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## REUSING PLASTIC MULCH FOR A SECOND STRAWBERRY CROP: EFFECTS ON ARTHROPOD PESTS, WEEDS, DISEASES AND STRAWBERRY YIELDS

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### ABSTRACT

Florida is the second largest producer of fresh-market strawberries (*Fragaria × ananassa* Duchesne; Rosales: Rosaceae) in the United States. The annual hill “plasticulture” production system used to grow strawberries makes this crop one of the most expensive to produce. The cost of production may be reduced if synthetic mulch can be reused and the dead plants (thatch) from the previous season left in the field, without negatively affecting crop yields. Field studies were conducted during the 2010/2011 and 2011/2012 strawberry growing seasons to evaluate the effect of re-using plastic mulch with or without dead strawberry plants from the previous season on arthropod populations, disease incidence, weeds and strawberry growth, and marketable yields of strawberries. The study was conducted in a commercial field in Citrus County, Florida using 2-yr old synthetic mulch on the bed. Two strawberry varieties ‘Albion’ and ‘Florida Festival’ were planted in 2010/2011 and 2011/2012 growing seasons, respectively. During transplanting, one treatment had all strawberry thatch (dead plant debris from previous season) removed from the soil before planting the new strawberry transplants, while in the second treatment the thatch was left to grow with the transplants. Data were collected throughout the growing seasons on plant growth, spider mites and insect pest populations, weeds, disease incidence, and marketable yield of strawberries. Re-using plastic mulch with or without strawberry thatch had no significant effect on plant size or populations of beneficial and pestiferous arthropods. However, re-using mulch with strawberry thatch reduced weed growth but increased the incidence of fungal diseases. As a result of fungal diseases and plant mortality, marketable yield for the variety “Florida Festival”, but not “Albion” was significantly lower in plots with the strawberry thatch than in those without thatch.

**Key Words:** double-cropping, Carolina geranium, plasticulture, *Colletotrichum* spp., two-spotted spider mites

### RESUMEN

Florida es el segundo mayor productor de fresas del mercado fresco (*Fragaria × ananassa* Duchesne; Rosales: Rosaceae) en los Estados Unidos. El sistema de producción anual con el uso de montículos “plasticultura” para el cultivo de fresas convierte este cultivo uno de los más caros de producir. Se puede reducir el costo de producción si el mantillo sintético puede ser re-utilizado y se dejan las plantas muertas (paja) de la temporada anterior en el campo, sin afectar negativamente el rendimiento del cultivo. Se realizaron estudios de campo durante las estaciones de la siembra de fresa en el 2010/2011 y 2011/2012 para evaluar el efecto de re-uso del mantillo (mulch) plástico con o sin plantas de fresa muertas de la temporada anterior sobre las poblaciones de artrópodos, la incidencia de enfermedades, el crecimiento de las malezas y fresa y el rendimiento comercial de las fresas. Se realizó el estudio en un campo comercial en el condado de Citrus, Florida usando una cama de abono sintético de 2 años de edad. Dos variedades de fresa ‘Albion’ y ‘Festival de la Florida’ fueron sembradas en las estaciones de crecimiento del 2010/2011 y del 2011/2012, respectivamente. Durante el trasplante, un tratamiento tenía toda la paja de fresa (restos de plantas muertas de la temporada anterior) retirado de la tierra antes de plantar los nuevos trasplantes de fresa, mientras que en el segundo tratamiento se dejó crecer las plantas trasplantadas con la paja. Se recolectaron los datos sobre el crecimiento de las plantas, las poblaciones de plagas de insectos y arañas rojas (Tetranychidae), malas hierbas, la incidencia de enfermedades y la producción comercial de fresas a través de las estaciones de crecimiento. El re-uso de la cobertura de plástico con o sin paja de fresa no tuvo ningún efecto significativo sobre el tamaño de las plantas o poblaciones de artrópodos beneficiosos y dañinos. Sin embargo, la re-utilización de mulch de paja de fresa redujo el crecimiento de malezas, pero aumento la incidencia de enfermedades causadas por hongos. Como resultado de las enfermedades de hongos y la mortalidad de las plantas, la producción comercial de la variedad “Festival de

la Florida” fue significativamente menor, pero no de la variedad”Albion “ en las parcelas con paja de fresa que en las sin paja.

Palabras Clave: doble cultivo, geranio de Carolina, plasticultura, *Colletotrichum* spp, araña roja de dos manchas

Florida is a major producer of strawberry (*Fragaria* × *ananassa* Duchesne; Rosales: Rosaceae) in the USA and the principal supplier of domestically grown winter berries in North America (Mossler & Nesheim 2003, 2007). The state ranks second behind California in terms of production and during the 2010-2011 growing season, the strawberry crop, harvested from 4,006 ha, was valued at US\$366.3 million. Florida strawberry acreage had rapidly increased ~ 26% in the last 6 years, from 7,300 (2,954 ha) to 9,900 (3,925 ha) between 2005 and 2011 (USDA-NASS 2011). Strawberry growers in Florida are able to enjoy a high premium price for strawberry fruit early in the growing season (Dec and Jan) when other states are not in production.

In Florida, most of the strawberry production is carried out in open fields using black plastic mulch “plasticulture” on raised beds that are fitted with drip irrigation tubes. The plastic mulch and irrigation tubing is removed at the end of the growing season (Chandler et al. 1993). Usually, the crop is planted between Sep and early Oct, and harvested from Dec through Mar or Apr depending on when the season ends (mainly determined by market price for strawberries). Plasticulture makes strawberry one of the most expensive crops to produce mainly because of the high costs of land preparation, planting, and installation of an irrigation system (Roskopf et al. 2005; Wright 2010). The average cost of production has been estimated to be ~ US\$35,914/ha [average variable cost per ha at US\$24,478 and US\$11,436 in fixed costs], which includes costs of land preparation, labor, strawberry transplants, fertilizer, weeding, insect and mite management, and disease control (Santos et al. 2011). One of the ways to reduce costs or to recoup some of the cost of production is to reuse the mulch fitted raised beds with the irrigation system to grow a second crop, thereby distributing the costs over the 2 seasons (Waterer et al. 2007; Santos et al. 2008; Wright 2010). This can be achieved through double-cropping, where a second crop is grown in the same production area as the first crop (Duval 2005; Santos et al. 2008). Using the plastic mulch for a second strawberry crop can be cost efficient and also a way of recycling the plastic mulch.

Growing a second strawberry crop on the same plastic involves desiccating the first crop at the end of the season in spring using a broad-spectrum herbicide (glyphosate, Roundup®) or a soil fumigant and leaving the dead strawberry plants and the roots in the bed. The plastic mulch, with

the beds fitted with irrigation drip tapes is left intact through the summer months for use in the fall when the strawberries are planted (Fig 1A). The beds are kept weed-free throughout the summer months and at transplant, manual labor is used to remove the dead strawberry plants, from the previous season before making new holes for the second crop. In order to sustain high production and profitability of this high-value crop, it is important to determine the effects of re-using plastic mulch with the dead strawberry plants from the previous season. Subsequently, we conducted studies to examine the effects of leaving the dead strawberry plants in the plastic mulch when planting the second crop; a strategy that would save growers money in terms of manual labor and time to remove the old dead plants. Our hypothesis was that the dead strawberry plants would increase arthropod populations; act as a reservoir for weed seeds, and/ or as a source of disease inoculum that could ultimately affect marketable yield of a second strawberry crop. To test this hypothesis 2 field experiments were conducted between 2010 and 2012 on a commercial strawberry farm.

## MATERIALS AND METHODS

Two field studies were conducted during 2010/2011 and 2011/2012 strawberry growing seasons on a commercial strawberry field located in Citrus County, Florida. Planting beds were 0.71 m wide on top and 0.25 m high covered with 1.25 mil black plastic mulch (Intergro, Clearwater, Florida). The beds were fumigated with Telone Inline® (dichloropropene and chloropicrin) (Dow Agro Sciences, Indianapolis, Indiana) at the rate of 35 gpa (393 L/ha) before transplanting strawberries. Two strawberry varieties ‘Albion’ and ‘Florida Festival’ were transplanted on 29 Sept 2010 and 12 Oct 2011, respectively. Plants were spaced ~30 cm between plants in the row and 45 cm between rows in double-offset rows on a bed fitted with 2 drip irrigation lines on each side of the bed. Overhead irrigation (approx. 10 - 12 h per day) was used for plant establishment for the first 2 weeks of the growing season and thereafter the drip irrigation was used. Growing procedures and management with respect to weeds, disease and insect management, and harvesting yields were carried out according to the standard strawberry production practices in Florida (Peres et al. 2010).

### Preparation of Two-Year Mulch Beds for a Second Strawberry Crop

To prepare the plastic mulch for a second crop, strawberry plants were desiccated using a fumigant, Telone EC at 12 gpa (134.8 L/ha) through the drip line in the spring of 2010 and 2011 for the 2010/2011 and 2011/2012 strawberry growing seasons, respectively. The use of this fumigant (Telone EC) killed both the strawberry plants and weeds present in the field. To maintain the planting beds through the summer months, drip irrigation tubing was maintained and flushed with sulfuric acid ( $H_2SO_4$ ) [General Chemical, Syracuse, New York] twice a month, and plots were irrigated once a week (unless it rained) and kept weed-free using herbicides including glyphosate and Trifluralin, Treflan® EC, Monterey chemical company, Fresno, California. Prior to planting the second strawberry crop, torn plastic mulch was repaired to avoid further tearing by the wind and beds were fumigated with Telone Inline® using the rates described above. At planting, the dead strawberry plants were either removed or left on the plastic mulch (depending on treatment).

### Experimental Setup and Treatments

The experimental area in each season consisted of 16 strawberry beds of 125 m and 100 m long during the 2010/2011 and 2011/2012 growing seasons, respectively. Experimental design was a randomized complete block design. Eight of the rows had the dead strawberry plants from the previous season removed before transplanting the new crop and the other half had the old plants left on the planting beds (not pulled-out). Accordingly, the 2 treatments evaluated were: 1) reusing the plastic mulch fitted with drip irrigation with thatch or dead plants from the previous season;

and 2) reusing the plastic mulch fitted with drip irrigation without thatch or dead plants removed from the previous season (Fig. 1B).

### Two-spotted Spider Mites and Arthropod Population Sampling

Forty strawberry leaves (trifoliate) [10 leaves per replicate] were collected biweekly for two-spotted spider mites (*Tetranychus urticae* Koch; Trombidiformes: Tetranychidae) and other arthropods sampling. The leaves were collected into Ziploc™ bags and transported back to the Small Fruit and Vegetable IPM Laboratory, University of Florida, Gainesville, Florida where arthropod counts were conducted under a microscope at 10X magnification. Foliar sampling was conducted between 23 Dec 2010 and 7 April 2011 and between 11 Nov and 8 March during the 2010/2011 and 2011/2012 growing seasons, respectively.

### Weeds

Weed sampling was conducted using a 1.0 m by 0.7 m (bed width) quadrant where the total number weed species encountered were counted. A total of 20 quadrants per treatment were evaluated 6 times during the 2011/2012 growing season. Weed densities and species composition were only studied in 2011/2012 after it was observed that weeds were problematic during the 2010/2011 growing season. Weed species confirmation was done at the Horticultural Sciences Department at the University of Florida, Gainesville, Florida.

### Disease Incidence

Plant mortality due to fungal diseases was monitored from transplanting until the end of

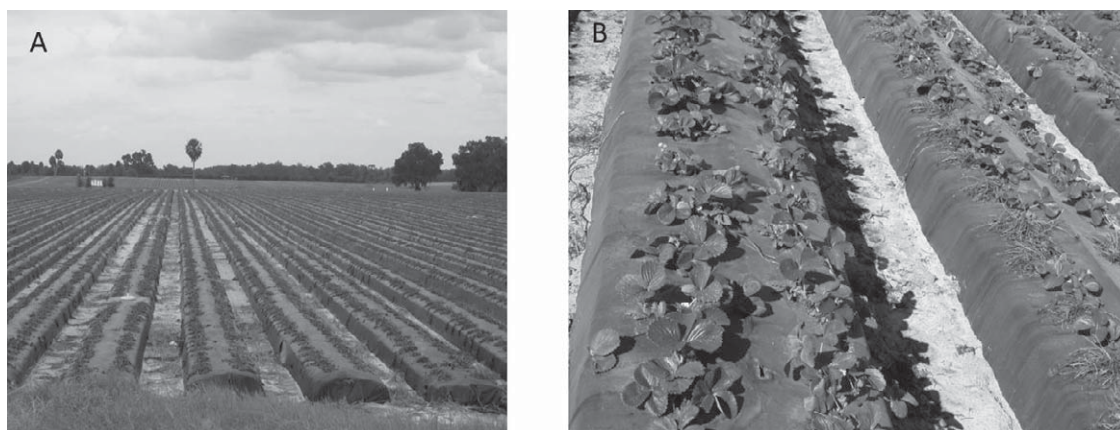


Fig. 1. Black plastic mulch (2-yr old) ready for a second strawberry crop **A**) and **B**) second strawberry crop growing without (left row) and with (right row) the dead strawberry plants from the previous season.



the season. Visual observation for anthracnose and any other fungal disease symptoms were observed biweekly. On each of the 16 rows, 50 plants were inspected. In addition to visual observation, samples were collected and sent to the Division of Plant Industry (DPI), Florida Department of Agriculture and Consumer Services, Gainesville, Florida for identification and/or confirmation of the disease-causing pathogen.

#### Plant Size and Marketable Yield

During each growing season, the dimensions of 30 strawberry plants per treatment, including height and width, were taken at early, mid, and late growing seasons. For marketable yields, berries were collected from 200 plants per treatment (50 plants from each replicate) twice per week (or as required), graded according to marketing standards and weighed separately as per treatment. Harvesting was conducted from 22 Nov 2010 to 26 Mar 2011, and 21 Nov 2011 to 8 Mar 2012 in the 2010/2011 and 2011/2012 growing seasons, respectively.

#### Data Analysis

To capture the effect of time and treatments, repeated measures multivariate analysis of variance (MANOVA) [SAS Institute 2002] was used to test the effect of the treatments on two-spotted spider mites in 2010/2011 growing season, weed population, and strawberry yields. The same analysis was carried out to test the effect of strawberry variety ('Albion' vs 'Florida Festival') and treatment on plant mortality. Other pests and beneficial arthropods population in 2010/2011 and 2011/2012 growing seasons, plant size and plant mortality were subjected to T-tests (PROC TTEST (SAS) to test treatment differences. Treatment means were considered significant when  $P \leq 0.05$ .

## RESULTS

### Spider Mites and Arthropod Populations

There were no significant differences in arthropod populations between plants growing on synthetic mulch with or without the dead strawberry plants during the 2010/2011 growing season (Table 1). Two-spotted spider mites were not recorded on strawberry plants until 26 Jan 2011 and thereafter. Although the spider mites population significantly increased over time ( $F = 6.63$ ;  $df = 8, 203$ ;  $P < 0.0001$ ), (Fig. 2), there were no significant ( $F = 0.7$ ;  $df = 1, 203$ ;  $P = 0.5$ ) differences between the 2 treatments and the treatment and time interaction was not significant ( $F = 1.80$ ;  $df = 1, 203$ ;  $P = 0.08$ ) [Fig. 2]. In terms of beneficial arthropods preying on two-spotted spider mites, six-spotted thrips [*Scolothrips sexmaculatus* (Pergande); Thysanoptera: Thripidae], big-eyed bug (BEB) eggs [*Geocoris* spp.; Hemiptera: Geocoridae], and *Neoseiulus californicus* McGregor (Mesotigmata: Phytoseiidae) were recorded in both treatments in very low numbers (Table 1). The melon aphid (*Aphis gossypii* Glover; Hemiptera: Aphididae) was the only other insect pest recorded during the season but like all other arthropods recorded on the strawberry leaves, there were no significant differences between the 2 treatments (Table 1).

In 2011/2012 growing season, very low insect and mite numbers were recorded on strawberry leaves (Fig. 3). Similar to the 2010/2011 season there were no significant differences in arthropod populations (two-spotted spider mites motiles;  $t = -0.70$ ,  $df = 7.5$ ,  $P = 0.50$ ; two-spotted spider mites eggs;  $t = -0.91$ ,  $df = 7.1$ ,  $P = 0.39$  whitefly immatures;  $t = -1.23$ ,  $df = 19.5$ ,  $P = 0.23$ ; lacewing eggs;  $t = -0.4$ ,  $df = 38$ ,  $P = 0.69$ ; BEB eggs;  $t = -1.0$ ,  $df = 6$ ,  $P = 0.39$ ; thrips;  $t = 0.44$ ,  $df = 6$ ,  $P = 0.68$ ) between plants growing on synthetic mulch with or without the dead strawberry plants (Fig. 3). In contrast to the previous (2010/2011) season, a few flower thrips, *Frankliniella* spp. (Thysanoptera:

TABLE 1. MEAN ( $\pm$  SE) ARTHROPOD POPULATIONS PER STRAWBERRY TRIFOLIATE LEAF FROM A SECOND STRAWBERRY CROP GROWING ON A 2-YR OLD PLASTIC MULCH WITH AND WITHOUT THE DEAD STRAWBERRY PLANTS FROM THE PREVIOUS SEASON IN CITRUS COUNTY, FLORIDA DURING THE 2010/2011 STRAWBERRY GROWING SEASON

	Mean arthropod populations per strawberry leaf (Mean $\pm$ SEM)			
	With dead plants	Without dead plants	t-value	P-value
TSSM <sup>1</sup> motiles <sup>1</sup>	18.4 $\pm$ 4.2	24.2 $\pm$ 6.6	0.74	0.46
<i>N. californicus</i> <sup>2</sup>	0.07 $\pm$ 0.04	0.01 $\pm$ 0.01	1.30	0.19
Melon aphid <sup>1</sup>	0.40 $\pm$ 0.1	0.40 $\pm$ 0.3	0.04	0.97
Six-spotted thrips <sup>2</sup>	0.02 $\pm$ 0.01	0.00 $\pm$ 0.0	1.43	0.15
Big-eyed bug eggs <sup>2</sup>	0.03 $\pm$ 0.02	0.02 $\pm$ 0.01	0.39	0.69

\*TSSM = Twospotted spider mites

<sup>1</sup>insect pests

<sup>2</sup>beneficial insect

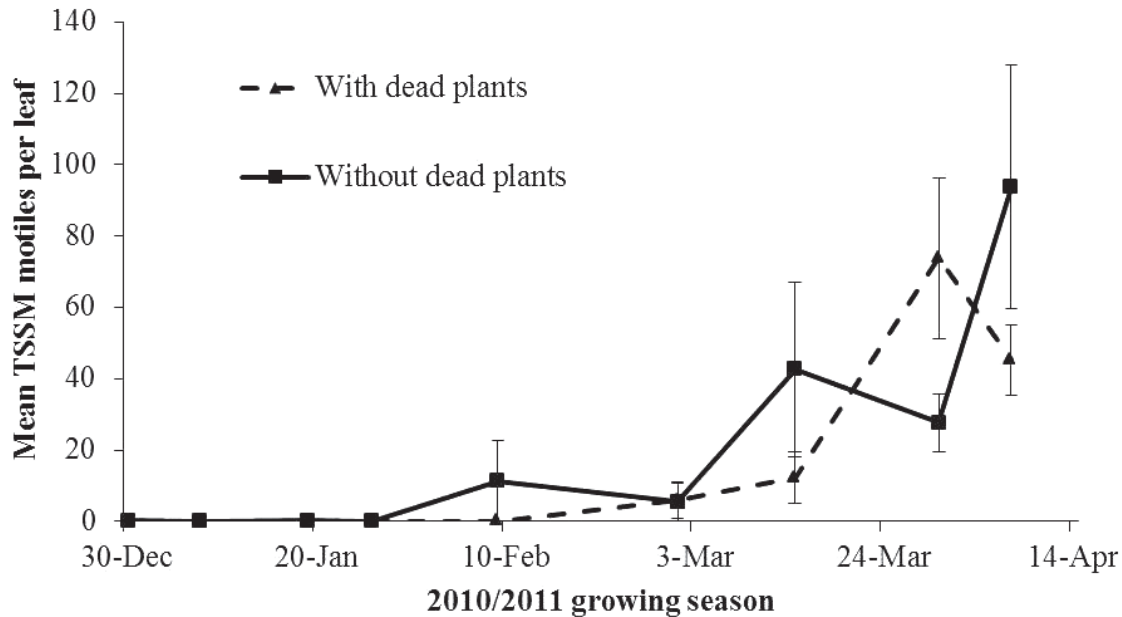


Fig. 2. Twospotted spider mites (*T. urticae*) population dynamics (mean  $\pm$  SE) on a second strawberry crop growing on 2-yr old plastic mulch with and without the dead strawberry plants from the previous season in 2010/2011 strawberry growing season.

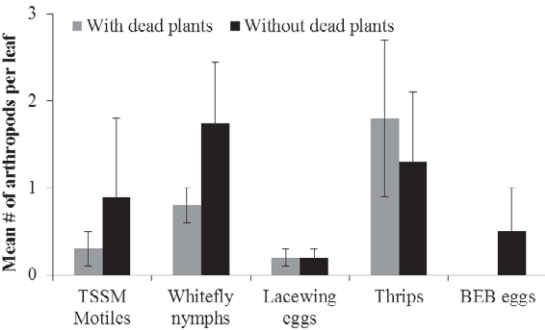


Fig. 3. Mean ( $\pm$  SE) arthropod populations counted per strawberry leaf on a second strawberry crop growing on 2-yr old plastic mulch with and without the dead plants from the previous season in 2011/2012 strawberry growing season. TSSM means twospotted spider mites and BEB means big-eyed bug.

Thripidae) were recorded during the 2011/2012 season.

Weeds

On average, significantly ( $F = 8.04$ ;  $df = 1, 36$ ;  $P = 0.0075$ ) more weeds per quadrant ( $2.95 \pm 0.4$  versus  $1.5 \pm 0.2$ ) were recorded on plots where the dead strawberry plants were removed at transplant as compared with plots where they were left in the field (Fig. 4). However, the ef-

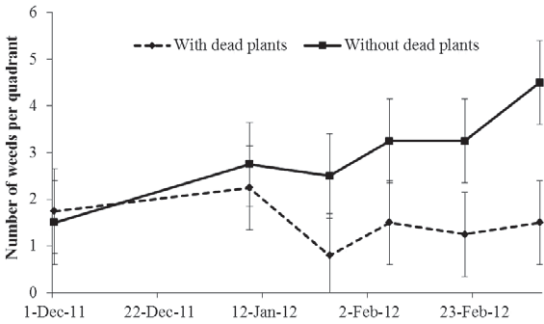


Fig. 4. Mean ( $\pm$  SE) number of weeds counted per quadrant ( $0.7 \text{ m}^2$ ) on strawberry plots growing on 2-yr old plastic mulch with and without the dead plants from the previous season in 2011/2012 strawberry growing season.

fect of time ( $F = 0.72$ ;  $df = 5, 36$ ;  $P = 0.6$ ) or time and treatment interaction ( $F = 0.84$ ;  $df = 5, 36$ ;  $P = 0.5$ ) was not significant. Carolina geranium (*Geranium carolinianum* L.; Geraniales: Geraniaceae), black medic (*Medico* spp.; Fabales: Fabaceae) and wild carrot (*Daucus carota* L.; Apiales: Apiaceae) comprised over 80% of the weed population. Other minor weeds recorded in the field were wandering cudweed (*Gnaphalium pensylvanicum* (Willd.) Cabrera; Asteraceae), sow thistle (*Sochus* spp.; Asterales: Asteraceae), field pennycress (*Thiaspi arvense* L.; Brassi-

cales: Brassicaceae) and Mexican tea (*Chenopodium ambrosioides* L.; Caryophyllales: Chenopodiaceae).

#### Plant Size and Marketable Yield

During both seasons, no significant differences [2010/2011; height;  $t = -1.64$ ;  $df = 48$ ,  $P = 0.1$ ; width;  $t = -1.68$ ;  $df = 48$ ,  $P = 0.09$  and 2011/2012; height;  $t = -0.12$ ;  $df = 198$ ,  $P = 0.9$ ; width;  $t = -0.84$ ;  $df = 198$ ,  $P = 0.4$ ] were recorded in plant size between the plants growing with and without the dead strawberry plants.

Leaving the dead strawberry plants in place while growing the new plants did not significantly affect strawberry yields ( $F = 0.48$ ;  $df = 1, 294$ ;  $P < 0.49$ ) [Fig. 5] in 2010/2011 growing season but yields increased significantly with time ( $F = 130.33$ ;  $df = 1, 294$ ;  $P < 0.0001$ ), but the interaction between time and treatment was not significant ( $F = 2.27$ ;  $df = 1, 294$ ;  $P < 0.06$ ). Conversely, leaving the dead strawberry plants in the field significantly reduced strawberry marketable yields ( $F = 5.28$ ;  $df = 1, 30$ ;  $P < 0.03$ ) in the 2011/2012 strawberry growing season and yield reduction with time was also significant, ( $F = 182.71$ ;  $df = 4, 30$ ;  $P < 0.0001$ ), but not the interaction between time and treatment ( $F = 0.76$ ;  $df = 4, 30$ ;  $P > 0.56$ ) [Fig. 5].

#### Disease Incidence

The number of missing plants per plot was significantly affected by the strawberry variety ( $F =$

47.37;  $df = 1, 102$ ;  $P < 0.0001$ ) and the treatment ( $F = 18.77$ ;  $df = 1, 102$ ;  $P < 0.0001$ ) and also the interaction between the treatment and variety ( $F = 11.07$ ;  $df = 1, 102$ ;  $P < 0.001$ ) [Fig. 6]. There was significantly higher plant mortality ( $P < 0.0001$ ) in the variety 'Florida Festival' compared to 'Albion'. Similarly, higher plant mortality was recorded on the plots where the dead strawberry plants were left to grow with the new transplants than where they were removed (Fig. 6). The high plant mortality recorded on these plots was as a result of fungal diseases. These diseases were identified as root and crown rot and Verticillium wilt.

#### DISCUSSION

In both growing seasons, there was no effect of leaving the dead strawberry plants on arthropod populations on the second strawberry crop, which is beneficial to the growers hoping to reuse the plastic mulch. This study was conducted using grower's standard production practices and therefore insecticides/miticides were used as required. The weather during the 2011/2012 growing season was mild and pest pressures were expected to be high; therefore, the grower used prophylactic pesticide treatments against arthropods. At the beginning of the season, methomyl (Lannate® [DuPont, Wilmington, Delaware] that has both insecticidal and miticidal effects was used to control mites and insect pests. In addition, chlorantraniliprole (Coragen®, Dupont, Wilmington, Delaware) and bifenazate (Acrامة®, Chemtura, Middlebury, Connecticut) were used

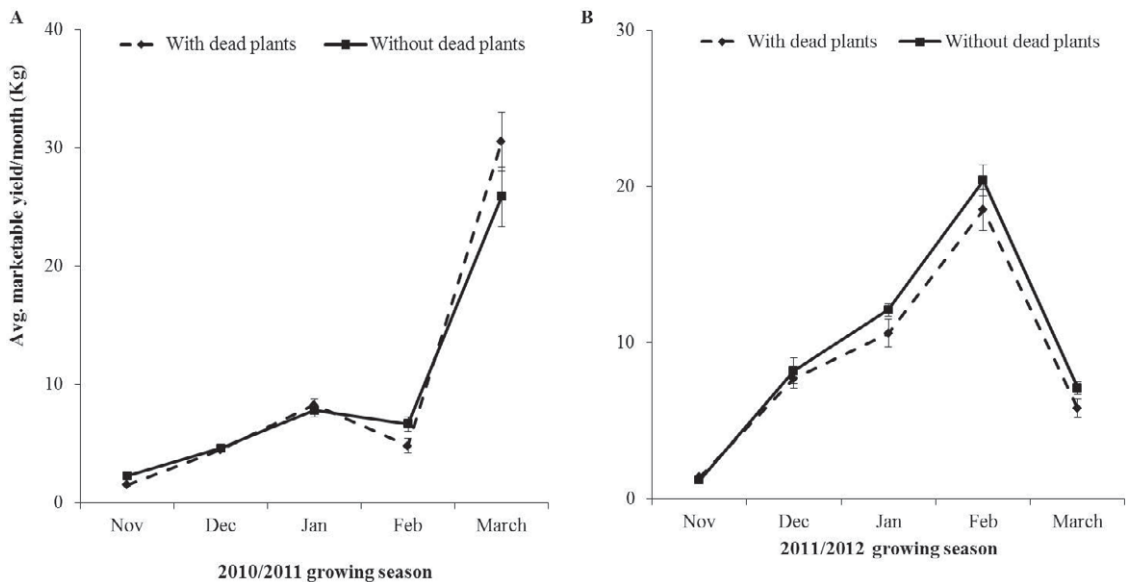


Fig. 5. Mean ( $\pm$  SE) strawberry marketable yield over time in A) 2010/2011 and B) 2011/2012 recorded on strawberry plants growing with and without dead strawberry plants from the previous season on a 2-yr black plastic mulch.

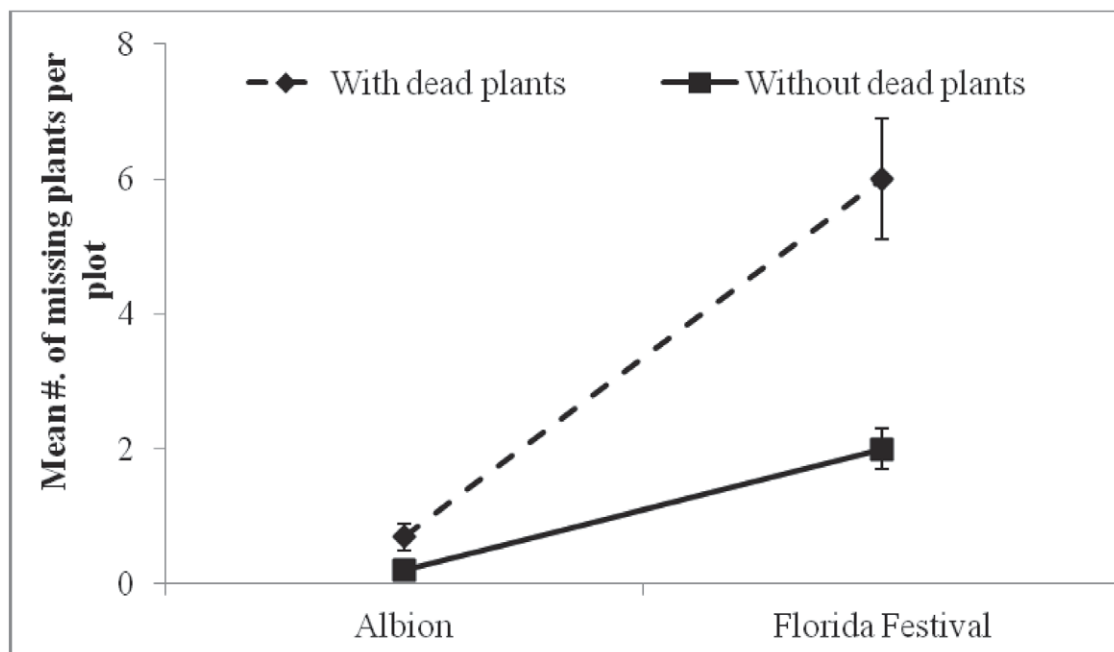


Fig. 6. Mean ( $\pm$  SE) number of missing plants from a second strawberry crop growing with and without the dead strawberry plants from the previous season on 2-yr black plastic mulch during the 2011/2012 growing season.

to control budworms and spider mites, respectively in Jan. As a result of the sprays, very low insect and mite numbers were recorded on strawberry leaves. The unusually warm temperatures in late Jan and Feb 2012 also resulted in more flowering plants including blueberries and weeds and hence the increase in numbers of thrips in the fields. The average temperature for February in 2012 was 64.3 °F (17.4 °C), which was also the third hottest month in a period of 30 years in Florida and above the usual monthly average temperature of 59.4 °F (15.2 °C). On the contrary, sub-optimal temperatures were experienced during the 2010/2011 growing season with Dec 2010 being the coldest month ever in history for Florida (2014 National Climatic Data Center-National Oceanic Atmospheric Administration [NCDC-NOAA]), which potentially delayed arthropod population establishment and growth (Nyoike & Liburd 2013). Unlike other growing seasons (personal observation), two-spotted spider mites were not recorded until the end of Jan 2010. Two-spotted spider mites thrive well in warm and dry temperatures and have base temperature of 10 °C, and therefore the freezing temperatures experienced in Dec and Jan months potentially had an effect on mite life cycle and population establishment (Nyoike & Liburd 2013). Fraisse & Peres (2011) discussed in detail the weather patterns that caused record cold winter temperatures in Florida during 2010/2011 growing season.

*Neoseiulus californicus* (McGregor) (Phytoseiidae) is a predatory mite that feeds on two-spotted spider mites and other soft-bodied organisms (Rhodes & Liburd 2006). This mite was recorded only during the 2010/2011 growing season. Other generalist predators that were encountered include the six-spotted thrips, *Scolothrips sexmaculatus* (Perg.) (Thripidae), and big-eyed bugs *Geocoris* spp. (Geocoridae), whose adults feed on two-spotted spider mites eggs and motile stages in strawberry systems (Fraulo et al. 2008; Nyoike & Liburd 2013). *Aphis gossypii* Glover (Aphididae) is a commonly encountered insect pest on strawberry leaves but is not considered a major pest of field-grown strawberries in Florida (Fraulo et al. 2008; Nyoike & Liburd 2013).

Removing the dead plants before planting the new transplants had a significant effect on weed growth during the second strawberry crop growing cycle. On plots where the old plants were removed, weeds were observed to germinate through the planting holes of the first strawberry crop. It may be advisable to utilize the same planting holes and avoid making new holes in the plastic mulch. However, we do not know if planting strawberries in the same hole will have adverse effects on the new transplants. The abundance of weed growth in the fields has been attributed to the loss of methyl bromide: chloropicrin [98:2], a formulation of methyl bromide that was very effective in controlling weeds. Although



a 50: 50 methyl bromide formulation is available, its use has been limited due to high cost and reduced effectiveness (Noling & Whiden 2009). Carolina geranium (*Geranium carolinianum* L.; Geraniales: Geraniaceae) was the main weed recorded when re-using the plastic mulch. Carolina geranium was one of the weeds listed to justify the use of methyl bromide as a critical pest management tool in strawberry production (Roskopf et al. 2005; US EPA 2005). Two other important weeds in strawberry production are black medic (*Medicago* spp.; Fabales: Fabaceae) and nutsedge (*Cyperus* spp.; Poales: Cyperaceae) but the sedges were not recorded in our study. Other minor weed species recorded were sow thistle (*Sonchus* spp.; Asterales: Asteraceae), Mexican tea (*Chenopodium ambrosioides* L.; Caryophyllales: Amaranthaceae) and wandering cudweed (*Gnaphalium pensylvanicum* Willd.; Asterales: Asteraceae).

Leaving or removing the dead strawberry plants from the previous season did not affect strawberry plant size (width and height) on the 2-yr old black plastic mulch during the 2 growing seasons. However, leaving the dead plants in the field resulted in high plant mortality for the strawberry variety 'Florida Festival' due to fungal diseases and hence the low yield recorded on those plots in 2011/2012 growing season. Strawberry variety 'Albion' was planted in 2010/2011 and 'Florida Festival' was planted in 2011/2012 growing season. The strawberry variety 'Florida Festival' appears to be more susceptible to fungal diseases than 'Albion' as the high plant mortality was not observed during the 2010/2011 growing season. We observed that plant mortality increased overtime throughout the season especially on the plots where old plants were left in the field. Although our data suggest that 'Florida Festival' is more susceptible to fungal diseases than 'Albion' variety, more research is needed before firm conclusions can be drawn.

The disease causing pathogens encountered during the 2 growing seasons were *Colletotrichum* spp., *Rhizoctonia solani*, and *Verticillium* spp., causative agents for root and crown rots and Verticillium wilt. It is possible that the dead strawberry plants were the source of the inoculum that caused the soil-borne diseases on the new transplants after surviving through the hot summer months in the field. Furthermore, *Colletotrichum acutatum* has been found to survive on dry strawberries through the summer months in Florida (Mertely & Peres 2010). Although temperatures during the summer months were not monitored in this experiment, Noling & Whiden (2009) reported that under the same conditions soil temperatures vary between 29.4 °C and 46.1 °C. It is not known whether these temperatures are sufficient to disinfect the soil.

Based on the estimated production costs of strawberries in Plant City, Florida for 2008-

2009 (Anonymous 2014), the benefits of reusing plastic mulch beds fitted (with irrigation tubing) for a second strawberry crop is approximately US\$2,500 per acre. The cost of plastic mulch is US\$115.00, irrigation tubing (US\$500), mulch disposal (US\$115) and land preparation costs including labor costs are US\$1,500. However, there are costs associated with leaving the plastic mulch for a second strawberry crop such as increased hand weeding, removing the dead plants before planting the new transplants, repairing the plastic mulch, flushing the drip lines once a month during the summer months, and occasionally watering the beds to prevent them from collapsing. The beds also must be maintained weed-free throughout the summer months, usually requiring herbicide such as glyphosate applications. The costs of herbicides acre are estimated at US\$151.35, hand weeding at US\$170, and removing the dead strawberry plants from the previous season at US\$170. Despite these costs, growers may agree that double cropping with a second strawberry crop may be worth pursuing because production costs are spread across 2 growing seasons, which enables them to recoup some of the costs during the second growing season. Although removing the dead strawberry plants resulted in an increase in weed populations, growers are optimistic that compatible herbicides will soon be available for use during the growing season.

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