grower cooperators. Baseline pre-plant RLN population densities were again determined from soil samples collected in each plot on 11 May for the spring-planted trial and 8 Aug. for the fall-planted trial (Table 2). Post-plant RLN population densities will be determined from soil and raspberry roots sampled on 10 Oct. 2017. Samples are currently being assayed by Dr. Inga Zasada. Soil samples were collected from the fall-planted trial only because the raspberry root system was too small for sampling; root samples from the fall-planted trial will be collected in Spring 2018.
7. **Soil temperature and moisture.** On 25 May for the spring-planted trial and 9 Aug. for the fall-planted trial, data loggers with sensors (EM50 Digital Data Logger and 5TM sensors; Decagon Device; Pullman, WA) were installed at a 4 in. depth and 2 in. from a plant in the third replicate of all treatments in both trials. Soil temperature and moisture were measured every 15 minutes and recordings will continue throughout the duration of the experiment.
8. **Plant growth.** Cumulative plant growth was measured monthly as primocane height and number from 10 plants per plot starting 26 May for the spring-planted

trial and 6 Sept. for the fall-planted trial. Measurements will continue through Oct. 2017 and will resume in Spring 2018.

9. **Fruit yield and quality.** Total machine harvestable yield will be determined from a minimum of 10 harvests in 2018 for the spring-planted trial and in 2019 for the fall-planted trial. Yield will be determined from a ~90 ft row length in the center of each plot in both trials. Fruit quality analyses will include determination of soluble solids concentration (measured as °Brix) and initial juice pH from a 30-berry sample per plot collected from three harvests (early, middle and late).
10. **Statistical analysis.** PSE and weed data were analyzed by using a non-parametric multiple comparisons Wilcoxon test (JMP 12; SAS Institute Inc.; Cary, NC) since they did not meet the assumption of equal variance. Plant height and primocane number were analyzed with a one-way ANOVA. The Tukey honest significant difference method was used for *post hoc* comparison at a 5% level of significance. To account for the randomized complete block design of the field experiment, all data were analyzed using block as random effects and treatment as fixed effects.

Preliminary Results and Discussion:

Percent soil exposure. Little mulch degradation was observed in the spring-planted trial across all mulch treatments during the period between mulch application (18 May 2017) to Sept. 2017 (Fig. 1A). By 29 Sept., average PSE across all BDM treatments was 7.6% (range was 5.6% to 9.6%). PSE in the spring-planted trial started to show differences between treatments on 14 July 2017, where PSE of BASF 0.6 was greater than PE (P = 0.01); deterioration of BASF 0.6 appeared along the drip line. By 29 Sept., PSE across all BDM treatments was greater than the PE mulch treatment (P = 0.01). Deterioration measured as PSE was slightly less for the thicker BDMs, but this observed difference was not significant. The increased deterioration observed across all BDM plots in Aug. and Sept. 2017 was attributed to moisture from the drip tape that caused the mulch to tear along the center of the bed. Additionally, raspberry prickles punctured the mulch as lengthening primocanes rested on the mulch surface (Fig. 2). There were no differences in PSE across treatments by 29 Sept. in the fall-planted trial, as mulch was applied only 6 weeks ago (9 Aug. 2017) (Fig. 1B).

Weed data. The maximum number of weeds in the spring-planted trial occurred in the bare ground control treatment, with the greatest weed number on 28 July and 29 Sept. 2017 (Fig. 3; P = 0.01 and 0.02, respectively). In the mulched treatments, a few weeds were present on the first sampling date in the BASF 0.5 and 0.6 treatments, where the mulch had been torn by initial application and installation of trellis posts. However, there were essentially no weeds thereafter. A pre-emergence herbicide of Surflan was applied once on 4 May 2017 to all treatments, but growers hand weeded bare ground control plots three times, with each weeding event requiring 45 mins for all the bare ground control plots in the field trial (a total row length of 600 ft). The most common weed species identified in the spring-planted trial were chickweed (*Stellaria media*), ladysthumb (*Persicaria maculosa*), pineapple weed (*Matricaria discoidea*), and crabgrass (*Digitaria sanguinalis*). There were also some potatoes (*Solanum tuberosum*) growing in the field due to previous land use. In the fall-planted trial, no weeds were observed in the mulch treatments, but there were 5 weeds per ft^2 on 29 Sept. in the bare ground treatment because the grower did not apply herbicide until Oct. 2017 (P = 0.012, data not presented) (Fig. 4). Aboveground weed biomass for the fall-planted trial is still being determined.

***Pratylechus penetrans* population density.** Baseline data show soil populations of RLN was at or close to 0 Pp/100 g soil in both trials and it is common to find these results early in the growing season following soil fumigation (Table 2). Dr. Zasada is presently extracting and analyzing root and soil samples collected in Oct. 2017 from the spring-planted trial, and soil samples from the fall-planted trial. We will then compare results to baseline RLN populations to determine if mulch treatments had an effect on RLN populations in the first year of establishment.

Soil temperature and moisture. In the spring-planted trial, soil temperature under the mulch treatments was higher than the bare ground control throughout the season (Fig. 5A). The exception to this was BASF 0.6, which had lower soil temperature than the bare ground control until 14 July, likely due to compacted soil that confounded the measurement. We moved the sensor to a new position thereafter and temperature in BASF 0.6 treatment was higher than bare ground control after 14 July. From 26 May to 30 Aug. 2017 (data for the BASF 0.6 treatment starts on 14 July), the average soil temperature across all mulch treatments was 70.5 °F (range was 69 to 72 °F), which was approximately 2.5 °F higher than the temperature of the bare ground control (68 °F). The average volumetric soil water content from 26 May to 30 Aug. was greatest for soil covered with PE mulch (0.31 m^3/m^3) followed by Bio360 0.6 and the bare ground control treatment (all 0.26 m^3/m^3) (Fig. 5B). Soil moisture in the BASF 0.5 treatment was lowest, averaging 0.17 m^3/m^3.

The equivalent or lower soil moisture content in the BDM treatments compared to the bare ground control was unexpected and may be caused by the distance of the sensor to the drip tape emitters. The distance of the soil temperature and moisture sensors to the drip tape emitters was measured on 15 Sept. 2017 and found to be 9, 11, 7, 9, 0, and 11 inches for the BASF 0.5, BASF 0.6, Bio360 0.5, Bio360 0.6, PE, and bare ground treatments, respectively. Although soil moisture in the BDM treatments was lower than the bare ground control, soil moisture was observed to increase according to mulch thickness. The lower soil moisture in the BDM treatments could be attributed to the diffusivity of the BDM materials, which may allow soil water to evaporate through the mulch. Soil evaporation could be increased in these treatments considering soil temperature was observed to be greater than the bare ground control.

In the fall-planted trial, all mulched plots had a higher soil temperature than the bare ground control (Fig. 6A). From 8 to 30 Aug. 2017, the average soil temperature in the mulched treatments was 75 °F (range was 74 to 76 °F), which was approximated 2 °F higher than the temperature of the bare ground control. The average soil volumetric soil water content (0.15 m^3/m^3) was higher across all mulch treatments compared to the bare ground control (0.12 m^3/m^3) from 8 to 30 Aug. 2017 (Fig. 6B).

Plant height and primocane number. In the spring-planted trial, plants across all mulched treatments had a higher primocane height than the bare ground control one month after planting (30 June; $P = 0.009$), and this difference in height remained through 29 Sept. 2017 (Fig. 7A). Number of primocanes per plant was the same until 30 Aug., when plants treated with PE and BASF 0.6 had a greater number of primocanes and were similar to plants in the Bio360 0.5 treatment (Fig. 7B; $P < 0.0001$). Primocane number collected on 29 Sept. followed the same trend as the 30 Aug. sampling date except there were fewer primocanes for all treatments, likely due to cane dieback caused by powdery mildew (*Sphaerotheca macularis*) and mite infestations (species not identified).

In the fall-planted trial, plants started to show height differences between treatments on 29 Sept. 2017, just one month after planting. PE mulch and Bio360 0.6 had a significantly higher primocane height than the bare ground treatment ($P = 0.04$) (Fig. 7C). No differences in primocane number were detected (data not presented).

Conclusions to Date and Future Work

Overall, BDMs and PE mulch performed well in commercial red raspberry production with plants established as TC plugs. Few weeds were observed in all mulched treatments in the spring-planted trial, and BDMs remained fully intact until minimal degradation was observed on 15 Aug. To date, no mulch degradation has been observed in the fall-planted trial. While these results suggest mulches are a viable tool for weed management in raspberry, it remains to be determined if they are more economically viable than herbicide application and hand weeding. In the spring-planted trial, plants grown with mulch exhibited greater primocane height and number than the bare ground control. Fall-planted raspberry also exhibited greater primocane growth in the mulched treatments relative to the bare ground control. Soil temperatures in both the spring- and fall-planted trials were higher across all mulch treatments than the bare ground control. While these first-year results are promising, it remains to be determined if these impacts will translate into greater yields and/or economic gains. Data collection will continue in both trials in 2018 and 2019.

Extension/Outreach Outputs

- Presentations
    - Zhang, H. (presenter), L.W. DeVetter, C. Miles, S. Ghimire, C. Benedict, and I. Zasada. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. 2017 WSU NWREC Summer Field Day. 11 July 2017. Mount Vernon, WA. Oral presentation.
    - Zhang, H. (presenter), L.W. DeVetter, C. Miles, S. Ghimire, C. Benedict, and I. Zasada. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. BDM Field Day. 11 Sept. 2017. Lynden, WA. Oral presentation.
    - Zhang, H. (presenter), L.W. DeVetter, C. Miles, S. Ghimire, C. Benedict, and I. Zasada. 2017. Application of Biodegradable Plastic Mulches on

Tissue Culture Red Raspberry. WSU Island County Master Garden Program. 23 Sept. 2017. Coupeville, WA. Oral presentation.
  - Zhang, H. (presenter), L.W. DeVetter, C. Miles, S. Ghimire, C. Benedict, and I. Zasada. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. WSU NWREC presentation to a group of students from British Columbia. 30 Sept. 2017. Mount Vernon, WA. Oral presentation.
- Newsletter articles
  - DeVetter, L.W. and C. Benedict. 2017. Exploring Biodegradable Plastic Mulches in Red Raspberry. Growing Produce. <http://www.growingproduce.com/fruits/berries/exploring-biodegradable-plastic-mulches-in-red-raspberry/>.
  - Zhang, H., L.W. DeVetter, C. Miles, S. Ghimire, C. Benedict, and I. Zasada. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. WSU Whatcom Ag. Monthly: Volume 6 Issue 9. < http://extension.wsu.edu/wam/application-of-biodegradable-plastic-mulches-on-tissue-culture-red-raspberry/ >.
- Website
  - Zhang, H, L.W. DeVetter, C. Miles, and S. Watkinson. 2017. Data Collection of Spring-planted Raspberry BDM Trial. WSU Small Fruit Horticulture Research & Extension Program. Video. <http://smallfruits.wsu.edu/>.
  - Zhang, H, L.W. DeVetter, C. Miles, and C. Benedict. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. WSU Small Fruit Horticulture Research & Extension Program. Video. <http://smallfruits.wsu.edu/>.
  - WSU Small Fruit Horticulture Research & Extension Program. 2017. BMDs in Raspberry Project. WSU NWREC, Mount Vernon, WA. < http://smallfruits.wsu.edu/articles-and-publications-on-bdms-in-raspberry/>.
- Factsheets
  - Zhang, H., L.W. DeVetter, C. Miles, C. Benedict, S. Ghimire, and E. Scheenstra. 2017. Application of Biodegradable Plastic Mulches on Tissue Culture Red Raspberry. Washington State University Extension Project Factsheet (in review).
  - Zhang, H., L.W. DeVetter, C. Miles, and S. Ghimire. 2017. Dimensions and costs of biodegradable plastic mulches and polyethylene for raspberry production. Washington State University Extension Project Factsheet (in review).

- Zhang, H., L.W. DeVetter, C. Miles, C. Benedict, S. Ghimire, and E. Scheenstra. 2017. Mechanically laying biodegradable plastic mulches in red raspberry planted as tissue culture plugs. Washington State University Extension Project Factsheet (in review).

Table 1. Mulch treatments applied on 11 and 18 May in spring- and 8 Aug. fall-planted red raspberry trials in Lynden, Washington.

Mulch product	Thickness	Manufacturer
BASF 0.5	0.5 mil	BASF Solutions; Maple Grove, MN
BASF 0.6	0.6 mil	BASF Solutions; Maple Grove, MN
Bio360 0.5	0.5 mil	Dubois Agrinovation; Saint Remi, Quebec, Canada
Bio360 0.6	0.6 mil	Dubois Agrinovation; Saint Remi, Quebec, Canada
Polyethylene (PE)	1.0 mil	FilmTech, LLC., Stanley, WI

Table 2. Baseline (pre-treatment) root lesion nematode (*Pratylenchus penetrans*; RLN) population densities in soil from the spring-planted trial (collected 11 May 2017) and the fall-planted trial (collected 8 Aug. 2017).

Treatment	RLN/100 g soil[z]	
	Spring-planted trial	Fall-planted trial
BASF 0.5	1.2	0
BASF 0.6	0	0
Bio360 0.5	0	0
Bio360 0.6	0	0
PE	1.2	0
Bare ground	0	0

[z]Values determined from 8 cores (1 in. diameter, 12 in. deep) per plot.

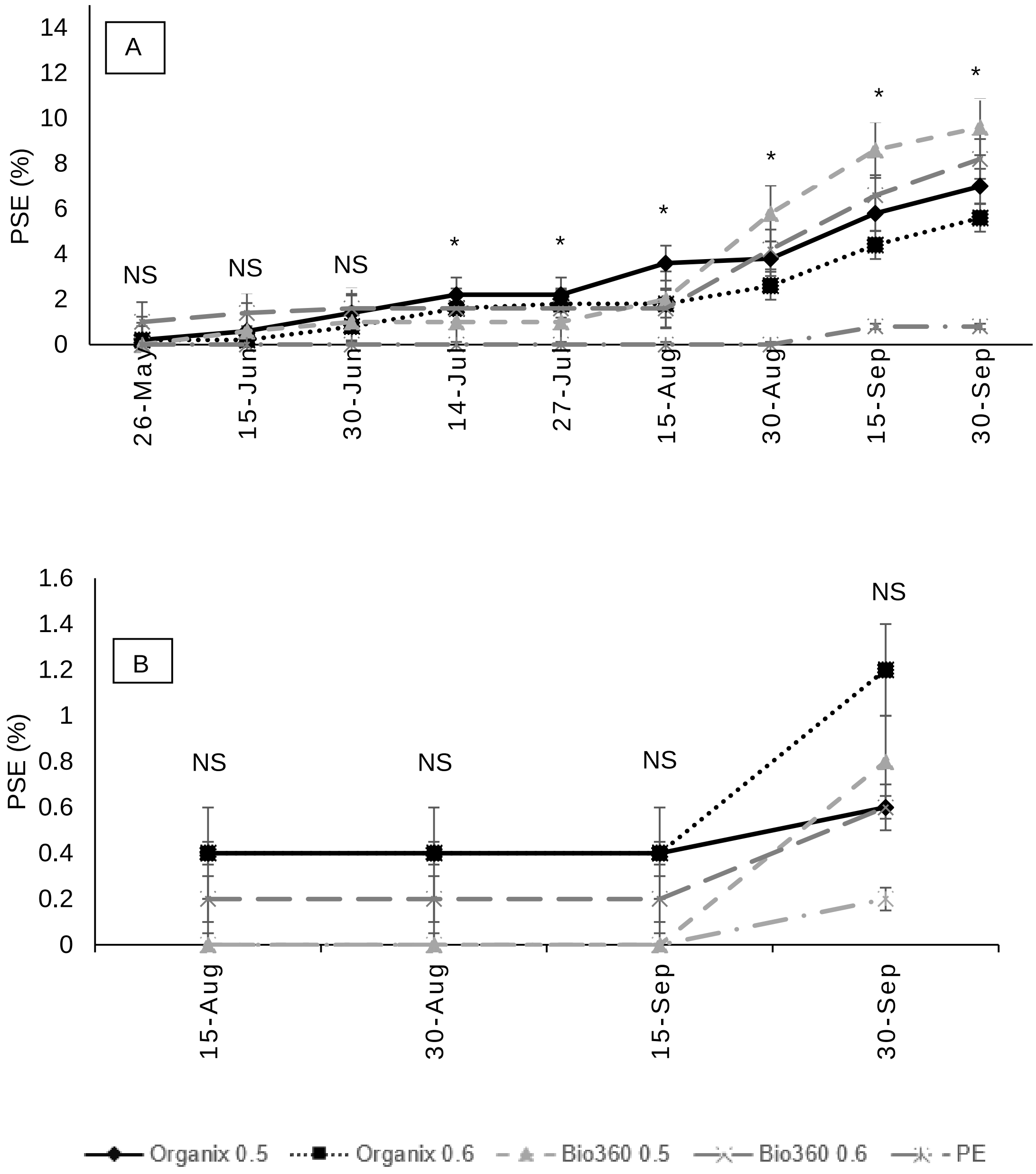

Figure 1. Percent soil exposure (PSE) in the spring-planted (A) and fall-planted trials (B) recorded twice monthly from a permanent 11 ft^2 area in each plot. Each data point represents a mean of 5 replicates ± SE. Where an error bar is not visible, it is small and masked by the data point symbol. NS, *, **, *** indicate not significant and significant at $P \leq 0.05$, 0.01, or 0.0001, respectively, using a non-parametric multiple comparisons Wilcoxon test. Note “Organix” is the BASF treatments.

Figure 2. Primocane prickles were observed to cause damage in the BDM treatments. Photos shows damage in the BASF 0.5 (A), BASF 0.6 (B), Bio360 0.5 (C), Bio36 0.6 (D) and PE (E) treatments in the spring-planted trial on 16 Oct. 2017. Damage along the center of the bed due to the drip tape (F) was observed on 30 Aug. 2017 in the BASF 0.5 treatment in the spring-planted trial.

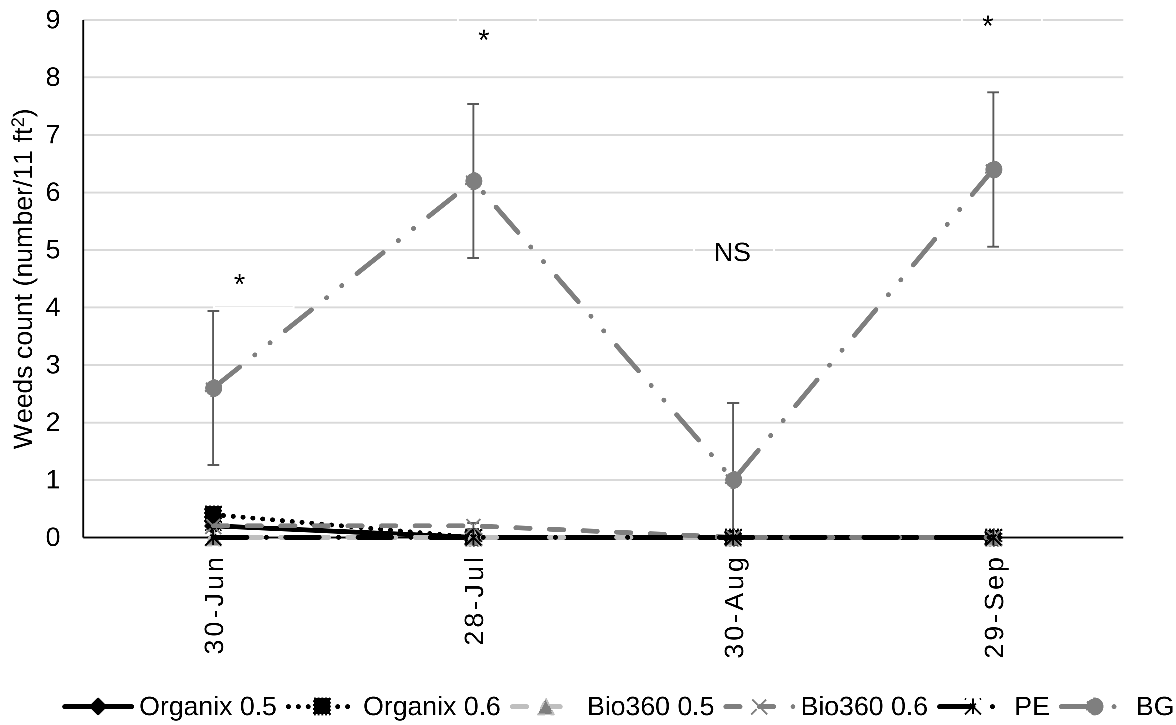

Figure 3. Number of weeds per 11 ft^2 on 30 June, 28 July, 30 Aug. and 29 Sept. 2017 in the spring-planted trial. Weed data were recorded monthly from a permanent sampling area in each plot. Each data point represents a mean of 5 replicates ± SE. Where an error bar is not visible, it is small and masked by the data point symbol. NS, *, **, *** indicate nonsignificant or significant differences by non-parametric multiple comparisons Wilcoxon test at *P* ≤ 0.05, 0.01, or 0.0001, respectively. Note “Organix” is BASF treatments.

Figure 4. Weeds incidence in a bare ground plot in the fall-planted trial (photo taken on 29 Sept. 2017).

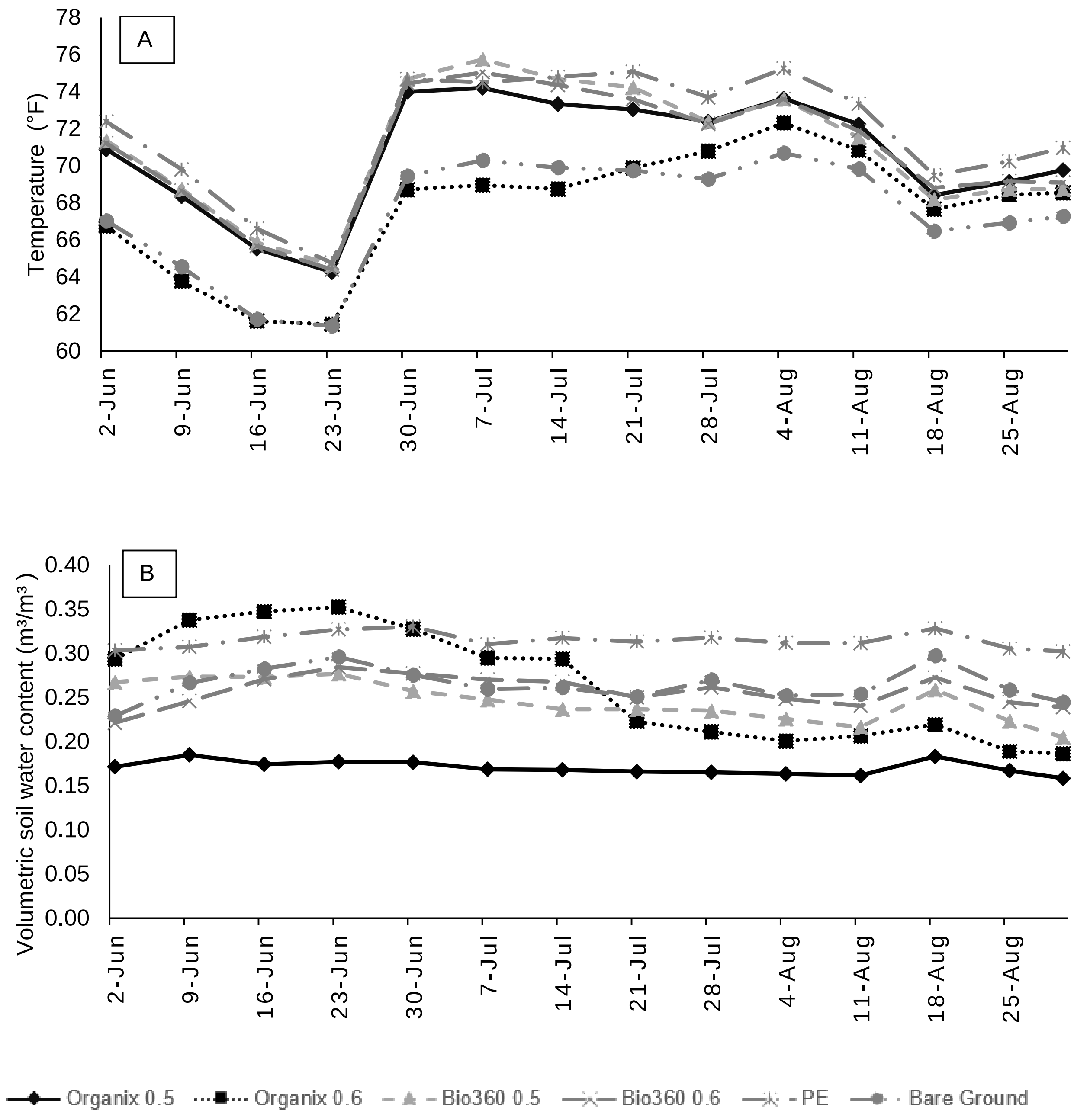

Figure 5. Average weekly soil temperature (A) and volumetric soil water content (B) recorded from sensors installed at a 4-in. depth in the spring-planted trial (values averaged over 24-hour period, from 25 May to 30 Aug. 2017). Note "Organix" is BASF treatments.

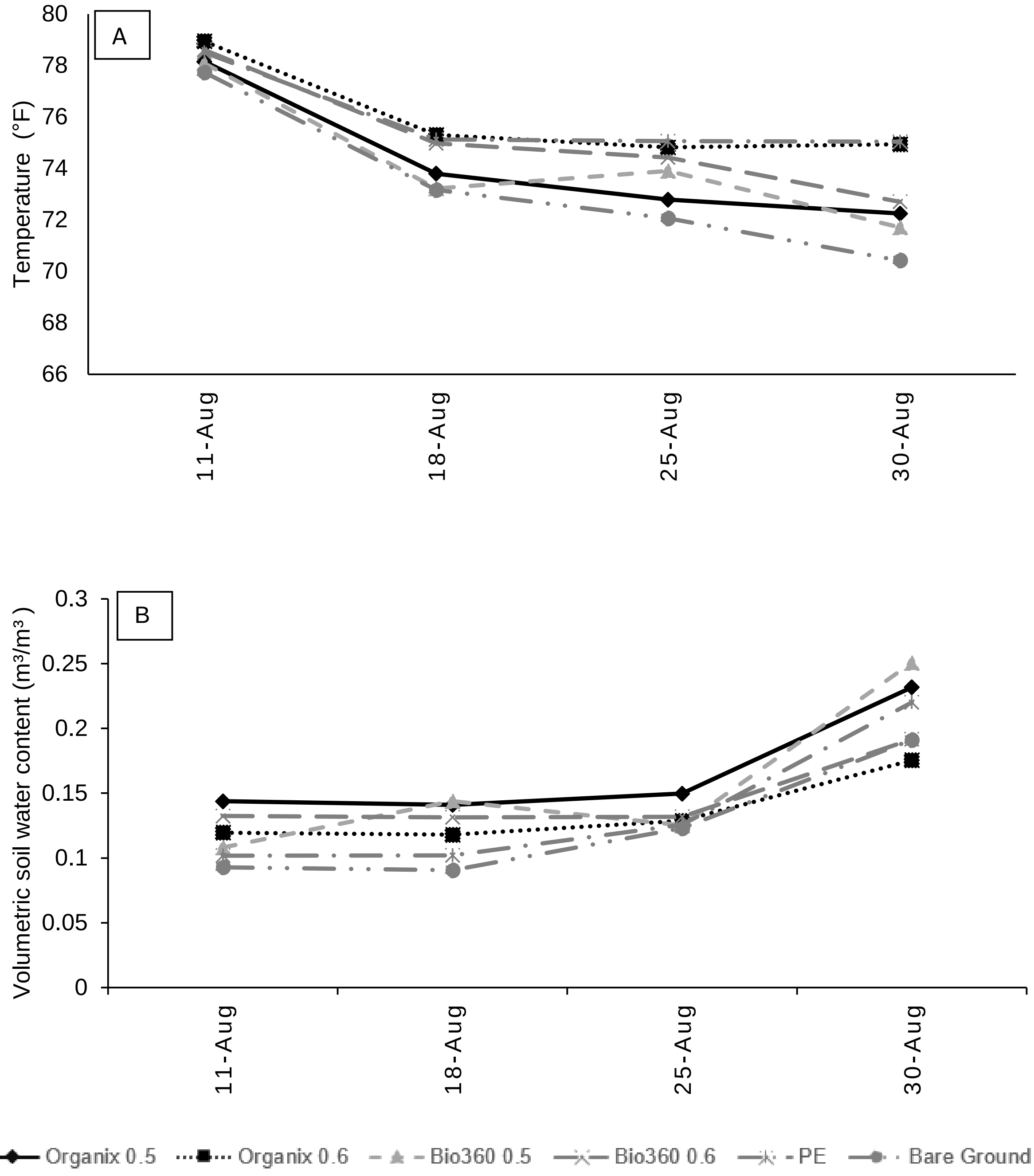

Figure 6. Average weekly soil temperature (A) and volumetric soil water content (B) recorded from sensors installed at a 4-in. depth in the fall-planted trial (values averaged over 24-hour period, from 8 May to 30 Aug. 2017). Note “Organix” is BASF treatments.

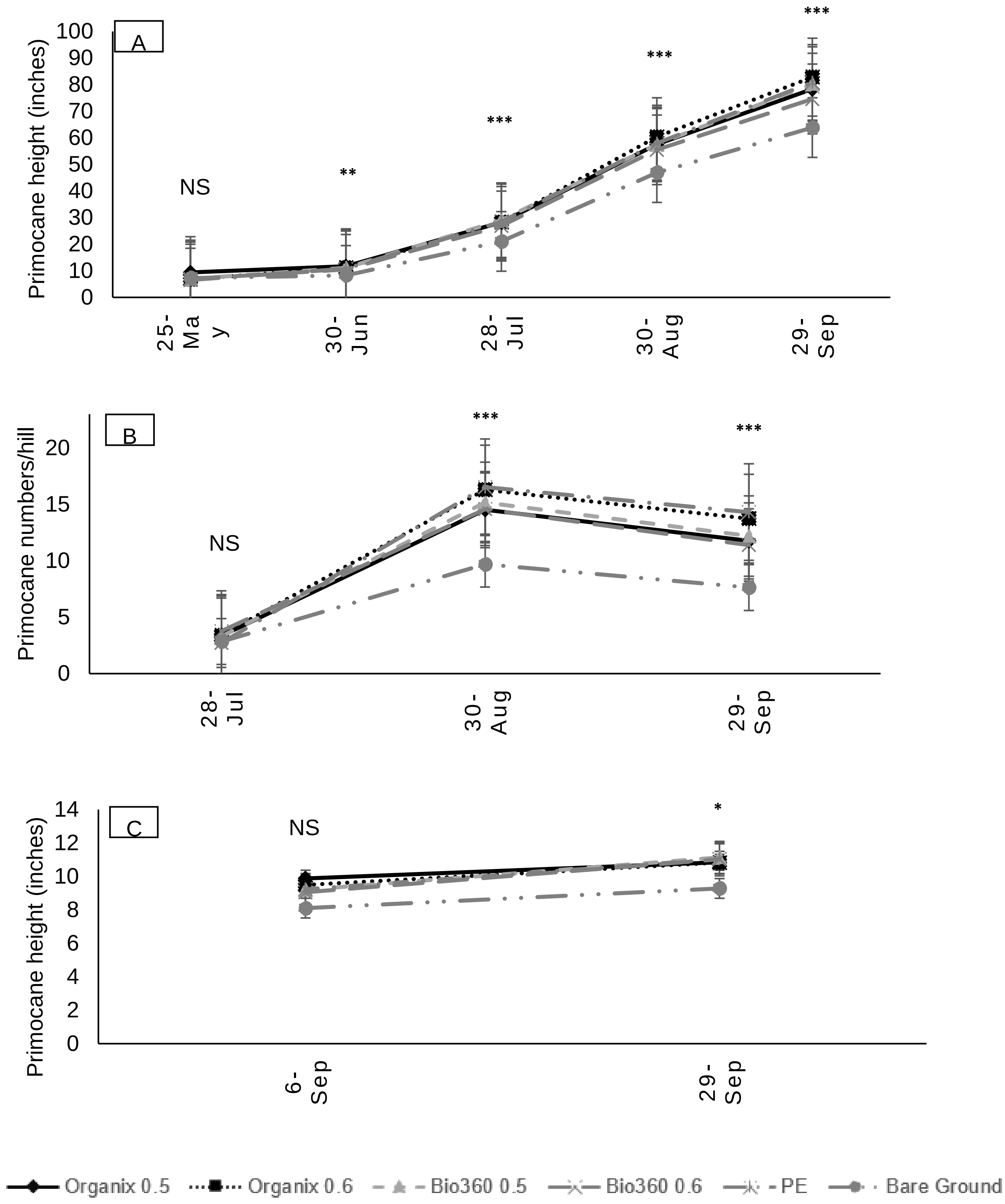

Figure 7. Average primocane height (A) and average primocane number (B) of 'WakeField' raspberry planted in spring 2017. Average primocane height (C) of 'WakeHaven' raspberry planted in fall 2017. NS, *, **, *** indicate nonsignificant or significant differences at *P* ≤ 0.05, 0.01, or 0.0001, respectively, using a means

comparison with a Tukey’s Honestly Significant Difference test. Note “Organix” is BASF treatments.