Economic Analysis of Biodegradable Paper versus Plastic Mulch for Organic Day-neutral Strawberry Production in the Upper Midwest

Gigi DiGiacomo[1], Amaya Atucha[2], Eric Burkness[3], Christelle Guedot[4], Jarret Miles Koenig[5], and Mary Rogers[3]

KEYWORDS. **biodegradable, cost-benefit, day neutral strawberry, economic, mulch, organic, paper, partial budget**

ABSTRACT. **Field trials were conducted in Minnesota and Wisconsin during 2022–2023 to evaluate production costs and net returns associated with a soil biodegradable paper mulch compared to three polyethylene (PE) plastic mulches in an organic day-neutral (DN) strawberry system. Assessing the economic viability of soil biodegradable mulch is critical for organic growers who may need to transition away from PE plastic mulches to comply with USDA-AMS National Organic Program (NOP) standards. To date, no published research has directly compared the economic performance of NOP-compliant biodegradable paper mulch in organic strawberry production. Our results indicate that while the paper mulch incurred higher initial costs and required more labor for weather-related maintenance, it yielded positive net returns when DN strawberries were marketed through direct-to-consumer channels at premium prices. Despite being the least profitable option overall, the biodegradable paper mulch represents an economically viable alternative to PE mulches under certain market conditions and offers promise for future NOP-compliant organic production systems.**

Strawberries (*Fragaria* ×*ananassa*) are in high demand across the United States; consumption has risen almost 3-fold since 1980 from 3.19 to 9.44 lb/capita in 2023 (USDA Economic Research Service 2024). Industry practitioners report that berries are the top fresh food growth category after meat and poultry, nationally (IRI, 2021).

Received for publication 28 Feb 2025. Accepted for publication 1 Apr 2025.

Published online 10 Jun 2025.

[1]Department of Applied Economics, University of Minnesota, St. Paul, MN, USA

[2]Department of Plant and Agroecosystem Sciences, University of Wisconsin-Madison, Madison, WI, USA

[3]Department of Horticulture, University of Minnesota, St. Paul, MN, USA

[4]Department of Entomology, University of Wisconsin-Madison, Madison, WI, USA

[5]Departments of Plant & Agroecosystem Sciences and Entomology, University of Wisconsin-Madison, Madison, WI, USA

Research for this project was funded by a US Department of Agriculture National Institute of Food and Agriculture Organic Transitions Grant #3002-11030-0092330.

J.M.K. is a master's student.

G.D.G. is the corresponding author. E-mail: gigid@umn.edu.

https://doi.org/10.21273/HORTTECH05639-25

The introduction of high-yielding DN strawberry cultivars offers growers in the Upper Midwest USA an opportunity to meet increasing local demand for strawberries by extending the fruiting season, incorporating strawberry plants into annual organic rotations, and mitigating the risks associated with overwintering crops in cold climates (USDA hardiness zones 3 and 4; USDA 2014). Research shows that high-yielding DN strawberry cultivars can be successfully grown as an annual crop in cooler production regions like the Upper Midwest USA extending the fruit production season from early summer to fall (Orde and Sideman 2021, 2023; Petran et al. 2017). Recent studies on DN strawberry production in the Upper Midwest USA indicate that fruit quality is comparable to June bearing (JB) cultivars, the traditional type of strawberry grown in the region, and that annual total yield per plant of DN cultivars exceeds their JB counterparts by up to 77% depending on the cultivar (Petran et al. 2017). Conversely, growers in the Northeastern and Mid-Atlantic, USA and Canada report that JB production generally outperformed that of DNs due in large part to challenges associated with disease and pest pressure among DN systems (Hodgdon et al. 2024; Orde and Sideman 2023).

DN strawberries are exposed to greater pest and weed pressure as compared with JB cultivars due to their longer fruiting season. Weed control in DN systems typically involves a combination of hand weeding, hoeing, cultivation, and mulch application (Fennimore and Boyd 2018). Among these methods, plastic polyethylene (PE) mulch, made from fossil fuels, is the most widely used and has been shown to reduce weed pressure compared with untreated fields (DeVetter et al. 2017; Haapala et al. 2014; Hodgdon et al. 2024; Johnson and Fennimore 2005; Moreno and Moreno 2008). In addition, plasticulture systems have been found to offer several agronomic benefits, including reduced overall pest exposure, improved soil moisture retention, and increased soil temperature, which all result in improved yields (Emmert 1957; Kasirajan and Ngouajio 2012).

The USDA-AMS NOP standards require that mulches used in certified organic production be composed of "fully biodegradable materials" (USDA-AMS, Title 7, §205.206). Currently, in the absence of commercially viable alternatives, PE mulch is permitted as a weed barrier so long as it is removed annually to preclude decomposition of plastic in the soil (USDA, Title 7 § 205.601). The annual removal of PE mulch in organic systems adds more labor and material expense compared with conventional non-organic systems and/or production regions where mulch used for DN strawberry plants can remain in place for 2 or more years (Ahokas et al. 2014; Nyoike and Liburd 2014; Shrefler and Brandenberger 2016). The higher costs of yearly mulch installation and removal has been shown to outstrip some of the yield gains from DN strawberries, resulting in profits that are comparable with perennial JB systems that rely on straw mulch for weed control (Orde and Sideman 2023).

PE mulch accrues additional direct and indirect costs due to its lack of biodegradability, necessitating disposal in landfills, incineration, or stockpiling on farms (Goldberger et al. 2019), which in turn can lead to greater carbon emissions, photochemical oxidant formation, and fossil fuel depletion (Dong et al. 2022; Moore and Wszelaki 2016). Moreover, residual film fragments from the PE mulch often remain in fields after removal (Velandia et al. 2020; Halley et al. 2001), which can interfere with the root development of subsequent crops and negatively impact soil health (Kasirajan and Ngouajio 2012; Serrano-Ruiz et al. 2023). PE mulch is also a major contributor of microplastics in the environment, which have negative effects across the food web including on soil microorganisms and aquatic and terrestrial plants (Dong et al. 2022; Khalid et al. 2023). While clinical studies on the impacts of microplastics on human health are lacking, high concentrations of microplastics are correlated with immune and stress responses and reproductive and developmental toxicity (Blackburn and Green 2022). These combined economic and environmental considerations underscore the importance of evaluating cost-benefit trade-offs of mulch alternatives in organic production systems.

The NOP has requested that the National Organic Standards Board review the development and use of biodegradable biobased mulch film (BBMF) as an alternative to PE mulch since 2012 (NOP 2023). Industry practitioners have been working to develop alternatives to PE mulch made from biodegradable plastics and soil biodegradable paper (Campanale et al. 2024; Gao et al. 2021; Haapala et al. 2014; Kasirajan and Ngouajio 2012; Li et al. 2021; Serrano-Ruiz et al. 2023). Of the biodegradable mulch alternatives, only paper is allowable for certified organic production. Paper mulches, made from cellulose, starch, and other renewable materials (Li et al. 2021), are broken down by the action of humidity and microorganisms and can be incorporated into the soil at the end of the growing season (Ahokas et al. 2014; Albertsson and Huang 1995). Paper mulch can achieve comparable yields to PE mulch while also positively impacting crop production by improving soil temperature, soil water content, weed control, and pest management (Anderson et al. 1996; Haapala et al. 2014; Harrington and Bedford 2004; Jenni et al. 2004). Because BBMFs made from paper do not produce wastes that require disposal, they offer a sustainable ecological alternative to PE plastic mulches (Immirzi et al. 2003; Kapanen et al. 2008; Russo et al. 2004, 2005).

The material and labor costs of annual PE mulches have been studied for a limited number of conventionally grown specialty crops. Paranhos et al. (2016) found that plasticulture systems sufficiently increased marketable yields in cabbage to offset the added direct costs of PE mulch. Conversely, Velandia et al. (2020) reported that using a biodegradable plastic in pumpkin production resulted in a net negative impact on profitability due to a 5% price discount caused by film adhesion on the fruit. Biodegradable plastic mulch material costs were two to three times that of PE mulch (Velandia et al. 2018).

Looking forward, Li et al. (2021) suggested that the labor expense of paper mulch use in conventional DN strawberry production would be high owing to difficulties of laying the material. They also speculated that additional costs would accrue to paper mulch under adverse weather conditions. Wind, hail, and heavy rain could cause the paper mulch to deteriorate resulting in increased weed competition and yield loss (Li et al. 2021). Several studies have observed complete degradation of paper mulch by rain events or the dislodging of paper due to wind before the end of a crop cycle, resulting in bare soil and increased weed pressure (Li et al. 2021; Harrington and Bedford 2004; Touchaleaume et al. 2016). However, no study has measured and compared the total direct (operating) costs of paper mulch and PE mulch in conventional or organic cropping systems.

We hypothesize that several opportunities exist to potentially offset the presumed higher costs associated with organic DN plasticulture and paper mulch systems. Significant price premiums exist for "locally grown" and "certified organic" produce in various direct market outlets and geographic locations, including the Upper Midwest (Connolly and Klaiber 2014; Curtis et al. 2014; Gliessman et al. 1996; Yue and Tong 2009). Examining weighted average retail prices for strawberries in Upper Midwest markets, we found that organic strawberries commanded a 40% to 46% premium over nonorganic strawberries in 2019 to 2020 (USDA-AMS, 2021). Other studies suggest that similar premiums exist for locally grown and direct marketed produce (Yue and Tong 2009) and for the use of biodegradable plastic mulch (Chen et al. 2019). Markets and consumer response across markets, however, are not homogeneous (Low and Vogel 2011; Martinez et al. 2010). It is currently unknown whether price premiums for direct market, local, and/or organic characteristics in strawberry are sufficient to offset the costs associated with growing and managing organic DN cultivars grown as an annual crop using traditional PE or biodegradable paper mulch.

Organic growers in the Upper Midwest require evidence-based information on the direct costs (including labor), net returns, and economic viability of PE and NOP-approved biodegradable paper mulch in DN strawberry production. Sixty-eight percent of Minnesota and Wisconsin berry producers surveyed (n = 101), many of them organic, expressed interest in growing DN strawberries but cited insufficient economic data as a major barrier to adoption (DiGiacomo 2021). To address this knowledge gap, a multistate interdisciplinary research project was undertaken in 2022 to 2023. Using controlled field experiments in St. Paul, MN, USA (44.9442°N, 93.0936°W) and Madison, WI, USA (43.073051°N, 89.401230°W), we compared the economic performance of three PE mulches and one biodegradable paper mulch for annual organic DN strawberry production. The primary objective of this study was to estimate farm-level profitability of organic DN strawberry production under alternative mulch systems, and to provide stakeholders with actionable insights into input costs, labor requirements, and net economic returns for each system.

Materials and methods

Field research was conducted at two certified organic sites: the West Madison Agricultural Research Station (WMARS) near Madison, WI (43.0753°N, 89.4081°W, USDA Hardiness Zone 5b), and the Minnesota Agricultural Experiment Station (MAES) on the St. Paul campus of the University of Minnesota (44.9442°N, 93.0936°W, USDA Hardiness Zone 5a) (USDA, Agricultural Research Service 2023). The WMARS includes 30 acres of certified organic land and is staffed by personnel with extensive experience, similar to that of professional growers, in organic horticulture crop production. Staff assisted with irrigation system design and installation, bed preparation, mulch treatment establishment, and general research plot maintenance. The MAES site encompasses 10 acres of certified organic land, with experienced Agricultural Service staff responsible for field preparation, planting, and research plot maintenance.

The experimental design was a randomized complete block with four replicates per treatment. Each replicate consisted of a single row treated with one mulch type along its entire length. Raised beds were constructed to be 3 feet wide and 5 inches high at both locations. Planted rows were 65 feet long in Wisconsin and 50 feet long in Minnesota. Beds were separated by 3-foot-wide alleyways, which were seeded differently each year. In year 1 (YR1), annual ryegrass was sown at a rate of 30 lb/acre, while in the following year, a 1:30 mixture of red clover/rye was seeded at a rate of 25 lb/acre (Albert Lea Seed Co., Albert Lea, MN, USA).

Four organically approved film-based mulches were applied to the beds at both locations using a mulch layer (model 2121-D; Buckeye Tractor Co., Columbus Grove, OH, USA) with the assistance of two staffers. The mulches used were (1) white PE mulch (Ag Resource Inc., Detroit Lakes, MN, USA); (2) black PE mulch (Ag Resource Inc., Detroit Lakes, MN, USA); (3) metallic PE mulch (Imaflex Co., Montreal, QC, Canada); and (4) biodegradable paper mulch (Weed Guard Plus, Aurora, CO, USA). The industry-standard white PE mulch served as the study control. The black PE mulch represented a low-cost practice for weed control. The metallic PE mulch was chosen for its superior pest management characteristics. Finally, the biodegradable paper mulch was chosen for its presumed labor-reducing and environmental benefits.

After mulch application, dormant bare-root plants of the cultivar Cabrillo (Lassen Canyon Nursery, Inc., Redding, CA, USA for 2022 in Wisconsin and Minnesota, and in 2023 for Wisconsin; Crown Nursery Strawberry Plants, Red Bluff, CA, USA for Minnesota in 2023) were planted by hand on 19 May 2022 and 7 May 2023 in Wisconsin and on 11 May 2022 and 10 May 2023 in Minnesota. In Wisconsin, plants were established in double rows with 12 inches between plants staggered down the length of the planting row, and 18 inches between rows of plants on each bed, whereas in Minnesota plants were established in a single row in the central section of the raised bed with plants spaced every 12 inches. Slits (2 to 4 inches long) were cut in the mulch and plants were inserted in the holes by hand with the top of the crown left uncovered.

Raised beds had one line of 0.50-inch diameter drip tape (Rain Bird Corporation, Azusa, CA, USA) placed in the center of the row with emitters spaced every 6 inches and emitter rate of 0.32 gallons per hour. Plants were irrigated once weekly or as necessary as determined by manual gauge-type tensiometer (Watermark 200SS; Irrometer Co., Riverside, CA, USA) placed at depths of 12 inches under the mulch. Moisture levels were read twice weekly. Irrigation was applied when tensiometer readings reached −4.35 PSI.

No pre-plant soil amendments were applied at either location. Plots at both locations were fertigated using drip tape applicators underneath each mulch type, at the rate of 5.1 lb per acre of nitrogen per week using an organically approved fertilizer (AgGrand Organic Series fertilizer, 4N–1.3P–2.5K, Zen Natural Organics, Portland, OR, USA). Fertility was supplemented twice over the growing season with a Fish and Seaweed Fertilizer (2–3–1) at a rate of 6.4 gallons per acre to supply micronutrients (Neptune's Harvest, Gloucester, MA, USA). Flowers were allowed to bloom, and runners were removed weekly throughout the growing season (24 Jun to 25 Aug 2022 in Wisconsin and 6 Jun to 28 Sep 2022 in Minnesota) and once every other week in 2023 at the Wisconsin location (30 May to 29 Jun 2023). Runners continued to be removed weekly in Minnesota, but runner removal was ended earlier in the season during year 2 (YR2) (14 Jun to 26 Jul 2023). Insecticide treatment was applied to control *Lygus lineolaris* (Hemiptera: Miridae), once in 2022 on Jul 28, and seven times in 2023 between 17 Jul and 13 Sep at the Wisconsin site using a pyrethrin-based insecticide, Pyganic 1.4 II EC (Valent U.S.A. LLC, San Ramon, CA, USA contains 1.4% pyrethrins).

In Minnesota, no insecticide treatments were used in YR1; however, in YR2, insecticide sprays were applied six times throughout the season (22 Jun 2023 to 27 Jul 2023). In 2023, all Minnesota plots were treated with a tank mix of Pyganic 5.0 II (15.6 oz/ac, contains 5.0% pyrethrins), Debug Tres (22 oz/ac, Arbico Organics, Oro Valley, AZ, USA), and Oxidate 5.0 (0.39% v/v or 15 oz/ac, Biosafe ® Systems, East Hartford, CT, USA). Foliar applications were made using a CO_2 backpack sprayer (1.5 ft boom and 1 Teejet XR8002 vs. flat-fan nozzle with no screen; 35 psi; 30 gal/acre) on 22 Jun, 29 Jun, 6 Jul, 13 Jul, 20 Jul, and 27 Jul.

Weeds were removed from the strawberry plant canopy every 10 to 14 d by hand at both locations throughout the growing season (1 Jul to 8 Sep 2022 and 6 Jul to 26 Sep 2023 in Wisconsin; 20 Jun to 28 Sep 2022 and 31 May 2022 to 27 Sep 2023 in Minnesota). Alleys were mowed as needed at both locations (1 Jul to 5 Aug 2022 and 6 Jul to 26 Sep 2023 in Wisconsin; 14 Jun to 22 Sep 2022 and 1 Jun to 19 Sep 2023 in Minnesota).

Strawberries were harvested three times per week in Wisconsin and two times per week in Minnesota from a 13-foot zone in each row and sorted for marketable fruit. Fruit meeting USDA grade 2 or higher were classified as marketable with no distinction made between grade 1 and grade 2 (USDA, Agricultural Marketing Service 2022). USDA grade 2 berries are those considered "free from decay and free from serious damage caused by dirt, disease, insects, mechanical or other means. Each strawberry has not less than one-half of its surface showing a pink or red color. Unless otherwise specified, the minimum diameter of each strawberry is not less than five-eighths inch." For each harvest, marketable yield per plant was calculated by dividing the marketable plot yield by the number of living plants in the plot.

A modified enterprise budget (direct material and labor costs, gross returns, net returns) was compiled for DN strawberries using each of the mulches in the study. Total direct (operating) costs were calculated by adding annual material and labor costs. Direct material costs were estimated by the research team in 2022 for each treatment based on field records and market prices. Apart from a 3.8% increase for inflation, material prices were assumed to remain unchanged in 2023. Material inputs included plants, mulch, drip lines, emitters, fertilizers, alley seed, fuel, insecticides, and harvest containers.

Direct labor input costs were calculated by multiplying the time spent per task by the regional wage rate for farm workers (USDA, National Agricultural Statistics Service, Farm Labor, Nov 2022 and 2023). Labor time was recorded in minutes by each research team for individual tasks using a time-keeping app for cell phones and/or a hand-written notebook and stopwatch timer. These records were transcribed into Microsoft Excel and compiled each season by treatment. Labor tasks were grouped into 10 categories: bed preparation (including alley cover crop seeding), mulch application (including drip tape install), planting, flower and runner removal, irrigation and fertigation, pest management, weeding, mowing, harvesting and grading, and postharvest clean-up. Tasks were designated as requiring "skilled" vs. "unskilled" labor, with skilled tasks assigned to experienced research staff and unskilled tasks to student field workers. For this study, it was assumed that skilled workers at both sites earned $18.33 per hour for spring-related tasks and $19.28 per hour for fall harvest and clean-up tasks (USDA, National Agricultural Statistics Service, Farm Labor, Nov 2022 and 2023). Unskilled labor at both sites was valued at the 2022 to 2023 average minimum wage for "small" businesses in Minnesota, equal to $8.53 per hour year-round (Ondieki et al 2024). Minnesota wage rates were reported as they more accurately reflected unskilled farm labor rates in the Upper Midwest region.

Postharvest material and labor estimates for storage, handling, packaging, transportation, and marketing efforts were not compiled, as this was outside the scope of the study. Moreover, these expenses vary substantially by market channel and proximity to market, making accurate estimates difficult (Hardesty and Leff 2009; King et al. 2010). Traditional wholesale markets and institutional sales channels demand significant resources for pre- and postharvest sorting, grading, packaging, and labeling activities. Alternatively, sales into direct market channels (farmers markets, pick your own, community-supported agriculture) forego many of the wholesale and retail packaging and labeling costs but accumulate added expenses in the form of transportation, sales, and advertising (Curtis et al. 2014; Hardesty and Leff 2009; King et al. 2010). Indirect ownership costs for land and machinery also were not included in this study and will need to be subtracted by growers from the "net returns over direct costs" presented to arrive at their actual net return for the organic DN strawberry enterprise.

Gross returns were calculated by multiplying marketable yield per plant for each treatment by observed market prices. Local, direct market prices of $8.00/lb were assumed based on ground truthing of market prices throughout 2022 to 2023 at three direct markets (Minneapolis Farmers Market, Minneapolis, MN; St. Paul Student Organic Market, St. Paul, MN; and an on-farm stand in Northfield, MN). The two farmers markets are in urban centers with one of them, the Minneapolis Farmers Market, representing the largest farmers' market in Minnesota. The third site in Northfield, MN, is located at a farm ~48 miles from the Twin Cities metropolitan area (TCMA) center. Together, the three markets represent diverse customer demographics. Prices at these locations ranged from $7.50/lb to $9.50/lb for strawberries with no differentiation by quality (size and grade) or market week; prices charged at each market location were consistent throughout the weekly collection period (July–Oct 2023). Conventional berries were priced between $7.50 and $8.00/lb and the organic berries were priced at $9.00 to $9.50/lb. Although the strawberries in our study are certified organic, we chose the higher of the conventional farmers market strawberry prices for the study to establish conservative baseline estimates.

Net returns were calculated for all mulch systems in both years of the study. Net returns are equal to the income generated after subtracting direct (variable) and indirect (overhead) costs from gross sales. Using the same methods and assumptions, production costs and returns for the control mulch and the other three mulches were estimated to explore the tradeoffs between gross returns, direct material, and labor expenses.

Last, a sensitivity analysis was prepared using variations on price and yield to identify profit opportunities for Upper Midwest growers of DN strawberries. Sensitivity analyses can be used to measure business exposure to risk, to identify market opportunities, and to test the robustness of results for financial feasibility and decision making (Frey and Patil 2002). A sensitivity analysis was performed by varying marketable yield and DN strawberry prices. Yields of 0.50 lb/plant (slightly below marketable yield averages observed in the study) to 1.25 lb/plant were explored alongside a range of prices, beginning at $7.00/lb ($0.50 below the lowest prices observed in the TCMA direct market channels for conventional strawberries) and increasing by $0.50/lb increments to $9.00/lb ($0.50 below the highest price observed for organic strawberries in the TCMA).

Results

Performance of PE mulches in Minnesota and Wisconsin. Marketable yield differed between years ($P < 0.001$, Table 1) and among treatments in Wisconsin ($P = 0.0067$), but there were no differences between years or treatment in Minnesota ($P = 0.84$); no significant interaction was found between year and location in either state ($P = 0.201$ and $P = 0.861$ in Wisconsin and Minnesota, respectively) as reported in a companion paper (Miles-Kroening 2024). The white and the black mulches in Wisconsin produced lower marketable yields than the metallic. The 2-year average yield for the metallic mulch in Wisconsin (0.76 lb/plant, Table 1) was substantially higher, 46%, than 2-year average metallic mulch yield observed in Minnesota (0.52 lb/plant). Overall, the Minnesota-Wisconsin 2-year average organic DN strawberry yield for the PE mulches ranged from 0.51 lb/plant (white, Table 1) to 0.64 lb/plant (metallic) with black falling in the middle (0.53 lb/plant).

Material costs for the higher yielding metallic mulch averaged $0.73/plant ($1.40/lb) in Minnesota and $0.75/plant ($0.99/lb) in Wisconsin (Table 2). On a per-plant basis, the metallic PE mulch treatment costs were ~50% higher than the total material costs for the white or the black PE mulch

Table 1. Organic day-neutral strawberry marketable yield using polyethylene and paper mulch in Minnesota and Wisconsin, 2022 to 2023.

Mulch treatment	Minnesota 2022	Minnesota 2023	Wisconsin 2022	Wisconsin 2023
Marketable yield	lb/plant	lb/plant	lb/plant	lb/plant
White	0.39	0.47	0.51	0.68
Black	0.50	0.53	0.40	0.71
Metallic	0.50	0.53	0.59	0.92
Paper	0.49	0.49	0.63	0.75
Mulch treatment	**Minnesota 2-yr avg**	**Wisconsin 2-yr avg**	**MN-WI 2-yr avg**	**MN-WI 2-yr avg**
Marketable yield	lb/plant	lb/plant	lb/plant	lb/acre[i]
White	0.43	0.60	0.51	7,379
Black	0.51	0.55	0.53	7,699
Metallic	0.52	0.76	0.64	9,163
Paper	0.49	0.69	0.59	8,490

[i] Assumes 14,400 plants per acre.

treatments. When factoring in the higher metallic mulch yields, however, the gap between metallic and other mulch material prices shrinks by varying degrees in both Minnesota and Wisconsin.

Labor costs were similar across all PE mulch treatments on a per-plant basis, although they differed substantially by study location (Table 2). Labor expenses were ∼38% higher in Wisconsin than Minnesota on average. After factoring in yields, this relationship reverses. A difference in labor costs within study locations also emerges between the industry-standard, white, and the other PE mulch treatments (Table 2). In Minnesota, labor costs for the white treatment totaled $5.43/lb and the other treatments averaged $4.38/lb (black) and $4.41/lb (metallic) over the 2-year period. In Wisconsin, labor costs varied from $3.21/lb (metallic) to $3.81/lb (white) and $4.61/lb (black). The higher average marketable yields clearly have a positive, downward effect on the metallic labor costs.

Total direct costs (materials and labor combined) for the PE mulches suggest that the metallic mulch ($4.70/lb) is the most economical on a per-pound basis for the 2-year average in Minnesota-Wisconsin combined (Table 2). Total direct costs for the black mulch averaged $5.00/lb and the white mulch averaged $5.14/lb over the same period and location.

Table 2. Organic day-neutral strawberry direct production costs in Minnesota and Wisconsin, 2022 to 2023. MN-WI = Minnesota-Wisconsin.

	Minnesota 2-yr avg	Wisconsin 2-yr avg	MN-WI 2-yr avg	MN-WI 2-yr avg
Material costs[i]	$/plant ($/lb)	$/plant ($/lb)	$/plant ($/lb)	$/acre[ii]
White	0.42 (0.97)	0.45 (0.75)	0.43 (0.84)	6,192
Black	0.46 (0.89)	0.46 (0.83)	0.46 (0.86)	6,624
Metallic	0.73 (1.40)	0.75 (0.99)	0.74 (1.20)	10,656
Paper	0.83 (1.69)	0.86 (1.25)	0.84 (1.43)	12,096
Labor costs[iii]	$/plant ($/lb)	$/plant ($/lb)	$/plant ($/lb)	$/acre[ii]
White	2.28 (5.43)	3.13 (3.81)	2.20 (4.60)	31,680
Black	2.28 (4.38)	3.17 (4.61)	2.21 (4.48)	31,824
Metallic	2.29 (4.41)	3.20 (3.21)	2.23 (3.79)	32,112
Paper	2.43 (4.77)	3.44 (3.52)	2.94 (4.14)	42,336
Total direct costs[iv]	$/plant ($/lb)	$/plant ($/lb)	$/plant ($/lb)	$/acre[ii]
White	2.70 (6.29)	2.57 (4.31)	2.63 (5.14)	37,872
Black	2.74 (5.33)	2.61 (4.70)	2.67 (5.00)	38,448
Metallic	3.02 (5.83)	2.92 (3.86)	2.97 (4.70)	42,768
Paper	3.25 (6.46)	4.30 (4.77)	3.78 (5.57)	54,432

[i] Material costs include plants, mulch, irrigation, alley seed, fertilizers, fungicides, insecticides, tractor fuel, and harvest containers.

[ii] Assumes 14,400 plants per acre.

[iii] Labor tasks were performed by skilled field staff and unskilled workers. The 2-year average wage rate, $18.31/h, was applied for skilled workers in the Lakes Region (USDA, National Agricultural Statistics Service, Farm Labor, Nov 2022 and 2023). The 2-year average minimum wage rate in Minnesota for “small employers with less than $500,000 in annual revenue,” $8.53/h, was charged for tasks performed by unskilled labor at both locations (Ondieki et al. 2024, Minnesota Department of Labor and Industry).

[iv] Direct costs include materials, fuel, and labor.

Performance of paper mulch compared with PE mulches. The soil biodegradable paper mulch did not significantly influence marketable yields over the 2-year study period in Minnesota compared with the PE mulches as reported by Miles-Kroening (2024). Paper mulch yields averaged 0.49 lb/plant in Minnesota and 0.69 lb/plant in Wisconsin compared with 0.43 lb/plant for white, 0.51 lb/plant for black, and 0.52 lb/plant for metallic in Minnesota and 0.55 lb/plant for black, 0.60 lb/plant for white, and 0.76 lb/plant for metallic in Wisconsin (Table 1). The 2-year marketable yield for the paper mulch averaged 0.59 lb/plant on average for Minnesota-Wisconsin combined.

Material costs for the paper treatment were the highest of all mulch treatments in Minnesota ($1.69/lb, Table 2) and Wisconsin ($1.25/lb). The 2-year material costs for the paper mulch averaged $1.43/lb for Minnesota-Wisconsin combined. Labor costs for the paper mulch, however, ranked third in Minnesota ($4.77/lb) and second in Wisconsin ($3.52/lb), averaging $4.14/lb for the 2-year period in Minnesota-Wisconsin combined (Table 2). Despite needed repairs to the paper mulch throughout the 2022 and 2023 seasons, which contributed to higher mulch installation expenses (Supplemental Material), labor savings were conferred due to better weed suppression, improved water retention (fewer waterings), and a modest reduction in plant termination and mulch removal at both study locations. At both locations, sections of paper remained intact in 2022 and 2023. Researchers removed only the larger pieces for composting and tilled the remaining paper into the soil as recommended.

Combining material and labor expenses, total direct costs for the paper mulch averaged $6.46/lb in Minnesota, $4.77/lb in Wisconsin, and $5.57/lb on average across both locations (Table 2). Higher yields and lower input expenses in Wisconsin

Table 3. Organic day-neutral strawberry gross and net returns[i] using polyethylene and paper mulch in Minnesota and Wisconsin, 2022 to 2023. MN-WI = Minnesota-Wisconsin.

Mulch treatment	Minnesota 2-yr avg	Wisconsin 2-yr avg	MN-WI 2-yr avg	MN-WI 2-yr avg
Gross returns[i]	$/plant	$/plant	$/plant	$/acre[ii]
White	3.44	4.80	4.08	58,752
Black	4.12	4.44	4.28	61,632
Metallic	4.14	6.04	5.09	73,296
Paper	3.93	5.50	4.72	67,968
Total direct costs[iii]	$/plant ($/lb)	$/plant ($/lb)	$/plant ($/lb)	$/acre[i]
White	2.70 (6.29)	2.57 (4.31)	2.63 (5.14)	37,872
Black	2.74 (5.33)	2.61 (4.70)	2.67 (5.00)	38,448
Metallic	3.02 (5.83)	2.92 (3.86)	2.97 (4.70)	42,768
Paper	3.25 (6.46)	4.30 (4.77)	3.78 (5.57)	54,432
Net returns[iv]	$/plant ($/lb)	$/plant ($/lb)	$/plant ($/lb)	$/acre[ii]
White	0.74 (0.31)	2.23 (1.31)	1.45 (0.75)	20,880
Black	1.38 (0.71)	1.83 (1.02)	1.61 (0.86)	23,184
Metallic	1.12 (0.58)	3.12 (2.36)	2.12 (1.35)	30,528
Paper	0.68 (0.33)	1.20 (0.83)	0.94 (0.55)	13,536

[i] Gross returns = yield * price where yield is measured as lb/plant and price is measured as $8.00/lb.
[ii] Assumes 14,400 plants per acre.
[iii] Direct costs include materials, fuel, and labor.
[iv] Net returns over direct costs = gross returns – direct returns.

compared with Minnesota translated into significantly higher gross and net returns in Wisconsin (Table 3) over the 2-year period. Net returns for the paper mulch in Minnesota averaged $0.33/lb, whereas in Wisconsin net returns averaged $0.83/lb. The average across both states was $0.55/lb for 2022 to 2023.

A sensitivity analysis for variations on yield and price is shown in Table 4. At $7.00/lb with an assumed 0.50 lb/plant yield, the 2-year average net returns over direct costs range from $12,911/acre for the black PE mulch to $15,103/acre for the most economically advantageous metallic PE mulch with the white mulch falling in the middle at $14,706/acre. The biodegradable paper mulch averaged $9136/acre under the same assumptions. When prices are increased from $7.00/lb to $9.00/lb (30%) returns over direct costs more than doubled to $29,106/acre for white, $27,311/acre for black, $29,503/acre for metallic, and $23,536/acre for paper mulch.

More significant was the change in net returns when yield was assumed to improve from 0.50 lb/plant to 1.0 lb/plant (100%). Previous DN strawberry field research in Minnesota observed yields of up to 1 pound per plant annually using the industry-standard white PE plastic mulch in open field conditions (Petran et al. 2017). The results from Petran et al. (2017) indicate that there is more income potential from improvement in yield/plant than price/lb. Using the assumed market price, $8.00/lb, net returns over direct costs for the white PE mulch almost tripled from $21,906/acre to $72,420/acre with assumed yields of 1.0 lb/plant (Table 4). Black, metallic and paper mulch all improved similarly under the same assumptions. At $9.00/lb with a 1.25 lb/plant yield, all the mulches, including paper, net more than $100,000 per acre over direct costs.

Table 4. Sensitivity analysis for organic day-neutral strawberry, Minnesota-Wisconsin 2-year average annual net returns over direct expenses, $/acre.[i]

Price/Pound	0.50 lb/plant	1.00 lb/plant	1.25 lb/plant
White			
$7.00/lb	$14,706	$58,020	$79,571
$7.50/lb	$18,306	$65,220	$88,571
$8.00/lb	$21,906	$72,420	$97,571
$8.50/lb	$25,506	$79,620	$106,571
$9.00/lb	$29,106	$86,820	$115,571
Black			
$7.00/lb	$12,911	$54,452	$75,245
$7.50/lb	$16,511	$61,652	$84,245
$8.00/lb	$20,511	$68,852	$93,245
$8.50/lb	$23,711	$76,052	$102,245
$9.00/lb	$27,311	$83,252	$112,245
Metallic			
$7.00/lb	$15,103	$57,548	$79,491
$7.50/lb	$18,703	$64,748	$88,491
$8.00/lb	$22,303	$71,948	$97,491
$8.50/lb	$25,903	$79,148	$106,491
$9.00/lb	$29,503	$86,348	$115,491
Paper			
$7.00/lb	$9,136	$43,252	$74,195
$7.50/lb	$12,736	$49,786	$82,745
$8.00/lb	$16,336	$56,320	$91,295
$8.50/lb	$19,936	$62,854	$99,845
$9.00/lb	$23,536	$69,388	$108,395

[i] Assumes 14,400 plants per acre. Totals rounded to nearest $5.00.

Discussion

This study makes a positive contribution to horticultural literature by answering important economic questions for growers about the use of PE plastic and soil biodegradable paper mulches in Upper Midwest organic DN strawberry production: 1) Do labor savings accrue from the use of paper mulches compared with PE mulches when accounting for all field tasks? and 2) Does the use of biodegradable paper mulch positively affect net income compared with PE mulch options?

Our study is the first to account for all labor expenses related to DN strawberry production in an organic system. We learned that labor accounted for 74% (paper), 81% (metallic), and 90% (white and black) of total direct costs on a per-pound basis over the 2-year study period for a small-scale operation of one acre. Labor costs as a share of total expenses were only lower for the paper mulch, however, because the material costs of the paper mulch were significantly higher than those for the PE mulches.

The cost of laying and maintaining the paper mulch proved more expensive than the PE mulches due to the texture of the material, which made it difficult to install and, during storm events, degradation of the paper increased the need for repairs (as observed by Li et al. 2021). In Wisconsin, 2022 storms necessitated additional labor to rebury mulch edging after wind lifted and ripped the paper. In Minnesota, similar weather events occurred the same year resulting in the paper mulch being lifted by wind from several sections of the plot. Minnesota field staff also needed to rebury the mulch and/or remove large sections of torn paper mulch altogether (Fig. 1A). In cases where the mulch was removed, the exposed bare ground became more susceptible to weeds, although overall weeding time for the paper mulch was not greatly affected. In 2023, Minnesota and Wisconsin experienced few storms and unusually dry weather, thus the paper mulch remained intact throughout the season (Fig. 1B). Of the total labor expenses, harvest costs accounted for ~50% on average (2022 to 2023 Minnesota-Wisconsin). We suggest that strawberry research accounting only for harvest-related labor, as is common, significantly underrepresents direct production costs.

Yield gains accruing to the paper mulch compared with the white and black mulches did generate additional revenue to help offset some of the higher labor costs. We note that gross returns to the paper were $4.72/plant ($67,968/acre) compared with $4.08/plant ($58,752/acre) for white and $4.28/plant ($61,632/acre) for black (Table 3). Only the metallic PE mulch generated gross returns that were greater than the paper mulch ($5.09/plant or $73,296/acre). However, due to higher material and labor input costs, as described, the paper mulch ultimately generated the lowest net returns of all mulches studied. Thus, the paper mulch negatively affected net returns over direct costs in our organic DN strawberry field trials. This is an important observation for organic growers should PE mulch eventually become prohibited from the national list of allowable organic inputs, thus necessitating the use of biodegradable paper mulch. In this case, organic prices beyond the current $4.50/lb for California-grown organic strawberries marketed in the TCMA (DiGiacomo, personal observation, 2023) will be needed to help offset higher costs of production. Assuming the production costs observed in the Minnesota-Wisconsin field trials are representative of other small-scale DN strawberry enterprises, Upper Midwest growers would not break even on direct expenses at the $4.50/lb organic retail price when using paper mulch; we have demonstrated that labor costs alone averaged $4.14/lb in Minnesota-Wisconsin for growers using paper mulch. If findings by Chen et al. (2018) hold true for other regions, including the Upper Midwest, organic growers using biodegradable paper mulch should be well positioned

Fig 1. (A) Paper mulch after weather incident, University of Minnesota, 2022. (B) Paper mulch intact, University of Minnesota, 2023.

to capture price premiums for the use of biodegradable mulch.

Further research on overwintering DN strawberries in the Upper Midwest may reveal opportunities to reduce costs for organic and conventional growers alike. DN strawberry termination (removal and disposal) is typically performed annually following standard practice in California. Depending on the overwintering methods used and the resulting marketable yields, some of the annual labor costs attributed to mulch installation and removal, as well as planting and plant termination, could be distributed over multiple years. Orde and Sideman (2021) evaluated the overwintering of DN strawberries in New England in open fields and low tunnels. They found that second-year marketable yields exceeded yields in the first year of production suggesting "great potential for profitability from an overwintered DN crop."

We also suggest additional research to explore the value of environmental benefits conferred by soil biodegradable paper mulch compared with PE plastic mulches—benefits such as reduced waste disposal, smaller carbon emissions, and fossil fuel preservation.

Practically speaking, regardless of mulches used, yields observed, and decisions to overwinter, Midwest growers will likely need to market strawberries as a specialty product appealing to consumer preferences for locally grown, organic, and ecological sustainability characteristics due to the high marginal costs of labor. Local and organic labeling will be needed to justify price points well above supermarket berries distributed from competitive outstate production areas. We assumed no seasonal variation in price for late-season local offerings or environmental benefits, nor did we assume growers would distribute berries that were unmarketable for fresh consumption to processing channels; no value was assigned to unmarketable fresh berries for the processing sector.

In summary, the metallic mulch performed the best economically of all the PE mulches studied despite higher upfront costs for the mulch itself. Higher marketable yields, lower labor costs ($/lb), and higher returns over direct costs produced overall net benefits that outweighed direct cost of production using the metallic PE mulch. Organic DN strawberry growers using white or black PE mulch should consider switching to metallic for improved profitability. Moreover, DN strawberries, priced right, can generate healthy profits for small-scale organic growers and secure a win for the environment when soil biodegradable paper mulch is used should this become a requirement under NOP regulations in the future.

References cited

Ahokas J, Güzel E, İnce A, Korpela A, Asikainen J, Kujanpää M, Mikkola H, Pitkänen M, Tamminen A, Vikman M. 2014. Paper based mulches as an alternative to polyethylene mulch in vegetable production. J Agri Mach Sci. 10(1):73–78.

Albertsson AC, Huang SJ. 1995. Degradable polymers, recycling and plastics waste management. Marcel Drekker, New York, NY, USA.

Anderson DF, Garisto M-A, Bourrut J-C, Schonbeck MW, Jaye R, Wurzberger A, DeGregorio R. 1996. Evaluation of a paper mulch made from recycled materials as an alternative to plastic film for mulch in vegetables. J Sust Agric. 7(1):39–61. https://doi.org/10.1300/J064v07n01_05.

Blackburn K, Green D. 2022. The potential effects of microplastics on human health: What is known and what is unknown. Ambio. 51(3):518–530. https://doi.org/10.1007/s13280-021-01589-9.

Campanale C, Galafassi S, Di Pippo F, Pojar I, Massarelli C, Uricchio VF. 2024. A critical review of biodegradable plastic mulch films in agriculture: Definitions, scientific background and potential impacts. Trends Analy Chem. 170(:117391–117316. https://doi.org/10.1016/j.trac.2023.117391.

Chen K, Marsh TL, Tozer PR, Galinato SP. 2019. Biotechnology to sustainability: Consumer preference for food products grown on biodegradable mulches. Food Res Int. 116:200–210. https://doi.org/10.1016/j.foodres.2018.08.013.

Connolly C, Klaiber HA. 2014. Does organic command a premium when the food is already local? Am J Agric Econ. 96(4):1102–1116. https://doi.org/10.1093/ajae/aau030.

Curtis KR, Yeager I, Black B, Drost D, Ward R. 2014. Food Dist Res Soc. 45(2): 46–65. https://doi.org/10.22004/ag.econ.186924.

DeVetter LW, Zhang H, Ghimire S, Watkinson S, Miles CA. 2017. Plastic biodegradable mulches reduce weeds and promote crop growth in day-neutral strawberry in western Washington. HortScience. 52(12):1700–1706. https://doi.org/10.21273/HORTSCI12422-17.

DiGiacomo G. 2021. Unpublished Qualtrics survey. University of Minnesota.

Dong H, Yang G, Zhang Y, Yang Y, Wang D, Zhou C. 2022. Recycling, disposal or biodegradable alternative of polyethylene plastic film for agricultural mulching? A life cycle analysis of their environmental impacts. J Cleaner Prod. 380(1):134950–134959. https://doi.org/10.1016/j.jclepro.2022.134950.

Fennimore SA, Boyd NS. 2018. Sustainable weed control in strawberry, p 383–403. In: Korres NE, Burgos NR, Duke SO (eds). Weed Control. CRC Press, Boca Raton, FL, USA. https://doi.org/10.1201/9781315155913.

Frey HC, Patil SR. 2002. Identification and review of sensitivity analysis methods. Risk Anal. 22(3):553–578. https://doi.org/10.1111/0272-4332.00039.

Gao X, Xie D, Yang C. 2021. Effects of PLA/PBAT biodegradable film mulch as a replacement of polyethylene film and their residues on crop and soil environment. Agric. Water Mgmt. 255:107053–107059. 107053. https://doi.org/10.1016/j.agwat.2021.107053.

Gliessman SR, Werner MR, Allison J, Cochran J. 1996. A comparison of strawberry plant development and yield under organic and conventional management on the central California coast. Bio Agri Hort. 12(4):327–338. https://doi.org/10.1080/01448765.1996.9754756.

Goldberger JR, DeVetter LW, Dentzman KE. 2019. Polyethylene and biodegradable plastic mulches for strawberry production in the United States: Experiences and opinions of growers in three regions. HortTechnology. 29(5):619–628. https://doi.org/10.21273/HORTTECH04393-19.

Haapala T, Palonen P, Korpela A, Ahokas J. 2014. Feasibility of paper mulches in crop production—a review. AFSci. 23(1):60–79. https://doi.org/10.23986/afsci.8542.

Halley P, Rutgers R, Coombs S, Kettels J, Gralton J, Christie G, Jenkins M, Beh H, Griffin K, Jayasekara R, Lonergan G. 2001. Developing biodegradable mulch films from starch-based polymers. Starch/Stärke. 53(8):362–367. https://doi.org/10.1002/1521-379X(200108)53:8<362::AID-STAR362>3.0.CO;2-J.

Hardesty SD, Leff P. 2009. Determining marketing costs and returns in alternative marketing channels. Renew Agric Food Syst. 25(1):24–34. https://doi.org/10.1017/S1742170509990196.

Harrington KC and Bedford TA. 2004. Control of weeds by paper mulch in vegetables and trees. New Zeal Plant Prot. 57:37–40. https://doi.org/10.30843/nzpp.2004.57.6938.

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

Immirzi B, Malinconico M, Romano G, Russo R, Santagata G. 2023. Biodegradable films of natural polysaccharides blends. J Mat Sci Let. 22(20):1389–1392. https://doi.org/10.1023/A:1025786708540.

Jenni S, Brault D, Stewart KA. 2004. Degradable mulch as an alternative for weed control in lettuce produced on organic soils. Acta Hortic. 638:111–118. https://doi.org/10.17660/ActaHortic.2004.638.13.

Johnson MS, Fennimore SA. 2005. Weed and crop response to colored plastic mulches in strawberry production. HortScience. 40(5):1371–1375. https://doi.org/10.21273/HORTSCI.40.5.1371.

Kapanen A, Schettini E, Vox G, Itävaara M. 2008. Performance and environmental impact of biodegradable films in agriculture: A field study on protected cultivation. J of Poly and the Env. https://doi.org/10.1007/s10924-008-0091-x.

Kasirajan S, Ngouajio M. 2012. Polyethylene and biodegradable mulches for agricultural applications: A review. Agron Sustain Dev. 32(2):501–529. https://doi.org/10.1007/s13593-011-0068-3.

Khalid N, Aqeel M, Noman A, Rizvi ZF. 2023. Impact of plastic mulching as a major source of microplastics in agroecosystems. J Hazard Mater. 445:130455. https://doi.org/10.1016/j.jhazmat.2022.130455.

King RP, Hand MS, DiGiacomo G, Clancy K, Gomez M, Hardesty S, Lev L, McLaughlin EW. 2010. Comparing the structure, size, and performance of local and mainstream food supply chains. USDA, Economic Research Service. Report. 99. https://www.ers.usda.gov/publications/pub-details/?pubid=46407. [accessed 31 Dec 2024].

Li A, Zhang J, Ren S, Zhang Y, Zhang F. 2021. Research progress on preparation and field application of paper mulch. Env Tech Innov. 24:101949–101924. https://doi.org/10.1016/j.eti.2021.101949.

Low SA, Vogel S. 2011. Direct and intermediated marketing of local foods in the United States. Economic Research Report, 128. US Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/webdocs/publications/44924/8276_err128_2_.pdf. [accessed 31 Dec 2024].

Martinez S, Hand M, Da Pra M, Pollack S, Ralston K, Smith T, Vogel S, Clark S, Lohr L, Low S, Newman C. 2010. Local food systems: Concepts, impacts and issues. Economic Research Report, 97. US Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/webdocs/publications/46393/7054_err97_1_.pdf. [accessed 31 Dec 2024].

Miles-Kroening JL. 2024. Organic day-neutral strawberry production in the Upper Midwest: impacts of film-based mulches on pollinator visitation and fruit yield [master's thesis]. University of Wisconsin–Madison, Madison, WI, USA. http://digital.library.wisc.edu/1793/85805.

Moore J, Wszelaki A. 2016. Plastic mulch in fruit and vegetable production: Challenges for disposal. Report No. FA-2016-02. Biodegradablemulch.org. [accessed 3 Dec 2024].

Moreno MM, Moreno A. 2008. Effect of different biodegradable and polyethylene mulches on soil properties and production in tomato crop. Sci Hort. 116(3):256–263. https://doi.org/10.1016/j.scienta.2008.01.007.

National Organic Program (NOP). 2023. Memorandum to the National Organic Standards Board. USDA Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/2023_NOP_BBMF_Memo_to_NOSB.pdf. [accessed 27 Feb 2025].

Nyoike TW, Liburd O. 2014. Reusing plastic mulch for a second strawberry crop: Effects on arthropod pests, weeds, diseases and strawberry yields. Fla Ent. 97(3):928–936. https://doi.org/10.1653/024.097.0351.

Ondieki G, Kavas E, Mah H. December 2024. Minnesota minimum-wage report, 2024. Minnesota Department of Labor and Industry. https://dli.mn.gov/sites/default/files/pdf/minimum_wage_report_2024.pdf. [accessed 30 Dec 2024].

Orde KM, Sideman RG. 2021. Winter survival and second-year spring yields of day-neutral strawberry are influenced by cultivar and the presence of low tunnels. HortTechnology. 31(1):77–88. https://doi.org/10.21273/HORTTECH04734-20.

Orde KM, Sideman RG (eds). 2023. Strawberry production guide for the Northeast, Midwest, and Eastern Canada. University of New Hampshire Cooperative Extension, Durham, NH, USA.

Paranhos LG, Barrett CE, Zotarelli L, Borisova T, Darnell R, Migliaccio K. 2016. Cost-benefit analysis of cabbage grown using a plasticulture and seepage bare ground production system in Florida. HortTechnology. 26(6):699–706. https://doi.org/10.21273/HORTTECH03444-16.

Petran A, Hoover E, Hayes L, Poppe S. 2017. Yield and quality characteristics of day-neutral strawberry in the United States Upper Midwest using organic practices. Bio Agri Hort. 33(2):73–88. https://doi.org/10.1080/01448765.2016.1188152.

Russo R, Giuliani A, Immirzi B, Malinconico M, Romano G. 2004. Alignate/Polyvinylalcohol blends for agricultural applications: structure-properties correlation, mechanical properties and greenhouse effect evaluation. Macromolecular Sym. 218(1):241–250. https://doi.org/10.1002/masy.200451425.

Russo R, Malinconico M, Petti L, Romano G. 2005. Physical behavior of biodegradable aliginate-poly(vinylalcohol) blend films. Poly Phy. 43(10):1205–1213. https://doi.org/10.1002/polb.20413.

Serrano-Ruiz H, Martin-Closas L, Pelacho AM. 2023. Impact of buried debris from agricultural biodegradable plast mulches on two horticultural crop plants: Tomato and lettuce. Sci Total Environ. 856:1–9. https://doi.org/10.1016/j.scitotenv.2022.159167.

Shrefler J, Brandenberger L. 2016. Use of plastic mulch and row covers in vegetable production. Cooperative Extension Service. Oklahoma State University. OSU Extension Facts F-6034. https://extension.okstate.edu/fact-sheets/use-of-plastic-mulch-and-row-covers-in-vegetable-production.html. [accessed 14 Jan 2025].

Touchaleaume F, Martin-Closas L, Angellier-Coussy H, Angellier-Coussy H, Chevillard A, Cesar G, Gontard N, Gastaldi E. 2016. Performance and environmental impact of biodegradable polymers as agricultural mulching films. Chemosphere. 144:433–439. https://doi.org/10.1016/j.chemosphere.2015.09.006.

USDA, National Agricultural Statistics Service. 2022. Table 33: Berries 2022 and 2017. 2022 Ag Census. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_2_County_Level/New_York/st36_2_033_033.pdf. [accessed 14 Jan 2025].

USDA, National Agricultural Statistics Service. November 2022. Farm Labor, All hired worker gross wage rates by economic class of farms. https://downloads.usda.library.cornell.edu/usda-esmis/files/x920fw89s/v405tw18s/dn39zk84n/fmla1123.pdf. [accessed 5 Jan 2025].

USDA, National Agricultural Statistics Service. November 2023. Farm Labor, All hired worker gross wage rates by economic class of farms. https://downloads.usda.library.cornell.edu/usda-esmis/files/x920fw89s/v405tw18s/dn39zk84n/fmla1123.pdf. [accessed 5 Jan 2025].

USDA, Agricultural Marketing Service. 2022. Grade of strawberries. https://www.ams.usda.gov/grades-standards/strawberries-grades-and-standards. [accessed 6 Dec 2024].

USDA, Agricultural Marketing Service. Title 7, Subtitle B, Chapter I, Subchapter M, Part 205, §205.206 Crop pest, weed, and disease management practice standard. 2025. https://www.ecfr.gov/current/title-7/subtitle-B/chapter-I/subchapter-M/part-205/subpart-C/section-205.206. [accessed 13 Dec 2024].

USDA, Agricultural Research Service. 2023. Plant hardiness zone map. https://planthardiness.ars.usda.gov. [accessed 6 Dec 2024].

USDA, Economic Research Service. 2024. Fruit and Tree Nuts Yearbook Tables, Table G-43, November 7, 2024. https://www.ers.usda.gov/data-products/fruit-and-tree-nuts-data/fruit-and-tree-nuts-yearbook-tables/. [accessed 13 Dec 2024].

Velandia M, Smith A, Wszelaki A, Galinato S, Marsh T. 2018. The economics of adopting biodegradable mulch films. Univ of TN Ext. https://doi.org/10.22004/ag.econ.302940.

Velandia M, DeLong KL, Wszelaki SS, Clark C, Jensen K. 2020. Use of polyethylene and plastic biodegradable mulches among Tennessee fruit and vegetable growers. HortTechnology. 30(2):212–218. https://doi.org/10.21273/HORTTECH04559-19.

Yue C, Tong C. 2009. Organic or local? Investigating consumer preference for fresh produce using a choice experiment with real economic incentives. HortScience. 44(2):366–371. https://doi.org/10.21273/HORTSCI.44.2.366.