Evaluating benefits of winter annual cover crop systems for organic sweet potato in North Carolina.

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Project Summary:

The use of cover crops for weed management has been effective in no-till row crops such as soybean by rolling and crimping to create a high biomass residue cover that suppresses weeds. Using a roller-crimper modified to work on hilled beds this research sought to assess the viability of winter cover crops seeded onto autumn formed beds and terminated in the spring as effective tools for weed control as compared to the disruptive and energy intensive management practice of repeated cultivation. By embedding increasing rates of organic N fertilizer in each cover crop treatment we attempted to determine if this management practice required modification to nutrient recommendations.

In the fall of 2018 cover crops were seeded in Goldsboro and Kinston, N.C. The field location in Goldsboro was located at the Center for Environmental Farming Systems (CEFS) and the two field sites will be referred as either CEFS or Kinston. Cover crops, rye (*Secale cereale* L.) and a rye-hairy vetch (*Vicia villosa* Roth) mixture, were terminated with a no-till roller-crimper in late May (Table 1). Slips were transplanted into the roller-crimped cover crop litter using a no-till transplanter (Figure 1). A conventional organic sweetpotato system with frequent cultivation for weed control was used as a control.All beds were organically managed and harvested in early October. Increasing N rates were nested within cover crop treatments to examine the interaction of cover crops and N.

Figure 1. Transplanting sweetpotato slips into rye-vetch cover crop at CEFS.

Cover crop biomass was low and weed suppression was limited under cover cropped systems. Soil available nitrogen levels were reduced under the cover crops, and tissue nitrogen reflected this differential. Yields were significantly reduced under cover cropped beds, likely due to monocot weed density and competition in the root zone for limited moisture and nitrogen. Conventional beds were significantly greater, but also showed limited yields due to field maintenance challenges and drought. In all systems, nitrogen rates did not affect yield. The presence of cover crops did not appear to increase the presence of wireworms in this preliminary research.

Introduction to Topic:

North Carolina is the second largest producer of organic sweetpotatoes in the U.S. In 2016, 21% of organically certified farms in North Carolina produced sweetpotatoes (*Ipomoea batatas* L.) and farmers reported 3,200 acres of organic sweetpotato production in the state, an increase of nearly 42% since 2014 (USDA-NASS 2018). At an average of 21,049 kg ha^{-1}, organic practices in 2016 constituted 3.5% of sweetpotato land area in the state (USDA-NASS, 2017). Conventional sweetpotatoes only slightly exceeded organic per ha yields, at 21,367 kg ha^{-1} (USDA-NASS, 2018). This small differential in yield does not reflect the differences in cost of production.

Despite a steady demand for organic sweetpotatoes, marketable yield and cost of production in this region are faced by challenges from weed, insect and soil fertility management. Through farmer consultation soil borne pests such a wireworm and weed proliferation were identified as two areas of concern for organic farmers in North Carolina. Our research was conducted to determine if cover cropping could mitigate the need for economically and environmentally costly weed management practices in organic sweetpotato systems. In addition, we attempted to determine if there was a trade-off from including cover crops in rotation by providing overwintering conditions for wireworms and if this translated to increased root damage and marketable yield losses.

Background:

Organic sweetpotato yields are often reduced due to weed pressure, wireworm damage and nitrogen availability for plant uptake (Jackson and Harrison, 2008a; Harrison and Jackson, 2011; Treadwell et al., 2007). It is not unusual for wireworms to damage as much as 40% of the sweetpotato crop in North Carolina, preventing fresh market sales (Barnes, Personal Communication, 2018). To manage weeds, organic sweetpotato farmers depend on repeated cultivation, a process that is energy and labor intensive. Based on North Carolina surveys, 97% of growers utilize cultivation to control weeds, and reported an average of 3.2 cultivations per season (Toth et al., 1997). Over two-thirds of these surveyed growers also relied on chemical management, indicating that organic growers likely require additional cultivations and hand management not captured in the survey data. In 2006, these numbers were unchanged (Haley and Curtis, 2006). Since cultivation becomes impractical once vines extend across the beds, growers frequently rely on mowing and costly hand removal to obtain adequate weed control after cultivation becomes too destructive. Fortunately, once sufficient stands are established, weeds are often suppressed by the canopy, though differential development of the leaf canopy by cultivar has been observed and can be of considerable concern given critical weed-free periods 2 to 6 weeks after transplant (Seem et al., 2003; LaBonte et al., 1999).The intensive tillage required for weed management produces a bare soil surface soil where erosion and soil organic matter reductions are easily facilitated (Nelson et al., 2009). Although the options for weed management in organic sweetpotatoes are limited, the integration of rolled and crimped cover crops, typically cereal rye, could provide enough residue biomass to limit germination of key weed species (e.g., Palmer amaranth; Myers et al., 2010).

In this study, we attempted to determine if fall planted cover crops on pre-formed transplant beds could generate a cover crop residue to inhibit weed germination from transplanting to vine closure. This approach would limit within season tillage for weeds and benefit the production system by increasing organic matter in the soil, a process that will improve soil health over a long period. Similar fall planted cereal rye have been effective in no-till field crops and have been adopted by organic growers in North Carolina (Smith et al., 2007; Reberg-Horton et al., 2012) and in the mid-Atlantic region (Mirsky et al., 2009, Ryan et al., 2011). Still, little is known about potential effects of N management, yield, pests, or quality of sweetpotatoes. From an entomological perspective, Jackson and Harrison (2008) found that sweetpotatoes can be successfully grown under a killed-cover crop production system without insecticides in South Carolina. Winter annual cover crops have been shown to benefit organic vegetable crops through improved soil health, reduced nitrate leaching and soil erosion (Wyland et al., 1996; Snapp et al., 2005; Brennan and Acosta-Martinez, 2017; Blanco-Canqui, 2018). Legume cover crops have also been shown to be a source of nitrogen to the following cash crop through mineralization of the residue and increase the rate of turnover within the soil organic nitrogen pool (Kuo et al., 2002).

Cover crop derived nitrogen can reduce the need for costly inputs (seabird guano, feather meal). Using a high biomass legume cover crop such as hairy vetch has been attempted for weed suppression via roller-crimping and can be effective in the mid-Atlantic but in the Southeast the moist and hot conditions tend to decompose the cover crop too rapidly for it to suppress weeds (Reberg-Horton et al., 2012). Alternatively, using a monoculture cereal rye can in some cases causes temporary immobilization of nitrogen as it is being decomposed (Jin et al., 2008) which risks inadequate nitrogen supply to the crop. This immobilization can be addressed by having a mix that includes as legume, such as in this study with cereal rye + hair vetch, with the N from the legume component being released at a greater rate than the immobilization from the decomposing rye (Reberg-Horton et al., 2012). Alternatively, it may require additional application of organic nitrogen fertilizers and therefore require an adjustment to recommended rates when roller-crimping is used for weed management.

Although the benefit of cover crops have been documented in several production systems, relatively little is known about the potential negative impacts that cover crops could have on the abundance invertebrate pests and diseases, and what impacts elevated pest pressure could have on cash crop quality. Cover crops may provide continuous green bridge that improves winter survival of soilborne crop pests (wireworms, diseases, nematodes; Seal et al. 1992), and could elevate risk for economic damage following the termination of the cover crop. Wireworm activity tends to increase following crops such as sorghum, pasture and rye (Adam, 2005).

Research involving organic sweetpotatoes is limited for the Southeast U.S. considering how important of an economic organic crop it is within traditional cropping rotations. A poultry litter rate response study was conducted in Alabama with application rates of 23-138 kg N ha^{-1}, the author noted that previous research found a decline yield and quality if rates applied above 138 kg N ha^{-1}) (Gichuhi et al, 2014). Gichuhi et al. (2014) also found positive correlations with nutritional components of the ‘Beaurgard’ sweetpotato variety but no yield improvement above the 23 kg N ha^{-1}. In general, N requirements in sweetpotatoes is highly variable based on cultivar, moisture, and temperature. Typically 75–135 kg N ha^{-1} is recommended for suitable yield and quality (Ankumah et al., 2003). Split applications and delayed applications have been explored, with optimal dates after transplant and rates mixed. Phillips et al. (2005) reported that in a 3-year study of the Beauregard cultivar, 28–56 kg N ha^{-1} was required to achieve maximum marketable yield in a Virginia sandy loam. Guertal and Kemble (1997) found that sweetpotato showed no response to N application rates up to 108 kg ha^{-1} on an Alabama fine sandy loam soil where initial soil testing showed high nutrient availability. The use of N fertilizer over the optimum rate has been documented to result in both no change in yield production compared to lower N rates, yield plateaus, or decreasing yields. Studies have shown excess N application to sweetpotato results in suppression of storage root formation and/or growth (Kuo and Chen, 1992; Saki et al., 2019). A two-year study of one cultivar on a Norfolk loamy sand soil in North Carolina by Villagarcia (1996) found that in the first year sweetpotato total yield peaked at 60 kg N ha^{-1} (21 t ha^{-1}) and increasing N application to 240 kg ha^{-1} did not alter yield. The contrasting responses of sweetpotato yield to N application rate imply the variable effects from soil nutrient availability, climatic conditions at the experimental site, and cultivar variability in nutrient requirement.

Treadwell at al. (2008) examined a cover crop mix of hairy vetch and rye with compost either incorporated in the spring or terminated in the spring with a flail mower or rolling cultipacker. Treadwell et al. (2007) found a flail mown cover crop was associated with reduced weed density in sweetpotatoes. The surface litter of cover crops did not affect yield when compared to conventional and incorporated cover crops in two out of three years of study. The exception resulted in a 45% yield reduction attributed to late stage monocot weed density and poor early season slip development. Previous cover cropping in sweetpotato research has suggested uncompromised yields, yield costs, and effective weed-suppression. This preliminary study seeks additional clarity. The objective of this research was to measure the yield response of organic sweetpotato grown under a rye and rye-vetch roller crimped cover crop when supplemented with additional N, and to quantify the potential weed-suppressive activity of winter cover crops when seeded on to sweetpotato hills formed in the fall. Because the sequence from cover crop to cash crop could have both benefits and unintended consequences, there is a real need to document these interrelated impacts through a multidisciplinary research approach. Results of these holistic studies will help to document both the potential positive and negative effects of integrating cover crops into a high value organic vegetable production system. The finding of this systems approach research will directly address the primary challenges facing organic sweetpotato farmers with innovative management options

Objectives Statement:

1. Compare the weed suppressive activity of rye or rye+vetch cover crops when applied to sweetpotato hills formed in the autumn to typical organic sweetpotato production practices.
    a. Measurable Outcome:
        i. Quantification of weed biomass estimates and weed composition as influenced by the rolled cover crops
        ii. A comparison of maximum attainable yield in the weed free checks compared to the three management options to assess background weed pressure in typical sweetpotato management compared to alternative

2. Assess the damage of wireworm larvae to sweetpotato in the presence of different cover crop combinations and a wireworm susceptible and resistant varieties.
    a. Measurable Outcome:
        i. Compare differences in wireworm populations at several points during the growing depending on cover crop presences
        ii. Assess the damage of wireworms to sweetpotato marketable yields depending on cover crop
        iii. Determine the efficacy of the wireworm resistant sweetpotato variety at mitigating root damage

3. Measure the yield response of organic sweetpotato grown on different cover crops when supplemented with a range of nitrogen rates and analyses the economic tradeoffs associated with each cover crop treatments.
    a. Measurable Outcome:
        i. Determine yield rate response curves for recommendations of maximum yield and most economic rate of nitrogen
        ii. Determine if an adjustment is required when a roller-crimper system is used for weed management

4. Deliver results through traditional extension meetings and online content targeting both organic and conventional sweetpotato producers in the Southeast.
    a. Measurable Outcome:
        ii. Disseminate results at the NCSU Organic Field Day and tour the experiment

Materials and Methods:

Two field experiments were established on North Carolina State University Research Field Stations at the Center for Environmental Farming Systems (CEFS) in Goldsboro, N.C. and the Caswell Research Station in Kinston, N.C. Both fields were established on long term organically managed land and were located within the major sweetpotato production region of North Carolina. Sweetpotatoes were produced using organic practices, weed management in the conventional beds was completed with cultivative row passes, and documented hours of hand-weeding for broadleaf forbs.Three cover crop treatments were evaluated in four replicates: rye (*Secale cereale* L.); a rye-hairy vetch (*Vicia villosa* Roth) mixture, and a no cover control in a split-plot design. Within each of the three cover crop treatments nine subplots were created. Six of the subplots were dedicated to a N rate study and assigned one of six N rates 0, 20, 40, 60, 80, 120 kg N ha^{-1} representing 0, 25, 50, 75, 100, 150% of the recommended rate for sweetpotatoes in the area. Two of the remaining three were maintained as a weed comparison, with one maintained as weed-free by hand pulling and hoeing, with the other as an un-weeded comparison. In the final bed, a wireworm resistant variety of sweetpotato developed at North Carolina State University (NCSU), NC04-0531. These three remaining beds were given the 100% (80 kg N ha^{-1}) N rate .

Field Management, Nutrient Sources, and Application Methods

Cover crop treatments were 10 m wide (eight rows), and individual sub-plots were 5 m wide (four rows) and 9.1 m long. Weed-free and un-weeded sub-plots were 5 m wide and 4.6 m long. Individual plots contained four rows, with the outer two rows being used for data collection and the inner two for harvest. Two guard rows separated each cover crop treatment.Cover crops were planted in mid-October of 2018 by broadcast seeding. Organic rye seed was broadcast at 134 kg ha^{-1}, rye/hairy vetch mixture was seeded at 62/28 kg ha^{-1}. Cover crop biomass was collected on May 28th in Kinston and May 29th at CEFS. Roller crimping occurred on June 3rd at both locations. All beds, except for the wireworm resistance plot, were planted with organically produced Covington sweetpotato slips and spaced 30 cm apart. Slips were planted on June 6th at the CEFS location, and June 5th at the Kinston location and sourced from Jones Family Farms in Bailey, N.C. Field sites were organically managed. During the growing season, conventional beds were cultivated and re-formed to control for weeds until an adequate canopy was established. Weed-free sub-plots were weeded once a week, cover cropped treatments were managed for broadleaf forbs, mainly *Amaranthus palmeri*, by weekly walk-through weeding. Fertilizer was applied once, on June 25th at both locations by hand application onto the transplant furrow. Fertilizer was applied as $NaNO_3$ at 0, 20, 40, 60, 80, 120 kg N ha^{-1} with potassium at 134 kg K_2O ha^{-1} on all plots.

During the field season, several complications arose that limited data collection and quality of data. At the Kinston location, machinery calibration and cover crop biomass prevented the no-till transplanter from working effectively (Figure 2). Rye-vetch beds were particularly difficult and were unable to be planted. The rye beds were considered to be a low-quality planting, and where possible slips were replanted by hand to a depth necessary to facilitate their growth and survival. The conventional beds were planted with minimal concern. At CEFS the same issues were solved, and planting proceeded in all beds without concern. The Kinston location also had overwhelming weed interference in both the conventional and rye cover crop treatments. The conventional beds were hand weeded due to missed cultivation windows, and the rye cover crop treatment was eventually dropped due to an overwhelming level of weed cover and transplant failures. Yield data from Kinston is considerably lower for this reason. Due to unusually dry conditions in the 2019 field season, CEFS was slow to develop (Table 1).

Figure 2. Transplanter complications in rye-vetch beds at Kinston.

Table 1. Cumulative rainfall by month compared to the 30-year average at both locations in 2019.

	Monthly Cumulative Rainfall (cm)					
Location	**April**	**May**	**June**	**July**	**August**	**September**
CEFS	7.4	2.9	7.2	6.1	3.7	4.1
Kinston	8.1	4.3	13.3	12.0	11.7	5.6
CEFS 30yr Average[a]	8.5	9.6	9.8	14.1	14.9	15.2
Kinston 30yr Average[a]	8.0	9.4	12.9	14.2	13.7	14.5

[a]30-year averages calculated from 1981-2010 data taken from NCEI COOP stations located closest to respective ECONet stations.

Sample Material Collection

Cover crop aboveground biomass was collected on May 28th and 29th before roller crimping on June 3rd, by taking two 0.5 m x 0.5 m squares from each whole-plot treatment (Table 2). The aboveground samples were dried at 65° C until a constant weight was achieved then weighed and recorded again. A representative, homogenized sample of the vetch cover crop biomass along with rye and vetch samples from the rye-vetch mixture were ground and tested for total N and carbon (C) using a Perkin-Elmer 2400 CHN elemental analyzer. Within each plot, total N and C was assessed at 30 days after fertilization (30d), 60 days after fertilization (60d), and on final sweetpotato tissue. Green tissue samples were taken at 30d and 60d from transplant on the outer two rows, where two plants were randomly selected from each plot. Harvest sweetpotato tissue cores were taken from five sweetpotatoes for each plot, if available the five were in the U.S. No. 1 category. All core samples were dried at 65° C for 72 hours before grinding. Samples were ground to <80-mesh. All tissue content was analyzed using a Perkin-

Elmer 2400 CHN elemental analyzer (Perkin Elmer Corp, Waltham, MA, USA) by the EATS laboratory at NCSU. Soil samples were collected pre-planting, at fertilization, at 30d post-fertilization, and at 60d post-fertilization. Five 0-15 cm soil cores were taken in a line across the bedded hill, two from the bottom, two from the mid-section and one at the crest, four times (two from each outer row), for a total of 20 samples. Soil cores were then homogenized, bagged, and transported to a freezer to await testing. Samples were analyzed for concentrations of soil NO_3-N and NH_4-N by a 1 M KCl extraction submitted to the EATS laboratory at NCSU for flow injection analysis methodology for colorimetric determination with a QuikChem IV (Lachat Instruments, Loveland, CO).

Table 2. Data collection dates for the 2019 field season.

Location	**Soil Sample Data Collection**				
	Pre-plant	**Fertilization**		**30d[a]**	**60d[b]**
CEFS	June 6th	June 25th		July 24th	August 19th
Kinston	June 5th	June 25th		July 23rd	August 12th
	Tissue Sample Data Collection				
	Cover crop	**30d**	**Weed Biomass**	**60d**	**Harvest**
CEFS	May 29th	July 8th	July 3rd	August 5th	October 3rd
Kinston	May 29th	July 8th	July 2nd	August 5th	October 11th

[ab]30d/60d represents 30/60 days after fertilization for soil samples, 30/60 days after transplant for tissue collection.

Statistical Analysis

The variability between treatments, fields, and years was determined using a mixed model and all data for crop and soil measurements were analyzed using PROC GLIMMIX or PROC GLM procedure in SAS version 9.4 (SAS Institute, Cary, NC). Degrees of freedom and specific comparisons to assess cover crop treatments, N applications, weeded vs. un-weeded, and cultivar comparison influences on tissue N, soil N, yield, and grade distribution were adjusted for valid statistical analyses. All mean comparisons used Tukey's HSD adjustments with significance at $p \leq 0.05$. Where applicable, data distributions that did not satisfy the assumptions underlying an analysis of variance procedure were fit to the correct distributions and analyzed with PROC GLIMMIX using a technique detailed by Stroup (2015).

Project Results:

Cover Crops

Cover crop biomass: At both locations, cover crop biomass showed a statistically significant response from cover crop treatments. Biomass measures of 6000-8500 kg ha^{-1} have been cited as necessary for reduced weed activity (Reberg-Horton et al., 2012). Treadwell et al. (2007), found no yield reductions when 8750-13820 kg ha^{-1} of a rye/hairy vetch mixture (seeded at 67/45 kg ha^{-1}) was flail mown and left on the surface. Based on previous studies, cover crop biomass at CEFS and Kinston were well under the levels reported necessary for reduced weed activity. In both environments the rye-vetch mixture produced the greatest biomass at only 3000 kg ha^{-1} (Table 3). The potential weed suppressive capabilities of the cover crop treatments was a point of concern immediately due to low biomass totals. The rye-vetch mixtures were dominated by hairy vetch, with rye generally between 5-15% of the biomass (at its greatest 21%) collected from the rye-vetch treatments (Data not shown). Rye treatments (1444-2159 kg ha^{-1}) lacked the desired density to prevent establishment of, and competition with, weeds that persisted beyond rye senescence and roller crimping.

Table 3. Cover crop biomass at CEFS and Kinston field locations in 2019 prior to sweetpotato planting.

Treatment	**Cover Crop Biomass (kg ha^{-1})**	
	CEFS	**Kinston**
Conventional	530 (15)[†] c[‡]	837 (12) c
Rye	1444 (70) b	2159 (35) b
Rye-vetch	2897 (91) a	3050 (11) a
F Value	306.2	222.95
Pr > F	<0.0001	<0.0001

[†]Numbers in parentheses are standard error (n=4).
[‡]Letters within columns that are the same are not significantly different at p=0.05

Weed Establishment

Weeds: Within the first month after transplant, weeds became a concern. In the initial window, a considerable weed stand established due to sufficient rainfall at Kinston (Table 4). CEFS was unusually dry and weeds there were slow to emerge and establish in the cover crop beds. This was likely a factor of moisture, as opposed to obstruction or shade on the soil surface, based on visual assessments. At the Kinston location, the rye cover crop and conventional no cover control beds were not statistically different in weed biomass or weed percent ground cover. Cultivation for weeds did not occur in the conventional beds in a timely manner, despite requests from the research group to the research station. Given adequate moisture, sun exposure, and a considerable seed bank, Palmer amaranth dominated the beds at Kinston with 1156 kg ha^{-1} of growth in the conventional and 1481 kg ha^{-1} under the rye cover. This likely had season long ramifications, based on other studies measuring the critical weed free period for sufficient sweetpotato yields (LaBonte et al., 1999). At the CEFS location, the rye and rye-vetch did not differentiate statistically, though both showed considerable weed stand establishment. Data was collected on the 2nd and 3rd of July, and hand weeding of forbs was initiated at this point. Based on field assessments, weed cover reached 100% ground cover, with a hay field like density by the end of July. This data confirmed concerns of inadequate biomass for weed suppression (Table 4).

Table 4. Cover crop treatment effect on weed biomass and weed percent ground cover at CEFS and Kinston in 2019.

Treatment	Weed Biomass (kg ha^{-1})		Weed Percent Ground Cover (%)	
	CEFS	Kinston	CEFS	Kinston
Conventional	0 (0)† b‡	1156 (91)	0 b	30.3 (2.5)
Rye	269 (34) a	1481 (103)	27.8 (4.3) a	41.3 (3.1)
Rye-vetch	185 (32) ab	n/a	17.6 (2.2) ab	n/a
F value	6.39	2.31	7.79	6.01
Pr > F	0.0327	n.s.	0.0215	n.s.

†Numbers in parentheses are standard error (n=4).

‡Letters within columns that are the same are not significantly different at p=0.05

Yield and Grade

***Marketable yield*:** Calculated as the sum of USDA Jumbo, No. 1, and canner grades, there was no significant differentiation in marketable yield based on N treatments. Cover crops did result in significant differentiation, with considerably greater yields in the CEFS conventional no cover treatment as compared to the rye and rye-vetch treatments (Table 5). Conventional productivity for marketable yields was low and not significantly different based on N rate at Kinston, ranging from 7232 to 9610 kg ha^{-1}. At CEFS, conventional no cover beds outperformed all other cover crop treatments. CEFS did not show a N response, this is likely due to internal variability and unusually dry conditions impacting the soil nutrient environment. At the CEFS location, rye and rye-vetch were not significantly different. Neither a quadratic plateau nor linear response fit the data (Figure 3.1).

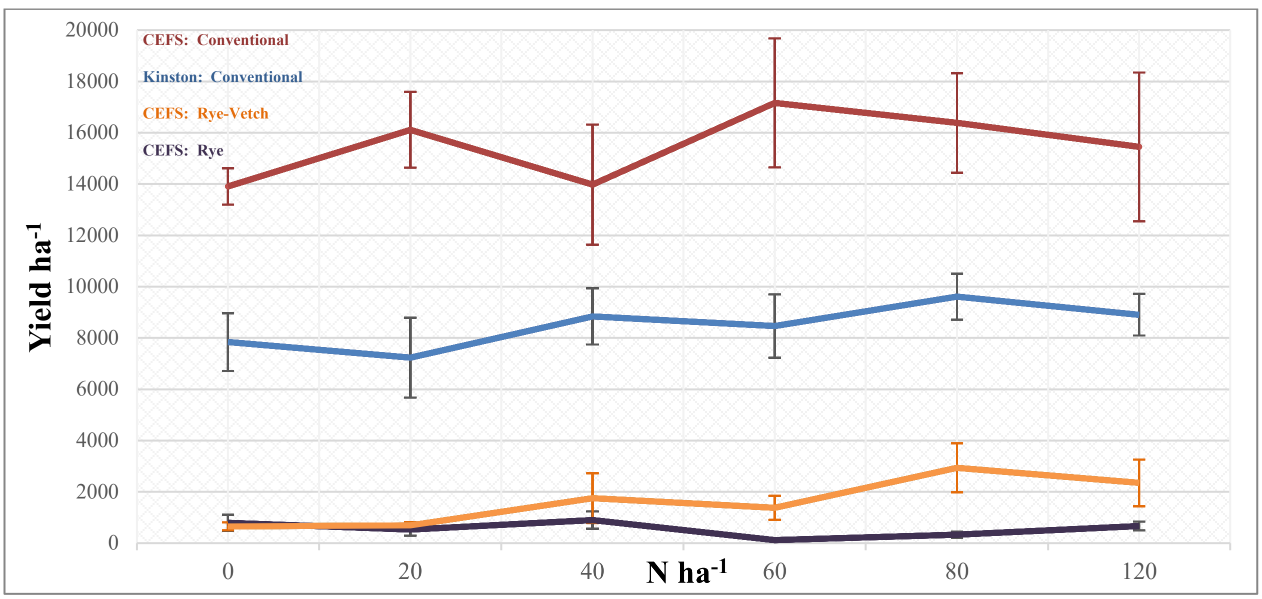

Figure 3. Yield by N rate with standard errors shown for all harvested treatments at CEFS and Kinston.

Previous research in the Southeast on a different cultivar showed that N rates as little as 28 kg ha^{-1} optimized yield and N use efficiency (Phillips et al., 2005). Other research has shown increasing yields at levels well beyond the applied N rates in this study (Taranet et al., 2017). North Carolina State University production guides recommend 80 lbs. acre^{-1} for 'Covington', but emphasis the lack of research into organic production and fertilization. With the high variability in the literature and concerns with drought and deer in this study, it is difficult to draw conclusions about N rates in the no cover conventional treatment especially at the Kinston location. It is, however, evident that low biomass, roller crimped cover crops for weed control is not a potential strategy for optimizing yield.

Table 5. CEFS marketable yield response [significant for cover crop under the factorial] in 2019.

Treatment	CEFS Main Effects 2019
Cover Crop	**Marketable Yield (kg ha^{-1})**
Conventional	15497 (802)† a‡
Rye	1626 (307) b
Rye-Vetch	557 (100) b
F Value	129.36
Pr > F	<0.0001

†Numbers in parentheses are standard error (n=4).
‡Letters within columns that are the same are not significantly different at p=0.05

Marketable yield for weed-free check and weedy check: Comparisons between weed-free and weedy beds showed potential maximized yields for cover crop treatments. Despite optimized weed-free yields, values were still significantly less than conventional weed free maintenance resulting primarily from cultivation. This differential is a possible result of soil density and structure, resulting from the lack of cultivation. It may also reflect the soil compression and disturbance that accompanied weekly hand-weeding. This data largely illustrates expect results, given previous evidence and predictable responses under un-weeded beds when compared to a weed free treatment (Table 6).

Table 6. CEFS marketable yield response comparison between weed free and weedy in 2019.

Treatment	Marketable Yield (kg ha^{-1})			
	CEFS		**Kinston**	
	Weed Free	**Weedy**	**Weed Free**	**Weedy**
Conventional	12239 (740)‡ a	12962 (790) a	10146 (652)	4689 (421)
Rye	7476 (421) b	911 (354) b	n/a	n/a
Rye-Vetch	9061 (504) b	323 (168) b	n/a	n/a
F Value	20.21	16.75	n/a	n/a
Pr > F	<0.0001	<0.0001	n/a	n/a

†Numbers in parentheses are standard error (n=4).
‡Letters within columns that are the same are not significantly different at p=0.05

Grade: There was no response from N treatments on sweetpotato grade distribution at CEFS, despite reported evidence indicating grade responses with N rate in other studies (Taranet et al., 2017). Despite considerable differences between cover crop treatments, the conventional no cover production showed little differentiation in grade distribution due to N rates. At Kinson, the 150% N rate did lead to a significantly higher production of Jumbo grade sweetpotatoes. There was not a significant effect from N rate on any other grade (Table 7).

Table 7. CEFS and Kinston grade response for N under the conventional no cover treatment in 2019.

Treatment	CEFS Grade Main Effects 2019			
	Jumbo	**Ones**	**Canners**	**Cull**
N	n.s.	n.s.	n.s.	n.s.
F Value	0.70	0.09	0.23	0.49
Pr > F	n.s.	n.s.	n.s.	n.s.
Treatment	**Kinston Grade Main Effects 2019**			
	Jumbo	**Ones**	**Canners**	**Cull**
N	*	n.s.	n.s.	n.s.
F Value	4.18	1.90	0.49	.60
Pr > F	0.0140	n.s.	n.s.	n.s.

Soil Nitrogen

***At planting*:** Both locations showed a statistically significant response to the cover crop treatments in soil N measures taken at planting. There were no discernable differences between the rye and no cover conventional control. At both locations the rye-vetch mixture resulted in greater soil total available N (TAN) at planting. At CEFS 18.2 mg kg^{-1} in the rye-vetch beds more than doubled other treatments. A muted but similar patter occurred at Kinston. This likely reflected the mineralization of a vetch dominated cover crop litter at the surface (Table 8).

***At fertilization*:** Three weeks after slip transplant, soil TAN showed no significant differences between cover crops treatments at the Kinston or the CEFS location. In late June both locations had seen an extended dry period and limited transplant growth. In Kinston, the rye-vetch treatments were dropped from the study prior to fertilization. Only CEFS presented a complete picture of the research goals. At CEFS, both the rye and rye-vetch litters were desiccated and incompletely covering the soil surface. Limited moisture was preventing their decomposition, and therefore minimizing any potential observation of mineralization or immobilization as a result of the weed suppressing litter layer. TAN values at both locations at fertilization reflect the elevated soil N environment typical of dry conditions (Table 8).

Table 8. Cover crop treatment effect on total available N at planting and fertilization in 2019.

Treatment	Total Available Nitrogen (TAN) 2019 (mg kg^{-1})[a]			
	CEFS		**Kinston**	
	Planting	**Fertilization**	**Planting**	**Fertilization**
Conventional	7.64 (0.20)[†] b[‡]	25.1 (2.31)	15.8 (0.78) b	39.6 (3.19)
Rye	8.04 (0.27) b	36.8 (4.99)	15.3 (0.88) b	50.9 (5.67)
Rye-Vetch	18.2 (0.36) a	37.1 (4.16)	22.2 (0.74) a	n/a
F value	46.32	1.82	31.01	5.12
Pr > F	<0.0001	n.s.	0.0007	n.s.

[a]Sum of KCl extractable NO_3^- and NH_4^+ from twenty 15cm cores taken from each sample plot.
[†]Numbers in parentheses are standard error (n=4).
[‡]Letters within columns that are the same are not significantly different at p=0.05

***At 30d*:** Post-fertilization a pattern of significant differentiation is evident in 30d soil test measurements, where the conventional no cover treatments show significantly greater TAN than the rye or rye-vetch beds (Table 9). This pattern holds true in both locations despite equal N application. Both N and cover crop are significant factors on 30d TAN, and there is a significant interaction. While observed increases in TAN with N rate are clear, the greatest differences come from between cover crop treatments. The conventional no cover TAN levels seem to indicate that the minimal weed cover in the conventional systems allowed for more and greater persistence of N in the soil, particularly in dry conditions in July. High weed biomass, as was observed under the rye and rye-vetch treatments, is the likely cause limiting and depleting mineralized N in the soil. Based on the minimal cover crop biomass, it seems likely that the majority of this effect is not the result of immobilization by the surface litter. The significant interaction at CEFS likely reflects the considerably different response to N when compared to the conventional plots.

If we assume a bulk density of 1.2 g cm^3, the upper 15 cm of soil at CEFS under the conventional treatment receiving the 100% N rate has about 78 kg ha^{-1} of total available N. That same 100% N rate at CEFS under the rye cover crop is evidenced as only 25 kg N ha^{-1}, and under rye-vetch as 36 kg N ha^{-1}. Given the significant emergence of weeds at this point, it seems likely that competitive weed uptake is the driving force behind this differential at CEFS, with a substantial uptake of close to 40 kg N ha^{-1} greater than under the conventional production. Dry conditions may also contribute to this response, given the minimal sweetpotato growth and extensive dry, bare soil, elevated N is not unreasonable, particular when compared to a shaded and semi-covered surface on undisturbed, uncultivated soil.

Table 9. CEFS and Kinston main effects [individual treatments and cover crop by N factorial] on in-season total available N soil measurements 30d after fertilization in 2019.

Treatments		**Main Effects 2019**			
Cover Crop[a]	**N (%)[a]**	**TAN (mg kg^{-1})**			
		CEFS	**Kinston**	**CEFS**	**Kinston**
		30d			**60d**
Conventional		18.8 (4.05)[†] cd[‡]	34.6 (4.56) ab	7.51 (1.84 [†] bc[‡]	42.9 (4.75)
Rye	0	6.57 (1.84) d	13.5 (3.92) c	2.67 (0.79) c	n/a
Rye-Vetch		7.02 (1.22) d	n/a	3.56 (0.80) c	n/a
Conventional		24.0 (3.36) bcd	33.8 (3.47) ab	6.75 (2.35)c	36.9 (4.60)
Rye	25	6.00 (1.28) d	14.7 (2.05) c	2.69 (0.69) c	n/a
Rye-Vetch		9.17 (0.29) d	n/a	3.56 (0.69) c	n/a
Conventional		34.9 (2.78) bc	34.6 (4.65) ab	13.1 (2.37) bc	40.44(6.21)
Rye	50	6.55 (1.39) d	15.5 (2.51) c	2.07 (0.24) c	n/a
Rye-Vetch		11.00 (1.95) d	n/a	3.83 (0.89) c	n/a
Conventional		33.8 (4.74) bc	38.4 (6.21) a	16.2 (5.20) bc	44.2 (7.28)
Rye	75	7.10 (1.16) d	15.4 (3.22) c	2.84 (0.78) c	n/a
Rye-Vetch		15.4 (2.20) cd	n/a	3.91 (0.55) c	n/a
Conventional		43.6 (1.96) b	47.5 (10.9) a	26.0 (9.47) ab	55.5 (6.51)
Rye	100	14.1 (4.58) cd	18.2 (4.67) bc	2.98 (0.61) c	n/a
Rye-Vetch		20.0 (3.54) cd	n/a	5.77 (1.12) (c	n/a
Conventional		70.4 (10.8) a	45.7 (4.42) a	40.4 (0.97) a	56.0 (7.27)
Rye	150	14.7 (1.16) cd	20.5 (3.38) bc	3.02 (1.19) c	n/a
Rye-Vetch		23.7 (10.3) bcd	n/a	7.76 (2.90) bc	n/a
F Value		15.47	13.57	7.76	2.22
Pr > F		<0.0001	<0.0001	<0.0001	n.s.
Factorial (3x6)		**Pr > F**			
Cover Crop		<0.0001	0.0059	0.0009	n/a
N		<0.0001	0.0117	0.0003	n.s.
Cover Crop*N		0.0014	n.s.	0.0009	n/a

[†]Numbers in parentheses are standard error (n=4).

At 60d**:** Post-fertilization the same pattern observed at 30d was seen at CEFS. Conventional no cover treatments were notably more responsive to increased N application in the TAN measurements, and significantly greater than the rye and rye-vetch treatments at the 100% and 150% N application rate (Table 9). At Kinston, where only the conventional no cover treatment was maintained to this sampling period, there was no differences detectable statistically from N treatments. Again, it seems likely that the significant weed biomass, resulting from the poor cover crop biomass, may be the explanation behind this clear difference between cover cropped and conventional beds.Weed cover has been tied to reduced crop yields in several sweetpotato studies. Research has indicated that the sweetpotato canopy as a photosynthate "source" is less important than the root zone "sink" due to competition for nutrients with weeds in determining sweetpotato yield (Kuo and Chen, 1992; Porter, 1990; LaBonte et al., 1999). Early measurements of TAN during the growing season do not contradict this pattern and seem to evidence the same mechanism limiting N uptake in the sweetpotatoes as a result of considerable weed competition.

Chemical Characteristics

Tissue at 30d**:** Tissue N follows the same pattern as 30d total available N levels at CEFS, where conventional beds had higher TAN, conventional plots also accumulated additional tissue N. This is likely due to increased uptake potential from elevated levels and the minimal weed competition (Table 10). This finding is supported in other studies, that indicate weed competition and available soil N have a direct effect on tissue N content (Kuo and Chen, 1992; Saki et al., 2019; Taranet et al., 2017). Data at Kinston did not show any significant differences (Table 10).

Table 10. CEFS and Kinston main effects [individual treatments and cover crop by N factorial] on in-season tissue percent N measurements 30d after transplant in 2019

Treatment (18) Cover Crop	N (%)	CEFS Main Effects 2019 Tissue Percent N (%) CEFS	Kinston	CEFS	Kinston
		30d		60d	
Conventional		4.81 (0.12)† a‡	3.92 (0.30)	3.02 (0.50)†	3.60 (0.23)
Rye	0	3.51 (0.20) cd	3.87 (0.29)	2.70 (0.46)	n/a
Rye-Vetch		3.74 (0.28) bcd	n/a	2.90 (0.54)	n/a
Conventional		4.38 (0.21) abc	3.80 (0.37)	3.19 (0.65)	4.07 (0.10)
Rye	25	3.45 (0.20) cd	4.24 (0.25)	2.88 (0.55)	n/a
Rye-Vetch		3.89 (0.30) abcd	n/a	3.21 (0.33)	n/a
Conventional		4.26 (0.19) abcd	3.82 (0.33)	3.28 (0.44)	4.14 (0.17)
Rye	50	3.57 (0.11) bcd	4.19 (0.15)	3.06 (0.43)	n/a
Rye-Vetch		3.69 (0.21) bcd	n/a	3.13 (0.45)	n/a
Conventional		4.86 (0.12) a	3.96 (0.09)	3.14 (0.55)	3.74 (0.31)
Rye	75	3.71 (0.22) bcd	4.12 (0.30)	3.25 (0.37)	n/a
Rye-Vetch		4.22 (0.25) abcd	n/a	3.10 (0.42)	n/a
Conventional		4.32 (0.18) abc	4.15 (0.25)	3.45 (0.34)	4.15 (0.16)
Rye	100	3.26 (0.13) d	3.81 (0.32)	3.07 (0.47)	n/a
Rye-Vetch		4.09 (0.15) abcd	n/a	3.69 (0.43)	n/a
Conventional		4.57 (0.21) ab	4.30 (0.27)	3.87 (0.03)	4.04 (0.21)
Rye	150	3.62 (0.21) bcd	4.01 (0.12)	3.29 (0.20)	n/a
Rye-Vetch		4.02 (0.23) abcd	n/a	3.44 (0.62)	n/a
F Value		5.99	0.49	0.75	1.48
Pr > F		<0.0001	n.s.	n.s.	n.s.
Factorial (3x6)			Pr > F		
Cover Crop		<0.0001	n.s.	n.s.	n/a
N		n.s.	n.s.	0.0409	n.s.
Cover Crop*N		n.s.	n.s.	n.s.	n/a

†Numbers in parentheses are standard error (n=4).
‡Letters within columns that are the same are not significantly different at p=0.05

Tissue at 60d**:** Tissue N at 60d did not have a cover crop response at either location. At CEFS, there was a N response. Nearly all tissue samples at 60d were below a critical 4% level reported by O'Sullivan et al. (1997), possibly due to unusual drought conditions at CEFS (Table 10). Despite the previously observed pattern in soil N and 30d tissue resulting from cover crops, 60d tissue samples did not continue this trend. Perhaps the mostly likely explanation is the cover crop treatment sweetpotatoes, in adapting and competing with weed cover, abandoned storage root formation and prioritized vertical tissue growth and nutrient allocation.

Final Harvest Tissue**:** Final tissue N, taken from cores of harvest storage roots did have a N and a cover crop response at CEFS. N was not significant at Kinston. The previously observed pattern in 30d tissue samples resulting from cover crops, returned in the final harvest. Despite adapting and competing with weed cover, storage root formation did still reflect the additional N availability. Storage root nutrient allocation followed soil N measurements, where elevated levels in the conventional (nearly weedless) cover treatments, and under increasing applications of nitrogen, led to additional tissue assimilation detected here (Table 11).

Table 11. CEFS and Kinston main effects [individual treatments and cover crop by N factorial] on harvested sweet potato tissue N measurements in 2019.

Treatment (18)		CEFS Main Effects 2019	
Cover Crop	**N (%)**	**Tissue Percent N (%)**	
		CEFS	**Kinston**
		60d	
Conventional		0.78 (0.07) bcdef	1.39 (0.08)
Rye	0	0.51 (0.07) f	n/a
Rye-Vetch		0.61 (0.05) ef	n/a
Conventional		0.87 (0.07) bcde	1.35 (0.07)
Rye	25	0.50 (0.02) f	n/a
Rye-Vetch		0.64 (0.04) ef	n/a
Conventional		0.97 (0.05) abcd	1.37 (0.07)
Rye	50	0.49 (0.02) f	n/a
Rye-Vetch		0.77 (0.09) bcdef	n/a
Conventional		0.98 (0.09) abc	1.28 (0.12)
Rye	75	0.58 (0.04) ef	n/a
Rye-Vetch		0.71 (0.03) cdef	n/a
Conventional		1.06 (0.03) ab	1.55 (0.02)
Rye	100	0.53 (0.02) f	n/a
Rye-Vetch		0.67 (0.04) ded	n/a
Conventional		1.21 (0.03) a	1.41 (0.06)
Rye	150	0.74 (0.08) cdef	n/a
Rye-Vetch		0.75 (0.10) bcdef	n/a
F Value		0.72	1.79
Pr > F		n.s.	n.s.
Factorial (3x6)		**Pr > F**	
Cover Crop		<0.0001	n/a
N		<0.0001	0.1764
Cover Crop*N		n.s.	n/a

†Numbers in parentheses are standard error (n=4).

Assess the damage of wireworm larvae to sweetpotato:

Wireworms, larval forms of click beetles, are a significant agricultural pest of multiple crops grown in the southeastern US. In organic sweetpotato, larval feeding on roots reduces the quality and marketability of the crop. Moreover, root injury also increases the potential for post-harvest disease during storage. In this study, we observed no significant difference in the amount of root damage between cover crop treatments and the standard cultivation practice (F=0.13, p-value=0.889). There was no significant difference between wireworm susceptible and resistant cultivars (F=1.50, p-value=0.371). The cover crop by cultivar interaction was not significant (F=1.01, p-value=0.538). These results support the idea that cover crops do not confer an additional risk for wireworm injury. In 2020, we replicated this study to more rigorously document the relationship between cover crops and sweetpotato cultivars.

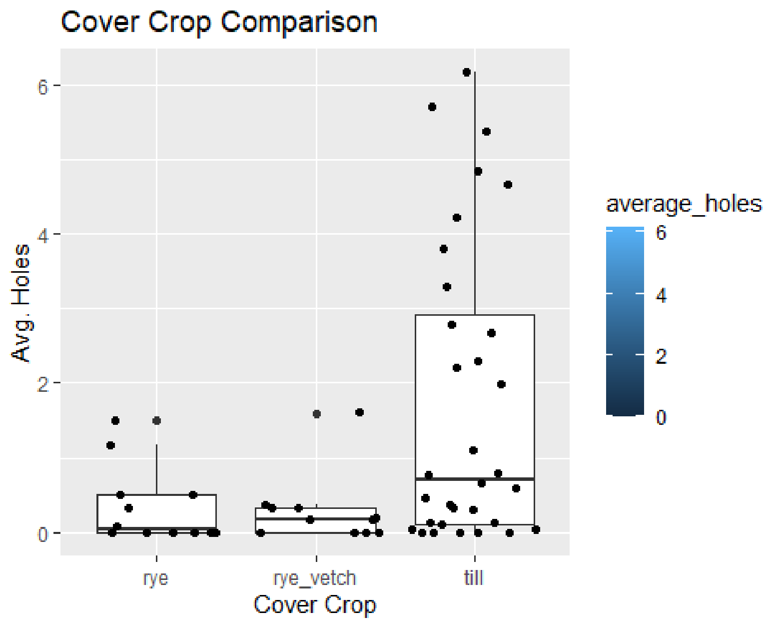

Figure 4: Wireworm damage averaged over both sites

Conclusions and Discussion:

As a preliminary study into the inclusion of cover cropping as a surface residue for weed-suppression in the production of sweetpotatoes, this study supports further research and efforts focusing on optimizing yield. Based on data collected in 2019, there are significant obstacles in management of sweetpotatoes associated with cover crop litter for weed management. Further questions and attention should be given to maximizing cover crop biomass and minimizing disturbance to the surface layer at transplant, as well as addressing questions regarding soil bulk density. This research seemed to support the potential implementation of a temporary weed control period under cover crop litter, early in the growing season, that would require supplemental hand weeding or mechanical cultivation later in the season, especially where weed pressure is particularly concerning. Management challenges due to deer, drought, and planting obscured N rate data. In general, more research and adaptation of strategies will be necessary before North Carolina sees agronomically viable adoption of roller crimped cover crops for weed suppression in organic sweetpotatoes.

For future research, determining early in the spring that the cover crop stand is sufficient, for example rye above 7 t ha^{-1}, will be key for decision making regarding attempting the management approach of roller-crimping for weed control. This decision will be the same one facing producers considering this technique. If the producer has a poor stand and uses roller-crimping for weed control instead of repeated cultivation weed inundation is a likely outcome. This severe weed issue coupled with regular soil sampling has provided unexpected and interesting insight into the dramatic impact actively growing weeds has on soil inorganic N. Nitrogen dynamics and weed interaction is rarely studied together in a purposeful way. This study really revealed that competition by weeds on the crop is not just water and light but these weeds can remove huge amounts of plant available N, creating conditions only more challenges for the crop to overcome. This preliminary data will be used as a compelling interaction for further research in organic agriculture with a focus on N dynamics, a potential source of N in N balance equations and how actively but manageable growing weeds contribute to soil C, soil health and soil water balance.

Outreach:

Results were presented at the NCSU Organic Field Day and a tour of the experiment was completed. SSARE board of directors toured the site during a larger tour of CEFS. Due to challenges in production resulting from transplant, drought, and deer (detailed in the materials and method section) the information produced in this study was not disseminated broadly based on concerns over reliability and reproducibility. It is being used as the foundation for further research being continued in 2020 and 2021 and after additional site years are completed will be disseminated more broadly.

Financial accounting:

Please see attached PDF with the finical report provided by the Office of Finance and Administration at NCSU**.**

Leveraged resources:

Both Dr. Woodley and Dr. Huseth were successful in leveraging the research proposed in this grant as part of a collaborative research grant within NCSU titled *"A Multifaceted Approach to Production and Pest Management in Organic Sweetpotato Systems"* through the USDA NIFA OREI granting program. This grant is $1.9 million dollars and Dr. Huseth and Dr. Woodley each received $150K to continue the research that was supported in this OFRF grant. This early grant by OFRF allowed us to overcome logistical challenges and provided keen insight into the complex dynamics of weed and nutrient management in these systems. The support of OFRF was absolutely critical to the getting this larger grant. Work published from this initial OFRF work combined with the OREI work will acknowledge the role OFRF played in this larger system level project. It is our hope that these multifaceted research projects will provide invaluable information to organic producers in the region, provided more tools to approach these challenges and increase the overall resilience of the organic cropping system.

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Photos and other addenda:

Figure A1. Pre-hilled beds, with rye, January 2019.

Figure A2. Roller crimping rye bed at Kinston.

Figure A3. Roller crimping rye beds at CEFS.

Figure A4. Rye-vetch bed at CEFS.

Figure A5. Roller crimping rye-vetch bed at CEFS.

Figure A6. Transplanting difficulties in rye-vetch beds at Kinston.

Figure A7. Transplant furrows, initially necessary for planting into the rye cover crop at Kinston.

Figure A8. Successful transplant into rye-vetch at CEFS.

Figure A9. Conventional transplant at Kinston.

Figure A10. 30d post-transplant, limited growth in all beds due to dry conditions at CEFS.

Figure A11. 30d post-transplant, early stage of weed establishment at CEFS.

Figure A12. 30d post-transplant, more effective weed-suppression in rye-vetch beds at CEFS.

Figure A13. 60d post-transplant, monocot weed establishment considerable in all cover crop beds, weed-free check and no-weeding beds shown.

Figure A14. 60d post-transplant, monocot weed establishment considerable in all cover crop beds, weed-free check and no-weeding beds shown.

Figure A15. Conventional bed prior to harvest at Kinston in 2019.

Figure A16. Prior to harvest, rye-vetch bed with weed-free check and other beds in background at CEFS.

Rep 1						Rep 2						Rep 3						Rep 4					
Rye		Rye+Vetch		Conv. Till		Rye		Conv. Till		Rye+Vetch		Conv. Till		Rye+Vetch		Rye		Rye		Conv. Till		Rye+Vetch	
Caswell Organic Sweetpotato Plot Map																							
150% N	0% N	100% N	Resistant	75% N	Resistant	0% N	Weedy Check	25% N	Resistant	Resistant	0% N	75% N	Weedy Check	0% N	150% N	25% N	100% N	50% N	75% N	Weedy Check	50% N	0% N	50% N
50% N	75% N	25% N	50% N	25% N	0% N	50% N	100% N	Weedy Check	0% N	25% N	Weedy Check	150% N	50% N	50% N	Weedy Check	150% N	Weedy Check	25% N	0% N	150% N	75% N	150% N	75% N
Resistant	25% N	Weedy Check	0% N	Weedy Check	150% N	75% N	25% N	150% N	100% N	100% N	150% N	0% N	25% N	Resistant	25% N	0% N	Resistant	150% N	Weedy Check	100% N	0% N	Weedy Check	Resistant
Weedy Check	100% N	75% N	150% N	100% N	50% N	150% N	Resistant	50% N	75% N	50% N	75% N	Resistant	100% N	100% N	75% N	50% N	75% N	Resistant	100% N	25% N	Resistant	100% N	25% N
CEFS Organic Sweetpotato Plot Map																							
150% N	Weedy Check	150% N	100% N	0% N	25% N	Weedy Check	25% N	Weedy Check	75% N	150% N	50% N	50% N	150% N	Resistant	0% N	50% N	150% N	75% N	100% N	100% N	25% N	0% N	150% N
50% N	Resistant	0% N	25% N	50% N	75% N	0% N	Resistant	100% N	0% N	Weedy Check	25% N	75% N	25% N	75% N	Weedy Check	Weedy Check	0% N	0% N	50% N	0% N	150% N	50% N	Resistant
75% N	25% N	Weedy Check	Resistant	150% N	100% N	100% N	150% N	50% N	Resistant	0% N	75% N	Weedy Check	100% N	50% N	25% N	75% N	Resistant	150% N	25% N	50% N	Weedy Check	25% N	75% N
100% N	0% N	50% N	75% N	Resistant	Weedy Check	50% N	75% N	25% N	150% N	Resistant	100% N	0% N	Resistant	150% N	100% N	100% N	25% N	Resistant	Weedy Check	75% N	Resistant	100% N	Weedy Check

Figure A17. Plot maps for the 2019 field season.