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Optimizing Agronomic Practices for Clover Persistence and Corn Yield in a White Clover–Corn Living Mulch System

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ABSTRACT

The area dedicated to corn (*Zea mays* L.) production increased 50% in the southeastern United States between 2006 and 2016, but producers need to find production systems that mitigate environmental impacts on erosive soils. Utilizing a perennial legume in a living mulch system may help stabilize the soil. The objectives of this study were to identify the most successful herbicide banding pattern (20 or 40 cm), corn row spacing (75 or 90 cm), and corn population density (60,000 or 90,000 plants ha^{-1}) to optimize potentially mineralizable nitrogen (PMN) from white clover (*Trifolium repens* L.) and maximize clover regrowth in a living mulch system. Plots were established at Floyd and Oconee Counties, Georgia, and tested over 2014 and 2015. Clover persistence and regrowth was best when initial clover suppression used a 20-cm band and corn was planted on 90-cm rows. Herbicide-induced PMN was greater for the wide herbicide band width, but shade-induced PMN was greater from the narrow band width. Corn shaded the clover at approximately 40 d after planting (DAP) and clover responded by senescing biomass as shading increased. Shading resulted in the majority of PMN regardless of other treatments variables. Corn grain yields were greater in the high population treatments, but there was a year × location × herbicide band width interaction. Considering clover persistence, PMN, and corn grain yield, we conclude that corn planted on 90-cm rows in 20-cm wide herbicide bands of dead clover is the best treatment for the living mulch system.

Core Ideas

- Living mulch cover crops help stabilize erosive soils during corn production.
- Wide rows enable the living mulch cover crop to re-establish for subsequent cropping.
- Herbicide bands must be kept to a minimum width to permit living mulch.
- Removal of crop residue is essential for white clover to perenniate in the living mulch system.
- White clover can supply over 100 kg ha^{-1} N to corn in the living mulch system.

Corn comprises the majority of feed grain production in the United States (Capehart, 2015). While the primary region of corn production is in the Midwest, corn hectarage in the Southeast increased 50% between 2006 and 2016 (USDA, 2016). However, soils on which corn is grown in the Southeast are erosive and, therefore, susceptible to land degradation (Markewich et al., 1990). One option to minimize the impact on erosive soils may be to use a living mulch production system. This system utilizes a perennial cover crop into which row crops are sown (Scheaffer and Moncada, 2012). The living mulch system is capable of providing numerous ecosystem and ecological benefits such as increase the supply of nutrients to the row crop (Teasdale et al., 2007; Deguchi et al., 2012), increase the efficiency of nutrient use (Ochsner et al., 2010), increase the species richness and function of the soil microbial (Nakamoto and Tsukamoto, 2006; Deguchi et al., 2007) and macrofauna ecosystems (Pelosi et al., 2009), improve soil stability (Hall et al., 1984), and reduce herbicide use and dissipation in the soil (Hall and Hartwig, 1990; Hartwig and Ammon, 2002).

Effective living mulches are those that have optimal growth in autumn and early spring, when row crops have not been established. Biologically fixed N can provide nutrition to the grain crop when perennial legumes are used as the mulch crop, thus reducing or eliminating the need for N fertilizer (Hartwig and Ammon, 2002). White clover may be a good living mulch crop because it can be as effective as herbicides to control weed infestations (Hartwig and Ammon, 2002). White clover also encourages the association between vesicular arbuscular mycorrhizae and the corn plant to assist in nutrient supply from soils with high P fixation capabilities (Deguchi et al., 2007). Thus, legume-based living mulches can lead to economic and environmental efficiency because of mineral nutrition supply, reduced herbicide needs, and control of soil erosion and nutrient leaching.

It is vital for cover crops to re-establish and perpetuate themselves in a living mulch system. Yet, despite the potential benefits of the living mulch system there have essentially been no studies to assess how agronomic practices might affect re-establishment of white clover once the row crop has been harvested. Agronomic practices in previous living mulch research vary widely in terms of mulch crop establishment and

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Abbreviations: DAP, days after planting; PMN, potentially mineralizable nitrogen.

suppression prior to row crop planting (Martin et al., 1999; Zemenchik et al., 2000; Duiker and Hartwig, 2004; Deguchi et al., 2007, 2012; Ochsner et al., 2010; Ziyomo et al., 2013). In some cases the plots of white clover used had established naturally and were highly infested with an assortment of weeds at the initiation of the experiments (Martin et al., 1999). Also, there is no consensus on how a leguminous living mulch might be suppressed. Suppression methods may be strip tillage (Martin et al., 1999), mowing the mulch crop (Martin et al., 1999; Deguchi et al., 2007), broadcast applications of herbicide (Zemenchik et al., 2000; Duiker and Hartwig, 2004; Ochsner et al., 2010; Ziyomo et al., 2013), banded applications of herbicide at set band widths (Martin et al., 1999; Zemenchik et al., 2000; Ziyomo et al., 2013), or some combination of these methods (Martin et al., 1999; Zemenchik et al., 2000; Ochsner et al., 2010; Ziyomo et al., 2013). Thus, there is a need for a systematic evaluation of the effect of agronomic practices on the success of a living mulch system, especially in terms of re-establishment of the mulch crop.

Previous research identified seeding rates for white clover, corn establishment practices, and herbicide regimens for establishing and maintaining a weed-free, white clover-corn living mulch system in Georgia (Hill, unpublished data, 2016). However, it remains to be determined whether a living mulch system conducive to white clover re-establishment can be developed. The objectives of this study were to identify the most successful herbicide band pattern, corn row spacing, and corn plant population density to maximize white clover regrowth for the following season in a white clover-based living mulch system.

MATERIALS AND METHODS

Site Descriptions

The experiment was performed in 2014 and 2015 at the J. Phil Campbell Research and Education Center located in Oconee County (33°52′3″ N, 83°26′58″ W, and 246 m elevation), and at the Northwest Georgia Research and Education Center located in Floyd County (34°20′20″ N, 85°07′40″ W, and 184 m elevation), Georgia. The soil at Oconee County was a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult) and the soil at Floyd County was a Wax loam (fine-loamy, siliceous, semiactive, thermic Typic Fragiudult). Both sites were equipped with automated meteorological stations to record temperature and rainfall throughout the duration of the experiment (Fig. 1).

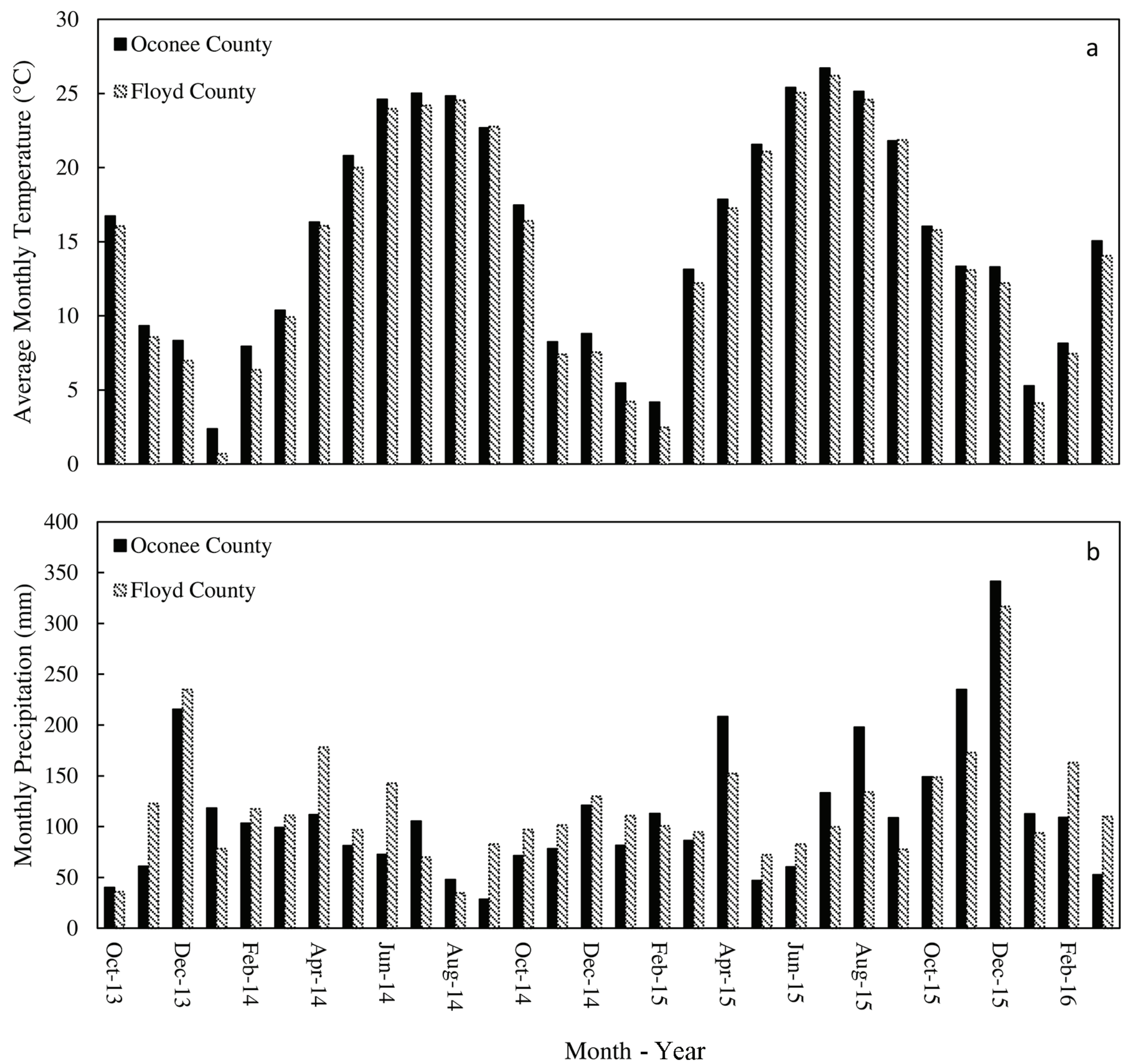

Fig. 1. Average monthly temperature and total monthly precipitation at Oconee and Floyd Counties, Georgia, throughout the white clover–corn living mulch system experimental period.

Soil Preparation and Plot Establishment

Prior to fall establishment of clover, soils were sampled and tested for available nutrients at the University of Georgia Soil Testing Laboratory. Soils were amended with lime, K, and P so that pH was at least 6.2, and available K and P were a minimum of 280 and 90 kg ha^{-1}, respectively. The research sites were prepared by disking the soil twice, followed by a cultipacking operation, and seeded on or about 20 Oct. 2013 with cultivar Durana white clover at a rate of 9 kg ha^{-1}. The seed was broadcast using a spin-cast manual push fertilizer/seed spreader (TurfEx, Madison Heights, MI) onto the seed bed, and the plot area was cultipacked a second time after broadcasting the clover seed to ensure proper seed–soil contact. The clover was allowed to establish under natural rainfall conditions throughout the fall, winter, and early spring months. Eight treatments consisting of a complete factorial of 90- or 75-cm row spacing, 40- or 20-cm herbicide banding applications to kill the clover, and corn population densities of 60,000 or 90,000 plants ha^{-1} were assigned to the research area using a randomized complete block design with three replications.

Plots at the Floyd County location were 6 by 3 m and 6 by 3.6 m for the 75-cm and 90-cm row spacing, respectively. Plots at the Oconee County location were 5 by 3 m and 5 by 3.6 m for the 75-cm and 90-cm row spacing, respectively. A combination of glyphosate [*N*-(phosphonomethyl)glycine] and dicamba (3,6-dichloro-2-methoxybenzoic acid) were applied at 1.12 and 1.20 kg a.i. ha^{-1}, respectively, using a hooded sprayer equipped with TeeJet 4002E spray tips (Spraying Systems Co., Wheaton, IL) which emitted 187 L water ha^{-1} (sprayed area) 14 d prior to planting corn. Shields were placed inside the sprayer hoods to limit the sprayed area to either 20 or 40 cm herbicide band widths. Corn cultivar DeKalb DKC64-69 (GENVT3P) was planted on 21 and 22 Apr. 2014 at the Oconee County and Floyd County locations, respectively, using a no-till planter (John Deere 7300 MaxEmerge, Deere and Company, Moline, IL) set at the appropriate row widths. In 2015, herbicide bands were sprayed on 31 March and 10 April and planted on 19 and 25 April, respectively, at the Oconee and Floyd County locations. A combination of atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) and pendimethalin (3,4-Dimethyl-2,6-dinitro-*N*-pentan-3-yl-aniline) was applied at 1.12 and 1.20 kg a.i. ha ^{1}, respectively, over the banded corn rows at the VE stage. The cropping area between the herbicide bands was not treated with herbicides throughout the growing season. Supplemental irrigation was applied using overhead sprinkler irrigation systems to maintain greater than 40% plant available soil water as estimated by the checkbook method (Sexton et al., 1996).

Clover Mass, Corn Height, and Corn Canopy Light Interception

Clover mass was monitored weekly during the corn growing season using a calibrated rising plate meter (Model F200, FarmWorks Precision Farming Systems, Fielding, NZ) (Lee et al., 2007). The rising plate meter was calibrated each week by placing the plate meter over a patch of clover from border rows of corn, recording the height reading, and hand clipping the clover from a 0.1 m^2 area immediately under the plate meter. A minimum of eight locations were sampled to calibrate the rising plate meter each week until corn harvest. The clover was placed in a drying oven at 60°C for 96 h and the dry weight recorded. Dry weight vs. plate meter height were fitted to a linear regression model. Regardless of week, the regression equations had coefficients of determination of 0.88 or greater and intercepts of 0.0. Clover was quantified from rising plate meter measurements made at 10 locations within each plot and weekly mean clover mass calculated from the regression equations.

Corn height was estimated weekly by calculating the average heights of 10 randomly selected corn plants from the center two rows of each plot. Corn canopy light interception was measured weekly until tasseling. A line quantum sensor (Li-Cor Model LI 191sb, Li-Cor, Lincoln, NE), was used to measure the amount of light above the corn canopy and the amount of light reaching the surface of the clover canopy at two locations between the center two rows of each plot. The percentage of light intercepted by the corn canopy was calculated using Eq. [1]:

$$\text{Percent light interception} = [1 - (\text{light at clover canopy}/\text{light above corn canopy})] \times 100 \quad [1]$$

Potentially Mineralizable Nitrogen

The intra-row loss of clover mass due to banded herbicide applications and the inter-row loss of clover mass were calculated using rising plate meter measurements. Samples of clover were hand harvested at the time of planting and weekly throughout the growing season. The samples were oven-dried at 60°C, ground through a 1-mm screen in a Cyclotec 1093 sample mill (FOSS North America, Eden Prairie, MN), and analyzed for total N using a pre-calibrated Foss Model 6500 near infrared reflectance spectrophotometer (FOSS North America, Eden Prairie, MN). Clover N values were constant over the growing season. Thus, herbicide-induced PMN was calculated as the product of the mean N content of the clover multiplied by the difference in clover mass due to death from herbicide bands. Shade-induced PMN was calculated on a weekly basis once light interception from the corn resulted in a reduction of clover biomass. Total shade-induced PMN was calculated as the sum of the products of the mean clover N content and weekly clover biomass reduction.

Grain Yield

Corn was harvested by hand at the R6 stage from a 3.0 m length of row from the center two rows of each plot. The ears were dried at 60°C for 1 wk after which the grain was removed using a mechanical corn sheller. The shelled grain was weighed, the weight adjusted to 15% moisture, and yield calculated.

Clover Re-establishment

Corn stover was removed after harvest during both years of the study to allow the clover to re-establish. Stover was removed in Oconee County by cutting stalks with a machete at 10 to 12 cm above the soil surface. In Floyd County the stover was mowed to 10 cm above the soil surface and bailed. Clover basal cover was monitored at 28-d intervals from harvest date until 15 March in the subsequent year using a 1 by 1 m point frame quadrat with 100 points. Two frames were randomly placed in each plot to estimate an average clover basal cover.

Statistical Analysis

Clover mass, corn height, and corn canopy light interception, were assessed with repeated measures within and among years. Treatment effects on clover mass, corn height, canopy light interception, and potentially mineralizable N were analyzed using DAP as a covariate using the PROC MIXED subroutine of SAS System (SAS Institute, Cary, NC). Row spacing, herbicide band width, population density, and replication were considered fixed effects while location and year were considered random effects in the SAS model. Clover re-establishment was similarly analyzed using days after harvest as the covariate. The statistical models indicated there was no population density effect on the response variables, but there was a row spacing × herbicide band width × location × year interaction for each response variable. Thus data were sorted by sampling event within each year and interactions analyzed using the PROC GLM subroutine of SAS. Means were separated using a Fisher's protected LSD ($P \leq 0.05$).

Grain yield, herbicide-induced PMN, and total shade-induced PMN were analyzed using year as a covariate using the PROC MIXED subroutine of SAS. Row spacing, herbicide band width, population density, and replication were considered fixed effects while location was considered random effects in the SAS model. The statistical models indicated there was a year × location interaction for herbicide-induced, total shade-induced, and total PMN. There was also a year × band width × row spacing interaction for herbicide-induced and shade-induced PMN. Data were sorted and the interactions analyzed using the PROC GLM subroutine of SAS. Means were separated using a Fisher's protected LSD ($P \leq 0.05$).

RESULTS

Environmental Conditions

Mean monthly temperatures were generally higher at Oconee County than at Floyd County, except during September 2014 and September 2015 (Fig. 1a). Temperatures fluctuated greatly throughout the experiment with the highest monthly mean temperature exceeding 26°C in July 2015

Table 1. The effect of row spacing on average (2 yr) corn yield when grown in a white clover–corn living mulch system in Floyd and Oconee Counties, Georgia.

County	Row width, cm: 75	Row width, cm: 90	LSD (0.05)
	Yield		
	——— Mg ha^{-1} ———		
Floyd	8.83	8.99	ns
Oconee	8.78	10.47	0.84
LSD (0.05)	ns	1.24	

at both locations and the lowest monthly means below 2.5°C in January 2014. Monthly rainfall totals also varied (Fig. 1b). Oconee County received as little as 28 mm and as much as 340 mm in September 2014 and December 2015, respectively, while precipitation in Floyd County ranged from 34 to 316 mm in August 2014 and December 2015, respectively.

Grain Yield

The analysis of variance indicated there was a corn population effect, and a location × row width interaction for yield. Data were sorted by location and analyzed for yield differences between row widths, and sorted by row width and analyzed for yield differences between locations. The lower population density yielded approximately 20% less than the high population density corn plots (data not shown). Because there were no population density interactions among the other treatment variables, the remaining discussion on yield will be for the high population density plots only.

There were no differences between the 75- and 90-cm row width treatments in Floyd County when grain yields were averaged over years, but the 90-cm row width treatment had greater yield in Oconee County than did the 75-cm row width treatment (Table 1). Average grain yields were similar among

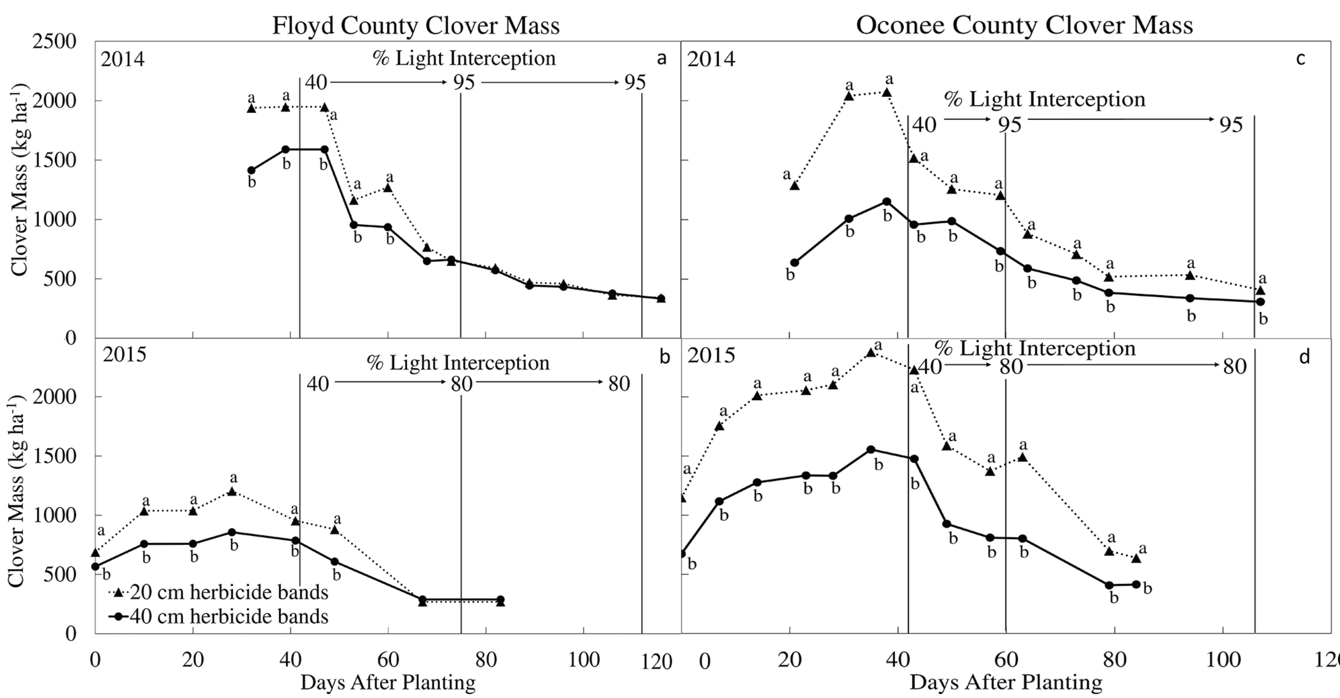

Fig. 2. The effect of herbicide band width on living clover mass in a white clover–corn living mulch system prior to- and after the onset of shading by corn in Floyd and Oconee Counties during 2014 and 2015. Means with different letters were significantly different at $P \leq 0.05$.

Table 2. The effect of herbicide band width on corn yield grown in a white clover–corn living mulch system at Floyd and Oconee Counties, Georgia, in 2014 and 2015.

County	Year	Herbicide band width, cm 20	40	LSD (0.05)
		Yield		
		Mg ha^{-1}		
Floyd	2014	13.09	13.64	ns
	2015	4.53	4.37	ns
	LSD (0.05)	1.39	2.27	
Oconee	2014	10.83	12.52	1.36
	2015	8.91	6.23	0.90
	LSD (0.05)	1.19	1.07	

the 75-cm row width regardless of location, but the 90-cm row width had a greater yield in Oconee County. There was also a location × year × herbicide band width interaction for yield. Data were sorted by location and year and analysis of variance conducted to determine the effects of herbicide band widths. Herbicide band width had no effect on yield in either 2014 or 2015 at Floyd County (Table 2). However in Oconee County, the 40-cm herbicide band width gave greater yields than the 20-cm herbicide band width in 2014, but in 2015 the 20-cm herbicide band width gave greater yields than the 40-cm band width. Yields were greater in 2014 than in 2015 regardless of location or herbicide band width. However, 2015 yield reductions at the Oconee County location were 18 and 50% for the 20- and 40-cm herbicide band widths, respectively, whereas yield reductions were 65 and 68% for those treatments at Floyd County. The reduction in yield at the Floyd county location was attributed to a heavy infestation of annual ryegrass (*Lolium multiflorum* L.) during late winter that impacted white clover growth.

Table 3. Percentage of clover killed by herbicide band prior to corn planting and width of living clover after application of herbicide band in a white clover–corn living mulch system.

Row width	Herbicide band width	Killed	Width of living clover
cm	cm	%	cm
75	40	53	35
75	20	27	55
90	40	44	50
90	20	22	70

Clover Mass, Plant Height, and Light Interception

Herbicide band width affected living clover mass present during the corn growing season (Fig. 2). Clover mass was greater in the 20-cm herbicide band width by virtue of a smaller proportion of the clover area exposed to the glyphosate and dicamba treatments prior to corn planting (Table 3). Light interception was not different among population density, row spacing, and herbicide band width within years (data not shown). The impact of shading occurred at 40% light interception regardless of year, population density, row spacing, or herbicide band width. Thus, maximum living clover mass occurred between 30 and 40 DAP at both locations (Fig. 2). Light interception was 40% once corn plants were 100 cm tall (approximately 42–45 DAP) which resulted in a significant decrease in living clover mass until maximum light interception occurred at maximum corn height, approximately 70 DAP. The decrease in living clover mass occurred at a slower rate thereafter. Maximum light interception was greater in 2014 (95%) than in 2015 (80%) (data not shown). Maximum corn height in 2014 was 250 cm and in 2015 was 200 cm at both locations.

Wide corn row spacing resulted in greater living clover mass until 42 to 45 DAP at both locations in both years (Fig. 3). The effect of light interception by increased corn height after

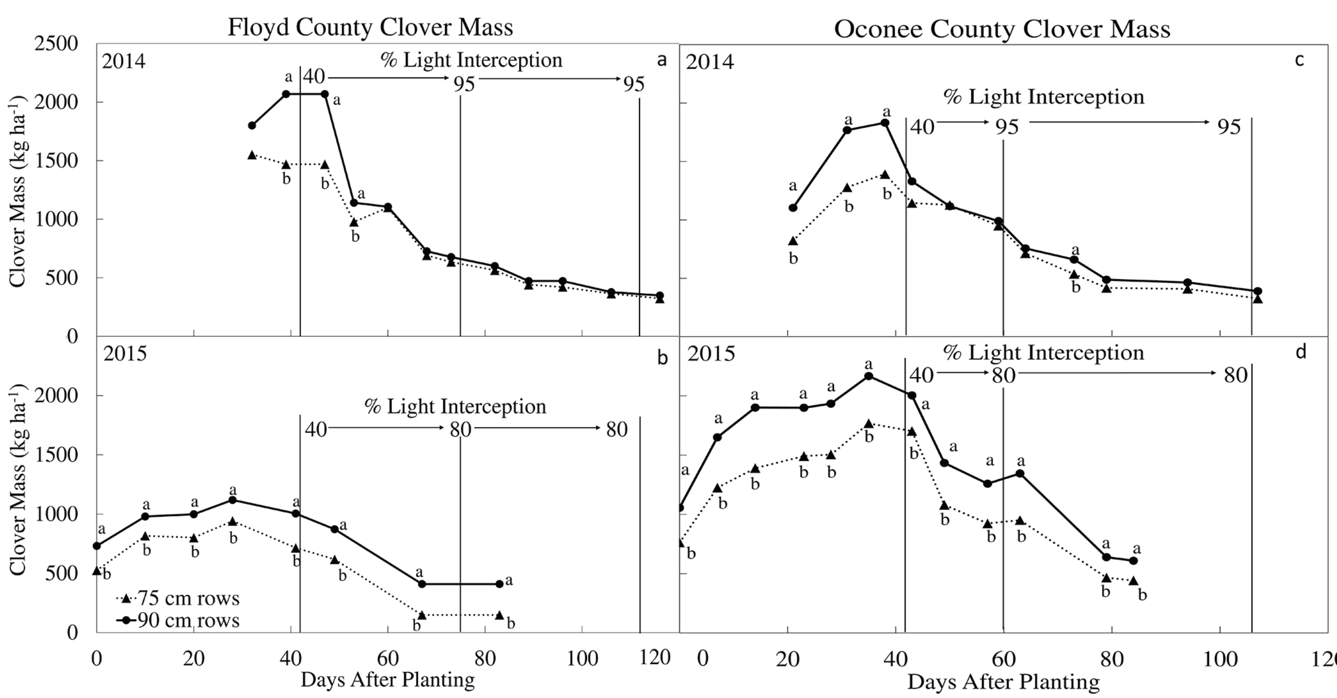

Fig. 3. The effect of corn row spacing on living clover mass in a white clover–corn living mulch system prior to- and after the onset of shading by corn in Floyd and Oconee Counties during 2014 and 2015. Means with different letters were significantly different at $P \leq 0.05$.

Table 4. Herbicide band-induced, shade-induced, and their total contribution to potentially mineralizable nitrogen (PMN) in a white clover–corn living mulch system at Floyd and Oconee Counties, Georgia, in 2014 and 2015.

	Year					
	2014			2015		
Location	Herbicide	Shade	Total	Herbicide	Shade	Total
	Potentially mineralizable N (kg ha^{-1})					
Floyd	41.7†	64.2‡	105.9§	12.7†	30.7‡	43.4§
Oconee	21.6†	56.3‡	77.9§	17.4†	50.8‡	68.3§
LSD (0.05)	6.0	ns	13.6	1.7	2.0	2.6

† Within location, herbicide-induced PMN significantly different from 1 yr to the next.

‡ Within location, total shade-induced PMN significantly different from 1 yr to the next.

§ Within location, total PMN significantly different from 1 yr to the next.

45 DAP resulted in equal living clover mass among wide and narrow rows for the remainder of the growing season at both locations in 2014 (Fig. 3a, 3c), but the wider rows had greater living clover mass when the corn was at the VT (77 DAP) stage in 2015 (Fig. 3b, 3d).

Potentially Mineralizable Nitrogen

There was a two-way interaction between location and year for total PMN (Table 4). Total PMN was greater in Floyd than Oconee County in 2014, but total PMN was greater in Oconee than Floyd County in 2015. Similarly, there were two-way interactions for the herbicide- and total shade-induced PMN. Herbicide-induced PMN was greater in Floyd than Oconee County in 2014, but the herbicide-induced PMN was greater in Oconee than Floyd County in 2015. Total shade-induced PMN was not different among locations in 2014, but was greater in Oconee than Floyd County in 2015. Herbicide-induced, total shade-induced and total PMN were greater in 2014 than 2015 regardless of location.

A more detailed statistical analysis of the sources of PMN revealed a three-way interaction between year, herbicide band width, and row spacing for herbicide-induced PMN (Table 5). Herbicide-induced PMN within the 40-cm herbicide band width was greater than that in the 20-cm herbicide band width in both the 75- and 90-cm rows in 2014 and 2015. The herbicide-induced PMN in the 20- or 40-cm herbicide band width treatments were not different within the 75- and 90-cm row width treatments in 2014, but in 2015 the 40-cm band width herbicide-induced PMN was greater in the 90-cm rows.

There was also a three-way interaction between year, herbicide band width, and row spacing for total shade-induced PMN. In 2014 there were no differences in PMN in the 20-cm herbicide band width treatment regardless of corn row spacing, but the 40-cm herbicide band width treatment in the 90-cm row spacing treatment had greater total shade-induced PMN than the 75 cm row spacing treatment. The total shade-induced PMN was greater in the 90-cm rows than the 75-cm rows in 2015 regardless of the herbicide band width. There was greater total shade-induced PMN in the 20-cm herbicide band width compared to the 40-cm herbicide band width regardless of row spacing in both years.

Clover Regrowth after Corn Harvest

There was a five-way interaction among year, location, row width, herbicide band, and days after harvest for clover re-establishment. Clover basal cover was approximately 60% 28 d after corn harvest in Floyd County during the autumn of 2014–2015 (Fig. 4a). Clover basal cover significantly increased until 56 d after harvest and remained between 80 and 90% throughout the winter and spring for all treatments except the 75-cm row spacing and 40-cm herbicide band width treatment. This was presumed to be due to death caused by low temperatures associated with a cold front. Even though, the clover recovered and had similar basal cover as the other treatments by the following spring. The clover basal cover in Floyd County was significantly less for all treatments during the winter of 2015–2016 than in the winter of 2014–2015 (Fig. 4b). Corn residue was cut with anticipation of removal, but excessive fall rains prevented raking and removing the residue from the plots until spring. Hence the residue laying on the surface shaded and killed a significant portion of the clover.

Basal cover was greater in the narrow herbicide band treatments regardless of row spacing in the recovery period of 2014–2015 in Oconee County (Fig. 4c). The 40-cm herbicide

Table 5. The effect of row spacing and herbicide band width on herbicide- and total shade-induced potentially mineralizable nitrogen (PMN) in a white clover-corn living mulch system. Data are means over two locations.

		Row spacing, cm			Row spacing, cm		
		75	90		75	90	
Year	Band width	N from herbicide		LSD (0.05)	N from shading		LSD (0.05)
	cm	kg ha^{-1}			kg ha^{-1}		
2014	20	24.2	20.4	ns	69.7	79.7	ns
	40	39.8	42.2	ns	33.6	57.8	9.3
	LSD (0.05)	7.6	12.4		14.6	15.0	
2015	20	10.6	9.9	ns	44.3	51.9	2.4
	40	18.0	21.9	3.2	30.5	36.4	4.2
	LSD (0.05)	3.3	2.3		2.7	3.9	

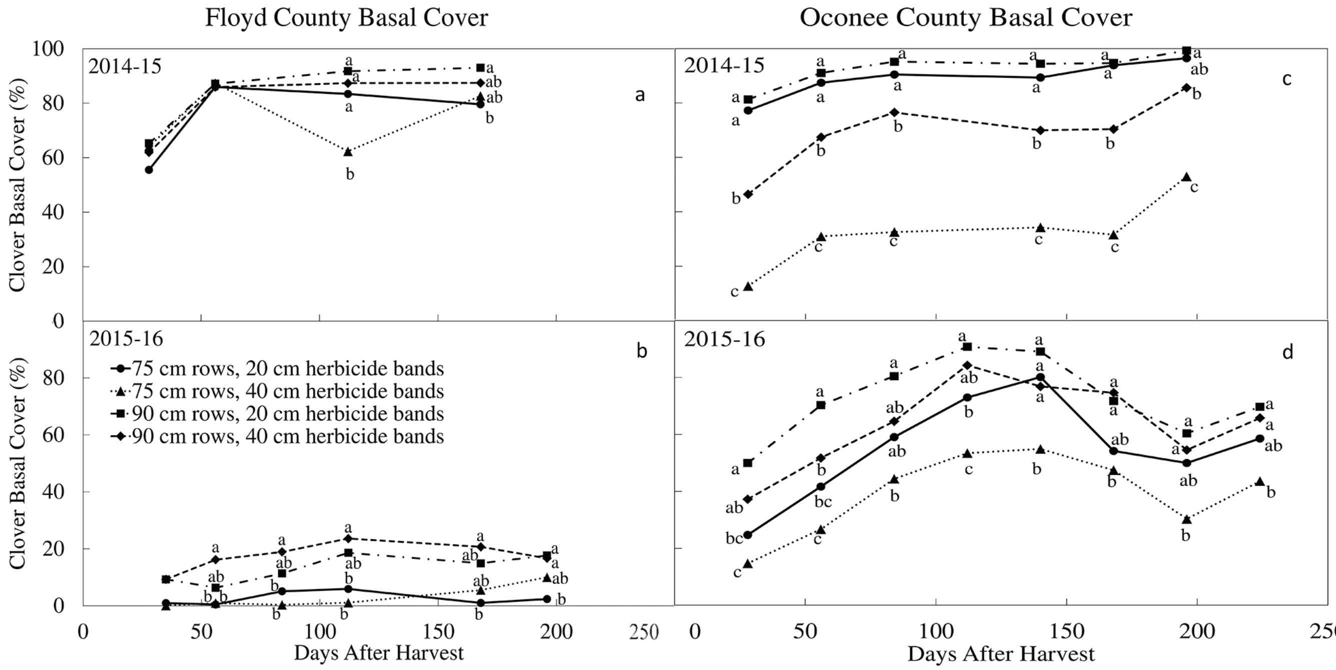

Fig. 4. The combined effects of corn row spacing and herbicide band width on clover re-establishment after corn harvest in a white clover–corn living mulch system. Means with different letters were significantly different at $P \leq 0.05$.

band treatment reduced clover basal cover throughout the 2014–2015 recovery period, but the 75-cm row spacing was more adversely affected by the herbicide treatment than was the 90-cm row spacing. Wide rows tended to give greater basal cover during the 2015–2016 recovery period than did the narrow rows (Fig. 4d). However, basal cover was greatest when the 90-cm row treatment was combined with the 20-cm herbicide band.

DISCUSSION

The living mulch concept that uses legumes to supply N to row crops must be viewed as a holistic system that considers sustainability of the cohort crops rather than treating each as independent components. Success of the living mulch system can only be attained once conditions are defined that foster perpetuation of the legume cover crop to optimize row crop production.

Applying glyphosate and dicamba to clover prior to corn establishment is necessary to provide initial nutrition to the corn for establishment. Previously, we found that killing a band of clover 14 d prior to planting corn was better than other timing of herbicide treatments (Hill, unpublished data, 2016). However, the optimum band width and corn row spacing combinations were not investigated. This provided the impetus for research to evaluate different planting configurations to optimize the cohort crops.

In areas where both cool- and warm-season plants grow, cool-season plants dominate in months when cool climatic conditions prevail while warm climatic conditions are conducive to warm-season plants (Ehleringer and Monson, 1993). In Georgia, periods of peak growth are spring and fall months for white clover and peak periods of growth are the summer months for corn. Thus, it is important to minimize the competitiveness of the clover early in the growing season during corn establishment, while it is important to mitigate the impact of corn in mid-summer when clover is most likely to experience environmental stress. Mitigation of the corn effects on the clover was accomplished by providing supplemental irrigation and removing corn stover after harvest.

Environmental stress on clover in mid-summer is not the only stress the clover plant experienced. It is possible that excessive shading may have resulted in clover death. Weed scientists have used crop shading as a fundamental tenant of weed control, emphasizing a need for weed control between rows of a crop until the time of canopy closure (Teasdale, 1995; Mashingaidze et al., 2009; Marín and Weiner, 2014). Therefore, the impact of shading by the corn crop on the clover was determined. Surprisingly, row spacing and corn population density had little impact on canopy light interception and, thus, clover shading. Yet there were dramatic impacts by other agronomic variables as to the regrowth potential of the clover on corn harvest. The percentage of the clover killed by the herbicide was related to the ability of the clover to re-grow over the fall–spring recovery period (Fig. 4). Although there was a strong relationship between clover re-establishment and banded herbicide patterns, this study used limited combinations to determine best management practices. It may be necessary to investigate additional clover suppressing patterns to find the optimal band widths required to maximize corn yields without compromising clover regrowth.

Numerous experiments have been conducted over the years to assess various aspects of corn production in a living mulch system. Experiments have been performed to evaluate suitable legume species as the mulch crop (Duiker and Hartwig, 2004), assess corn yield (Martin et al., 1999), identify suitable corn cultivars (Ziyomo et al., 2013), and assess nitrate leaching in the living mulch system (Ochsner et al., 2010). However, these experiments focused on row-crop productivity with minimal evaluation of the impact on legume regrowth. Many of the experiments tested a limited set of agronomic practices for corn production within the living mulch system and to a lesser extent agronomic practices that optimize perpetuation of the system (Zemenchik et al., 2000; Duiker and Hartwig, 2004; Ochsner et al., 2010; Ziyomo et al., 2013). Our study was unique from the standpoint of understanding the interactions between row spacing, herbicide methodologies, corn height and light interception on clover mass during crop growth, clover re-establishment after corn harvest, and corn yield. Based on the limits of this study, we concluded that using a narrow herbicide band (20-cm) to suppress clover prior to planting corn on a wide row (90-cm) will provide the optimal corn and clover productivity compared to the other treatment combinations. However, these parameters are by no means a formula for success of the living mulch system because of the necessity to define requirements of supplemental irrigation and the agronomic variables needed to sustain crop rotations while maintaining the clover stand.

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