horticulturae

Article

# Influence of Sunn Hemp Biomass Incorporation on Organic Strawberry Production

**Yurui Xie, Zachary E. Black, Nan Xu, Jeffrey K. Brecht, Dustin M. Huff and Xin Zhao ***

Horticultural Sciences Department, University of Florida, Gainesville, FL 32611, USA
* Correspondence: zxin@ufl.edu

**Abstract:** Sunn hemp (*Crotalaria juncea* L.), a warm season leguminous cover crop, is commonly used in rotation with organic strawberry production in Florida's subtropical environment. This study was conducted to explore the impacts of sunn hemp on growth and yield performance of the subsequent organic strawberry crop in sandy soils, taking into consideration the nutrient contribution from soil incorporation of sunn hemp biomass. Sunn hemp was seeded during the summer off-season and terminated before flowering, three weeks prior to the fall planting of two strawberry cultivars ('Strawberry Festival' and 'Camino Real'). With sunn hemp residues incorporated into the soil, two application rates of nitrogen (N) through pre-plant organic fertilization for the strawberry season were used, including N at a rate of 84 kg/ha, without consideration of the N credit from sunn hemp, and N at a rate of 19.8 kg/ha, with consideration of the estimated N credit from sunn hemp. A summer fallow without cover crop and with a pre-plant organic fertilizer application at the N rate of 84 kg/ha was included as the control. Overall, the sunn hemp incorporation at three weeks after termination did not benefit the strawberry plant growth or fruit yield in this study, with rather low levels of soilborne pathogen and nematode infestations. Both sunn hemp treatments exhibited a significantly lower level of total soil N compared to the summer fallow plots at the end of the strawberry season. The reduction in the pre-plant N fertilization resulted in lower above-ground plant dry weight and accumulation of N, phosphorus (P), and potassium (K) at the end of the strawberry season, along with fewer leaves and smaller crowns of the strawberry plants during the early season. Both sunn hemp treatments decreased early fruit yields, while the sunn hemp treatment with the reduced N fertilization also led to a significant reduction in the total fruit number and weight, although no significant differences in the whole-season marketable fruit yield were observed among the nutrient management treatments. Overall, 'Strawberry Festival' yielded higher than 'Camino Real', but the effects of nutrient management did not vary with the strawberry cultivars. Further studies are needed to enhance organic strawberry nutrient management involving rotational cover crops.

**Keywords:** *Fragaria ×ananassa* Duch.; *Crotalaria juncea* L.; cultivar; fruit yield; growth; nutrient management; pre-plant fertilization



**Citation:** Xie, Y.; Black, Z.E.; Xu, N.; Brecht, J.K.; Huff, D.M.; Zhao, X. Influence of Sunn Hemp Biomass Incorporation on Organic Strawberry Production. *Horticulturae* **2023**, *9*, 1247. https://doi.org/10.3390/horticulturae9111247

Academic Editor: Toktam Taghavi

Received: 28 September 2023
Revised: 24 October 2023
Accepted: 31 October 2023
Published: 20 November 2023



## 1. Introduction

Strawberry (*Fragaria ×ananassa* Duch.), one of the most valuable small fruit crops in the United States, is also a top organic commodity, reaching 2145 ha in harvested acreage and $336 million in value of sales in 2021 [1]. Florida is a leading state in winter strawberry production focused on the high-value early market. Growers' interest in organic strawberry production has been increasing in Florida in recent years, as shown by the increase in the number of certified organic farms according to the recent U. S. organic production surveys [1].

Cover cropping is an essential part of soil quality and fertility management practices in organic crop production systems. The appropriate use of cover crops improves soil organic matter (OM) and health, reduces soil compaction and erosion, and suppresses weeds. Leguminous cover crops are also employed as green manure, contributing to increased

N availability [2,3]. The integration of cover crop residues into nutrient management programs for organic crop production promotes nutrient cycling and helps optimize the benefits of using rotational cover crops. An estimation of 90–100 kg/ha of N could be supplied annually by the winter legume cover crop hairy vetch (*Vicia villosa* Roth.) to no-tillage corn [4]. Different legumes and grass species not only differ in their biomass accumulation, but also vary in their N release rate [5]. In addition to environmental factors such as soil temperature and moisture, the rate of N mineralization and release from cover crop residues is largely determined by the carbon to nitrogen (C:N) ratio of the cover crop at termination. A C:N ratio near 24:1 facilitates microbial digestion to achieve a relatively fast breakdown of plant residues, whereas a larger C:N may result in a temporary N deficit to the following cash crops due to N immobilization [6,7]. On the other hand, a C:N ratio lower than 24:1 may speed up N release early in the growing season, making it difficult to meet crop N demand during yield development.

Growing cover crops prior to the strawberry season has been shown to be an effective tool for weed management; but previous studies have reported different results regarding the cover crop effects on the growth and yield of strawberry plants. Sudangrass (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), soybean (*Glycine max* L.), or velvetbean [*Mucuna deeringiana* (Bort) Merr.] utilized as annual summer rotational cover crops were found to suppress summer weed populations but had no effect on organic strawberry growth or yield in North Carolina when short-day 'Chandler' strawberry plants were transplanted into plasticulture beds in the fall [8]. In contrast, a study conducted in Iowa indicated that sudangrass, big bluestem (*Andropogon gerardii* Vitman), or switchgrass (*Panicum virgatum* L.) that had been grown for multiple years with a final incorporation into the soil the summer before strawberry planting not only reduced fall weed population and biomass, but also improved plant establishment and increased fruit yield of the conventional June-bearing 'Honeoye' strawberry crop in a matted-row system [9].

In Florida, summer cover crops have been used in rotation with the fall planting of strawberries by organic growers, with sunn hemp (*Crotalaria juncea* L.) being the most common one due to its suppressive effects on sting nematodes (*Belonolaimus longicaudatus* Rau.), a major pest in Florida strawberry production [10]. Sunn hemp residues exhibited allelopathic effects on the seed germination of weeds and certain vegetable crops, but there are no known effects on field-grown strawberries. Sunn hemp can produce 5050–11,235 kg/ha of dry biomass with about 2.85% of N in plant residues and provide 100–200 kg/ha of total available N to the subsequent cash crop [11–13]. Sunn hemp was considered to be a well-suited cover crop in the Southeastern U.S. which could provide 33% to 50% of the total N needed for most crops, assuming a 50% availability of the N accumulated from sunn hemp after 60 days of seeding [13]. However, despite the popularity of using sunn hemp in rotation with organic strawberry cultivation, research-based information is scarce regarding its effects on the plant performance of the following strawberry crop, as well as on the role of sunn hemp in the nutrient management of organic strawberry plants given its considerable contribution of N release.

In this study, the effects of sunn hemp as a summer rotational crop on the subsequent strawberry production were assessed by considering the nutrient availability from sunn hemp biomass accumulation in terms of plant growth and fruit yield of two strawberry cultivars in an organic production system.

## 2. Materials and Methods

### *2.1. Experimental Design and Field Trial Establishment*

The field trial was conducted during the 2014–2015 strawberry season on a certified organic land at the University of Florida Plant Science Research and Education Unit (PSREU) in Citra, FL, USA (lat. 29.41° N, long. 82.16° W). This region has a humid subtropical climate, and the Candler sand soil at the experimental site is classified as arenosols according to the World Reference Base for Soil Resources (WRB). During the experimental period, the average daily air temperature was 19.3 °C and the accumulative precipitation reached 745.5 mm (Figure 1).

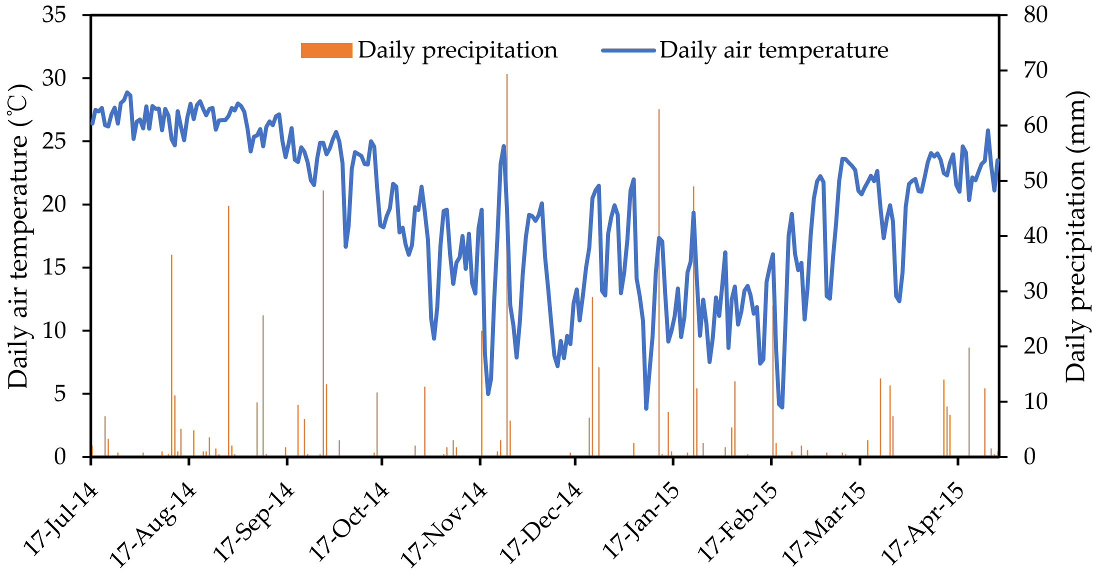


**Figure 1.** Daily air temperature and precipitation in Citra during the entire experimental period. The data reported were from 17 July 2014 to 29 April 2015. Data source: Florida Automated Weather Network (FAWN): https://fawn.ifas.ufl.edu/ (accessed on 31 October 2023).

The field experiment was arranged in a split-plot design with four replications and eighty plants per subplot. The soil and nutrient management practice for organic strawberry production was the whole plot factor, while the strawberry cultivar was the subplot factor. There were three soil and nutrient management treatments in the whole plots, which were randomized in a complete block design, including: (1) sunn hemp as a summer cover crop before the strawberry production season, with a pre-plant N fertilization rate at 84.0 kg N/ha for the strawberry season; (2) sunn hemp as a summer cover crop before the strawberry production season, with a reduced pre-plant N fertilization providing 19.8 kg/ha of N, assuming that 50% of the N from sunn hemp incorporation would be available for strawberry uptake, based on the sunn hemp biomass estimation and tissue analysis for nutrients; and (3) a summer fallow control without sunn hemp and with a pre-plant fertilization rate at 84.0 kg/ha of N. The two short-day strawberry cultivars used in this study were 'Strawberry Festival' and 'Camino Real'.

The sunn hemp was broadcast seeded at 44.8 kg/ha on 17 July 2014, and the plants were incorporated into the soil using flail-mowing and roto-tilling at a depth of about 13 cm on 22 September 2014, at which time < 5% of the plants started to flower. The plots were tilled twice more at a 13 cm depth before the bed formation and the strawberry transplanting on 14 October 2014. The plots without sunn hemp were maintained as a summer fallow before strawberry planting. In order to minimize the weed pressure effect, the summer fallow plots were tilled three times at a soil depth of approximately 13 cm on 13 August, 7 September, and 14 October 2014. All the field plots were hand-weeded during the strawberry season.

The organic fertilizers used for the pre-plant application included a mixture of MicroSTART60 3N-0.9P-2.5K (Perdue AgriRecycle, LLC., Seaford, DE, USA), Howard Organic Bonemeal 7N-5.2P-0K (Howard Fertilizer & Chemical Co., Inc., Orlando, FL, USA), and Jobe's Organics Bone Meal 2N-6.1P-0K (Easy Gardener Products, Inc., Waco, TX, USA). They were banded in the bed location and incorporated during bed formation. The pre-plant phosphorus (P) and potassium (K) fertilization rates were determined according to the soil test results. For the reduced pre-plant fertilization treatment, the P and K availability from the sunn hemp residues was also factored into the calculation. GATOR 96002 Organic

Liquid 3N-0P-5.0K (Howard Fertilizer & Chemical Co., Inc., Orlando, FL, USA) was used for in-season fertigation through drip irrigation. The in-season fertilization for the organic strawberry production remained the same for all treatments. All the fertilizer products utilized are approved for use in certified organic crop production. The pre-plant application rates of N, P, and K, as well as the application rates throughout the whole strawberry season for each soil and nutrient management treatment, are presented in Table 1.

**Table 1.** Nitrogen (N), phosphorus (P), and potassium (K) sources and rates for full and reduced pre-plant fertilization treatments used in the organic strawberry field trial in Citra, FL, USA.

| | N (kg/ha) | P (kg/ha) | K (kg/ha) | Organic Fertilizer and Ratio (Based on Weight) |
|---|---|---|---|---|
| Pre-plant fertilization [1] | | | | |
| Full N rate | 84.0 | 45.5 | 21.4 | MicroSTART60: Howard Organic Bone Meal = 3:2 |
| Reduced N rate | 19.8 | 38.8 | 5.6 | Jobe's Organics Bone Meal: MicroSTART60 = 2:1 |
| In-season fertigation [2] | 152.2 | 0.0 | 253.6 | GATOR 96002 Organic Liquid 3N-0P-5.0K |
| Whole-season fertilization [3] | | | | |
| Full N rate | 236.2 | 45.5 | 275.0 | Pre-plant fertilization at the full rate plus fertigation |
| Reduced N rate | 172.0 | 38.8 | 259.2 | Pre-plant fertilization at the reduced rate plus fertigation |

[1] Part of nutrient management treatments, applied before strawberry transplanting on 14 October 2014; [2] Liquid fertilizer applied after the strawberry plant establishment through drip irrigation. The same fertigation rates were used in both the full N rate and reduced N rate treatments; [3] Total fertilization applied during the whole strawberry season, including the pre-plant and in-season fertilization.

### 2.2. Field Planting of Strawberry

There were four 26.7 m long planting beds in each replication (block), with each planting bed being divided into three sections for the three soil and nutrient management treatments; two nearby sections of two parallel beds represented a subplot (80 strawberry plants), where each of the strawberry cultivars was planted. Strawberry plug plants (Luc Lareault Nursery, Lavaltrie, QC, Canada) were transplanted into double rows spaced 30.5 cm apart on the raised beds on 14 October 2014. The planting beds were 1.0 m wide at the base and 0.8 m wide at the top, 17.8 cm high, and spaced 1.5 m apart from their center The beds were covered with 1.25 mil black polyethylene mulch (Intergro, Inc., Clearwater, FL, USA). Timer-controlled irrigation was applied twice per day, for 45 min (min) each, and the irrigation schedule was adjusted as needed. The plants were fertigated through a drip irrigation system (30.5 cm emitter spacing) under the plastic mulch at the N application rate of 0.67 kg/ha per day starting on 14 November 2014, later increased to 1.12 kg/ha per day from 5 December 2014, and finally adjusted to 1.34 kg/ha per day from 6 March 2015 until the end of the season. AgroFabric Pro42 row covers that transmit 60% of light (Universal Enterprises Supply, Pompano Beach, FL, USA) were applied for frost protection. The predatory mites *Phytoseiulus persimilis* and *Neoseiulus californicus* (Spidex and Spical; Koppert Biological Systems, Inc., Howell, MI, USA) were released on 21 November 2014 to control the two-spotted spider mites.

### 2.3. Soil and Plant Tissue Analyses

The sunn hemp was sampled for above- and below-ground tissue in five randomly selected areas from each of the whole plots with sunn hemp being grown in the summer, using 0.5 m × 0.5 m quadrants. After drying the fresh tissue at 65 °C for two weeks to a constant weight, the total amount of dry weight of the sunn hemp was recorded. The dried sunn hemp samples were sent to Waters Agricultural Laboratories, Inc. (Camilla, GA, USA) for measuring the N, P, and K contents. The total N was analyzed using the dry-combustion method, while the P and K contents were analyzed with the open-vessel wet-digestion method, followed by an inductively coupled argon plasma (ICAP) spectroscopy analysis. The total amounts of N, P, and K provided by the sunn hemp were calculated based on the dry biomass and corresponding tissue nutrient analysis results.

Soil samples were collected at a 30 cm depth for soil nutrient analysis twice during the season, as follows: before sunn hemp incorporation (22 September 2014) and after the final harvest (29 April 2015). The first soil sampling comprised three replicated samples from each of the twelve whole plots, and the second soil sampling was composed of three replicated samples from each of the twenty-four subplots. The soil organic matter (OM) content, cation exchange capacity (CEC), total soil N, and levels of extractable P, K, calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and boron (B) were analyzed using the Mehlich-1 extraction method (Waters Agricultural Laboratories, Inc., Camilla, GA, USA). The soil test results before strawberry planting were used to develop the soil fertility management program for the strawberry season.

Strawberry tissue macronutrient (N, P, K, Ca, Mg, and S) and micronutrient (Fe, Mn, Zn, Cu, and B) analyses were conducted (Waters Agricultural Laboratories, Inc.) in the early season (26 November 2014), 43 days after transplanting (DAT) and after the final harvest (22 April 2015, 190 DAT) by sampling 14 of the most recently matured leaves from each subplot. The nutrient contents of the dried strawberry leaf samples were determined following the same protocols used for the sunn hemp tissue analyses.

### 2.4. Strawberry Growth and Yield Assessments

The strawberry plants showing open flowers were counted on 4, 10, and 17 November and on 2 December 2014. Four randomly selected strawberry plants from each subplot were marked on 14 November 2014 for growth assessments including leaf number, canopy size, crown diameter, and chlorophyll content index at different stages, as follows: early season (14 November and 4 December 2014, 31 and 51 DAT, respectively), early and peak harvest (18 December 2014 and 22 January 2015, 65 and 100 DAT, respectively), and late season (12 March and 22 April 2015, 149 and 190 DAT, respectively). Only the fully matured leaves that emerged after transplanting were counted. The smallest and the largest canopy diameters were measured, and the average of the two was used to determine the canopy size. The overall crown diameter was measured at approximately 1 cm above the soil line using an electronic caliper (General Tools & Instruments, Secaucus, NJ, USA). The leaf chlorophyll content index was were examined on ten most recently matured leaves in each subplot using a SPAD 502 Plus Chlorophyll Meter (Spectrum Technologies, Inc., Aurora, IL, USA). The above- and below-ground biomass of the strawberry plants, excluding flowers or fruit, was assessed on 1 May 2015 after the final harvest. Three randomly selected plants from each subplot were collected from the field, cleaned, separated at the soil line, and oven-dried at 60 °C for four weeks to a constant weight. The dry samples were then weighed to estimate the plant biomass accumulation over the whole season. The above-ground plant accumulation of N, P, and K was also estimated based on the dry biomass and leaf tissue nutrient contents.

Fruit with calyx attached were picked from all the field plots. The strawberries were harvested from 4 December 2014 to 6 April 2015, approximately twice per week, with a total of 26 harvests conducted. The fruit number and weight were measured to determine marketable and unmarketable fruit yields. The strawberry fruit (>5 g) with red color over at least 80% of the surface area and without decay, disease, pest, or mechanical damages was considered as marketable fruit.

### 2.5. Statistical Analyses

The data analysis was conducted using the Glimmix procedure of the SAS statistical software package for Windows (Version 9.2; SAS Institute, Cary, NC, USA). A two-way analysis of variance (ANOVA) was performed following the split-plot design. The Fisher's Least Significant Difference (LSD) test was used for multiple comparisons of different measurements among treatments at $\alpha = 0.05$.

## 3. Results and Discussion

### 3.1. Soil and Plant Tissue Analyses

The soil tests before sunn hemp incorporation showed comparable levels of soil OM, CEC, total N, and extractable P, Ca, Mg, S, Fe, Mn, Zn, Cu, and B between the sunn hemp plots and the summer fallow plots, but the former had a significantly lower level of available K in the soil (Table 2). A previous study conducted in Florida sandy soils also reported a significant reduction in the soil test of K levels following cover cropping over the summer season [14]. After the final strawberry harvest, i.e., about seven months following the soil incorporation of the sunn hemp residues, similar levels of soil OM, CEC, and available nutrients were observed among the sunn hemp treatments and the summer fallow control, except for the total soil N level. While the total soil N level was similar among the sunn hemp plots despite their different pre-plant fertilization rates, it was significantly lower compared to the summer fallow plot. This finding was surprising given the total amount of above-ground dry biomass (4620.5 kg/ha) of sunn hemp and the N accumulation (117.1 kg/ha) at soil incorporation prior to the strawberry planting. The above-ground accumulation of N in sunn hemp observed in the present study is within the commonly reported range of 73–207 kg/ha [15]. The average C:N ratio of the sunn hemp residues at termination was 21:1, suggesting that a relatively fast decomposition might have occurred after soil incorporation [11–13,16]. According to Wang et al. (2011) [17], the breakdown of sunn hemp residues usually takes place within two weeks following soil incorporation in tropical areas. A previous study in Florida sandy soils also showed that approximately 50% of N could be released during the first four weeks after sunn hemp residue incorporation [18]. Another field decomposition study of sunn hemp residues demonstrated that as much as 64% of N could be released within the first two weeks following sunn hemp termination, with the total N release reaching 79% after 6 months [19]. Moreover, N mineralization and release from organic amendments is strongly correlated with soil temperature and moisture, being generally faster in warmer and moist soils until the soil water potential reaches its maximum [20–24]. In this study, the daily average soil temperature at 10-cm depth ranged from 13.5 to 28.3 °C, and 107.2 mm of rainfall occurred between sunn hemp termination (22 September 2014) and four weeks after strawberry transplanting (11 November 2014) [25]. Given that the active plant uptake of nutrients, particularly N, may not occur until the field establishment of the strawberry crop (at least 7–10 DAT), it was likely that most of the mineralized N from the sunn hemp residues had already been lost from the root zone through denitrification and leaching prior to strawberry transplanting. It was reported that the fast release of available N from sunn hemp was likely exceeding the demand of strawberry plants and could potentially result in N losses [26].

**Table 2.** The soil organic matter (OM), cation exchange capacity (CEC), and nutrient levels before sunn hemp incorporation (22 September 2014) and after the strawberry final harvest (29 April 2015) in Citra, FL, USA.

| | Before Sunn Hemp Incorporation | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | OM (%) | CEC (meq/100 g) | TN (%) | P | K | Ca | Mg | S (mg/kg) | Fe | Mn | Zn | Cu | B |
| Management (M) | | | | | | | | | | | | | |
| SF w/full N | 0.77 | 3.8 | 0.04 | 35.9 | 10.4 a | 453.6 | 56.1 | 17.4 | 8.0 | 2.1 | 0.3 | 0.1 | 0.1 |
| SH w/full N | 0.76 | 3.7 | 0.05 | 35.1 | 8.8 b | 460.8 | 52.9 | 11.0 | 9.5 | 1.9 | 0.3 | 0.1 | 0.1 |
| SH w/reduced N | 0.79 | 3.8 | 0.07 | 35.9 | 8.8 b | 471.4 | 53.5 | 11.6 | 8.3 | 1.7 | 0.3 | 0.1 | 0.1 |
| Significance | NS | NS | NS | NS | * | NS | NS | NS | NS | NS | NS | NS | NS |

**Table 2.** *Cont.*

| Treatment | OM (%) | CEC (meq/100 g) | TN (%) | P | K | Ca | Mg | S (mg/kg) | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | After Strawberry Final Harvest | | | | | | | | | | | | |
| Management (M). | | | | | | | | | | | | | |
| SF w/full N | 0.67 | 4.5 | 0.19 a | 50.6 | 76.5 | 588.5 | 31.3 | 14.2 | 7.3 | 2.0 | 0.8 | 0.2 | 0.2 |
| SH w/full N | 0.78 | 4.9 | 0.15 b | 45.9 | 94.1 | 661.3 | 32.4 | 6.7 | 6.9 | 1.9 | 0.8 | 0.2 | 0.2 |
| SH w/reduced N | 0.74 | 4.9 | 0.15 b | 49.2 | 89.3 | 664.1 | 33.8 | 7.9 | 7.0 | 2.3 | 1.0 | 0.2 | 0.2 |
| Significance | NS | NS | * | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Cultivar (C) | | | | | | | | | | | | | |
| Strawberry Festival | 0.73 | 4.7 | 0.16 | 47.8 | 80.3 b | 622.8 | 32.1 | 10.9 | 7.1 | 2.1 | 0.8 | 0.2 | 0.2 |
| Camino Real | 0.73 | 4.8 | 0.16 | 49.3 | 93.0 a | 653.1 | 32.8 | 8.3 | 7.0 | 2.0 | 0.9 | 0.2 | 0.2 |
| Significance | NS | NS | NS | NS | ** | NS | NS | NS | NS | NS | NS | NS | NS |
| M × C interaction | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

SF: summer fallow; SH: sunn hemp; OM: organic matter; CEC: cation exchange capacity; TN: total nitrogen. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, and **: nonsignificant or significant at $p \leq 0.05$ or 0.01, respectively.

With regard to the strawberry cultivar impact on the soil nutrients after the final harvest, 'Camino Real' resulted in a significantly higher level of soil K than 'Strawberry Festival' (Table 2), suggesting a possibly higher demand of K by 'Strawberry Festival'. The sting nematode infestation did not interfere with the treatments in this study as the soil tests of each subplot at the end of the strawberry season showed an undetectable level of sting nematode population. The soil pH did not differ significantly among the different soil nutrient management treatment plots or between the different cultivar plots; however, it showed an increase, from 6.4 to 7.4, from before the sunn hemp incorporation to after the strawberry harvest, during the experimental period. The strawberry leaf tissue nutrient contents were not significantly affected in the early season (43 DAT) and after the final harvest (190 DAT) by different soil and nutrient management practices, except for the Mn and S after the final harvest. The leaf Mn levels were significantly higher in the sunn hemp treatment with the reduced pre-plant N fertilization compared to the treatment with the full N fertilizer rate, as well as the summer fallow plots. The strawberry leaf content of S was significantly higher in the summer fallow plots relative to the sunn hemp plots (Table 3). In contrast, strawberry cultivar had a greater impact on leaf nutrient contents, although the varietal difference varied during the production season (Table 3). The early season leaf tissue analysis showed that the strawberry plants were adequate in the levels of N, K, Ca, S, B, Mn, and Fe, high in P and Mg, but slightly deficient in Zn and Cu [27]. The leaf tissue contents of P, Cu, and Zn were significantly higher in 'Camino Real' than 'Strawberry Festival' in the early season, whereas 'Strawberry Festival' had higher levels of leaf P, Mg, S, Fe, Mn, and B after the final harvest (Table 3). The soil and nutrient management by cultivar interaction was detected for Zn in the early season, as shown by the higher level of Zn in the summer fallow control for 'Camino Real' but not 'Strawberry Festival'. The interaction effects were also found in the strawberry leaf P, S, and B contents after the final harvest. The 'Strawberry Festival' grown with the reduced pre-plant N fertilization had significantly lower levels of P and S compared to the full pre-plant N fertilization treatments with or without sunn hemp, while the sunn hemp with the full pre-plant N fertilization resulted in the highest B content in the 'Strawberry Festival' leaves but the lowest B level in 'Camino Real'. The total N, P and K accumulation in the strawberry leaf tissue after the final harvest showed a significant reduction in N, P, and K in the plants grown in the reduced pre-plant N fertilization plots in contrast to the full N rate plots. No difference was observed between the two strawberry cultivars (Table 4).

**Table 3.** Nutrient management and cultivar effects on nutrient contents of the most recently matured leaves in the early season (26 November 2014, 43 DAT) and after the final harvest (22 April 2015, 190 DAT) in the organic strawberry field trial in Citra, FL, USA.

| Treatment | N | P | K | Ca | Mg | S | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Early Season | | | | | | | | | | |
| | (g/100 g) | | | | | | (mg/kg) | | | | |
| Management (M) | | | | | | | | | | | |
| SF w/full N | 3.18 | 0.47 | 1.75 | 1.41 | 0.57 | 0.21 | 73.6 | 45.3 | 16.3 | 3.4 | 30.3 |
| SH w/full N | 3.20 | 0.44 | 1.85 | 1.41 | 0.58 | 0.21 | 72.6 | 46.0 | 15.0 | 3.6 | 31.4 |
| SH w/reduced N | 3.15 | 0.44 | 1.83 | 1.46 | 0.59 | 0.20 | 69.4 | 39.0 | 14.4 | 3.5 | 30.9 |
| Significance | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Cultivar (C) | | | | | | | | | | | |
| Strawberry Festival | 3.21 | 0.41 b | 1.85 | 1.49 | 0.60 | 0.21 | 70.6 | 42.7 | 13.7 b | 3.3 b | 30.8 |
| Camino Real | 3.15 | 0.48 a | 1.77 | 1.37 | 0.56 | 0.20 | 73.2 | 44.2 | 16.8 a | 3.8 a | 30.9 |
| Significance | NS | ** | NS | NS | NS | NS | NS | NS | *** | * | NS |
| M × C interaction | NS | NS | NS | NS | NS | NS | NS | NS | * | NS | NS |
| | After Final Harvest | | | | | | | | | | |
| Treatment | N | P | K | Ca | Mg | S | Fe | Mn | Zn | Cu | B |
| | (g/100 g) | | | | | | (mg/kg) | | | | |
| Management (M) | | | | | | | | | | | |
| SF w/full N | 1.94 | 0.32 | 2.22 | 1.18 | 0.39 | 0.20 a | 69.4 | 21.6 b | 19.8 | 5.3 | 17.6 |
| SH w/full N | 2.07 | 0.33 | 2.38 | 1.18 | 0.34 | 0.19 b | 72.5 | 19.6 b | 19.4 | 5.4 | 18.6 |
| SH w/reduced N | 2.00 | 0.30 | 2.17 | 1.22 | 0.36 | 0.19 b | 70.9 | 29.8 a | 18.1 | 5.6 | 17.9 |
| Significance | NS | NS | NS | NS | NS | * | NS | ** | NS | NS | NS |
| Cultivar (C) | | | | | | | | | | | |
| Strawberry Festival | 2.02 | 0.33 a | 2.25 | 1.23 | 0.38 a | 0.20 a | 75.0 a | 24.8 a | 18.8 | 5.3 | 19.7 a |
| Camino Real | 1.99 | 0.31 b | 2.26 | 1.16 | 0.34 b | 0.19 b | 66.8 b | 22.6 b | 19.3 | 5.5 | 16.4 b |
| Significance | NS | * | NS | NS | ** | * | * | * | NS | NS | ** |
| M × C interaction | NS | ** | NS | NS | NS | * | NS | NS | NS | NS | * |

SF: summer fallow; SH: sunn hemp; DAT: days after transplanting. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, **, and ***: nonsignificant or significant at $p \leq 0.05$, 0.01, or 0.001, respectively.

**Table 4.** Strawberry plant above- and below-ground dry biomass after the final harvest and the estimated above-ground plant accumulation of N, P, and K in the organic strawberry field trial in Citra, FL, USA.

| Treatment | Above-Ground Biomass (g/plant) | Below-Ground Biomass (g/plant) | N (g/plant) | P (g/plant) | K (g/plant) |
|---|---|---|---|---|---|
| Management (M) | | | | | |
| SF w/full N | 56.06 a | 26.53 | 1.08 ab | 0.18 a | 1.25 a |
| SH w/full N | 57.21 a | 26.14 | 1.18 a | 0.19 a | 1.36 a |
| SH w/reduced N | 48.59 b | 24.46 | 0.97 b | 0.15 b | 1.05 b |
| Significance | * | NS | ** | * | * |
| Cultivar (C) | | | | | |
| Strawberry Festival | 51.79 | 25.28 | 1.04 | 0.17 | 1.17 |
| Camino Real | 56.12 | 26.14 | 1.11 | 0.17 | 1.27 |
| Significance | NS | NS | NS | NS | NS |
| M × C interaction | NS | NS | NS | NS | NS |

SF: summer fallow; SH: sunn hemp. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, and **: nonsignificant or significant at $p \leq 0.05$ or 0.01, respectively.

The strawberry leaf tissue nutrient analysis results indicated a limited nutrient contribution from the sunn hemp residues to the following strawberry crop over a long production period of over five months (Table 4). Although sunn hemp has been shown as a potential cover crop in the southeastern U.S to provide N for promoting corn yield in the following season [28], our findings indicated that the role of sunn hemp in increasing soil

N might be restricted by the warm, humid conditions at the time of sunn hemp termination and during the early season of strawberry production. Moreover, flail mowing sunn hemp might also have accelerated the decomposition of the plant residues, resulting in N losses prior to acquisition by the strawberry plants.

### 3.2. Strawberry Plant Growth

The reduced pre-plant N fertilization treatment resulted in fewer leaves, smaller crowns of the strawberry plants, and a lower leaf chlorophyll content index than the full pre-plant N fertilization treatments at 31 DAT (Table 5). The canopy size was also smaller in the sunn hemp plot with the reduced N fertilization in contrast to the one with the full N fertigation at 31 DAT, but it did not differ significantly from the control without sunn hemp (Table 5). The leaf number and crown diameter remained significantly lower in the reduced fertilization treatment than in the full rate sunn hemp treatment at 51 DAT (Table 5). 'Strawberry Festival' consistently had significantly more leaves than 'Camino Real' at each sampling date from 31 to 100 DAT. A larger canopy size at 65 and 100 DAT and a greater crown diameter at 100 DAT were also observed in 'Strawberry Festival', whereas the leaf chlorophyll content index was significantly lower in 'Strawberry Festival' at 51 DAT (Table 5). As expected, 'Camino Real' had fewer plants with open flowers than 'Strawberry Festival' in the early season flower count. Moreover, 'Strawberry Festival' grown in the reduced pre-plant fertilization treatment exhibited significantly fewer plants with open flowers than the full rate sunn hemp treatment and the summer fallow control. The above-ground biomass assessment after the final harvest revealed a significant reduction in the reduced pre-plant fertilization treatment compared to the full rates with or without sunn hemp, while no difference was detected between the two cultivars, nor in the below-ground biomass (Table 4).

These results of strawberry plant growth parameters indicated that reducing pre-plant fertilization (from 84.0 to 19.8 kg/ha) in the sunn hemp treatment compromised the early growth and development of strawberry plants. In addition, without modifying the fertilization rate for the strawberry crop, growing sunn hemp as a summer rotational cover crop did not show any effects on promoting the growth of strawberry plants, since there were no significant differences between the two full fertilization treatments with and without sunn hemp. Sunn hemp planted in April in the southeastern coastal area of the U.S. and grown over a 90-day period has been reported to produce 8900–13,000 kg/ha of biomass with approximately 135–285 kg/ha of N, at a seeding rate of 13 kg/ha (planted in rows) [13]. In contrast, in the present study, the sunn hemp produced less dry matter (4617 kg/ha) and less N (about 117 kg/ha), with a higher broadcast seeding rate (44.8 kg/ha) in Florida sandy soils but a shorter and later growing period of 67 days from July to September. A relatively high seeding rate was used in our study for weed suppression. A previous report of sunn hemp evaluation in Hawaii showed that the planting date and soil pH exhibited greater impacts on sunn hemp biomass accumulation than the seeding rate [17]. Regardless of the high level of biomass (12,200 kg/ha) and N accumulation (171 kg/ha) in sunn hemp after a 98-day establishment in northern Florida [18], previous studies demonstrated substantial N losses after sunn hemp termination, which resulted in reduced N availability to the subsequent winter corn crop grown in Florida sandy soils.

**Table 5.** Nutrient management and cultivar effects on leaf number, canopy size, crown diameter, and leaf chlorophyll content index of strawberry plants in the early season (14 November and 4 December 2014, 31 and 51 DAT, respectively), early and peak harvest (18 December 2014 and 22 January 2015, 65 and 100 DAT, respectively), and late season (12 March and 22 April 2015, 149 and 190 DAT, respectively) in Citra, FL, USA.

| Treatment | Early Season and Peak Harvest | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Leaf Number Per Plant | | | | Canopy Size (cm) | | | | Crown Diameter (mm) | | | | Leaf Chlorophyll Content Index (SPAD Value) | | |
| | 31 DAT | 51 DAT | 65 DAT | 100 DAT | 31 DAT | 51 DAT | 65 DAT | 100 DAT | 31 DAT | 51 DAT | 65 DAT | 100 DAT | 31 DAT | 51 DAT | 65 DAT |
| Management (M) | | | | | | | | | | | | | | | |
| SF w/full N | 3.4 a | 5.3 ab | 6.3 | 11.4 a | 13.9 ab | 21.7 | 24.1 | 26.5 | 11.9 a | 17.0 b | 19.3 ab | 27.9 | 45.0 a | 49.4 | 50.8 |
| SH w/full N | 3.4 a | 5.5 a | 6.2 | 11.6 a | 14.9 a | 21.8 | 24.4 | 27.0 | 11.8 a | 17.9 a | 20.0 a | 30.9 | 45.1 a | 49.4 | 50.5 |
| SH w/reduced N | 3.0 b | 4.7 b | 5.7 | 9.8 b | 12.9 b | 19.9 | 23.1 | 25.5 | 10.6 b | 16.3 b | 18.2 b | 26.0 | 41.4 b | 47.9 | 50.7 |
| Significance | * | * | NS | * | * | NS | NS | NS | * | * | * | NS | * | NS | NS |
| Cultivar (C) | | | | | | | | | | | | | | | |
| Strawberry Festival | 3.5 a | 6.0 a | 7.1 a | 12.7 a | 14.2 | 21.6 | 24.9 a | 27.1 a | 11.7 | 17.3 | 19.5 | 31.3 a | 43.0 | 47.8 b | 50.1 |
| Camino Real | 3.1 b | 4.4 b | 5.0 b | 9.2 b | 13.6 | 20.7 | 22.8 b | 25.5 b | 11.1 | 16.8 | 18.9 | 25.2 b | 44.6 | 50.0 a | 51.2 |
| Significance | *** | *** | *** | *** | NS | NS | *** | ** | NS | NS | NS | ** | NS | ** | NS |
| M × C interaction | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

| Treatment | Late Season | | | | | | |
|---|---|---|---|---|---|---|---|
| | Leaf Number Per Plant | | Canopy Size (cm) | | Crown Diameter (mm) | | Leaf Chlorophyll Content Index (SPAD Value) |
| | 149 DAT | 190 DAT | 149 DAT | 190 DAT | 149 DAT | 190 DAT | 190 DAT |
| Management (M) | | | | | | | |
| SF w/full N | 15.6 | 17.9 | 25.9 | 28.5 | 36.3 | 55.1 | 41.1 |
| SH w/full N | 16.9 | 16.5 | 26.7 | 28.9 | 42.1 | 62.6 | 40.7 |
| SH w/reduced N | 14.0 | 16.7 | 25.1 | 29.5 | 37.9 | 58.5 | 41.6 |
| Significance | NS | NS | NS | NS | NS | NS | NS |
| Cultivar (C) | | | | | | | |
| Strawberry Festival | 15.8 | 16.8 | 25.8 | 29.3 | 40.0 | 62.3 | 42.1 |
| Camino Real | 15.1 | 17.3 | 25.9 | 28.6 | 37.6 | 55.2 | 40.1 |
| Significance | NS | NS | NS | NS | NS | NS | NS |
| M × C interaction | NS | NS | NS | NS | NS | NS | NS |

SF: summer fallow; SH: sunn hemp; DAT: days after transplanting. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, **, and ***: nonsignificant or significant at $p \leq 0.05$, 0.01, or 0.001, respectively.

*3.3. Strawberry Fruit Yield*

With respect to the whole-season yield components (Table 6), 'Strawberry Festival' had greater marketable (by 69.6%) and total fruit numbers (by 36.6%), as well as a higher marketable fruit yield (by 29.3%) than 'Camino Real', whereas 'Camino Real' produced larger berries, as shown by the higher average marketable fruit weight (by 31.5%). The comparisons of soil and nutrient management practices did not indicate any significant difference between the two full pre-plant N fertilization treatments (with or without sunn hemp), while the reduction in pre-plant N fertilization (with sunn hemp) led to significantly lower total fruit number and yield by about 12.7%, relative to the full pre-plant N fertilization treatments (Table 6). This reduction in crop productivity was in line with the decreases in the strawberry plant above-ground biomass and accumulation of N, P, and K after the final harvest (Table 4). However, the marketable fruit number and yield and the average marketable fruit weight did not differ significantly among the nutrient management practices (Table 6).

**Table 6.** Nutrient management and cultivar effects on the total and marketable strawberry yield components in the organic strawberry field trial in Citra, FL, USA.

| Treatment | Marketable Fruit Number (No./plant) | Total Fruit Number (No./plant) | Marketable Fruit Yield (g/plant) | Total Fruit Yield (g/plant) | Average Marketable Fruit Weight (g/plant) |
|---|---|---|---|---|---|
| Management (M) | | | | | |
| SF w/full N | 11.0 | 22.9 a | 203.1 | 357.0 a | 19.0 |
| SH w/full N | 10.6 | 22.8 a | 194.5 | 353.3 a | 18.9 |
| SH w/reduced N | 10.3 | 20.4 b | 179.5 | 309.9 b | 18.3 |
| Significance | NS | ** | NS | * | NS |
| Cultivar (C) | | | | | |
| Strawberry Festival | 13.4 a | 25.4 a | 216.9 a | 351.8 | 16.2 b |
| Camino Real | 7.9 b | 18.6 b | 167.8 b | 328.4 | 21.3 a |
| Significance | *** | *** | *** | NS | *** |
| M × C interaction | NS | NS | NS | NS | NS |

SF: summer fallow; SH: sunn hemp. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, **, and ***: nonsignificant or significant at $p \leq 0.05$, 0.01, or 0.001, respectively.

In terms of the monthly yield components from December 2014 to April 2015, both sunn hemp treatments (with full or reduced pre-plant N fertilization) showed significantly lower marketable and total fruit numbers and yields in December compared to the summer fallow control (Table 7). Reducing the pre-plant N fertilization (with sunn hemp) also led to decreases in the total fruit number during March–April (by 14.7%) and in the total fruit yield in February (by 12.8%), in comparison to the full pre-plant N fertilization treatments. In addition, both sunn hemp treatments showed lower total fruit yields (by 13.0%) in January than the weedy fallow control. While the yield of 'Strawberry Festival' peaked in February and the fruit size decreased in the late season, 'Camino Real' maintained its fruit size in the late season and produced a greater yield during March–April. Overall, 'Strawberry Festival' outperformed 'Camino Real' in the monthly fruit number and yield from December to February (Table 7).

**Table 7.** Nutrient management and cultivar effects on monthly marketable and total fruit numbers and yields per plant in the organic strawberry field trial in Citra, FL, USA.

| Treatment | Marketable Fruit Number (No./plant) | | | | Total Fruit Number (No./plant) | | | | Marketable Fruit Yield (g/plant) | | | | Total Fruit Yield (g/plant) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dec | Jan | Feb | Mar–Apr | Dec | Jan | Feb | Mar–Apr | Dec | Jan | Feb | Mar–Apr | Dec | Jan | Feb | Mar–Apr |
| Management (M) | | | | | | | | | | | | | | | | |
| SF w/full N | 0.9 a | 2.6 | 3.2 | 4.4 | 0.9 a | 4.4 | 5.2 | 12.3 a | 13.5 a | 48.1 | 67.1 | 74.3 | 14.1 a | 74.9 a | 100.7 a | 167.4 |
| SH w/full N | 0.7 b | 2.3 | 3.2 | 4.4 | 0.7 b | 4.1 | 5.2 | 12.8 a | 9.9 b | 42.1 | 65.5 | 77.0 | 10.5 b | 64.7 b | 99.6 a | 178.4 |
| SH w/reduced N | 0.6 b | 2.5 | 2.9 | 4.3 | 0.6 b | 4.4 | 4.7 | 10.7 b | 8.1 b | 41.4 | 57.1 | 72.8 | 8.8 b | 65.6 b | 87.3 b | 148.1 |
| Significance | * | NS | NS | NS | ** | NS | NS | * | * | NS | NS | NS | * | * | * | NS |
| Cultivar (C) | | | | | | | | | | | | | | | | |
| Strawberry Festival | 1.1 a | 3.0 a | 4.5 a | 4.7 | 1.2 a | 4.9 a | 6.8 a | 12.6 a | 15.1 a | 47.7 a | 83.2 a | 70.7 | 16.2 a | 68.9 | 115.9 a | 150.7 b |
| Camino Real | 0.3 b | 1.9 b | 1.7 b | 4.0 | 0.3 b | 3.7 b | 3.4 b | 11.2 b | 5.9 b | 40.0 b | 43.2 b | 78.7 | 6.2 b | 67.9 | 75.8 b | 178.5 a |
| Significance | *** | *** | *** | NS | *** | *** | *** | * | *** | * | *** | NS | *** | NS | *** | * |
| M × C interaction | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

SF: summer fallow; SH: sunn hemp. The means within the same column followed by the same letter do not differ significantly according to Fisher's least significant difference test at $p \leq 0.05$. NS, *, **, and ***: nonsignificant or significant at $p \leq 0.05$, 0.01, or 0.001, respectively.

The results of the strawberry yield indicated that the cultivar differences outweighed the effects of soil and nutrient management in both the whole-season and monthly yields of the organically grown strawberries in the present study. The higher early yield observed in the summer fallow control plots compared to the sunn hemp plots might be associated with the tillage effects on the off-season weed control that could have impacted the weed pressure during the following strawberry season. In this study, the summer fallow control plots were tilled twice for weed management before sunn hemp termination. Miler et al. (2014) [29] reported that a summer fallow with roto-tilling twice before bell pepper production resulted in greater nutsedge (*Cyperus* spp.) suppression compared to the no tilling control. Although the whole-season marketable yield was not affected by the sunn hemp treatments, the reduced early yield during the production season in the sunn hemp plots, especially with the reduced pre-plant N fertilization, indicated that relying on the N release from sunn hemp to supplement pre-plant fertilization might not be feasible for promoting plant establishment and early fruiting. It was likely that the fast release of mineralized N from the sunn hemp residues and the potential losses of N from the rootzone either before or after strawberry planting compromised the strawberry plant growth and flowering in the early season, which was particularly evident for 'Strawberry Festival', which flowered earlier than 'Camino Real'. Interestingly, previous studies on tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum annuum* L.) production did not show benefits of sunn hemp residues in fruit yield improvement at a whole-season N application rate of 200 kg/ha until the third year, in comparison with the conventional summer fallow [30]. Hence, the impact of sunn hemp on organic strawberry production deserves to be systematically examined in long-term studies.

Pre-plant N fertilization has been reported to benefit crop establishment and yield performance for soybean (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.) [31–33]; however, the effects of pre-plant N application were inconsistent in several previous studies on Florida strawberries. No difference in either the monthly or total strawberry yield between pre-plant N fertilization at a rate of 56 kg/ha and the control without pre-plant N application was observed [34]. Soilless culture of strawberry plants in coconut coir and pine bark also showed similar early and total marketable fruit yields among different pre-plant N fertilization levels [35]. In contrast, Santos and Ramirez-Sanchez (2009) [36] and Santos (2010) [37] found that pre-plant N fertilization at 56 kg/ha together with S application at 30–64 kg/ha might help increase both the early and total marketable strawberry yields in Florida.

Overall, the strawberry marketable yield in the current study was relatively low because of the high cull percentage compared to previous studies by others [38,39]. Botrytis, anthracnose, and pest damage were observed in this field trial, which were the main causes of the unmarketable yield. Moreover, the lower yield might be related to consecutive frost events encountered in the production season during 19–20 November and 10–16 December 2014, and 28–29 January and 19–21 February 2015 [25], which resulted in a marketable yield reduction due to the extended frost protection with row covers.

## 4. Conclusions

In this study, growing sunn hemp as a summer rotational crop did not show any growth or yield improvement effects on the winter production of 'Strawberry Festival' and Camino Real' strawberries in Florida sandy soils. Decreasing the pre-plant N fertilization rate by taking into consideration the nutrients, particularly N, provided by the soil incorporation of sunn hemp residues reduced the early and total fruit yields, suggesting that the nutrient contribution by sunn hemp to the strawberry yield performance might be limited. The influence of nutrient management did not vary with the strawberry cultivars used, but overall, 'Strawberry Festival' was shown to be a better yielding cultivar than 'Camino Real' under organic production in this study. Given the environmental impacts of cover crop residue decomposition and nutrient release, long-term studies are needed to better understand the soil nutrient dynamics and strawberry plant nutrient uptake as affected by sunn hemp incorporation. Sunn hemp cropping systems and termination methods and timing also need to be considered to help match the cover crop nutrient release with the subsequent strawberry crop demand for improved crop establishment and fruit yield development.

**Author Contributions:** Conceptualization, X.Z.; methodology, X.Z., Y.X. and Z.E.B.; formal analysis, Y.X. and X.Z.; investigation, Y.X., Z.E.B. and X.Z.; data curation, Y.X.; writing—original draft preparation, Y.X. and X.Z.; writing—review and editing, Y.X., N.X., Z.E.B., J.K.B., D.M.H. and X.Z.; funding acquisition, X.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded in part by a National Strawberry Sustainability Initiative grant from the Walmart Foundation that was administered by the University of Arkansas System Division of Agriculture Center for Agricultural and Rural Sustainability.

**Data Availability Statement:** Data are contained within the article.

**Acknowledgments:** We thank Buck Nelson and his crew for their assistance with the field work conducted at the University of Florida Plant Science Research and Education Unit.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References


1. U.S. Department of Agriculture. 2021 Certified Organic Survey. Available online: https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Organic_Production/ (accessed on 25 August 2023).
2. Muramoto, J.; Smith, R.F.; Shennan, C.; Klonsky, K.M.; Leap, J.; Ruiz, M.S.; Gliessman, S.R. Nitrogen contribution of legume/cereal mixed cover crops and organic fertilizers to an organic broccoli crop. *HortScience* **2011**, *46*, 1154–1162. [CrossRef]
3. Parr, M.; Grossman, J.M.; Reberg-Horton, S.C.; Brinton, C.; Crozier, C. Roller-crimper termination for legume cover crops in North Carolina: Impacts on nutrient availability to a succeeding corn crop. *Commun. Soil Sci. Plant Anal.* **2014**, *45*, 1106–1119. [CrossRef]
4. Ebelhar, S.A.; Frye, W.W.; Blevins, R.L. Nitrogen from legume cover crops for no-tillage corn. *Agron. J.* **1984**, *76*, 51–55. [CrossRef]
5. Ranells, N.N.; Wagger, M.G. Nitrogen release from grass and legume cover crop monocultures and bicultures. *Agron. J.* **1996**, *88*, 777–882. [CrossRef]
6. Ozores-Hampton, M. Developing a vegetable fertility program using organic amendments and inorganic fertilizers. *HortTechnology* **2012**, *22*, 743–750. [CrossRef]
7. U.S. Department of Agriculture Natural Resource Conservation Service. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf (accessed on 19 January 2022).
8. Garland, B.C.; Schroeder-Moreno, M.S.; Fernandez, G.E.; Creamer, N.G. Influence of summer cover crops and mycorrhizal fungi on strawberry production in the southeastern United States. *HortScience* **2011**, *46*, 985–991. [CrossRef]
9. Portz, D.N.; Nonnecke, G.R. Rotation with cover crops suppresses weeds and increases plant density and yield of strawberry. *HortScience* **2011**, *46*, 1363–1366. [CrossRef]
10. Desaeger, J. Meloidogyne Hapla, the northern root-knot nematode, in Florida strawberries and associated double-cropped vegetables. *UF/IFAS Ext.* **2019**, ENY-070. Available online: https://edis.ifas.ufl.edu/publication/IN1224 (accessed on 31 October 2023). [CrossRef]
11. Li, Y.; Hanlon, E.A.; Klassen, W.; Wang, Q.; Olczyk, T.; Ezenwa, I.V. Cover crop benefits for South Florida commercial vegetable producers. *UF/IFAS Ext.* **2022**, SL-242. Available online: https://edis.ifas.ufl.edu/publication/SS461 (accessed on 31 October 2023). [CrossRef]
12. Wang, Q.; Li, Y.; Klassen, W.; Hanlon, E.A. Sunn hemp-a promising cover crop in Florida. *UF/IFAS Ext.* **2022**, SL-306. Available online: https://edis.ifas.ufl.edu/publication/TR003 (accessed on 31 October 2023). [CrossRef]
13. Schomberg, H.H.; Martini, N.L.; Diaz-Perez, J.C.; Phatak, S.C.; Balkcom, K.S.; Bhardwaj, H.L. Potential for using sunn hemp as a source of biomass and nitrogen for the Piedmont and Coastal Plain regions of the southeastern USA. *Agron. J.* **2007**, *99*, 1448–1457. [CrossRef]
14. Bhadha, J.H.; Xu, N.; Rabbany, A.; Amgain, N.R.; Capasso, J.; Korus, K.; Swanson, S. On-farm soil health assessment of cover-cropping in Florida. *Sustain. Agric. Res.* **2021**, *10*, 17–32. [CrossRef]
15. Gaskin, J.; Cabrera, M.; Kissel, D. Predicting nitrogen release from cover crops: The cover crop nitrogen availability calculator. *UGA Coop. Ext.* **2016**. Available online: https://extension.uga.edu/publications/detail.html?number=B1466 (accessed on 31 October 2023).
16. Lynch, M.J.; Mulvaney, M.J.; Hodges, S.C.; Thompson, T.L.; Thomason, W.E. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. *Springerplus* **2016**, *5*, 973. [CrossRef] [PubMed]
17. Wang, K.H.; Sipes, B.S.; Hooks, C.R.R.; Leary, J. Improving the status of sunn hemp as a cover crop for soil health and pests management. *Hanai'Ai Newsl.* 2011. Available online: https://projects.sare.org/wp-content/uploads/946541V8-Wang-sunnhemp.pdf (accessed on 30 October 2023).

18. Cherr, C.M.; Scholberg, J.M.S.; McSorley, R. Green manure as nitrogen source for sweet corn in a warm–temperate environment. *Agron. J.* **2006**, *98*, 1173–1180. [CrossRef]
19. Stallings, A.M.; Balkcom, K.S.; Wood, C.W.; Guertal, E.A.; Weaver, D.B. Nitrogen mineralization from 'AU Golden' sunn hemp residue. *J. Plant Nutr.* **2017**, *40*, 50–62. [CrossRef]
20. Agehara, S.; Warncke, D.D. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil Sci. Soc. Am. J.* **2005**, *69*, 1844–1855. [CrossRef]
21. Cabrera, M.L.; Kissel, D.E.; Vigil, M.F. Nitrogen mineralization from organic residues. *J. Environ. Qual.* **2005**, *34*, 75–79. [CrossRef]
22. Fan, X.H.; Li, Y.C. Nitrogen release from slow-release fertilizers as affected by soil type and temperature. *Soil Sci. Soc. Am. J.* **2010**, *74*, 1635–1641. [CrossRef]
23. O'Connell, S.; Shi, W.; Grossman, J.M.; Hoyt, G.D.; Fager, K.L.; Creamer, N.G. Short-term nitrogen mineralization from warm-season cover crops in organic farming systems. *Plant Soil* **2015**, *396*, 353–367. [CrossRef]
24. Quemada, M.; Cabrera, M.L. Temperature and moisture effects on C and N mineralization from surface applied clover residue. *Plant Soil* **1997**, *189*, 127–137. [CrossRef]
25. Florida Automated Weather Network. Available online: http://fawn.ifas.ufl.edu (accessed on 19 January 2022).
26. Li, J.; Zhao, X.; Maltais-Landry, G.; Paudel, B.R. Dynamics of Soil Nitrogen Availability Following Sunn Hemp Residue Incorporation in Organic Strawberry Production Systems. *HortScience* **2021**, *56*, 138–146. [CrossRef]
27. Agehara, S.; Hochmuth, G. Fertilization of strawberries in Florida. *UF/IFAS Ext.* **2023**, CIR-1141. Available online: https://edis.ifas.ufl.edu/publication/CV003 (accessed on 31 October 2023). [CrossRef]
28. Balkcom, K.S.; Reeves, D.W. Sunn-hemp utilized as a legume cover crop for corn production. *Agron. J.* **2005**, *97*, 26–31. [CrossRef]
29. Miller, M.R.; Dittmar, P.J.; Vallad, G.E.; Ferrell, J.A. Nutsedge (*Cyperus* spp.) control in bell pepper (*Capsicum annuum*) using fallow-period weed management and fumigation for two years. *Weed Technol.* **2014**, *28*, 653–659. [CrossRef]
30. Avila, L.; Scholberg, J.; Roe, N.; Cherr, C. Can sunn hemp decrease nitrogen fertilizer requirements of vegetable crops in the Southeastern United States? *HortScience* **2006**, *41*, 1005. [CrossRef]
31. Osborne, S.L.; Riedell, W.E. Starter nitrogen fertilizer impact on soybean yield and quality in the northern Great Plains. *Agron. J.* **2006**, *98*, 1569–1574. [CrossRef]
32. Touchton, J.T.; Rickerl, D.H. Soybean growth and yield responses to starter fertilizers. *Soil Sci. Soc. Am. J.* **1986**, *50*, 234–237. [CrossRef]
33. Vetsch, J.A.; Randall, G.W. Corn production as affected by tillage system and starter fertilizer. *Agron. J.* **2002**, *94*, 532–540. [CrossRef]
34. Agehara, S.; Santos, B.M.; Whidden, A.J. Nitrogen fertilization of strawberry cultivars: Is preplant starter fertilizer needed? *Univ. Fl. IFAS Ext.* **2007**, HS1116. [CrossRef]
35. Cantliffe, D.J.; Castellanos, J.Z.; Paranjpe, A.V. Yield and quality of greenhouse-grown strawberries as affected by nitrogen level in coco coir and pine bark media. *Proc. Fla. State Hortic. Soc.* **2007**, *120*, 157–161.
36. Santos, B.M.; Ramirez-Sanchez, M. Effects of preplant nitrogen fertilizer sources on strawberry. *Proc. Fla. State Hortic. Soc.* **2009**, *122*, 240–242. [CrossRef]
37. Santos, B.M. Effects of preplant nitrogen and sulfur fertilizer sources on strawberry. *HortTechnology* **2010**, *20*, 193–196. [CrossRef]
38. Fernandez, G.E.; Butler, L.M.; Louws, F.J. Strawberry growth and development in an annual plasticulture system. *HortScience* **2001**, *36*, 1219–1223. [CrossRef]
39. Hargreaves, J.C.; Adl, M.; Warman, P.R.; Rupasinghe, H.P. The effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. *J. Sci. Food Agric.* **2008**, *88*, 2669–2675. [CrossRef]