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Cover Crop Mixes for Soil Health

Year 2 Progress Report

USDA Natural Resources Conservation Service Brooksville Plant Materials Center
Annual Progress Report Prepared by Janet M. Grabowski

Summary of Preliminary Results

- The continued use of cover crops as well as the elimination of tillage in our plots is resulting in incremental increases in soil health measurements. However, our soils are still characteristically infertile due to their parent material and weathering.
- Residue carried over from the previous study year was a sizeable component of the ground cover ratings taken one month after planting the cover crop treatments.
- As we saw in year 1, the daikon radish (*Rhaphanus sativus*) roots pushed up out of the ground due to the compacted plow layer created by a previous history of tillage in the field. Measurements taken with a penetrometer and bulk density determinations using soil cores taken from the plots confirmed the persistence of this plow layer.
- Cereal rye (*Secale cereale*) was the main component in the biomass harvested in year 1, but in year 2, daikon radish shoots and legumes were present in much larger proportions.
- We mechanically terminated and planted the corn commodity crop in one pass and weather conditions after planting prevented us from spraying to adequately control both the cover crops (right) and weeds in the plots before corn emergence.
- Although soil health is improving, yields of corn decreased in the second year compared to the first year of the study.

Introduction

The United States Department of Agriculture, Natural Resources Conservation Service, Brooksville Plant Materials Center (PMC) in Brooksville, Florida is participating in a national study looking at the effect of various cover crop mixes on measurements of soil health. We are cooperating on this study with six other PMCs in California, Maryland, Missouri, North Dakota, Washington, and Oregon. The cover crop mixes we are testing are composed of regionally adapted members of three functional groups of plants: grasses, legumes, and forbs (specifically brassicas, which are members of the mustard family). We planted these mixes at rates of 20, 40, and 60 seeds per square foot. After termination of the cover crops, we planted a regionally adapted commodity crop in all plots. This report presents preliminary results from the first and second years of a planned three-year study at the Brooksville PMC. Results at the conclusion of the study may vary from those presented here as more data is collected.

Methods

The Brooksville PMC is located about 60 miles north of Tampa in the South-Central Florida Ridge. At this location, the two grasses included in the cover crop mixtures were cereal rye and common oat (*Avena sativa*). The two legumes in the mix were crimson clover (*Trifolium incarnatum*) and hairy vetch (*Vicia villosa*). The two brassicas were daikon radish and rapeseed (*Brassica napus*). Table 1 lists the species compositions of the various mixtures. There was also a non-planted control plot. Weeds were not controlled in the control plot during the first year; in the second year, weed growth was controlled using a non-selective herbicide (glyphosate). Field corn (*Zea mays*) was the commodity crop grown both years at this location.

Table 1. Species components in cover crop mixes planted in the soil health plots at the Brooksville PMC. (Note: % of mix is on seed number, not weight basis).

Mix Composition	Grasses	Legumes	Brassicas
2-species	50% cereal rye	50% crimson clover	None
4-species	45% cereal rye	22.5% crimson clover, 22.5% hairy vetch	10% daikon radish
6-species	22.5% cereal rye, 22.5% oats	22.5% crimson clover, 22.5% hairy vetch	5% daikon radish, 5% rapeseed

Four replications of each seed mix treatment were planted in a randomized complete block. Because of existing terraces on the site, the blocks were not adjacent to each other and plots were somewhat smaller (24- by 45-feet) than at the other PMCs. The soils are classified as either fine sands or fine sandy loams. Soil texture analysis showed that they consisted of 90-95.5% sand, 3-6.1% silt, and 0-4.5% clay.

Prior to planting both crops, soil samples were taken, composited by block, and analyzed at the University of Florida, Institute of Food and Agricultural Sciences, Extension Soil Testing Lab to determine fertilizer needs. No phosphorus or potassium were recommended for the cover crops mixes in the fall of year 2; 60 pounds of potassium was recommended for replications 2 and 4 for the corn crop, but this was not applied. Per the study protocol, no nitrogen fertilizer was applied on any plots.

Prior to planting the cover crops, soil compaction in each sub-plot was determined using a penetrometer, also called a soil compaction tester (DICKEY-John Corp., Auburn, IL). Bulk density of the soil was determined at the 0 to 2-inch and 2 to 4-inch depths in each sub-plot (right) using the protocol outlined in the USDA Soil Quality Test Kit Guide (USDA, ARS, NRCS, 2001). Samples (0-2 inch and 2-6 inch) were also collected and sent them to the Kellogg Soil Survey Laboratory (Lincoln, NE) for analysis to determine physical and chemical characteristics of the soil.

Nutrient availability and biological activity (0-6 inch) as measured by the Haney Test (Dr. Richard L. Haney, USDA- Agricultural Research Service, Temple, TX) was determined before planting the cover crops and at two additional times during the crop year (before planting the commodity crop and after harvesting the commodity crop). Additionally, prior to planting both the cover crops and the commodity crop, soil moisture (7-inch depth, HydroSense II, Campbell Scientific, Logan, UT) and temperature (3-inch depth, Durac dial thermometers, Bel-Art-H-B Instruments, Wayne, NJ) was determined for five locations in each sub-plot.

The legume and brassica seed were mixed with a bulking agent (chicken crumbles) and broadcast on the plot by hand on Nov. 12 and 13, 2013. The cereal rye and oat seed was planted using a no-till drill (Truax Co. Inc., Minneapolis, MN) on the following day.

92.53 degreeTemperatures during the cover crop growing period were mild, with few freezing events recorded (Fig. 1). A total of 15.5 inches of rainfall was measured from cover crop planting to termination (Fig. 2). There were more rainfall events during the winter months than is typical for our area; however, the month of December was still dry, with few days when was rainfall was recorded and little accumulation during each event. Approximately 0.3 in of water per week was applied via overhead irrigation to supplement natural rainfall.

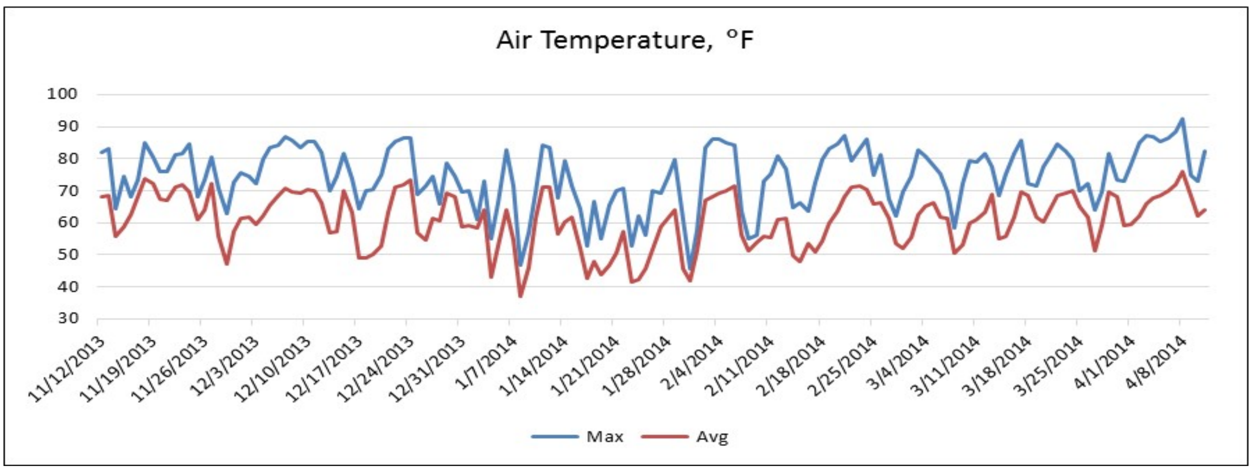

Figure 1. Maximum and average air temperature recorded at the Brooksville PMC from the first day of cover crop planting (Nov. 12, 2013) until termination (Apr. 11, 2014).

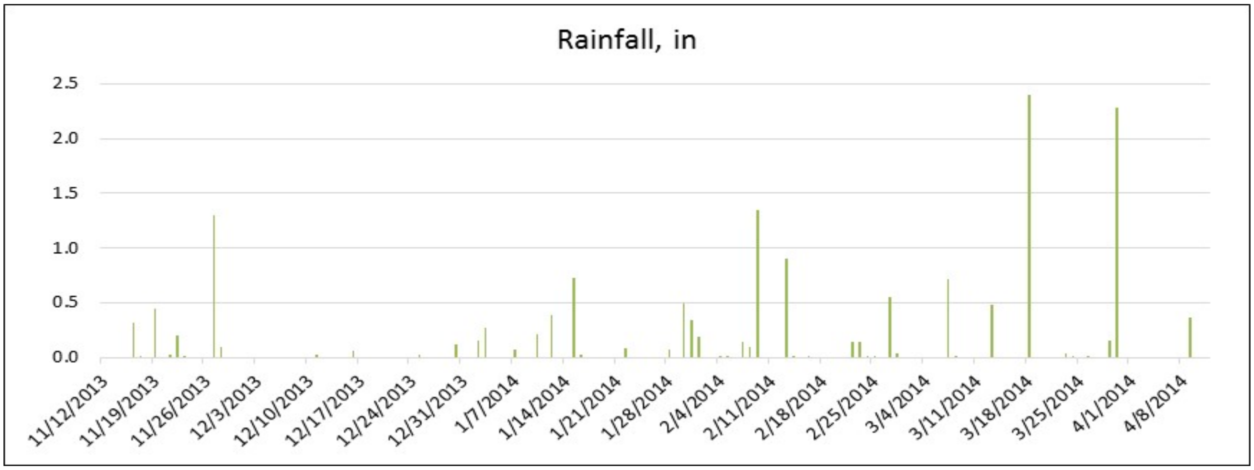

Figure 2. Rainfall recorded at the Brooksville PMC from the first day of cover crop planting (Nov. 11, 2013) until termination (Apr. 11, 2014).

We took photographs of each main treatment plot every two weeks during the cover crop growing period. Ground cover was determined monthly by using a line transect positioned diagonally across the sampling sub-plot and the presence of a plant (cover crop or weed), dead organic matter, or bare soil was determined at each one-foot interval. We also measured average height of the plant canopy every 30 days until termination. Prior to termination of the cover crops, biomass dry matter (DM) production was determined by harvesting plants from a 0.5 m^2 subsample in each plot. We separated the plants into functional groups (grass, legume, brassica, or weed); the samples were dried (60 °C) and weighed so that the percent contribution of each type of plant to the total biomass could be estimated. We also measured DM yield of the radish roots by pulling all roots from the 0.5 m^2 sample area. Tissue nitrogen content (Dairy One, Ithaca, NY) was determined for the combined aboveground biomass of all species and separately for radish roots.

The cover crops were mechanically terminated using a roller crimper (I&J Manufacturing, Gap, PA) mounted in the front of the tractor and the corn commodity crop was planted using a 4-row no-till planter (Kinze Manufacturing, Williamsburg, IA) on Apr. 11, 2014 (left). Even though irrigation was available, the university recommendations for dryland corn population of 20,000 plants per acre was used; the drill was calibrated to deliver this target rate plus 10%, or 22,000 seeds per acre. Winds for several days after planting were above the 10 mph cutoff for preventing spray drift. On Apr. 23, 2014, when the corn was 2-3-inches tall, the Roundup-Ready corn was sprayed with a generic glyphosate formulation (Helosate Plus Advanced) labeled for corn at the rate of 2 qts/100 gal (2 lb ai/ac). This was the only herbicide application made in 2014 for control of weeds in the corn. The corn commodity crop was irrigated twice weekly, applying approximately 0.6-inches of water per week. We hand harvested corn from each sub-plot on Aug. 8 and 11, 2014, and kernels were shelled from the cobs, dried, and weighed to determine yield. Following harvest, the plots were burned down with a Roundup/2,4-D mix in preparation for the next cover crop treatment planting.

Results and Discussion

Soil Quality

Bulk density at the 2-4-inch soil depth was higher than at the 0-2-inch depth in both years of the study and there were no differences between bulk densities for any of the treatments (Table 2). For sandy soil types, bulk density values over 1.8 grams per cubic centimeter can restrict root growth (NRCS, No Date). The bulk densities we measured indicate that restriction of root growth is probably occurring at the 2-4 inch soil depth in many of the treatment plots.

Table 2. Mean bulk density of soil cores taken from two soil depths prior to planting cover crop treatments in the first year (fall 2012) and second year (fall 2013) at the Brooksville PMC.

		Year 1		Year 2	
Mix	**Rate ($seeds/ft^2$)**	**0-2 in Depth (g/cm^3)**	**2-4 in Depth (g/cm^3)**	**0-2 in Depth (g/cm^3)**	**2-4 in Depth (g/cm^3)**
2-species	20	1.52 a[1]	1.78 a	1.53 a	1.83 a
2-species	40	1.44 a	1.59 a	1.54 a	1.73 a
2-species	60	1.42 a	1.66 a	1.53 a	1.69 a
4-species	20	1.52 a	1.69 a	1.56 a	1.72 a
4-species	40	1.46 a	1.75 a	1.55 a	1.81 a
4-species	60	1.40 a	1.65 a	1.55 a	1.64 a
6-species	20	1.48 a	1.70 a	1.50 a	1.89 a
6-species	40	1.48 a	1.77 a	1.62 a	1.81 a
6-species	60	1.37 a	1.60 a	1.55 a	1.86 a
Control		1.40 a	1.74 a	1.45 a	1.78 a

[1]Means in columns with the same letters are not significantly different at P<0.05 by Tukey HSD.

Soil resistance measurements taken with a penetrometer prior to planting the cover crops were much higher at 6-12 inch soil depth than at either the shallower or the deeper depths (Table 3). Research conducted primarily on cotton has shown that almost no root growth can occur at resistance values above 300 pounds per square inch (psi) (Duiker, 2002). The picture (left) shows that the roots of the daikon radish plants in our plots had difficulty penetrating this layer of soil, where readings were near or above 300 psi. The compacted layer resulted from a prior history of tillage in the fields. There were no differences detected in soil resistance values for any of the seed mix treatments or the control. The readings for year 2 of the study were virtually unchanged from those taken the previous year (data not presented), which indicates that the cover crop mixes have not had any measurable effect in ameliorating this plow layer. However, since we have only grown the cover crop mixes in these plots for two years, we cannot infer that they will not ultimately have a beneficial effect in reducing these resistance values and decreasing bulk density.

Table 3. Mean maximum resistance readings using a soil penetrometer at three soil depths prior to planting the cover crop treatments for the second year (fall 2013) at the Brooksville PMC.

		Soil Resistance (psi)		
Mix	**Rate (seeds/ft^2)**	**0-6 in**	**6-12 in**	**12-18 in**
2-species	20	197 a[1]	313 a	292 a
2-species	40	190 a	298 a	261 a
2-species	60	177 a	281 a	240 a
4-species	20	168 a	300 a	288 a
4-species	40	179 a	293 a	269 a
4-species	60	165 a	292 a	261 a
6-species	20	174 a	296 a	254 a
6-species	40	172 a	285 a	261 a
6-species	60	202 a	306 a	292 a
Control		192 a	292 a	271 a

[1]Means in columns with the same letters are not significantly different at P<0.05 by Tukey HSD.

The Soil Health Tool or Haney Test uses data from both biological and chemical soil tests and was developed to quantify levels of organic and inorganic nutrients that will be available for plants growing in the soil. One component of the data report that we received from this test is the soil health calculation. This calculation looks at the relationship between soil microorganisms and the pools of organic carbon and nitrogen in the soil (O'Brien, 2014). It is a simple numerical value landowners can use to assess soil quality and with repeated sampling can track the effect of management on soil quality. Soil health numbers range from 1 to >50 (Haney, ND). Prior to planting in year 1, soil health calculations for the plot area were very close to the minimum reportable number of 1 (Table 4). The soils here are primarily Ultisols formed from deposits of marine origin and are inherently low in nutrients (Watts and Collins, 2008). The soil health calculation increased throughout the first year after the cover crops and corn commodity crop were grown in these plots (Table 4). However, there were no significant differences found between soil health numbers for any of the cover crop treatments or the control. The soil health number continued to increase during the second year of the study, but again, no treatment differences were detected (Table 5). Since there were no measurable effects from the individual cover crop treatments, the increase is most likely due primarily to an elimination of tillage and that a growing plant or plant residue on the soil surface is being maintained throughout the year.

Table 4. Mean Haney Test soil health calculation for soil collected during the first year (2012-2013) of planting cover crop treatments and commodity crop at the Brooksville PMC.

		Soil Health Calculation[1]		
Mix	**Rate (seeds/ft²)**	**Pre-Cover Crop Planting**	**Pre-Corn Planting**	**Post-Corn Harvest**
2-species	20	1.34 a[2]	1.43 a	2.92 a
2-species	40	1.55 a	1.93 a	3.28 a
2-species	60	1.90 a	2.04 a	3.15 a
4-species	20	2.15 a	2.06 a	3.58 a
4-species	40	1.84 a	1.81 a	3.50 a
4-species	60	1.82 a	2.04 a	3.73 a
6-species	20	1.88 a	1.59 a	3.17 a
6-species	40	1.59 a	1.78 a	3.25 a
6-species	60	1.49 a	1.95 a	3.47 a
Control		2.14 a	1.92 a	3.83 a

[1]Measure of soil health derived from respiration and soil fertility levels as determined by methods developed by Dr. Rick Haney, USDA, ARS, Temple, TX. Range of values - 1 (low health) to over 50 (high health).
[2]Means in columns with the same letters are not significantly different at P<0.05 by Tukey HSD.

Table 5. Mean Haney Test soil health calculation for soil collected during the second year (2013-2014) of planting cover crop treatments and commodity crop at the Brooksville PMC.

		Soil Health Calculation[1]		
Mix	**Rate (seeds/ft²)**	**Pre-Cover Crop Planting**	**Pre-Corn Planting**	**Post-Corn Harvest**
2-species	20	3.02 a[2]	3.21 a	5.20 a
2-species	40	3.35 a	3.17 a	5.45 a
2-species	60	3.28 a	4.00 a	5.24 a
4-species	20	3.60 a	5.28 a	5.65 a
4-species	40	3.04 a	4.08 a	5.28 a
4-species	60	2.85 a	3.95 a	5.24 a
6-species	20	3.00 a	3.90 a	5.10 a
6-species	40	2.59 a	3.83 a	5.25 a
6-species	60	3.26 a	4.29 a	5.33 a
Control		3.02 a	3.50 a	5.58 a

[1]Measure of soil health derived from respiration and soil fertility levels as determined by methods developed by Dr. Rick Haney, USDA, ARS, Temple, TX. Range of values - 1 (low health) to over 50 (high health).
[2]Means in columns with the same letters are not significantly different at P<0.05 by Tukey HSD.

Nitrogen can be present in the soil in both organic and inorganic forms. The Haney Test determines the total amount of nitrogen in both forms that is available for plant growth. This value is reported in pounds per acre, which allows the landowner to determine how much of the fertilizer requirement for the commodity crop can be contributed by the soil. In our plots, the initial amount of nitrogen prior to planting in year 1 was low (Table 6). The total nitrogen was reduced after the cover crops were terminated (pre-corn crop). A lack of rainfall after planting in 2012 likely effected nodulation and nitrogen-fixation ability of the legumes in the cover crop mixes. The treatment differences we saw were primarily due to differences in cereal rye populations in the plots that caused differential utilization of the available nitrogen (Grabowski and Williams, 2014). In year 2, available nitrogen prior to planting the cover crop mixes was higher than in the prior year, which may be due to the improving health of the soil in the plots. However, nitrogen levels still decreased after cover crop termination and there were no differences between the cover crop and the control plots. The plots were irrigated, so there was adequate moisture for the legumes in the cover crop mixes to form nodules (Table 7); however, legume DM was still low (see Biomass and Nutrient Content section). In all probability, the non-leguminous cover crops and weeds consumed more nitrogen than the legumes in the mix produced, so little was available for the corn commodity crop.

Table 6. Mean Haney Test total soil nitrogen for soil collected during the first year (2012-2013) and second year (2013-2014) of planting cover crop treatments at the Brooksville PMC.

		Year 1		Year 2	
Mix	**Rate (seeds/ft^2)**	**N Pre-Cover Crop (lb/ac)**	**N Pre-Corn Crop (lb/ac)**	**N Pre-Cover Crop (lb/ac)**	**N Pre-Corn Crop (lb/ac)**
2-species	20	23.7 a[1]	7.7 b	47.6 a	12.8 a
2-species	40	29.2 a	9.3 ab	48.1 a	14.3 a
2-species	60	31.5 a	10.8 ab	48.9 a	18.0 a
4-species	20	33.2 a	11.9 ab	55.6 a	26.0 a
4-species	40	35.3 a	16.3 a	43.6 a	19.7 a
4-species	60	31.1 a	10.8 ab	50.7 a	18.0 a
6-species	20	30.6 a	8.7 ab	49.0 a	18.1 a
6-species	40	28.1 a	7.8 b	53.1 a	16.5 a
6-species	60	31.0 a	9.4 ab	45.8 a	20.6a
Control		33.0 a	10.7 ab	50.5 a	21.9 a

[1]Means in columns with different letters are significantly different at $P<0.05$ by Tukey HSD.

Cover crop growth and residues can cause reductions in both soil moisture and temperature, which can affect germination of the subsequent commodity crop (SARE, 2010). Table 7 shows the soil moisture and temperatures that we recorded prior to planting both crops in the cycle in year 2. The soil moisture levels are reported in volumetric water content (VWC), which is the ratio of the water volume to the soil volume. For sandy soil types such as those at the PMC, the field capacity of the soil is at approximately 6.5% VWC (Campbell Scientific, 2014). Prior to planting the cover crops, the plots had been fallow after the corn was harvested in August; so without an actively transpiring crop present, the moisture readings were all above field capacity. After termination of the cover crops, soil moisture varied primarily due to the control plots, which were fallow, having had the highest VWCs. Differences in soil moisture between the cover crop treatment plots were minimal. Soil temperatures followed a similar pattern. There were no differences between any of the treatment plots before the cover crops were planted. However, after termination, the temperatures in the control plots were higher than in the plots containing cover crops. Without plant cover, more sunlight reached the soil surface and increased evaporation. Differences between cover crop treatments were again minimal and may have been due to differences in plant growth or residue amounts in the plots. In Florida, low soil temperatures following winter cover crops is typically not a factor that will affect germination or establishment of the subsequent commodity crop.

Table 7. Mean soil moisture (7-in depth) and soil temperatures (3-in depth) recorded at the Brooksville PMC Nov. 14, 2013 when the cover crops were planted and after termination of the cover crops on Apr. 11, 2014.

		Before Cover Crop Planting		At Cover Crop Termination	
Mix	**Rate (seeds/ft²)**	**VWC[1] %**	**Temperature °C**	**VWC %**	**Temperature °C**
2-species	20	10.7 a[2]	23.1 a	6.5 b	26.5 ab
2-species	40	10.8 a	23.4 a	7.7 ab	25.5 abc
2-species	60	10.7 a	23.4 a	8.7 ab	24.0 c
4-species	20	10.4 a	23.3 a	7.4 ab	24.2 c
4-species	40	12.2 a	23.6 a	7.8 ab	24.5 bc
4-species	60	11.4 a	23.3 a	6.3 b	23.6 c
6-species	20	10.5 a	23.3 a	7.7 ab	25.5 abc
6-species	40	9.5 a	23.4 a	6.7 ab	24.8 bc
6-species	60	10.9 a	23.2 a	7.2 ab	24.0 c
Control		12.3 a	23.3 a	9.8 a	27.2 a

[1]VWC = Volumetric Water Content. Field capacity for soil types at the study site is about 6.5% VWC.
[2]Means in columns with the same letters are not significantly different at $P<0.05$ by Tukey HSD.

Soil Surface Cover and Plant Canopy

The NRCS Conservation Practice Standard Cover Crop, Code 340, specifies that coverage of canopy and residue should be 90% or greater to control wind and water erosion (NRCS, 2014). Canopy ratings for the Brooksville PMC planting in year 2 showed that all plots, including the control, reached 90% or greater ground coverage by either plant growth or residue by about 2 months after planting and several treatments exceeded this threshold in the first month (Fig. 3). For the first rating date, a high percentage of the ground cover for all treatments was dead organic material rather than a live plant and there were no differences between the various treatments in residue recorded (Table 8). The effect of residue declined as the canopy became more dense (data not presented). With the contribution of residue carried over from the previous year's planting, all seeding rates and mixes provided sufficient ground cover to control erosion by NRCS standards.

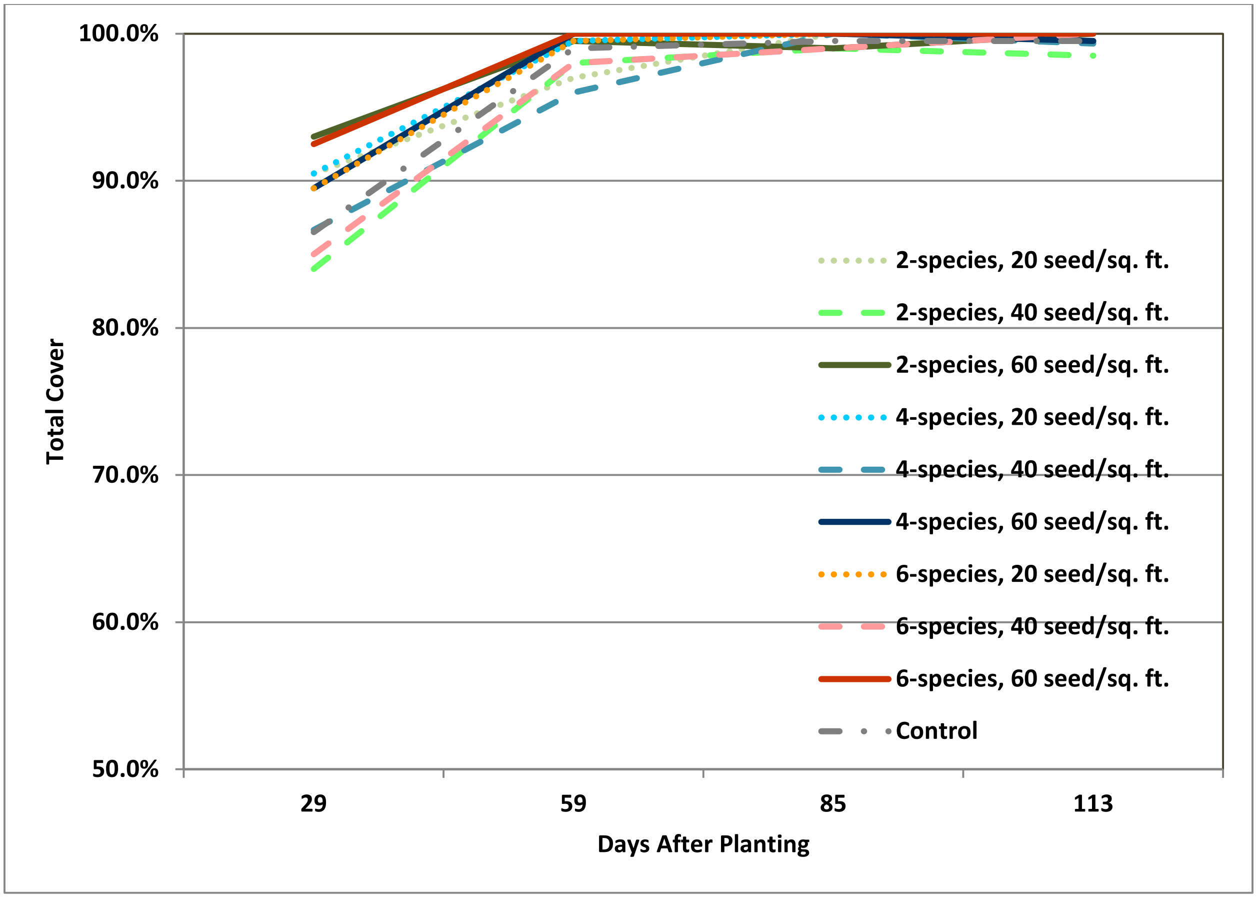

Figure 3. Percent total ground cover (plant or residue) in the treatment plots at the Brooksville PMC rated monthly. Cover crop planting began on Nov. 12, 2013 and the cover crops were terminated on Apr. 11, 2014.

Plant growth in the control plots was not controlled until late in the evaluation period, so there was a significant amount of weed growth in addition to residue in these plots at all rating dates. There was also a large contribution of native and non-native cool-season weeds to the plant canopy in all cover crop treatment plots. The weeds found most frequently were Florida pusley or Mexican clover (*Richardia* spp.), cudweed [*Gamochaeta* spp. (syn. *Gnaphalium* spp.)], and Canada toadflax [*Nuttallanthus canadensis* (syn. *Linaria canadensis*)]. In the fourth replication and to a lesser extent in the third replication, black medic (*Medicago lupulina*), a non-native legume, was commonly encountered when the line transects were taken, but this species was not recorded as being present in the first two replications.

Table 8. Mean occurrence of dead organic matter (residue) in line transects taken at the Brooksville PMC on Dec. 11, 2013 (29 days after planting)

Mix	Rate (seeds/ft^2)	Residue Recorded % of Points
2-species	20	47.5 a[1]
2-species	40	46.0 a
2-species	60	42.0 a
4-species	20	25.0 a
4-species	40	32.5 a
4-species	60	27.5 a
6-species	20	21.0 a
6-species	40	31.5 a
6-species	60	49.0 a
Control		45.0 a

[1]Means with the same letters are not significantly different at P<0.05 by Tukey HSD.

There were significant differences between treatments in average height of the plant canopy in both study years (Table 9). The plants present in the control plots were cool-season weeds, primarily those listed in the paragraph above. Many of these species form rosettes or have trailing growth habits and are therefore a great deal shorter than cereal rye, which were the tallest plants in the cover crop mixes. So, the low height numbers for these plots were expected. With a few exceptions, the cover crops were generally shorter in the second year of the study than in the first. This was because the cereal rye plants were not growing as vigorously as in the previous year (above). In the first year, a lack of precipitation after planting likely affected nodulation and growth of the legumes was poor (Grabowski and Williams, 2014). However, in this study year, because the plots were irrigated, water was not limiting. Daikon radish also grew vigorously and formed large plants (photo, page 5). Perhaps competition from these other species affected growth of the cereal rye in the cover crop mixes. Available nitrogen in the soil when the cover crops were planted (Table 6) is below university recommendations of 80 pounds per acre for cool-season annual grasses (Newman, et al., 2008) and a lack of fertility may have affected growth of the cereal rye plants.

Table 9. Mean height of plant canopy measured for both study years at the Brooksville PMC during the final monthly evaluation prior to cover crop termination.

Mix	Rate (seeds/ft²)	Average Canopy Height (cm)[1]	
		Year 1	Year 2
2-species	20	139.0 a[2]	89.0 abc
2-species	40	143.0 a	121.9 ab
2-species	60	142.0 a	133.8 a
4-species	20	108.5 b	73.1 c
4-species	40	48.0 de	77.1 bc
4-species	60	88.5 bc	80.5 bc
6-species	20	82.5 bc	67.7 c
6-species	40	63.1 cd	66.2 cd
6-species	60	82.0 bc	62.3 cd
Control		25.6 e	21.0 d

[1]Year 1 measurements were taken on Mar. 25, 2013 (118 days after planting) and Year 2 measurements were taken on Mar. 5, 2014 (113 days after planting).
[2]Means in columns with the different letters are significantly different at P<0.05 by Tukey HSD.

Biomass Production and Nutrient Content

The grasses were the largest component of biomass harvested in the 2-species mix plots in year 2 (Table 10, but in the treatments were brassicas were planted, brassicas dominated the cereal rye. Better soil moisture due to irrigation may account for the improved emergence and growth of the brassicas, primarily the daikon radish. As in the previous year, rapeseed was only a minor component of brassicas harvested in the 6-species treatment plots (data not presented). Percentage of legumes in all plots increased in the second year compared to the first year of planting (0-9%, Grabowski and Williams, 2014). Irrigation applied after planting probably increased nodulation and growth of the legumes compared to the first year when there was no irrigation. However, there was still no treatment effect on the percentage of legumes in the biomass in year 2 (Table 10). There were no differences in the percentage of weeds present in the samples harvested from any of the plots.

Aboveground plant biomass was lower in the second year of the study compared to the first year for most of the cover crop treatments, and no differences due cover crop mixture was found (Table 11). The reduced growth of the cereal rye plants is most likely the primary cause of this decrease. Biomass production is partially dependent on the fertility under which the plants were grown (Newman et al., 2007). Lower than recommended N availability (80 lb/ac; Newman et al., 2008) and competition for N from the daikon radish is probably responsible for the lower cereal rye yields. In year 1, treatment differences were not due to differences between cover crop treatments, but because the control having lower DM than some of the cover crop treatments. Since the control plots were chemically fallowed in second year, they were not included in the statistical analysis and lack of DM differences between cover crop mixtures was therefore consistent across the two years.

Table 10. Percentage by weight of each plant type found in the plant material harvested Mar. 31-Apr. 3, 2014 from 0.5 m^2 samples in cover crop seed mix plots at the Brooksville PMC.

Mix	Rate (seeds/ft^2)	Grasses	Legumes	Brassicas	Weeds
2-species	20	60% abc[1]	25% a	0% c	15% a
2-species	40	81% ab	13% a	0% c	6% a
2-species	60	84% a	12% a	0% c	4% a
4-species	20	13% d	39% a	46%ab	2% a
4-species	40	13% d	28% a	56% a	3% a
4-species	60	20% cd	27% a	48% a	5% a
6-species	20	23% cd	29% a	43% ab	5% a
6-species	40	35% bcd	45% a	18% bc	2% a
6-species	60	29% cd	34% a	35% ab	2% a
Control[2]		----	----	----	----

[1]Means in columns with different letters are significantly different at P<0.05 by Tukey HSD.
[2]Control plots were treated with non-selective herbicide in Year 2 to control all plant growth.

Table 11. Mean aboveground biomass yield and nitrogen content within the plant tissue harvested prior to cover crop termination for both study years at the Brooksville PMC.

		Year 1[1]		Year 2[1]	
Mix	Rate (seeds/ft^2)	Dry Matter Yield (lb/ac)	N in Dry Matter	Dry Matter Yield (lb/ac)	N in Dry Matter
2-species	20	5539 ab[2]	1.0% b	3680 a	1.3% b
2-species	40	6455 a	1.0% b	6022 a	1.2% b
2-species	60	7276 a	1.3% b	5992a	1.2% b
4-species	20	5630 ab	1.3% b	5080 a	2.4% a
4-species	40	4664 ab	1.5% ab	5590 a	2.3% a
4-species	60	6321 a	1.2% b	3180 a	2.3% a
6-species	20	5790 ab	1.4% ab	4877 a	2.5% a
6-species	40	4890 ab	1.4% ab	4361 a	2.4% a
6-species	60	5821 ab	1.2% b	4471a	2.3% a
Control		2428 b	2.1% a	----[3]	---[3]

[1]Harvests dates: Year 1 Mar. 26-27, 2013 (118-119 days after planting); Year 2 Mar. 31-Apr. 3, 2014 (139-142 days after planting).
[2]Means in columns with different letters are significantly different at P<0.05 by Tukey HSD.
[3]Control plots were treated with non-selective herbicide in Year 2 to control all plant growth.

Simulated RUSLE2 runs for corn for grain production planted no-till into a rye cover crop at this location give a cover crop biomass requirement of 4000 pound per acre at cover crop t7ermination. Only one of the cover crop treatments fell below this target production value. However, most Florida producers that are using cereal rye cover crops to control erosion and prevent weed growth aim for biomass yields of 2 to 5 tons per acre (4000 to 10,000 lb/ac) to control weeds and will fertilize their cover crops accordingly to obtain this amount of production (Love et al., 2012).

Nitrogen content in the plant tissue was higher in the 4- and 6-species plots than in the 2-species plots (Table 11). This is due to the higher percentage of grasses in the biomass harvested from the 2-species plots (Table 10) which were planted with only cereal rye and crimson clover. Small grains at maturity have less than 1 percent nitrogen (Treadwell et al., 2008) and the cereal rye plants in these plots were mature when harvested. The nitrogen content of the biomass in the 4- and 6-species mixes increased compared to that measured during the previous year (Table 11) partly due to an increased presence of legumes, but mainly due to the daikon radish in these plots (Table 10). Daikon radish is an efficient scavenger of nitrogen in the soil (SARE, 2010; Sundermeier, 2008); the radish plants were less mature at termination than the cereal rye.

Yield of diakon radish roots was much higher for all treatments in year 2 of the study than in the first year (Table 12). Due to an earlier planting date, there was about a 3-week longer growing period, which allowed for more root growth. However, the radish plants may also be responding to improving soil health (Tables 4 and 5) and slightly higher nitrogen levels present in the soil prior to planting in the second year (Table 6). Nitrogen content in the root tissue was lower than in the previous year, most likely due to the age of the roots. There were differences in nitrogen content between the treatments, but no pattern due to seed mix or seeding rate was apparent (Table 12). Our nitrogen levels were well below the below the 2.5% nitrogen content reported by Sundermeier (2008) at the Ohio State University for diakon radish root tissue. Due to the maturity of the plants we harvested, much of the nitrogen assimilated by the roots would have been mobilized to the fruits to promote seed formation. However, in Ohio, as well as at many of the other PMC sites in this study, fall-sown daikon radish plants will be winterkilled when temperatures drop below 20-25 degrees F (Sundermeier, 2008), when the plants are most likely still in a vegetative growth stage. Allowing the radish plants to grow to maturity would not be prudent for most producers, because of the potential to become a weed in the commodity crop (Newman et al., 2007). Radish seedlings are volunteering in our plots and in addition to competing with the corn plants, could be affecting the seeding rate treatments by increasing the number of radish seeds in the plots.

Commodity Crop Production

Corn yields in both study years were very low (Table 13). No treatment differences occurred in either year. In year 1, there were five plots where no corn was harvested and in year 2, this number increased to 11, or more than 1/4th of the plots with no ears produced in the sample area. University of Florida extension publications recommend nitrogen applications of 150 pounds per acre for dryland corn production to more than 200 pounds for corn under irrigation (Wright et al., 2003). Our Haney Test results (Table 6) show that the available nitrogen in our plots at corn planting was only a small fraction of this recommended rate in both years. Further exacerbating low N availability is the fact that when cover crops, such as the mature daikon radish and cereal rye plants, are terminated late in the spring, nitrogen can be immobilized no matter what cover crop is grown and become unavailable for the commodity crop (Blanco-Canqui et al., 2015; Newman et al., 2007). This would explain the lower grain

Table 12. Mean yield of daikon radish roots harvested prior to cover crop termination for both years at the Brooksville PMC and nitrogen content within the root tissue.

Mix	Rate (seeds/ft^2)	Year 1[1]		Year 2[1]	
		Radish Root Yield (lb/ac)	N in Radish Root	Radish Root Yield (lb/ac)	N in Radish Root
4-species	20	725.5 a[2]	1.08% ab[1]	2404.3 a	0.68% ab
4-species	40	911.8 a	0.90% ab	2526.0 a	0.53% b
4-species	60	390.0 a	1.00% ab	1549.8 ab	0.68% ab
6-species	20	452.3 a	1.18% a	1041.0 ab	0.63% ab
6-species	40	419.8 a	0.93% ab	605.3 b	0.63% ab
6-species	60	340.0 a	0.75% b	1525.5 ab	0.75% a

[1]Harvests dates: Year 1 Mar. 26-27, 2013 (118-119 days after planting); Year 2 Mar. 31-Apr. 3, 2014 (139-142 days after planting).
[2]Means with different letters are significantly different at P<0.05 by Tukey HSD.

Table 13. Yield of field corn at 15.5% moisture for plots seeded to cover crops the previous fall at the Brooksville PMC and the control plots.

Mix	Rate (seeds/ft^2)	Corn Yield (bu/ac)	
		Year 1[1]	Year 2[1]
2-species	20	3.4 a[2]	1.2 a
2-species	40	8.5 a	12.2 a
2-species	60	18.2 a	16.4 a
4-species	20	58.5 a	22.2 a
4-species	40	45.1 a	11.0 a
4-species	60	39.3 a	23.8 a
6-species	20	30.3 a	2.9 a
6-species	40	20.4 a	9.5 a
6-species	60	31.6 a	17.6 a
Control		21.2 a	22.3 a

[1]Harvests dates: Year 1 Aug. 20-23, 2013 (117-120 days after corn planting); Year 2 Aug. 8 and 11, 2014 (119 and 122 days after corn planting)
.[2]Means in columns with the same letters are not significantly different at P<0.05 by Tukey HSD.

yield we saw even though the soil health in our plots improved from year 1 to year 2 (Table 4 and 5). Other nutrient imbalances or other factors that we are not measuring could have affected growth of the corn plants. For example, both crimson clover and hairy vetch are known nematode host plants (Gill and McSorley, 2011; Newman et al., 2007), particularly root knot nematode, which could be affecting corn growth (Wang et al., 2004). However, we did not check the roots for the presence of galls or have the soil tested for the presence of other nematode species.

Weed Suppression

Cover crop residues on the soil surface can help to suppress emergence of weeds in the subsequent commodity crop. Recommended biomass production of 4 to 6 tons per acre dry matter are required to produce a deep enough layer of residues to cause a reduction in weed emergence (Treadwell et al, 2008). The photograph to the right shows a large population of weeds, mainly nutsedge (*Cyperus* spp.), in one of our study plots in year 2. Biomass production ranged from about 1.5 to 3 tons per acre (Table 11), which was not sufficient to control weeds. We terminated and planted the corn in one pass in year 2 and were not able to apply herbicides to burn down the existing vegetation because of windy conditions. The corn seeds germinated quickly due to high soil temperatures, and at that point, we could only apply the lower rate of glyphosate labeled for application over the top of emerged corn (see Methods section). Additionally, since the planting population was low and the growth of our corn plants was poor, we did not have good canopy closure. Poor canopy closure creates a season-long weed issue no matter what cover crop termination and spraying program used.

In addition to nutsedge and several other ruderal species that were present, we also had varying populations of the planted cover crops as weeds in the corn crop in year 2, as shown in the photo on Page 1. Rather than killing the plants, the roller crimper served to release cover crops that were in younger stages of maturity, such as hairy vetch, from competition. We also had seedlings of daikon radish that germinated following the mechanical treatment. Although it does not seem logical, many of these cool-season plants held on throughout the summer. They generally did not provide as much competition with the corn as some of the other weeds; however, they did add to the mass of weeds competing with the corn plants.

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