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An Evaluation of Cover Crop Species and Mixtures for Tennessee Organic Production Systems

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Cover crops provide a source of fertility and weed control, and there is increased interest in cover crops for use in organic crop production. A replicated field study was established to evaluate the performance of thirteen cover crop systems. Treatments consisted of grass and legume bicultures. Grass cover crops included three cultivars of cereal rye (Secale *cereale* L.), triticale (× *Triticosecale*), black oat (*Avena strigosa* Schreb), and spelt (*Triticum spelta* L.). Legumes included crimson clover (*Trifolium incarnatum*), common vetch (*Vica sativa* L.), woolypod vetch (*Vica villosa var. glabrescens* W.D.J. Koch), two cultivars of hairy vetch (*Vica villosa* Roth) and white lupin (*Lupinus albus* L.). Aboveground biomass and weed biomass was analyzed for each treatment. Aboveground biomass ranged from 177 kg ha^{-1} to 13341 kg ha^{-1} in year one and 280 kg ha^{-1} to 13093 kg ha^{-1} in year two. Bicultures of 'Trical 815' triticale and 'Dixie' crimson clover produced the highest total biomass (13341 kg ha^{-1} in year one and 13093 kg ha^{-1} in year two). In the first trial year all cover crop mixtures significantly reduced weed biomass compared to the no cover crop control. Results suggest that these cover crop mixtures vary in their usefulness in Tennessee organic crop production systems.

Organic agriculture is a growing production system driven by consumer demand for food produced sustainably without the use of synthetic products. In accordance with the USDA- National Organic Program (NOP) standards, organic producers must implement a crop rotation plan that includes cover crops in order to maintain soil organic matter, provide pest management and erosion control, and manage plant nutrients (USDA-AMS, 2015). The expansion of organic production has led to an increased interest in cover cropping systems. Additional research on winter biculture cover crops (Ranells and Wagger 1997b) and region specific organic cover cropping systems (Price and Norsworthy 2013) for growers in the southeastern US is needed.

Cover crops provide numerous benefits while fulfilling several guidelines set by the USDA-NOP. Cover crops improve soil fertility and physical properties (Hubbard et al. 2013, Sainju and Singh 1997), reduce erosion (Baets et al. 2011), reduce NO_3 leaching and runoff (Meisinger et al. 1991), increase soil N for subsequent crops (Ranells and Wagger 1997a), and suppress weeds (Price and Norsworthy 2013, Clark and Panciera 2002).

Cover crops under conservation tillage improve soil health by increasing soil N, C, saturated hydraulic conductivity, organic matter, and volumetric soil moisture content while improving soil structure by decreasing bulk density (Hubbard et al. 2013). Winter cover crops reduce NO_3 leaching through evapotranspiration of soil water, reduced runoff, and increased immobilization. It is estimated that winter cover crops have the greatest impact on NO_3 leaching in the humid Southeast (Meisinger et al. 1991).

Organic crop production systems must maintain soil fertility and crop nutrients without the use of synthetic fertilizers (USDA-AMS, 2015). Cover crop mulches provide N for succeeding crops and can increase crop yield (Abdul-Baki et al. 1996). Grass/legume bicultures utilize the benefits of both N-fixation of legumes and soil inorganic N scavenging ability of grasses. (Ranells and Wagger 1997b). Legume and grass bicultures accumulate more N than grass monocultures and more aboveground biomass than legume monocultures (Ranells and Wagger 1997a). A rye-vetch cover crop mixture may be superior to monoculture vetch or rye

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because intermediate net N-mineralization rates result in decreased N leaching and denitrification losses, leading to greater N availability for subsequent crops (Rosecrance et al. 2000).

Weed control in organic cropping systems can be difficult because only physical or mechanical methods and nonsynhetic herbicides can be used (USDA-AMS, 2015). Crop rotations including cover crops are a common cultural method for organic weed control. Winter cover crops affect weeds by reducing winter weed establishment and weed pressure (Webber et al. 2012, p.188). Clark and Panciera (2002) reported that a rolled winter cover crop of rye reduces or eliminates the need for herbicides in no-till crop production systems. Rye, vetch, and rye-vetch winter cover crops can suppress winter annual weed biomass 71 to 98% (Hayden et al. 2012). Rye was the most effective for weed suppression, but rye-vetch mixtures can be as effective while providing a source of nitrogen for successional crops. Cover crops incorporated into the soil as green manure suppress weed density and aboveground biomass during the successional crop's growing season (Campiglia et al. 2010). Several varieties of cover crops also suppress weeds through the presence allelochemicals in their residues (Bhowmik and Inderjit 2003).

The purpose of this study was to evaluate winter cover crop species mixtures and variety performance for use in Tennessee organic production systems. Cover crop performance was evaluated based on aboveground biomass production, weed suppression, and maturity date. The cover crop mixtures were studied to determine the benefits of each mixture and provide information to organic growers in Tennessee.

Materials and Methods

On 11 October 2013 and 24 October 2014 cover crops were established at the University of Tennessee's Organic Crops Unit in Knoxville TN. The 2013 and 2014 plots were established at different locations on the Organic Crops Unit. The total experimental area was two 21.95-m wide × 53.64-m long blocks divided into a randomized complete block design with four replicates. Each plot was 3.66-m wide × 6.71-m long, containing one treatment (Table 1). The plots were flail mowed once and disked on two separate occasions to incorporate the summer cover crop and terminate perennials. The legume seeds were inoculated with appropriate inoculants.

Cover crop seed was planted using an ALMACO precision seeder at recommended seeding rates (Table 2). Black

Table 1. Cover crop treatments and assigned numbers as applied to the randomized complete block design.

Treatment No.	Abbreviation	Treatment
1	Control	Control (no cover crop)
2	Rye(WA)-CC	'Wrens Abruzzi' Cereal Rye/'Dixie' Crimson Clover
3	Rye(E)-CC	'Elbon' Cereal Rye/'Dixie' Crimson Clover
4	Rye(S)-CC	'Spooner' Cereal Rye/'Dixie' Crimson Clover
5	Triticale-CC	'Trical 815' Triticale/'Dixie' Crimson Clover
6	BOatF-CC	'Soil Saver' Black Oat (Fall seeded)/'Dixie' Crimson Clover
7	BOatW-CC	'Soil Saver' Black Oat (Winter seeded Feb.)/'Dixie' Crimson Clover
8	Spelt-CC	'Sungold' Spelt/'Dixie' Crimson Clover
9	HVetch(PP)-O	'Purple Prosperity' Hairy Vetch/'Jerry' Common Oat
10	HVetch(PB)-O	'Purple Bounty' Hairy Vetch/'Jerry' Common Oat
11	CVetch-O	Common Vetch/'Jerry' Common Oat
12	WVetch-O	'Lana' Woolypod Vetch/'Jerry' Common Oat
13	WLupin-O	'AU Alpha' White Lupin/'Jerry' Common Oat

Table 2. Species and seeding rates of winter cover crops evaluated.

Species	Cultivar	Latin Name	Seeding Rate
		Non-Legumes	
Cereal Rye	Wrens Abruzzi	Secale *cereale* L.	65 seeds/m^2
Cereal Rye	Elbon	*Secale cereale* L.	65 seeds/m^2
Cereal Rye	Spooner	*Secale cereale* L.	65 seeds/m^2
Black Oat (Fall Seeded)	Soil Saver	*Avena strigose* Schreb	65 seeds/m^2
Black Oat (Winter Seeded)	Soil Saver	*Avena strigosa* Schreb	129 seeds/m^2
Common Oat	Jerry	*Avena sativa* L.	65 seeds/m^2
Spelt	Sungold	*Triticum spelta* L.	65 seeds/m^2
Triticale	Trical 815	× *Triticosecale*	65 seeds/m^2
		Legumes	
Crimson Clover	Dixie	*Trifolium incarnatum*	46 seeds/m^2
Common Vetch		*Vica sativa* L.	107 seeds/m^2
Hairy Vetch	Purple Bounty	*Vica villosa* Roth	107 seeds/m^2
Hairy Vetch	Purple Prosperity	*Vica villosa* Roth	107 seeds/m^2
Woolypod Vetch	Lana	*Vica villosa var. glabrescens* W.D.J. Koch	107 seeds/m^2
White Lupin	AU Alpha	*Lupinus albus* L.	43 seeds/m^2

oat was seeded in winter on 10 Feb. 2014 and 12 Feb. 2014 using a drill.

Flowering times of each cover crop were visually determined using the Feekes scale (1-11.4) for grasses and a 0 to 5 (no bud to fully flowering) scale for legumes. On 13 March 2014 and 14 May 2015 weed presence was determined by randomly sampling a 0.25-m^2 area of each plot. The species and number of weeds was identified and area percentage of grass, legume, and total cover determined by visual estimate.

On 13, 14 May 2014 and 27 May 2015 aboveground biomass samples were

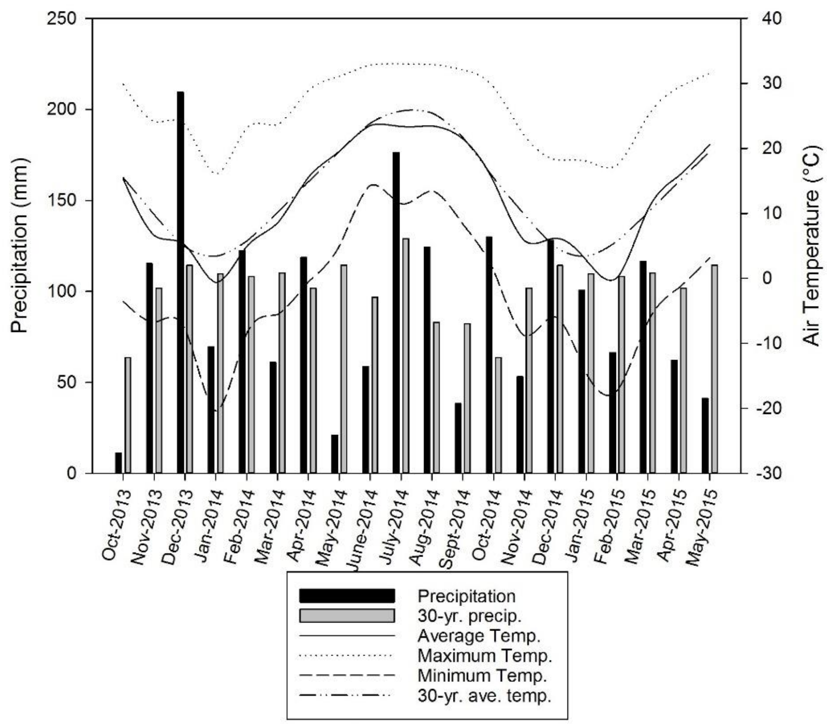

Fig. 1. Mean monthly precipitation, mean monthly air temperature, maximum monthly air temperature, and minimum monthly air temperature at the University of Tennessee Organic Crops Unit, Knoxville, October 2013 to May 2015, and 30-yr mean temperature and precipitation for Knoxville, TN.

randomly sampled from a 0.25-m^2 area in each block at the soil surface using electric grass shears. Samples were separated into cover crop species and non-leguminous weeds, dried at 60°C for minimum of 48 hours, and weighed to determine dry weight aboveground biomass.

Statistical Analysis

Mixed model statistical analysis (PROC GLIMMIX) was performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC), where the block and the interaction of block and cover crop were considered random effects. Differences between the means were considered significant at $P \leq 0.05$.

Results and Discussion

Most grass cover crop varieties reached the swollen boot development stage by early April (Fig. 2.). The 2015 'Wrens Abruzzi' rye treatment reached flowering stage earlier than other grasses, while 'Trical 815' triticale was the least developed over the sampling dates. 2014, 2015 'AU Alpha' white lupin and 2014 'Dixie' crimson clover were the earliest fully flowering legumes (Fig. 3.). 2014 common vetch and 'Purple Bounty' hairy vetch were the least developed legumes over the sampling period.

Mechanical termination of cover crops such as mowing, rolling, roll-chopping, and undercutting are common herbicide-free termination methods. Timing of the crop termination relative to the maturity of the crop is crucial for weed control and avoiding re-growth (Clark and Panciera 2002). There is a trend for increased kill at later crop growth stages (Creamer and Dabney 2002). Wagger (1989) reported that a two week delay in desiccation resulted in biomass increases of

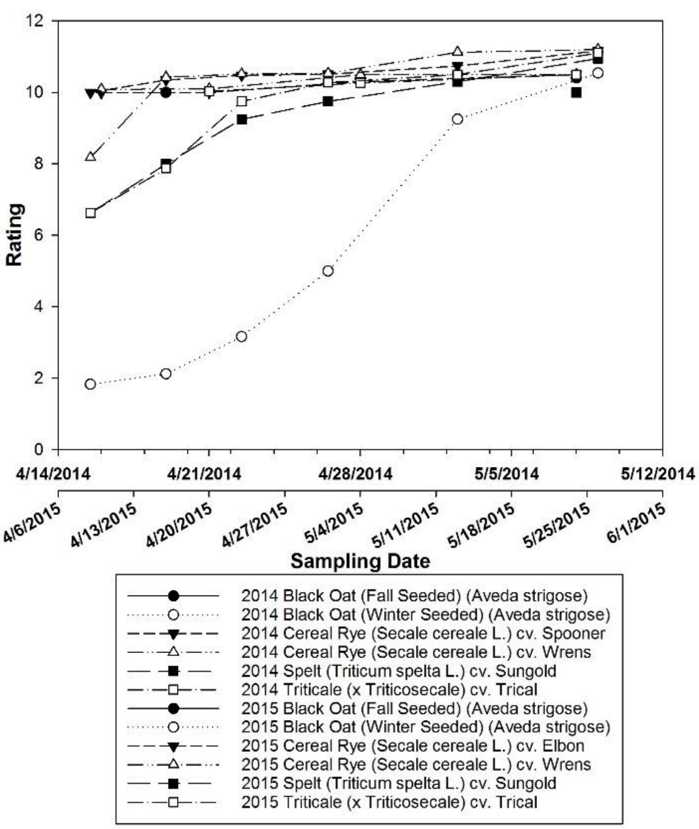

Fig. 2. Feekes' scale growth stage rating for grass cover crop varieties.

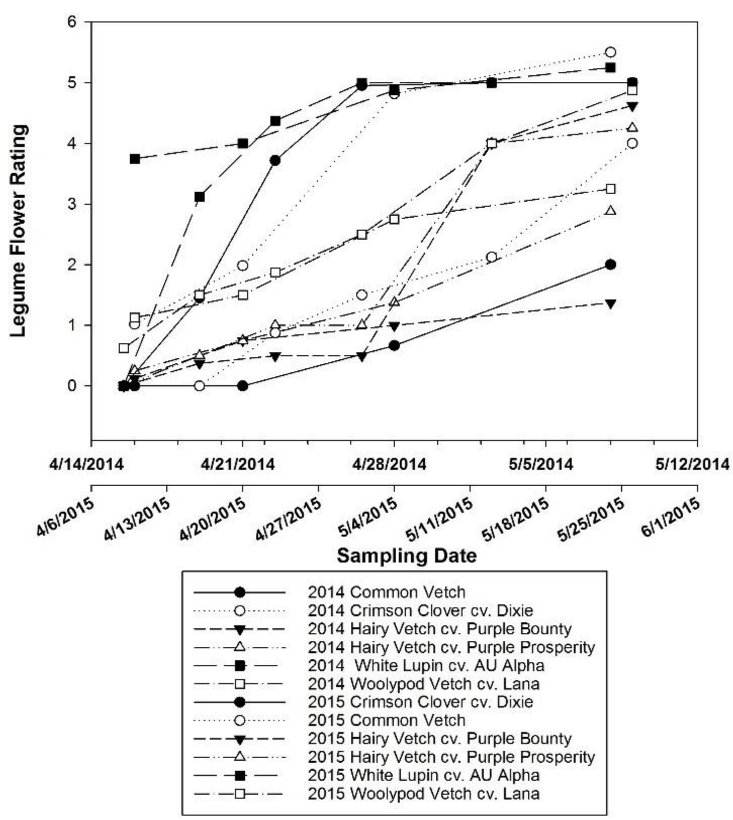

Fig. 3. Flower development rating (1-5) for legume cover crop varieties.

39, 41, and 61% for rye, crimson clover, and hairy vetch. Cover crops desiccated early decomposed faster (Wagger 1989). Clark et al. (1994) reported a nitrogen content that was 1.6 to 2 times greater in a late killed cover crop than an early killed cover crop using hairy-vetch and cereal rye cover crop mixtures.

similar in grass/legume bicultures. Nelson et al. reported that rye, barley, and wheat are the most promising cover crops with respect to cover density, weed competitiveness, and degree of kill by glyphospate. Silva reported that winter triticale produced significantly more biomass than rye and barley (Silva 2014).

Table 3. Mixed model analysis of variance for response variables of aboveground biomass as affected by treatment (cover crop), time (year of sampling), and the interaction.

Response Variable	Treatment	Time	Treatment × Time
		P value	
Grass Biomass	<0.01	0.5038	0.1563
Legume Biomass	<0.01	<0.01	<0.01
Grass + Legume Biomass	<0.01	0.0165	<0.01
Weed Biomass	<0.01	0.3310	<0.01

Average aboveground grass biomass was significantly affected by treatment ($P < 0.01$), but not by year or the interaction of treatment and year ($P > 0.05$; Table 3). The greatest average aboveground grass biomass was observed from the 'Trical 815' triticale and 'Dixie' crimson clover cover crop mixture (7105 kg ha^{-1}), and the 'Wrens Abruzzi' cereal rye and 'Dixie' crimson clover cover crop mixture (7027 kg ha^{-1}). These mixtures were statistically similar for aboveground grass biomass yield (Fig. 4). The lowest grass biomass producing cover crop mixtures were those containing oats ('Jerry' common oat, which primarily served as a nurse crop for legume establishment, or 'Soil Saver' black oat). Oat biomass ranged from 0 kg ha^{-1} ('Purple Prosperity' hairy vetch and 'Jerry' common oat, 'Purple Bounty' hairy vetch and 'Jerry' common oat, 'AU Alpha' white lupin and 'Jerry' common oat mixtures) to 357 kg ha^{-1} ('Soil Saver' black oat (winter seed) and 'Dixie' crimson clover). All treatments containing oat were statistically similar (Fig. 4). Poor winter survivability is the likely cause of low oat biomass (Ranells and Wagger 1997a). Ranells and Wagger 1997a found that biomass production of oat and rye were

Legume aboveground biomass was significantly affected by treatment ($P < 0.01$), year ($P < 0.01$), and the interaction ($P < 0.01$; Table 3). The highest annual yields were observed from the 'Purple Bounty' hairy vetch and 'Jerry' common oat mixture in 2015 (8210 kg ha^{-1}) and the 'Sungold' spelt and 'Dixie' crimson clover mixture (7220 kg ha^{-1}) in 2015 (Fig. 5), which were statistically similar. The lowest legume producing cover crop mixtures were measured for the 'Soil Saver' black oat (fall seeded) and 'Dixie' crimson clover treatment) in 2014 (0 kg ha^{-1}) and the 'AU Alpha' white lupin and 'Jerry' common oat mixture in 2015 (280 kg ha^{-1}), which were statistically similar.

In multiple cover crop trials, crimson clover and hairy vetch have been found to be the most promising, highest biomass producing cover crops (Parr et al., Holderbaum et al., Nelson et al.). Crimson clover had the highest fall growth and early soil coverage, while vetch had higher winter survival and spring growth (Holderbaum et al.). Ranells and Wagger (1997b) found that Austrian winter pea and grass bicultures produced the greatest total biomass, but

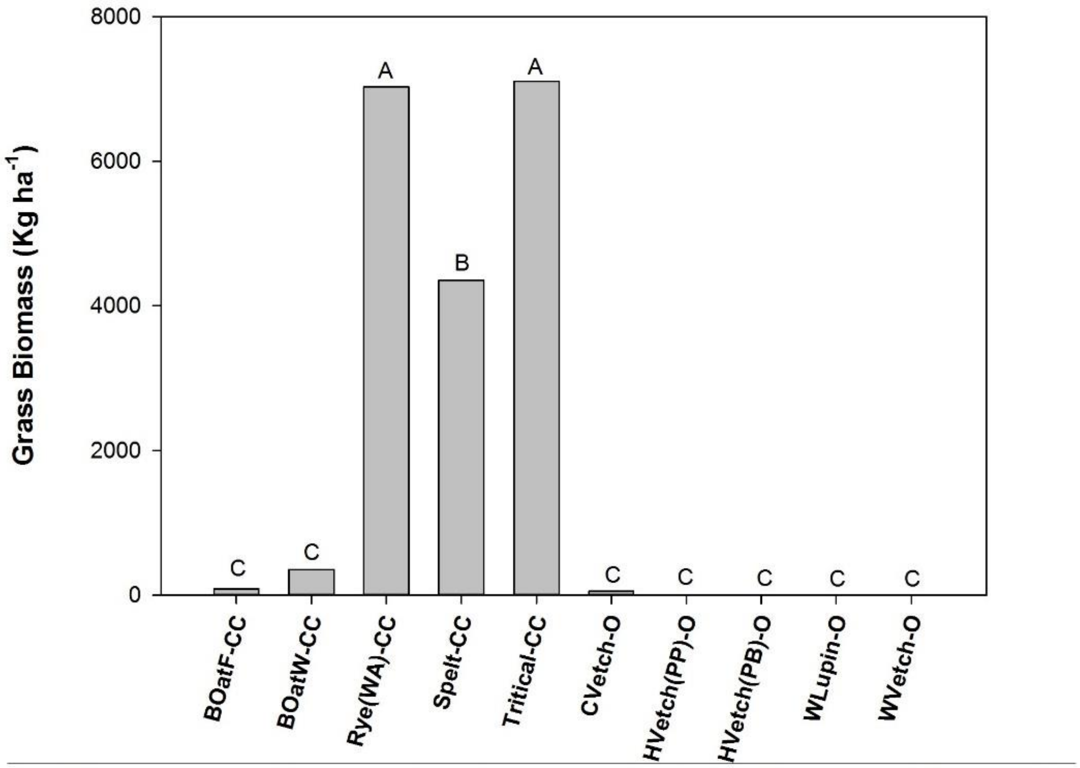

Fig. 4. Aboveground grass biomass as affected by treatment. Bars indicated by the same letter are not significantly different, $P > 0.05$.

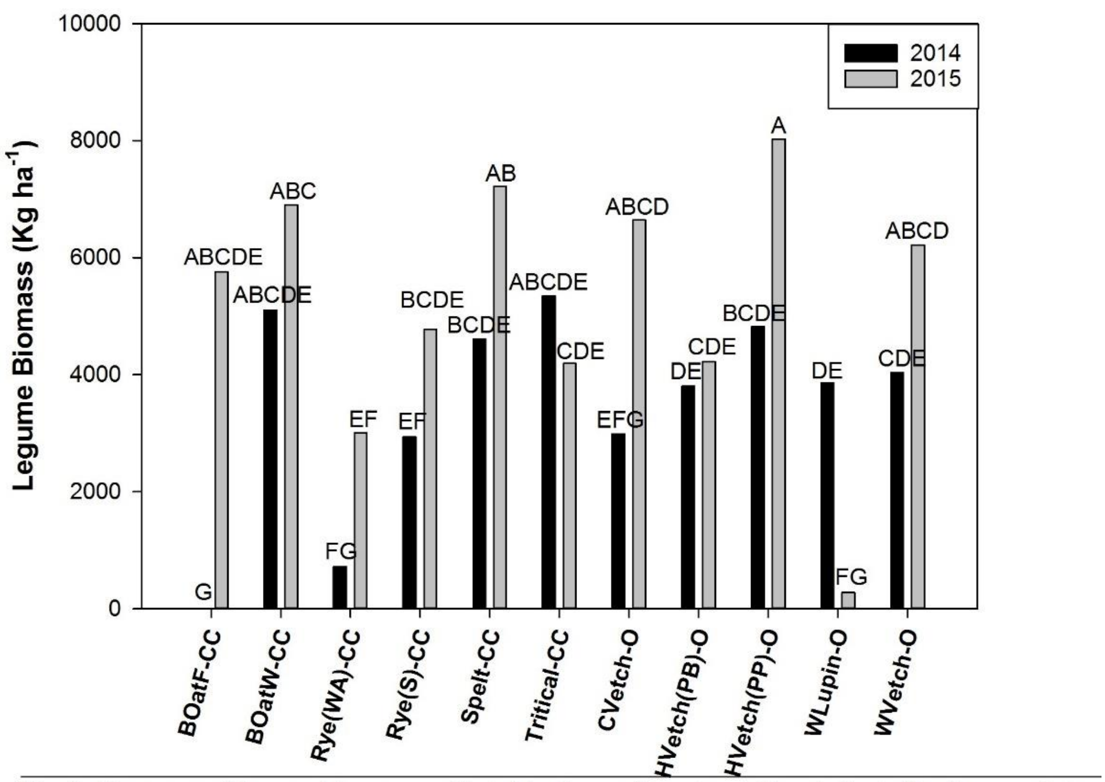

Fig. 5. Aboveground legume biomass as affected by time and treatment. Bars indicated by the same letter are not significantly different, $P > 0.05$.

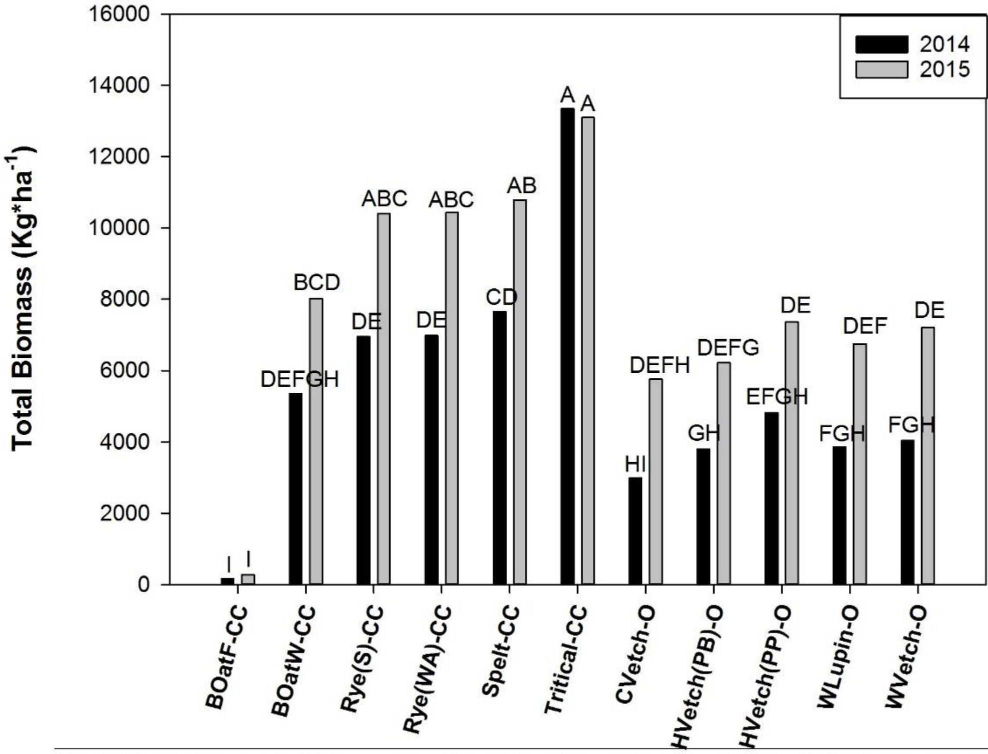

Fig. 6. Total aboveground biomass as affected by time and treatment. Bars indicated by the same letters are not significantly different, $P > 0.05$.

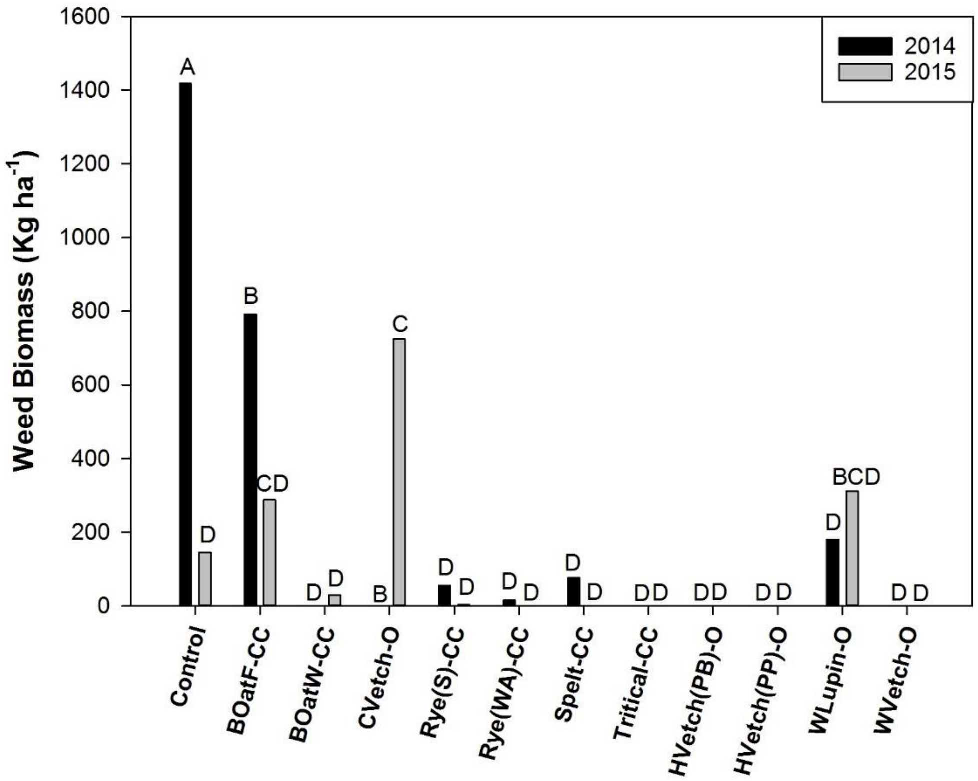

Fig. 7. Aboveground weed biomass as affected by treatment and time. Bars indicated by the same letter are not significantly different, $P > 0.05$.

hairy vetch and common vetch bicltures were similar.

Total aboveground biomass (grass and legume) was significantly affected by treatment ($P < 0.01$) and the interaction of treatment and year ($P < 0.01$; Table 3). The total biomass in almost all 2014 treatments was less than the 2015 treatments (Fig. 6). Differences in yield can be attributed to weather differences, with the 2013/2014 treatments experiencing colder temperatures than the 2014/2015 treatments (Fig. 1.). The highest total aboveground biomass was observed in the 'Trical 815' triticale and 'Dixie' crimson clover cover crop mixture for 2014 (13341 kg ha^{-1}) and 2015 (13093 kg ha^{-1}), with both years being statistically similar. The lowest total aboveground biomass was observed in the 'Soil Saver' black oat (fall seeded) and 'Dixie' crimson clover treatment for both 2014 (177 kg ha^{-1}) and 2015 (280 kg ha^{-1}), which were statistically similar (Fig. 6).

Weed biomass was significantly affected by treatment ($P < 0.01$) and the effect of treatment on year ($P < 0.01$; Table 3). The control plot had the highest weed biomass (1418 kg ha^{-1}) in 2014 that was observed in the trial (Fig. 7). In 2014 all cover crop treatments were statistically different than the control plot, having less weed biomass. The 2015 control plot was statistically different than the 2014 control plot. This difference can be attributed to the presence of volunteer crimson clover in the 2015 trial from previous cover crop establishment, which grew uninhibited in the bare control plots and competed with weeds. The 2015 control plot contained 6225 kg ha^{-1} of unseeded crimson clover, while the 2014 control plot contained 500 kg ha^{-1}. Less weed biomass was present in all cover crop treatments compared to the control in 2015 except for AU Alpha' white lupin and 'Jerry' common oat, and common vetch and 'Jerry' common oat.

Weeds present in trial plots included jagged chickweed (*H. umbellatum*), mouse ear chickweed (*Cerastium vulgatum*), neckweed (*Veronica peregrina*), henbit (*Lamium amplexicaule*), Carolina cranesbill (*Geranium carolinum*), purple deadnettle (*Lamium purpureum*), dandelion (*Tataxacum officinale*), and burdock (*Arcticum minus*).

High biomass producing crops act as smother crops and compete with weeds for resources including nutrients, water, and sunlight. Cover crops reduce weed seed germination and seeding though shading and lowering soil temperatures. Rye can reduce weed presence through allelopathy by releasing allelochemicals that inhibit weed germination and growth (Weston 1996).

Summary and Conclusions

As demonstrated by cover crop biomass and weed biomass, cover crops have the ability to control weeds in an organically-managed crop rotation system. Cover crops also scavenge nutrients, increase soil fertility, increase soil health, and reduce erosion, runoff, and leaching (Hubbard et al. 2013, Sainju and Singh 1997, Baets et al. 2011, Meisinger et al. 1991, Ranells and Wagger 1997a, Price and Norsworthy 2013, Clark and Panciera 2002). These benefits make cover crops especially useful in organically managed production systems which have reduced inputs. Cover crop mixtures of grasses and legumes have the N scavenging ability of grasses and the N fixing ability of legumes (Ranells and Wagger 1997b) while producing more biomass than legumes alone (Ranells and Wagger 1997a).

This study found that the greatest average aboveground grass biomass was observed from the 'Trical 815' triticale and

'Dixie' crimson clover cover crop mixture (7105 kg ha^{-1}), and the 'Wrens Abruzzi' cereal rye and 'Dixie' crimson clover cover crop mixture (7027 kg ha^{-1}). Oat varieties produced the least biomass. The highest legume biomass was observed from 'Purple Bounty' hairy vetch in 2015 (8210 kg ha^{-1}) and the 'Sungold' spelt and 'Dixie' crimson clover mixture (7220 kg ha^{-1}) in 2015. The highest total aboveground biomass was observed in the 'Trical 815' triticale and 'Dixie' crimson clover cover crop mixture for 2014 (13341kg ha^{-1}) and 2015 (13093 kg ha^{-1}). Almost all cover crops reduced weed biomass, and in the first year of the trial all cover crop treatments were statistically different than the control plot, having less weed biomass.

The purpose of this study was to provide organic growers in Tennessee with information about the yield and desirability of cover crop varieties and mixtures for use in Tennessee organic production systems. Growers must consider the benefits of each cover crop variety and mixture for use in their organic cropping system.

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