Organic Kale and Cereal Rye Grain Production Following a Sunn Hemp Cover Crop

Ted S. Kornecki * and Kipling S. Balkcom

USDA-ARS, National Soil Dynamics Laboratory—Conservation Systems Research, Auburn, AL 36832, USA; kip.balkcom@usda.gov
* Correspondence: ted.kornecki@usda.gov; Tel.: +1-334-887-8596

Received: 1 October 2020; Accepted: 2 December 2020; Published: 4 December 2020

Abstract: A four-year field experiment was initiated in 2011 at the EV. Smith Research Station, in central Alabama, to determine the effect of sunn hemp (Crotalaria juncea L.) termination methods on organically grown kale (Brassica oleracea, var. acephala L.) for fresh market and cereal rye (Secale cereale, L.) for grain. Three different termination methods for the sunn hemp cover crop were chosen: (1) rolling/crimping with an experimental two-stage roller/crimper, (2) rotary mowing, and (3) rotary mowing with incorporation (disking). Kale plots were harvested in the winter and rye plots were harvested in the following spring. Kale plots were fallow from January to June (kept mowed) until planting sunn hemp again across all plots in late spring of the next growing season. Over four growing seasons, average sunn hemp biomass (dry basis) was 10,981 kg ha\(^{-1}\) with plant height of 2.4 m. The average C/N ratio of sunn hemp was 23:1. Sunn hemp biomass amounts differed among growing seasons (from 5589 to 14,720 kg ha\(^{-1}\)) due to different weather conditions. Kale yield also varied across growing seasons, with the highest yield of 17,565 kg ha\(^{-1}\) measured in 2012 and the lowest (3915 kg ha\(^{-1}\)) in 2014 due to massive weed pressure. Generally, sunn hemp residue management affected kale yield, with greater yields measured for mowed and incorporated residue (15,054 kg ha\(^{-1}\)) compared with lower yields for mowed (6758 kg ha\(^{-1}\)) and rolled sunn hemp (5559 kg ha\(^{-1}\)). Lower yields were related to poor kale seed-to-soil contact (hair pinning) from large amounts of sunn hemp residue on the soil surface. Over four growing seasons, cereal rye grain yield varied among growing seasons, with an average yield of 1358 kg ha\(^{-1}\). Moreover, sunn hemp residue treatments affected grain yield, with greater yields for rolled (1419 kg ha\(^{-1}\)) and mowed residue (1467 kg ha\(^{-1}\)) compared with a lower yield (1187 kg ha\(^{-1}\)) for mowed and incorporated sunn hemp residue.

Keywords: organic kale; sunn hemp; cover crop termination; roller/crimper; cereal rye grain

1. Introduction

In conservation systems, cover crops are utilized to improve soil properties and enhance cash crop growth. During the past decade, use of cover crops in conservation agriculture has steadily increased. Benefits associated with cover crops include reduced soil erosion, reduced runoff, and increased infiltration and water holding capacity. In addition to improved soil quality and soil water, legume cover crops can fix nitrogen from the air and release the nitrogen into the soil to be used by subsequent cash crops. Legume cover crops are especially important in organic production systems, where commercial fertilizer options are limited and very expensive. In addition, production of healthy food and vegetables by local small farms is on the rise as US customers recognize a need to consume good-quality food and vegetables. Grocery stores and restaurants have found success in marketing locally grown and organic vegetables to their customers for added value and profit. Kale (Brassica oleracea, var. acephala L.) offers an abundance of vitamins and minerals beneficial to...
human health. It is one of the most cold hardy of all vegetables, able to withstand temperatures below freezing down to minus 8 °C. Brassicas, including kale, are an excellent source of vitamin K, vitamin A (in the form of carotenoids), manganese, vitamin C, dietary fiber and calcium. In addition, brassicas are a very good source of vitamin B1, vitamin B6 and iron [1].

According to the National Agricultural Statistics Service [2], in the United States, 2500 farms reported harvesting kale in 2012, which is a 262% increase from 954 farms in 2007. Moreover, the harvested area of kale production for fresh market significantly increased from 1616 hectares in 2007 to 2532 hectares in 2012 [2,3].

Kale can be cultivated in a wide range of soils. The best production can be achieved on low acid or neutral (pH 6–6.5) deep soils with loamy texture and proper water and air capacity. Brassica plants have a high nutrient uptake demand. Thus, basic soil preparation includes deep plowing with incorporation of high amounts of organic manure [4]. Kale crops respond positively to nitrogen fertilizer by improving vegetative growth and delaying premature bolting, although concern about nitrate (NO3-N) accumulation in plant tissues and environmental pollution should be emphasized [5].

To reduce nitrogen fertilizer use, there is a need to determine the ability of a legume cover crop sunn hemp (Crotalaria juncea L.) to fix and release atmospheric nitrogen that can be available to a cash crop (i.e., kale). Sunn hemp (summer legume) originated in India and Pakistan and has major benefits including protection from soil erosion, building organic matter from its large amount of biomass (from 5560 to 6670 kg ha\(^{-1}\)) as well as producing from 133 to 156 kg ha\(^{-1}\) of nitrogen in a short period of time. Sunn hemp seeds are produced mainly in India, Columbia, South Africa, and in the USA in Hawaii [7]. According to USDA-NRCS [6], biomass production of sunn hemp as a summer cover crop in Alabama can exceed 5600 kg ha\(^{-1}\) biomass and 134 kg ha\(^{-1}\) of nitrogen. Balkcom and Reeves [8] reported that average sunn hemp biomass production in central Alabama was 7600 kg ha\(^{-1}\), with a nitrogen content of 144 kg ha\(^{-1}\).

Sunn hemp management, such as planting date, can affect the performance of a subsequent crop. Balkcom et al. [9] examined how two different sunn hemp planting dates following wheat (Triticum aestivum, L.) harvest (early and late June) and corn (Zea mays L.) harvest (late August and early September) affected biomass production of cereal rye (Secale cereale L.) grown as a winter cover crop. Rye biomass production following sunn hemp planted after wheat averaged 38% greater over two growing seasons compared to fallow. Rye biomass production following sunn hemp planted after corn was equivalent to fallow over the two growing seasons. Despite the ability of sunn hemp to produce significant biomass within short periods of time, Balkcom et al. [9] attributed the lower growing degree accumulation following corn limited sunn hemp biomass production. As a result, the N benefit was minimal compared to sunn hemp following wheat.

Termination is also an important management consideration. In no-till systems, appropriate termination methods of cover crop residue is essential. Planting cash crop seeds into soil with large amounts of cover crop residue on the soil surface can be difficult. Many researchers reported that large amounts of different cover crop residues caused a hair pinning condition where seeds did not have adequate seed-to-soil contact for optimum germination and growth [10]. A previous field study conducted by Kornecki et al. [11,12] with no-till cotton (Gossypium hirsutum L.) indicated that large amounts of cereal rye residue on the soil surface caused wrapping of cover crop residue on row cleaners and coulters that prevented a good contact between seeds and soil, which created the hair pinning condition.

For centuries, cereal rye has been an important grain largely consumed in different parts of the world—Scandinavia, predominantly with influence in Finland, Russia, Germany, Poland, Ukraine and other regions of the former Soviet Union with harsh, colder climates. Rye consumption is closely associated with regional cuisines. Cereal rye is a weather-resilient cereal grain, capable of being grown in soils and conditions inhospitable to wheat and other grains [13].

Traditionally used in breads, crispbreads, and fermented beverages, rye can be substituted for wheat, brown rice, spelt, or other grains in a wide variety of dishes, both spicy and sweet. In the
United States, it is mostly valued as a minor grain; however, its use has increased considerably in recent decades due to its perceived perception for improved nutritional quality. The growing interest of rye among consumers as a whole and processed grain is mainly due to the potential health benefits related to bioactive enriched whole grain with the potential reduced risk of chronic diseases such as cardiovascular diseases, certain types of cancer and type 2 diabetes [14–16]. Further, the role of high dietary fiber in rye towards positive health benefits has been widely reported [15,17]. Similarly, previous studies have also suggested that high bioactive profiles such as phenolic acids and lignans in cereals, particularly in rye, can contribute to its health promoting functions [18,19].

Cover crops can be managed with a variety of methods. One is mechanical termination utilizing rolling/crimping technology. This requires injuring the plant with the crimping bars without cutting stems [20]. A common practice to accelerate the termination process is to utilize commercial herbicides such as Glyphosate (Roundup™) as a supplement to rolling/crimping. This practice, however, is not permitted in organic systems. Because of this restriction, mechanical termination by rollers/crimpers must be as effective as chemical applications. In conservation systems, rolling/crimping is especially important to manage tall cover crops such as sunn hemp. Flattening and crimping of a living cover crop scarifies and damages plant tissue, which accelerates its termination by promoting desiccation. Dried-out residue forms a thick mulch that covers the soil surface; this reduces soil erosion, reduces weed germination and growth, increases infiltration and conserves water for the following cash crop [21]. Other methods are mowing or mowing with incorporating cover crop residues, but these methods can generate problems such as re-growth of cover crops and exposing the soil surface to rainfall causing soil erosion. Additionally, loose residue can interfere with cash crop planting.

Therefore, the objective of this study was to determine the effect of sunn hemp cover crop termination methods (rolling/crimping, mowing only, and mowing with incorporation of sunn hemp) on organically grown kale and cereal rye for grain (Figure 1).

Figure 1. Cash crops: (a) kale for fresh market; (b) cereal rye for grain.

2. Materials and Methods

A field experiment was initiated in 2011 at the EV. Smith Research Station, Field Crops Unit (32°25′19″ N, 85°53′7″ W), near Shorter, in central Alabama on Marvyn Series soil, having taxonomic class: fine-loamy, kaolinitic, thermic Typic Kanhapludults. The Marvyn series consists of very deep, well drained, moderately permeable soils on uplands of the Southern Coastal Plain. At the top horizon (from 0 to 18 cm), soil is a dark grayish brown loamy sand; weak fine granular structure; very friable; many fine roots; about 5 percent, by volume, rounded pebbles less than one inch in diameter; moderately acid; abrupt smooth boundary. This area is characterized by a humid subtropical climate, with an average annual precipitation during four years of conducting experiment of 1185 mm, with an average maximum temperature of 24.1 °C and minimum temperature of 10.7 °C. [22]. Monthly precipitation, maximum and minimum temperature between May 2011 and June 2015 are presented in Figure 2.
Three different cover crop management treatments (main effects) were used to study effects of termination methods for sunn hemp (seeds from South Africa, cultivar: not stated) as a cover crop on the yield of two selected organic cash crops cereal rye (for grain) and kale for fresh market consumption. The following treatments to manage sunn hemp were applied:

1. Rolling/crimping sunn hemp using an experimental two-stage roller/crimper (Figure 3a).
2. Mowing sunn hemp utilizing a rotary mower (Figure 3b), and
3. Mowing sunn hemp with incorporation: mower and disking (Figure 3c).

![Figure 2. Monthly rainfall amounts with maximum and minimum temperatures during the experiment for four growing seasons (purple bars represent rainfall exceeding 140 mm) [22].](image)

Figure 2. Monthly rainfall amounts with maximum and minimum temperatures during the experiment for four growing seasons (purple bars represent rainfall exceeding 140 mm) [22].

The experiment was a randomized complete block design with four replications for each treatment (Figure 4). The experiment was initiated in late spring (25 May 2011) by drilling (no-till) sunn hemp (45 kg ha⁻¹) using a Tye no-till drill (Agco, Duluth, GA, USA; 2.13 m width) across the experimental area (24 plots), and was repeated each growing season (May–June). Sunn hemp was terminated in early fall (September–October) of each growing season using previously described termination methods (Figure 3). A complete list of field activities for the whole experiment is shown in Table 1. Kale seeds (Siberian Dwarf Variety) were planted into sunn hemp residue (11 kg ha⁻¹) with different residue...
treatments three weeks after its termination (end of September and October) in half of the experimental area using the Tye no-till drill. To obtain a 0.38 m row spacing for kale, every other row on the Tye drill was blocked off. At the same time, cereal rye was planted (101 kg ha$^{-1}$) with the same equipment (row spacing 0.18 m) to the other half (12 plots with different sunn hemp residue treatments); in each growing season, rye was harvested for grain using a Massey Ferguson 8XP plot combine (last week of May, first week of June, Figure 5a). Kale was harvested by hand at the end of November (2012) and at the beginning of December (2011, 2013, 2014) and ended in January of each year (Figure 5b). Harvested kale plots were left fallow until replanting sunnhemp for both the kale and rye areas at end of May (2011 and 2012) and second week of June (2013 and 2014). In the 2011/2012 kale harvest season, there were two harvests 33 days apart; in 2012/2013, there were 3 harvests spaced 20 days between the first and second harvest and 27 days between second and third harvest. In the 2013/2014 and 2014/2015 kale harvest seasons, there were also three harvests with 27 days between the first and the second harvest and 14 days between the second and third harvest.

Figure 4. Experiment layout: randomized complete block design with four replications for two cash crops.

Figure 5. (a) Harvesting cereal rye for organic grain; (b) hand harvesting of organic kale vegetable.
Biomass samples were cut from two 0.25 m² sampling areas in each plot for both sunn hemp and rye. Spring rye samples were collected (Table 1) when rye was at the early milk growth stage (Zadoks growth stage = 73) [24]. Subsamples of sunn hemp cover crop and cash crop: cereal rye and kale tissues (for kale, during kale harvest, Table 1) were collected, dried (55 °C), and ground to pass through a 2 mm screen with a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA), then ground further to pass through a 1 mm screen with a Cyclone grinder (Thomas Scientific, Swedesboro, NJ, USA).

Cash crop subsamples were analyzed for total N concentration (%) by dry combustion on a LECO TruSpec-CN analyzer (Leco Corp., St Joseph, MI, USA). C and N contents present in the sunn hemp tissue were determined by multiplying total C and N concentrations (%) by the corresponding sunn hemp biomass production.

Soil samples were collected with a Giddings (Windsor, CO, USA) UTV mounted soil probe at sunnhemp termination and again at cash crop planting to monitor soil nitrogen availability during the 3 weeks between termination and planting. Eight soils cores were collected per plot with a 100 cm long stainless-steel probe (3.8 cm diam.) to a depth of 30 cm.

Each soil core was split into two depths of 0–15 cm (shallow) and 15–30 cm (deep), composited, mixed, and placed into appropriate sample boxes. Soil was dried at 55 °C for 24–48 h.

NO₃-N and NH₄-N concentrations were determined using potassium chloride (KCl) extraction. Ten grams of soil was weighed and extracted with 50 mL of 2 M KCl solution. Cups with the soil-KCl solution were covered with labeled lids and placed in a shaking machine (Lab-Line Instruments, Melrose Park, IL, USA; model 4633) at 180 RPM for 1 hour. After completing shaking, the samples were settled for 1 hour. After that, funnel stands, funnels, filters, and vials were employed to filter the soil sample solution. The Whatman #42 filters were placed to each funnel and the settled soil-KCL solution were filtered through the filter directly to vials. Vials were secured and transferred to Auto Analyzer 3. The NO₃-N and NH₄-N amounts in soil were based on procedures from Seal Analytical Inc., (Mequon, WI, USA), formally Bran Luebbe/Technicon using the Auto Analyzer 3 and built-in an extensive methods library for fully automated soil analysis.

Different cover crop sunnhemp residue management treatments and years were considered fixed effects and blocks were considered random [25]. Where differences in each year for dependent variables (cover crop biomass, kale yield and cereal rye grain yield) were significant, and when interactions between treatments and years occurred, data were analyzed separately. Treating year as a fixed effect enabled us to examine treatment differences across growing seasons.

Data were subjected to analysis of variance using SAS, Release 9.2 [26]. The ANOVA GLM procedure and treatment means were separated with Fisher’s protected Least Significant Differences (LSD) test at the 10% (α = 0.10) probability level [26].

### Table 1. Field activities of the experiment during the 2011/2012, 2012/2013, 2013/2014 and 2014/2015 growing seasons at the E.V Smith Research Center in Central Alabama.

| Field Activity                                | Growing Season |
|-----------------------------------------------|----------------|
|                                               | 2011–2012      | 2012–2013      | 2013–2014      | 2014–2015      |
| Planting sunn hemp cover crop                 | 05/25/2011     | 05/29/2012     | 06/11/2013     | 06/16/2014     |
| Collecting biomass of sunn hemp               | 09/19/2011     | 09/06/2012     | 09/11/2013     | 09/17/2014     |
| Collecting soil samples                       | 09/19/2011     | 09/06/2012     | 09/11/2013     | 09/18/2014     |
| Rolling/crimping cover crop                   | 09/19/2011     | 09/06/2012     | 09/11/2013     | 09/18/2014     |
| Mowing cover crop                             | 09/19/2011     | 09/06/2012     | 09/11/2013     | 09/18/2014     |
| Mowing + incorporating cover crop             | 09/09/2011     | 09/06/2012     | 09/11/2013     | 09/18/2014     |
| Collecting soil samples                       | 10/04/2011     | 09/26/2012     | 10/14/2013     | 10/20/2014     |
| Planting rye and kale                         | 10/04/2011     | 09/26/2012     | 10/14/2013     | 10/20/2014     |
| Harvest 1 Kale (collecting samples)           | 12/09/2011     | 11/28/2012     | 12/12/2013     | 12/11/2014     |
| Harvest 2 kale (collecting samples)           | 01/12/2012     | 12/18/2012     | 01/08/2014     | 01/07/2015     |
| Harvest 3 kale (collecting samples)           | X              | 01/15/2013     | 01/22/2014     | 01/21/2015     |
| Collecting biomass of cereal rye               | 03/30/2012     | 04/16/2013     | 04/16/2014     | 04/20/2015     |
| Harvesting cereal rye for grain                | 05/21/2012     | 05/31/2013     | 06/04/2014     | 06/08/2015     |
3. Results and Discussion

3.1. Sunn Hemp Production

Statistical analyses showed that “YEAR” was significantly different (p-value < 0.0001) with respect to both variables: height and biomass for sunn hemp. Height and biomass amount for sunn hemp during each growing season are shown in Table 2. Corresponding average plant height for sunn hemp was 2.40 m, but sunn hemp plants were shorter in 2013 and 2014 compared with 2011 and 2012 (Table 2). Sunn hemp biomass production averaged over four growing seasons was 10,981 kg ha$^{-1}$, which was in the upper range of 3362–11,208 kg ha$^{-1}$ for biomass production reported in Alabama [27].

Table 2. Sunn hemp production: height (m) and biomass (kg ha$^{-1}$) in each growing season.

| Year   | 2011  | 2012  | 2013  | 2014  | 4 Year Average |
|--------|-------|-------|-------|-------|----------------|
| Height | 2.56 a* | 2.50 a | 2.29 b | 2.26 b | <0.0001 2.40 |
| Biomass| 14,365 a | 14,720 a | 5589 c | 9252 b | <0.0001 10,981 |

* Same lower-case letters in rows represents no significant difference with respect to the variable YEAR with significance level $\alpha = 0.1$.

These differences were influenced by differences in weather and soil growing conditions. The greatest sunn hemp biomass was produced in 2012 (14,720 kg ha$^{-1}$; height 2.50 m), and in 2011, generating 14,365 kg ha$^{-1}$ with a height of 2.56 m. Lower biomass was reported in 2014 (9252 kg ha$^{-1}$, height 2.26 m), and the lowest biomass was produced in 2013 (5589 kg ha$^{-1}$, height of 2.29 m). Sunn hemp growth and production of biomass in 2013 was likely weather related. Unusually high rainfall amounts occurred in June (195 mm) and July (165 mm) of 2013 (Figure 2), which coincided with planting on 11 June 2013. This wet period may have inhibited early season sunn hemp growth.

3.2. Nitrogen and Carbon Content for Sunn Hemp Cover Crop

Analysis of variance results presented in Table 3, indicate that factor YEAR had a significant effect on both variables: N and C content in sunn hemp plant (p-value < 0.0001). The average carbon percentage for sunn hemp was 46.5% (Table 4) although small differences were observed across growing seasons. The range of carbon percentage was 46.1 in 2012 and 2013, to 47.4% in 2014 (data not collected in 2011). The nitrogen content averaged over three growing seasons was 2.1% and ranged from 1.8% in 2013, to 2.6% in 2012. Subsequently, the C to N ratio was between 18.1:1 in 2012 to 25.9:1 in 2013 with an average C:N ratio of 23.2:1 over three growing seasons (Table 4). A report by USDA-NRCS [28] indicated that a C:N ratio of plant residues near 24:1 is ideal for microorganisms to process and release nutrients for subsequent cash crops and maintain soil health.

Table 3. Analysis of variance results for plant N and C content in sunn hemp cover crop.

| Source | DF | F Value | Pr > F | F Value | Pr > F |
|--------|----|---------|--------|---------|--------|
| BLOCK  | 3  | 0.44    | 0.727  | 0.38    | 0.7659 |
| YEAR   | 2  | 47.64   | <0.0001| 12.03   | <0.0001|

* Degrees of freedom.

Table 4. Sunn hemp plant content of C and N (kg ha$^{-1}$) based on sunn hemp’s biomass.

| Growing Season | Sunn Hemp Biomass (kg ha$^{-1}$) | C-Content | N-Content | C%  | N%  | C/N Ratio |
|----------------|----------------------------------|-----------|-----------|-----|-----|-----------|
| 2012           | 14,720                           | 6782      | 376       | 46.1| 2.6 | 18.1:1    |
| 2013           | 5589                             | 2578      | 99        | 46.1| 1.8 | 25.9:1    |
| 2014           | 9252                             | 4385      | 172       | 47.4| 1.9 | 25.5:1    |
| Average        | 9854                             | 4582      | 216       | 46.5| 2.1 | 23.2:1    |
Results from this study indicate that a C:N ratio of 23.4:1 in sunn hemp was in this desirable range. Moreover, a study conducted by Gan et al. [29] indicated that legumes such as chickpea, dry pea and lentil (Cicer arietinum L.) had C:N ratios of 18.8, 14.8 and 19.3, respectively. There are different legume choices that can be used as a summer cover crop with a desirable C:N ratio for optimal microbial activity in soil. Sunn hemp was chosen for this experiment based on its ability to produce significant biomass in a short period of time and reach plant maturity suitable for mechanical termination without sacrificing benefits of a cover crop. Furthermore, the termination period coincided with the optimum planting window for kale and a favorable window for rye.

3.3. Kale Yield Harvested for Fresh Market

Variable “BLOCK” was highly significant for kale yield (p-value = 0.0010). Moreover, kale yield was affected by both “YEAR” (p-value < 0.0001) and “TRT” (p-value < 0.0001) (Table 5). There were significant YEAR*TRT interactions for kale yield, thus, data for these variables were analyzed separately for each year. Different sunn hemp residue management (rolling, mowing, and mowing with incorporation) had a strong effect (p-value < 0.0001) on kale yield (Table 5).

Table 5. Analysis of variance results for dependent variables kale and rye with respect to yield. TRT (cover crop sunn hemp mowed, rolled or incorporated).

| Source      | DF | F Value | Pr > F | F Value | Pr > F |
|-------------|----|---------|--------|---------|--------|
| BLOCK       | 3  | 6.96    | 0.0009 | 3.91    | 0.0171 |
| YEAR        | 3  | 458.19  | <0.0001| 53.81   | <0.0001|
| TRT         | 2  | 90.57   | <0.0001| 8.16    | 0.0013 |
| YEAR*TRT    | 6  | 39.62   | <0.0001| 2.20    | 0.0683 |

* Degrees of freedom.

The “YEAR” differences were related to different weather conditions and growing conditions (weed pressure) in each growing season. The kale yield in 2011 for mowed and incorporated residue was significantly higher (17,846 kg ha\(^{-1}\), p-value < 0.0001) compared with mowed only (4792 kg ha\(^{-1}\)) and rolled only treatments (2792 kg ha\(^{-1}\)), although no significant difference in kale yield was observed between rolled and mowed cover crop residue (Figure 6). When incorporating mowed residue (a similar method of managing a green manure) it would promote greater N release, which would be available for plant uptake to increase kale yield, compared with mowed or rolled with no soil incorporation that would release N much slower.

Thavarajah et al. [30] examined effects of different cover crops on organic kale yield. They concluded that ryegrass was most suitable of the cover crops examined by producing high kale yield (42,846 kg ha\(^{-1}\)) followed by faba bean (33,624 kg ha\(^{-1}\)). In contrast, Lynex, a winter pea cover crop was associated with the lowest kale yield (16,224 kg ha\(^{-1}\)), which was comparable to kale yield from this study in 2011. Possibly selecting a legume in this experiment was not the best choice to promote the highest kale yield. In 2012, no differences in kale yield were reported among rolled (17,095 kg ha\(^{-1}\)), mowed (18,358 kg ha\(^{-1}\)) and mowed with incorporation (17,243 kg ha\(^{-1}\)) residue treatments (p-value = 0.494). Same as for 2011, in 2013, significant differences in kale yield occurred among residue management treatments (p-value < 0.0001), with significantly higher kale yield observed for mowed and incorporated residue (13,728 kg ha\(^{-1}\)), followed by mowed residue (3545 kg ha\(^{-1}\)) and the lowest (2336 kg ha\(^{-1}\)) for rolled residue. Extreme amounts of residue left on the surface of both mowed and rolled methods prevented the cutting coulters on the no-till drill to completely cut and allow adequate soil penetration for the disc openers to place seeds which can lead to “hair pinning” often seen in no-till farming systems. Likewise, in 2014, significant differences among sunn hemp residue management treatments were reported (p-value < 0.0001), with significantly higher kale yield for mowed and incorporated residue (11,397 kg ha\(^{-1}\)), followed by unusually low kale yield for mowed residue (337 kg ha\(^{-1}\)) and rolled residue (12 kg ha\(^{-1}\)). The main reason
for these differences was unusually high weed pressure on rolled and mowed sunn hemp residue plots that almost entirely inhibited kale growth. Weed pressure increased from year to year in this organic system as no commercial chemicals were applied to manage tough weeds like pigweed (*Amaranthus palmeri*, L.) and nutsedge (*Cyperus esculentus*, L.). One effective weed control measure, particularly for pigweed, is tillage. Burying this small-seeded weed has been promoted as a successful weed control strategy, but this is obviously not preferred from a soil health standpoint. It is possible that despite the surface residue present, disking was more effective because seed were buried that prevented germination and subsequent emergence. It is also possible that disking prevented any weed escapes. Regardless of the benefits of surface cover, if any weeds emerged and formed seed, the problem would be much worse for the subsequent years. Actually, in 2011, there was no significant weed pressure. However, starting in 2012, and continuing through 2013, and 2014, there was an increasing weed population present. The prevalence of weeds starting in 2012 with no control likely increased the weed seed bank each year that caused the continued proliferation of weeds the following years.

![Figure 6](image_url)

**Figure 6.** Sunn hemp residue management treatment effect on kale yield (kg ha\(^{-1}\)). Same lower-case letters in each growing season represents no difference in kale yields with respect cover crop treatments. 

N/S = non-significant.

3.4. Soil NO\(_3\)-N and NH\(_4\)-N Amounts for Kale

Based on analysis of variance results presented in Table 6, the amounts of NO\(_3\)-N and NH\(_4\)-N in soil for kale were influenced by factors: TRT DEPTH and TIME. In addition, NO\(_3\)-N amounts were dependent on factor YEAR. Amounts of NO\(_3\)-N and NH\(_4\)-N in soil for kale with respect to growing seasons, sampling time, sampling depth and sunn hemp residue management treatment are shown in Table 7.

**Table 6.** Analysis of variance results for soil NO\(_3\)-N and NH\(_4\)-N amounts (kg ha\(^{-1}\)) for kale. TRT (cover crop sunn hemp mowed, rolled or incorporated), DEPTH (sampling depths: 0–15 cm and 15–30 cm) and TIME (sampling at cover crop termination or at planting cash crops).

| Source            | * DF | Soil NO\(_3\)-N Amount F Value | Pr > F | Soil NH\(_4\)-N Amount F Value | Pr > F |
|-------------------|------|---------------------------------|--------|----------------------------------|--------|
| BLOCK             | 3    | 2.09                            | 0.1036 | 1.34                             | 0.2640 |
| YEAR              | 3    | 39.02                           | <0.0001| 0.45                             | 0.7144 |
| TRT               | 2    | 3.82                            | 0.0239 | 2.55                             | 0.0809 |
| DEPTH             | 1    | 132.14                          | <0.0001| 205.56                           | <0.0001|
| TIME              | 1    | 167.89                          | <0.0001| 3.89                             | 0.0501 |
| YEAR*TRT          | 6    | 1.31                            | 0.2547 | 1.67                             | 0.1311 |

* Degrees of freedom.
Table 7. Soil NO$_3$-N and NH$_4$-N amounts on kale plots: at sunn hemp termination and at kale planting (kg ha$^{-1}$) with respect to growing seasons, sampling time (term is the sampling at the cover crop termination; plant is the sampling at planting kale), sampling depth and sunn hemp residue management treatment.

| Nutr. | Growing Season | Sampling Time | Sampling Depth (cm) | Sunn Hemp Management Treatment |
|-------|----------------|---------------|---------------------|-------------------------------|
|       | 2011 | 2012 | 2013 | 2014 | Term | Plant | 0-15 | 15-30 | Mow and Incorpor. | Mow | Roll |
| NO$_3$-N | 15.0 b * | 16.5 b | 35.4 a | 40.3 a | 13.4 b | 40.3 a | 38.7 a | 14.9 b | 30.5 a | 26.5 ab | 23.5 b |
| p-val. | <0.0001 | <0.0001 | <0.0001 | 0.0239 | 0.0809 |
| NH$_4$-N | 8.5 | 8.7 | 9.5 | 8.6 | 8.1 b | 9.5 a | 13.7 a | 3.9 b | 8.0 b | 8.6 ab | 9.8 a |
| p-val. | 0.7144 | 0.0501 | <0.0001 | 0.0809 |

* Same lower-case letters in each row for each chemical (i.e., NO$_3$-N) and variable (i.e., growing season) represent no difference in the soil amount of the particular nutrient.

3.4.1. Soil NO$_3$-N Amount

Results indicate that the NO$_3$-N amounts differed among all four growing seasons ($p$-value < 0.0001) (Table 6), and NO$_3$-N amounts in soil increased consistently to the next growing season from 15.0 kg ha$^{-1}$ in 2011 to 40.3 in 2014 (Table 7). The measured NO$_3$-N amounts over all four growing seasons was significantly higher ($p$-value < 0.0001) at the shallower depth (0–15 cm) (38.9 kg ha$^{-1}$) compared to the deeper depth (15–30 cm) (14.9 kg ha$^{-1}$). The amount of NO$_3$-N at sunn hemp termination was significantly lower (13.4 kg ha$^{-1}$) compared to NO$_3$-N amounts at kale planting (40.3 kg ha$^{-1}$) indicating that the NO$_3$-N increase was related to nitrogen release during the sunn hemp decomposition period. In fact, sunn hemp residue management treatments had a significant effect on NO$_3$-N amounts in soil ($p$-value = 0.0239), where mowing with incorporation treatment released significantly higher amounts of NO$_3$-N (30.5 kg ha$^{-1}$) compared to rolled residue only (23.5 kg ha$^{-1}$). The NO$_3$-N amount measured for the mowing only treatment was 26.5 kg ha$^{-1}$, which was not statistically different from the rolling and mowing with incorporation treatments.

3.4.2. Soil NH$_4$-N Amount

Amounts of NH$_4$-N in soil were not significantly different among growing seasons ($p$-value = 0.7144) with an average amount of 8.8 kg ha$^{-1}$. In contrast, a significant difference in NH$_4$-N amounts was observed between depths ($p$-value < 0.0001) with greater amounts (13.7 kg ha$^{-1}$) in the 0–15 cm depth compared to the 15–30 cm depth (3.9 kg ha$^{-1}$). The amount of NH$_4$-N varied between sampling times ($p$-value = 0.0501) with a lower NH$_4$-N amount (8.1 kg ha$^{-1}$) present at sunn hemp termination compared to kale planting (9.5 kg ha$^{-1}$). Likewise, NH$_4$-N amounts among sunn hemp management treatments were different ($p$-value = 0.0809) with greater NH$_4$-N amounts (9.8 kg ha$^{-1}$) for rolled sunn hemp residue compared to lower NH$_4$-N amount (8.0 kg ha$^{-1}$) for mowed with incorporation. The NH$_4$-N amount for mowed residue was 8.6 kg ha$^{-1}$ and was not different from rolled and mowed with incorporation residue treatments (Table 7).

3.5. Nitrogen Content in Kale

Significant differences for N contents in kale occurred for Year and were also dependent on sunn hemp management treatments. In addition, there were significant interactions between Year and TRT for N contents (Table 8); therefore, data were analyzed separately for each year.
Table 8. Analysis of variance results for nitrogen content in kale for fresh market based on the harvested biomass. TRT (cover crop sunn hemp mowed, rolled or incorporated).

| Source            | * DF | Kale N Content | F Value | Pr > F |
|-------------------|------|----------------|---------|--------|
| BLOCK             | 3    | 4.45           | 0.0099  |
| YEAR              | 3    | 133.76         | <0.0001 |
| TRT               | 2    | 161.45         | <0.0001 |
| YEAR*TRT         | 6    | 36.41          | <0.0001 |

* Degrees of freedom.

The N content in kale tissue with respect to treatment effects for each growing season is presented in Table 9. In 2011, significantly higher N amounts (126 kg ha⁻¹) were associated with mowed and incorporated sunn hemp residue (p-value = 0.0002), compared with lower N-content values for mowed (37 kg ha⁻¹) and rolled (21 kg ha⁻¹) sunn hemp residue (without significant difference between these treatments). In 2012, N content amounts in kale were not different (p-value = 0.9408) among sunn hemp residue treatments with an average kale N content of 194 kg ha⁻¹. However, in the 2013 and 2014 growing seasons, significantly higher kale N contents were observed for mowed residue with incorporation (p-value < 0.0001) that corresponded to N contents of 352 kg ha⁻¹ in 2013 and 121 kg ha⁻¹ in 2014. Similar to 2011 growing season, lower kale N contents were associated with rolled and mowed sunn hemp residue treatments with no difference between these treatments.

Table 9. Kale N content (kg ha⁻¹) across each growing season and treatment.

| Cover crop Management Treatment | Kale N Content | 2011 | 2012 | 2013 | 2014 |
|--------------------------------|----------------|------|------|------|------|
| Rolled only                    | 21 b *         | 192  | 56 b | 0.3 b|
| Mowed only                     | 37 b           | 197  | 88 b | 6 b  |
| Mowed with incorporation       | 126 a          | 192  | 352 a| 121 a|

| p-value                        | 0.0002         | 0.9408| <0.0001| <0.0001|

* Same lower-case letters in each column (Year) represents no difference in plant nitrogen contents with respect to rolling treatments.

3.6. Cereal Rye Cash Crop for Grain

Cereal rye grain yield averaged over four growing seasons and treatments was 1358 kg ha⁻¹. However, grain yield was significantly different (Table 5) with respect to variable BLOCK (p-value =0.0171) and the variable YEAR (p-value < 0.0001). In addition, there was a significant interaction between YEAR*TRT (p-value = 0.0683). Therefore, data for cereal rye grain were analyzed separately for each year.

In the 2011, 2012 and 2014 growing seasons, there was no difference in rye grain yield between rolled, mowed, and mowed with incorporated sunn hemp residue. In contrast, treatments had an effect on cereal rye grain yield (p-value = 0.0003) in 2013 with significantly higher cereal rye grain yield measured following rolling only (2193 kg ha⁻¹) and mowed sunn hemp (2098 kg ha⁻¹) treatments compared to mowed with incorporation (1553 kg ha⁻¹) sunn hemp residue (Figure 7). These differences were likely weather related. In February 2013, there were several rainfall events with unusually high cumulative rainfall amounts of 315 mm. It is possible that cereal rye planted into rolled or mowed sunn hemp surface residue across an undisturbed soil was protected from rainfall energy that reduced soil erosion and runoff, which lead to better cereal rye development. In contrast, mowed residue with incorporation did not protect the soil from rainfall energy that caused soil sealing, which may have suppressed cereal rye growth [31,32]. Moreover, in 2014, the experimental area had high weed pressure (especially for plots with mowed and incorporated residue) and severe lodging of cereal rye plants.
Organic practices were followed across the experimental area that did not allow commercial herbicide use for weed control. These combined aspects likely caused the decrease in rye grain yield observed.

Cereal rye grain yield for Wrens Abruzzi variety obtained in this experiment were similar to yields reported in Georgia (1993–1995 data) averaging 1476 kg ha$^{-1}$ (23.7 bushels/acre) [33].

3.7. Soil NO$_3$-N and NH$_4$-N Amounts for Cereal Rye

Analysis of variance regarding soil NO$_3$-N and NH$_4$-N with respect to cereal rye are shown in Table 10, were dependent on factors: YEAR DEPTH and TIME. Moreover, NO$_3$-N amounts in soil were dependent on treatments (TRT) for sunn hemp. Amounts of NO$_3$-N, NH$_4$-N, in soil for cereal rye at each growing season, two depths, sampling time and sunn hemp termination treatments are presented in Table 11.

![Figure 7. Sunn hemp residue management treatment effect on cereal rye grain yield (kg ha$^{-1}$). Same lower-case letters in each growing season represents no difference in cereal rye grain yields with respect cover crop treatments. N/S = non-significant.](image)

**Table 10.** Analysis of variance results for soil NO$_3$-N and NH$_4$-N amounts (kg ha$^{-1}$) for cereal rye. TRT (cover crop sunn hemp mowed, rolled or incorporated), DEPTH (sampling depths: 0–15 cm and 15–30 cm) and TIME (sampling at cover crop termination or at planting cash crops).

| Source      | DF | Soil NO$_3$-N Amount F Value | Soil NH$_4$-N Amount F Value |
|-------------|----|-------------------------------|------------------------------|
| BLOCK       | 3  | 3.12                          | 0.96                         |
| YEAR        | 3  | 28.40                         | 6.36                         |
| TRT         | 2  | 2.84                          | 0.82                         |
| DEPTH       | 1  | 67.43                         | 131.37                       |
| TIME        | 1  | 141.01                        | 7.81                         |
| YEAR*TRT   | 6  | 0.96                          | 1.64                         |

N/S = non-significant.
Table 11. Soil NO$_3$-N, NH$_4$-N amounts on cereal rye plots: at sunn hemp termination and at cereal rye planting (kg ha$^{-1}$) with respect to growing seasons, sampling time, sampling depth and sunn hemp residue management treatment.

| Nutr. | Growing Season | Sampling Time | Sampling Depth (cm) | Sunn Hemp Management Treatment |
|-------|----------------|---------------|---------------------|--------------------------------|
|       | 2011 | 2012 | 2013 | 2014 | Term | Plant | 0–15 | 15–30 | Mow | Mow & Incorp. | Mow | Roll |
| NO$_3$-N | 12.1 c * | 15.5 c | <0.0001 | 28.8 b | 37.6 a | 10.4 b | <0.0001 | 36.6 a | 27.6 a | 32.6 a | 14.4 b | 27.1 a | 21.0 b | 22.4 b |
| p-val. | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0609 | 0.0609 | 0.0609 |
| NH$_4$-N | 9.2 b | 8.2 b | 12.0 a | 7.4 b | 8.1 b | 10.3 a | 13.8 a | 4.6 b | 9.9 | 8.8 | 8.9 |
| p-val. | 0.0004 | 0.0058 | <0.0001 | <0.0001 | 0.4413 | 0.4413 | 0.4413 |

* Same lower-case letters in each row for each chemical (i.e., NO$_3$) and variable (i.e., growing season) represents no difference in the soil amount of particular chemical.

3.7.1. Soil NO$_3$-N Amount

Soil NO$_3$-N amounts for cereal rye were different among all four growing seasons ($p$-value < 0.0001; Table 12), with a consistent increase in soil NO$_3$-N content from 12.1 kg ha$^{-1}$ in 2011 to 37.6 kg ha$^{-1}$ in 2014 (Table 11). Over four growing seasons, soil NO$_3$-N amounts were significantly higher the 0–15 cm soil depth (32.6 kg ha$^{-1}$) compared to the 15–30 cm soil depth (14.4 kg ha$^{-1}$) ($p$-value < 0.0001). The amount of soil NO$_3$-N measured at sunn hemp termination was significantly lower (10.4 kg ha$^{-1}$) compared to the soil NO$_3$-N amount measured at cereal rye planting (36.6 kg ha$^{-1}$) that indicated that the soil NO$_3$-N increase was related to N being released during the sunn hemp decomposition process following termination (Table 13). In addition, sunn hemp residue management treatments affected soil NO$_3$-N amounts in soil ($p$-value = 0.0609). Mowing with incorporation released significantly greater amounts of soil NO$_3$-N (27.1 kg ha$^{-1}$) compared to rolled residue (22.4 kg ha$^{-1}$) and the mowing only treatment (21.0 kg ha$^{-1}$). No differences were observed between the rolled and mowing only treatments for soil NO$_3$-N amounts. The process of incorporation increased the amount of exposure of soil microbes to sunn hemp residue through the mixing of residue and the soil, which enables the soil microbes to break the residue down faster compared to leaving it on the soil surface.

Table 12. Analysis of variance results for nitrogen content in cereal rye. TRT (cover crop sunn hemp mowed, rolled or incorporated).

| Source      | DF | N Content in Plant Tissue | F Value | Pr > F |
|-------------|----|--------------------------|---------|--------|
| BLOCK       | 3  | 7.69                     | 0.0005  |        |
| YEAR        | 3  | 0.47                     | 0.7052  |        |
| TRT         | 2  | 3.17                     | 0.0549  |        |
| YEAR*TRT    | 6  | 1.60                     | 0.1776  |        |
Table 13. Cereal rye N content (kg ha\(^{-1}\)) for each growing season and treatment.

| Cover crop Management Treatment | Cereal Rye N Content |          |          |          | Average |
|---------------------------------|----------------------|----------|----------|----------|---------|
|                                 | 2011                 | 2012     | 2013     | 2014     |         |
| Rolled only                     | 106                  | 113 a    | 105      | 81       | 101 a   |
| Mowed only                      | 73                   | 84 b     | 82       | 89       | 82 b    |
| Mowed with incorporation        | 108                  | 80 b     | 78       | 89       | 89 ab   |
| \(p\)-value                    | 0.2989               | 0.0211   | 0.2146   | 0.8071   | 0.0549  |
| Averaged over treatments        | 96 A **              | 92 A     | 88 A     | 86 A     | 91      |

Same lower-case letters in each column (Year) represents no difference in plant nitrogen contents with respect to rolling treatments. ** Same upper-case letters in last row represents no difference in plant nitrogen with respect growing seasons (averaged over treatments).

3.7.2. Soil NH\(_4\)-N Amount

Soil NH\(_4\)-N amounts were significantly different among growing seasons (\(p\)-value = 0.0004), with the highest soil NH\(_4\)-N amounts (12.0 kg ha\(^{-1}\)) measured in 2013 compared to lower amounts in 2011 (9.2 kg ha\(^{-1}\)), 2012 (8.2 kg ha\(^{-1}\)), and 2014 (7.4 kg ha\(^{-1}\)), with no differences observed among the 2011, 2012, and 2014 growing seasons (Table 12). Soil NH\(_4\)-N amounts also varied between sampling times (\(p\)-value = 0.0058) with lower soil NH\(_4\)-N amounts (8.1 kg ha\(^{-1}\)) measured at sunn hemp termination and higher amounts (10.3 kg ha\(^{-1}\)) measured at cereal rye planting. Amounts of soil NH\(_4\)-N were different at sampled depths (\(p\)-value < 0.0001) with greater amounts measured for the 0–15 cm depth (13.8 kg ha\(^{-1}\)) compared to the 15–30 cm depth (4.6 kg ha\(^{-1}\)). In contrast, soil NH\(_4\)-N amounts were not affected by sunn hemp management treatments (\(p\)-value = 0.4413) with an average amount of 9.2 kg ha\(^{-1}\) measured over sunn hemp residue treatments.

3.8. Nitrogen Content in Cereal Rye

The variables YEAR and YEAR*TRT did not affect plant N contents in cereal rye (\(p\)-values = 0.7052 and 0.1776; Table 12). In contrast, sunn hemp management treatments did affect cereal rye plant N-contents (\(p\)-value = 0.0549). The average cereal rye plant N content across all growing seasons and treatments was 91 kg N ha\(^{-1}\) (Table 13). Greater cereal rye N contents were measured for rolled sunn hemp residue (101 kg ha\(^{-1}\)) compared to mowed residue N contents (82 kg ha\(^{-1}\)). Mowed sunn hemp residue with incorporation N contents (89 kg ha\(^{-1}\)) were equivalent to rolled and mowed sunn hemp residue treatments.

No differences were observed for cereal rye N contents among sunn hemp management treatments in 2011 (96 kg ha\(^{-1}\)), 2013 (88 kg ha\(^{-1}\)), or 2014 (86 kg ha\(^{-1}\)). In 2012, sunn hemp management treatments affected cereal rye plant N contents with rolled residue producing greater N contents (113 kg ha\(^{-1}\)) compared to mowed residue (84 kg ha\(^{-1}\)) and mowed residue with incorporation (88 kg ha\(^{-1}\)).

4. Conclusions

Sunn hemp biomass averaged over the growing seasons was 10,981 kg ha\(^{-1}\), producing an average total C percentage of 46.5% with an average total N percentage of 2.1%. The average C:N ratio was 23:1. Except in 2012, higher kale yield was observed for mowed and incorporated sunn hemp, compared to lower yields for the mowed and rolled residue. These differences were related to weather condition (extensive rainfall) and the different sunn hemp residue managements methods for large amounts of sunn hemp residue. In three growing seasons (2011, 2012 and 2014), grain yield from cereal rye was not affected by sunn hemp termination methods, although in 2013, cereal rye grain yield was higher for rolled and mowed sunn hemp residue compared to lower grain yield for mowed with incorporation treatment. It appears that better soil planting conditions due to rolling and mowing sunn hemp compared with mowed and incorporated residue resulted in higher cereal rye grain yield. Soil NO\(_3\)-N and NH\(_4\)-N for kale plots varied with sampling depth. Greater amounts were measured.
in the 0–15 cm layer. Likewise, soil NO$_3$-N amounts varied across each growing season. In contrast, there were no differences in amounts of NH$_4$-N among growing seasons. Higher NO$_3$-N and NH$_4$-N amounts were measured at kale planting compared to amounts measured at sunn hemp termination. For cereal rye plots, soil NO$_3$-N and NH$_4$-N varied significantly across each growing season and with sampling depth. Sunn hemp management treatments did not affect soil NH$_4$-N, in contrast, sunn hemp management treatments did effect soil NO$_3$-N. Sampling time at cereal rye planting resulted in higher amounts of NO$_3$-N and NH$_4$-N compared to amounts measured at sunn hemp termination.

Author Contributions: T.S.K. and K.S.B. collaborated on experimental conceptualization, experimental investigation, and agreeing to the published version of the manuscript.

Funding: This research was funded by the USDA-ARS, and received no external funding.

Acknowledgments: The authors acknowledge Corey Kichler, agricultural engineer, Jeffery Welker, biological science technician and Morris Welch, engineering technician at the USDA, National Soil Dynamics Laboratory, Auburn, Alabama for their technical assistance, data collection, planting and harvesting of cash crops.

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

References

1. Ayaz, F.A.; Glew, R.H.; Millson, M.; Huang, H.S.; Chuang, L.T.; Sanz, C.; Hayırlıoglu-Ayaz, S. Nutrient contents of kale (Brassica oleracea L. var. acephala DC.). Food Chem. 2006, 96, 572–579. [CrossRef]

2. United States Department of Agriculture; National Agricultural Statistics Service. 2012 Census of Agriculture, Summary and State Data; Geographic Area Series, Part 51 AC-12-A-51; National Agricultural Statistics Service: Washington, DC, USA, 2014; Volume 1. Available online: https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,Chapter_1_US/usv1.pdf (accessed on 14 August 2020).

3. Vegetable Growers News. More Growers Riding the Kale Production Bandwagon. 18 June 2015. Available online: https://vegetablegrowersnews.com/article/more-growers-riding-the-kale-production-bandwagon/ (accessed on 2 September 2020).

4. Šamec, D.; Urlić, B.; Salopek-Sondi, B. Kale (Brassica oleracea var. acephala) as a superfood: Review of the scientific evidence behind the statement. Crit. Rev. Food Sci. Nutr. 2019, 59, 2411–2422. [CrossRef] [PubMed]

5. Mazahar, S.; Sareer, O.; Umar, S.; Iqbal, M. Nitrate accumulation pattern in Brassica under nitrogen treatments. Braz. J. Bot. 2015, 38, 479–486. [CrossRef]

6. United States Department of Agriculture; National Agricultural Statistics Service. Sunn Hemp: A cover Crop for Southern and Tropical Farming Systems. Soil Qual. Inst. Agron. Tech. Note 1999. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053283.pdf (accessed on 7 September 2020).

7. Wang, Q.; Li, Y.; Klassen, W.; Hanlon, E.A., Jr.; Sunn Hemp—A Promising Cover Crop in Florida. University of Florida, The Institute of Food and Agricultural Sciences. 2018. Extension SL 306. Available online: https://edis.ifas.ufl.edu/pdffiles/TR/TR00300.pdf (accessed on 29 August 2020).

8. Balkcom, K.S.; Reeves, D.W. Sunn-Hemp Utilized as a Legume Cover Crop for Corn Production. Agron. J. 2005, 97, 26–31. [CrossRef]

9. Balkcom, K.S.; Massey, J.M.; Mosjidis, J.A.; Price, A.J.; Enloe, S.F. Planting date and seeding rate effects on sunn hemp biomass and nitrogen production for a winter cover crop. Int. J. Agron. 2011, 8. [CrossRef]

10. Aikins, K.A.; Antillea, D.L.; Jensena, T.A.; Blackwell, J. Performance comparison of residue management units of different no-till row cleaners on cotton emergence and yield. Trans. ASABE 2005, 52, 383–391. [CrossRef]

11. Kornecki, T.S.; Raper, R.L.; Arriaga, F.J.; Schwab, E.B.; Bergtold, J.S. Impact of rye rolling direction and different no-till row cleaners on cotton emergence and yield. Trans. ASABE 2009, 52, 383–391. [CrossRef]

12. Kornecki, T.S.; Arriaga, F.J.; Price, A.J.; Balkcom, K.S. Effects of different residue management methods on cotton establishment and yield in a no-till system. Appl. Eng. Agric. 2012, 28, 787–794. [CrossRef]

13. Jones, J.M.; Jones, C.I.M. Cultural Differences in Processing and Consumption. In Encyclopedia of Grain Science; Walker, C., Wrigley, C., Corke, H., Eds.; Academic Press: Oxford, UK, 2004; pp. 349–355. [CrossRef]

14. Andreassen, M.; Christensen, L.; Meyer, A. Content of phenolic acids and ferulic acid dehydrodimers in 17 rye (Secale cereale L.) varieties. J. Agric. Food Chem. 2000, 48, 2837–2842. Available online: http://refhub.elsevier.com/S0733-5210(17)30309-0/sref3 (accessed on 25 August 2020). [CrossRef] [PubMed]
15. Sandberg, J.C.; Bjorck, I.M.E.; Nilsson, A.C. Rye based evening meals favourably affected glucose regulation and appetite variables at the following breakfast; A randomized controlled study in healthy subjects. *PLoS ONE* **2016**, *11*, e0151985. [CrossRef]

16. Ye, E.Q.; Chacko, S.A.; Chou, E.L.; Kugizaki, M.; Liu, S. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *J. Nutr.* **2012**, *142*, 1304–1313. [CrossRef]

17. Ounnas, F.; Prive, F.; Salen, P.; Gaci, N.; Tottey, W.; Calani, L.; Bresciani, L.; Lopez-Gutierrez, N.; Hazane-Puch, F.; Laporte, F. Whole Rye Consumption Improves Blood and Liver n-3 Fatty Acid Profile and Gut Microbiota Composition in Rats. *PLoS ONE* **2016**, *11*, e0148118. [CrossRef] [PubMed]

18. Fardet, A.; Edmond Rock, E.; Rémesy, C. Is the in vitro antioxidant potential of whole-grain cereals and cereal products well reflected in vivo. *J. Cereal Sci.* **2008**, *48*, 258–276. [CrossRef]

19. Gani, A.; Wani, S.M.; Masoodi, F.A.; Hameed, G. Whole-grain cereal bioactive compounds and their health benefits: A review. *J. Food Process. Technol.* **2012**, *3*, 146–156. [CrossRef]

20. Kornecki, T.S.; Price, A.J.; Raper, R.L. Performance of different roller designs in terminating rye cover crop and reducing vibration. *Appl. Eng. Agric.* **2006**, *22*, 633–641. [CrossRef]

21. Derpsch, R.; Friedrich, T.; Kassam, A.; Hongwen, L. Current status of adoption of no-till farming in the world and some of its main benefits. *Int. J. Agric. Biol. Eng.* **2010**, *3*, 1–25. [CrossRef]

22. AWIS. Agricultural Weather Information Service, Inc. 2015. Available online: http://www.awis.com/ (accessed on 16 August 2020).

23. Kornecki, T.S. Multistage Crop Roller. U.S. Patent # 7,987,917 B1, 2 August 2011.

24. Zadoks, J.C.; Chang, T.T.; Konzak, C.F. A decimal code for the growth stages of cereals. *Weed Res.* **1974**, *14*, 415–421. [CrossRef]

25. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*, 2nd ed.; John Wiley & Sons, Inc.: New York, NY, USA, 1984.

26. SAS. *Proprietary Software Release 9.2*; SAS Institute, Inc.: Cary, NC, USA, 2013.

27. The Alabama Cooperative Extension System. 2020. Available online: https://www.aces.edu/blog/topics/forages-livestock/sunn-hemp/ (accessed on 17 September 2020).

28. Gan, Y.T.; Liang, B.C.; Liu, L.P.; Wang, X.Y.; McDonald, C.L. C: N ratios and carbon distribution profile across rooting zones in oilseed and pulse crops. *Crop Pasture Sci.* **2011**, *62*, 496–503. Available online: www.publish.csiro.au/journals/cp (accessed on 10 September 2020). [CrossRef]

29. USDA Natural Resources Conservation Service. Carbon to Nitrogen Ratios in Cropping Systems. 2011. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf (accessed on 12 August 2020).

30. Thavarajah, D.; Siva, N.; Johnson, N.; McGee, R.; Thavarajah, P. Effect of cover crops on the yield and nutrient concentration of organic kale (*Brassica oleracea* L. var. acephala). *Sci. Rep.* **2019**, *9*, 10374. [CrossRef] [PubMed]

31. Al-Kisi, M.; Hanna, M.; Tidman, M.; Methods for Measuring Crop Residue. *Integr. Crop Manag.* **2002**, *IC-488*. Available online: https://crops.extension.iastate.edu/encyclopedia/methods-measuring-crop-residue (accessed on 20 August 2020).

32. Balkcom, K.; Schomberg, H.; Reeves, W.; Clark, A.; Baumberdt, L.; Collins, H.; Delgado; Duiker, J.S.; Kaspar, T.; Mitchell, J. Managing cover crops in conservation tillage systems. In *Managing Cover Crops Profitably*, 3rd ed.; Clark, J., Ed.; Handbook Series Book 9; Sustainable Agriculture Network: Beltsville, MD, USA, 2007; pp. 44–61.

33. Buntin, G.D.; Cunfer, B.M. (Eds.) *Southern Small Grains Resource Management Handbook*; The University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension: Athens, GA, USA, 2017; Available online: https://secure.caes.uga.edu/extension/publications/files/pdf/B%201190_3.PDF (accessed on 6 September 2020).

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).