The *Journal of Cotton Science* 3:74-83 (1999)

http://journal.cotton.org, © The Cotton Foundation 1999

AGRONOMY

Winter Annual Cover Crops in a Virginia No-till Cotton Production System: I. Biomass Production, Ground Cover, and Nitrogen Assimilation

J.B. Daniel*, A.O. Abaye, M.M. Alley, C.W. Adcock, and J.C. Maitland

INTERPRETIVE SUMMARY

Management of crop residue is a critical part of no-till production systems. In many cases the use of winter annual cover crops enables producers to meet conservation tillage standards set by the Natural Resource Conservation Service. The objectives of our study were to evaluate selected winter annual cover crops for biomass production, percent ground cover, and nitrogen assimilation and determine which cover crop performs best in the southern Piedmont of central Virginia.

The study was conducted in Blackstone, VA, on a Mayodan sandy loam soil in 1995 and 1996 and on a Dothan-Norfolk sandy loam soil in 1997. The experiment design used was a split block with four replications. Cover crops were randomly assigned to strips within each block. Tillage practices (conventional and no-till) were randomly assigned to strips perpendicular to cover crop strips. The cover crop treatments were crimson clover (*Trifolium incarnatum L.*), hairy vetch (*Vicia vilosa L.*), hairy vetch and rye (*Secale cereale L.*), rye, wheat (*Triticum aestivum L. emend. Thell.*), and white lupin (*Lupinus albus L.)*. No-till plots were chemically desiccated using glyphosate (2 lb/acre). At cotton planting the insecticide aldicarb and the fungicide metalaxyl were applied in-furrow at 5 and 10 lb/acre, respectively. Growing season moisture varied by year.

Which cover crops produced the most biomass for surface residue?

Rye produced more biomass than any other cover crop treatment with a three year average of 2,721 lb/acre. On average hairy vetch + rye produced 2,322 lb A^{-1}; crimson clover, 2,182; wheat, 2,166; hairy vetch, 1,565; and white lupin, and 845 lb A^{-1} biomass. Cover crop biomass production was not affected by tillage treatment. Tillage had no effect on the amount of biomass produced by each cover crop treatment.

Which cover crop provided the highest percent ground cover after cotton planting?

The rye cover crop provided the highest percent ground cover after cotton planting. Rye, hairy vetch + rye, and wheat consistently provided more ground cover after cotton planting compared with the other cover crop treatments. Lupin consistently provided the least ground cover. The small grain cover crops were more resistant to weathering and decomposition and provided more ground cover further into the cotton growing season compared with the legume cover crops.

Did the cover crop treatments provide enough ground cover after cotton planting to comply with Natural Resource Conservation Service conservation tillage standards?

Within a range of near average winter temperatures all cover crop treatments with the exception of lupin provided enough surface residue after cotton planting, to meet these federal conservation tillage standards.

Which cover crop assimilated the most N during the growing season?

Crimson clover was the highest N assimilating legume and rye was the highest N assimilating small grain at 70 and 66 lb N/acre, respectively. Nitrogen in the legume cover crops is derived from residual soil N (NO^-_3 + NH^+_4),and N_2 fixed by rhizobia associated with the legume. Nitrogen in non-legume cover crops is from residual soil N supplies. The more N assimilated into cover crop

J.B. Daniel, A.O. Abaye, M.M. Alley; and C.W. Adcock, Dept. of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State Univ., Blacksburg, VA 24061; J.C. Maitland, Southern Piedmont Agric. Research & Extension Center, Blackstone, VA 23824. Received 3 February 1999. *Corresponding author (cotton@vt.edu).

biomass, the less soil N available for potential leaching in to surface and ground waters.

ABSTRACT

Cotton (*Gossypium hirsutum* L.) may not provide sufficient surface residue to reduce erosion and protect the soil between crops. A winter annual cover crop might alleviate erosion during the time between cotton crops. This experiment was conducted to evaluate selected winter annual cover crops for biomass production, ground cover, and aboveground N assimilation. Six cover crops, crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia vilosa* L.), hairy vetch and rye (*Secale cereale* L.), rye, wheat (*Triticum aestivum* L. em.. Thell.), and white lupin (*Lupinus albus* L.), and two tillage systems (conventional and no-till) were arranged in a split block design with four replications. Percentage ground cover measurements were taken each year prior to desiccation and immediately after cotton planting for 1995 and 1996. In 1997, additional measurements were taken 50 d after cotton planting. Hairy vetch + rye, rye, and wheat provided the most ground cover after cotton planting, while lupin provided the least. All cover crops, with the exception of lupin, provided enough ground cover (>30%) after cotton planting to comply with Natural Resource Conservation Service conservation standards, except during years with below normal winter temperatures. Fifty days after cotton planting, small grain residues provided more ($P < 0.05$) ground cover compared with legume residues. Averaged over the three experimental years, biomass production from the different cover crops ranged from 946 to 3,047 kg ha^{-1}. The average amount of aboveground N assimilated by cover crops ranged from 32 to 78 kg N ha^{-1}, and was closely related to the amount of cover crop biomass produced. Growth and biomass production of cover crops was greatly affected by the climatic conditions during each season.

Cotton is grown on approximately 42,000 ha annually in Virginia. The production area has increased four fold since 1993. Although most of the cotton is grown in the Coastal Plain, cotton acreage is increasing in the southern Piedmont region, where the topography confines agricultural production to small fields with significant slopes that are not well suited for cotton production.

Cotton is considered a low residue crop that may not provide sufficient surface residue to reduce erosion and protect the soil. Denton and Tyler (1994) reported the use of winter annual cover crops in a no-till cotton production system as an economically feasible approach to control soil erosion problems. Winter annual cover crops can provide the required surface residue to comply with the Natural Resource Conservation Service (NRCS) conservation tillage Code 329 standards (Bauer and Busscher, 1996). NRCS standards require 60 % ground cover remaining on the soil surface after cotton planting for no-till practices and 30% ground coverage after cotton planting for minimum tillage practices (NRCS, 1992(a)).

In addition to erosion control, cover crops can enhance soil productivity and sustain water quality. After many years of conservation tillage research in Tennessee, Bradley (1995) states that cover crops supply significant amounts of organic matter to the soil and, with time, improve soil tilth, moisture holding capacity, cation exchange capacity, and overall productivity of the soil. Surface residues slow the velocity of runoff water and enhance infiltration and percolation of water via improved soil structure (Moseley et al., 1996).

Cover crops assimilate N into plant biomass, reducing the potential leaching of nutrients and contamination of surface and ground water (Meisinger et al., 1991). Thompson and Varco (1996) reported that leguminous cover crops can biologically fix N needed for the following cotton crop, decreasing fertilizer expenses. Small grain cover crops recycle residual soil nutrients from the previous growing season (Breitenbeck and Hutchinson, 1994). Smart and Bradford (1996) found in addition to protecting the soil and water by using a conservation tillage system, fuel, labor, equipment expenses, and time are saved by eliminating seedbed preparation and the need for large, high-powered cultivation equipment.

The magnitude of the beneficial effects from the cover crops depends on the amount of biomass produced by the cover crop (Holderbaum et al., 1990). Munawar et al. (1990) reported that the amount of biomass (kg ha^{-1}) produced by cover crops and the distribution of the residue remaining on the soil surface is important to the effectiveness of the conservation tillage system. Biomass production directly affects soil properties and water quality in an agricultural system. If the amount of cover crop biomass is too thick it may interfere with proper seed to soil contact at cotton planting. Without proper equipment adjustments, too much biomass can result in decreased emergence and poor stand establishment. Smart and Bradford (1996) found that planting cotton into surface residue decreases wind speeds and provides protection from blowing sands which can damage and sometimes kill the seedlings. Cover crop residue also provides protection by insulating the cotton seedlings from cool temperatures of the early growing season (Stevens et al., 1996).

The objectives of this study included evaluation of different winter annual cover crops for biomass production, ground cover, and N assimilation in the central Virginia Piedmont.

MATERIALS AND METHODS

A field study was conducted during 1995, 1996, and 1997 at the Southern Piedmont Agricultural Research and Extension Center, in Blackstone, VA. The soil type at the site was a Mayodan sandy loam (fine, mixed, semiactive, thermic Typic Hapludults) for 1995 and 1996 and a Dothan-Norfolk sandy loam (fine, loamy, koalinitic, thermic Plinthic and Typic Paleudults) for 1997. The experiment design used was a split block with four replications. Cover crops were randomly assigned to strips within each block. Tillage practices (conventional and no-till) were randomly assigned to strips perpendicular to cover crop strips. Plots were 4.27 m wide and 7.63 m long with 4 rows (1.1 m wide).

The cover crops were crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia vilosa* L.), hairy vetch and rye (*Secale cereale* L.), rye, wheat (*Triticum aestivum* L. em. Thell.), and white lupin (*Lupinus albus* L.). Seeding rates were 56 kg ha^{-1} for crimson clover and hairy vetch, 28 and 112 kg ha^{-1} for the hairy vetch/rye mixture, and 224 kg ha^{-1} for wheat, rye, and lupin. Seeding rate for all the cover crops was doubled the recommended seeding rates to ensure establishment. No fertilizer was applied to cover crops.

The cover crops were planted on 3 Oct. 1994, 11 Oct. 1995, and 29 Oct. 1996. In the fall of 1994 and 1995 the field was disked, the no-till plots were bedded, the cover crop treatments were broadcast, and all plots were rolled with culti-packer. In 1996, cover crops were planted the same except all plots were planted on flat ground. In the spring, shortly before chemical desiccation of cover crops and before tillage was applied (Table 1), percentage ground cover was estimated, and cover crop biomass was determined within each cover crop plot. Percentage ground cover was estimated for each cover crop treatment using the NRCS line transect method (NRCS, 1992(b)). Percentage ground cover measurements were taken each year prior to desiccation and immediately after cotton planting for 1995 and 1996, and in 1997 additional measurements were taken 50 d after cotton planting. Cover crop biomass yields were obtained by clipping a 0.25 m^2 quadrat at 2.5 cm above ground level.

The samples were dried in a forced-air oven at 60 ^{o}C, ground, sieved (1 mm screen), and analyzed for total N by a commercial laboratory. Approximately 3 wk prior to the estimated cotton planting date, the conventional tillage plots were mowed and disked while the no-till plots were desiccated with glyphosate (2.24 kg ha^{-1}). The no-till plots received an additional burndown herbicide application when needed (Table 1). About 1 mo after the second burndown application the cotton (cultivar DLP 50) crop was planted at the rate of 16.4 seeds per m of row (Table 1). Cotton was

Table 1. Cover crop desiccation and cotton planting dates, and herbicides used at planting for the 1995, 1996, and 1997 cotton growing seasons in the Piedmont of Virginia..

Year	Cover crop desiccation date	Cotton planting date	Herbicides used at planting for no-till cotton weed management	
			Common Name	Rate
1995	†March 31	§May 19	Pendimethalin	0.56 kg ha^{-1}
	‡April 14		Fluometuron	1.12 kg ha^{-1}
			Paraquat	0.69 kg ha^{-1}
1996	†April 12	May 15	Fluometuron	0.56 kg ha^{-1}
	‡April 23		Metolachlor Paraquat	1.68 kg ha^{-1}
				0.52 kg ha^{-1}
1997	†April 15	§May 29	Pendimethalin	0.74 kg ha^{-1}
			Fluometuron	1.12 kg ha^{-1}

† First burndown herbicide application.
‡ Second burndown herbicide application.
§ Replant date due to poor cotton stand.

Table 2. Analysis of variance of biomass and percentage ground cover for years 1995, 1996 and 1997. Data were recorded in the spring, shortly before chemical dessication of cover crops and before tillage was applied.

Source of variation	df	Biomass	Ground cover, %
		-------- Observed Prob > F -------	
Year (Y)	**2**	**0.001**	**0.001**
Rep (year)	**9**	**0.35**	**0.06**
Cover crops (C)	**5**	**0.001**	**0.001**
Y x C	**10**	**0.001**	**0.001**

planted using a four-row no-till planter equipped with a fluted coulter to cut through surface residue followed by a double disk opener to make a furrow for the seed, and press wheels to firmly cover the seed with soil. Aldicarb (granular insecticide) and metalaxyl (granular fungicide) were applied in-furrow at planting at 5.6 and 11.2 kg ha^{-1}, respectively. Fertilizer N, P, K and B according to soil test recommendations were broadcast onto no-till plots and disked into conventional tillage plots.

Data analysis

Analysis of variance was calculated using the SAS software package (SAS Institute, 1993). Effects of treatment (cover crops and tillage), field block, date (when needed), year, and all two and three-way interactions were tested. Mean separations were performed by Duncan's Multiple Range Test if the ANOVA *F*-statistic indicated significant effects at the 0.05 probability level (SAS Institute, 1993).

RESULTS AND DISCUSSION

Cover crop biomass production

Biomass and percentage ground cover data from the three experimental years are shown for each

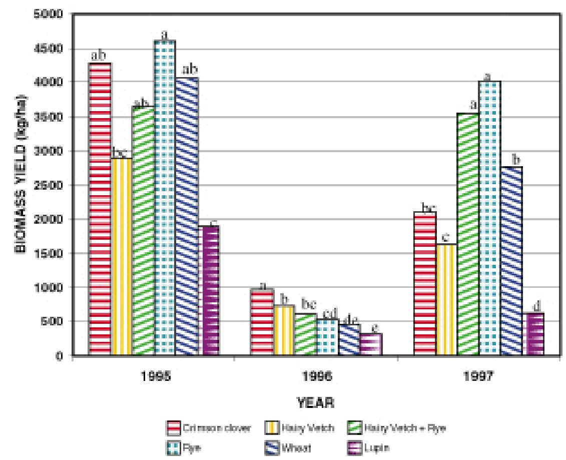

Fig. 1. Cover crop biomass yield obtained prior to desiccation for the 1995, 1996, and 1997 growing seasons. Means for bars within years followed by the same letter are not significantly different *P* = 0.05 (Duncan's Multiple Range Test).

year due to a year by cover crop treatment interaction (*P* < 0.001) (Table 2). Cover crop biomass yield was highest in 1995, lowest in 1996, and intermediate in 1997 (Fig 1). Within each year biomass production varied with type of cover crop. However, with the exception of the 1995-1996 season which experienced severe weather conditions, crimson clover, hairy vetch + rye, rye and wheat were the top biomass performers in the 1994-1995 and 1996-1997 seasons. Lupin always produced the least biomass. Hairy vetch alone was intermediate in production.

As one might expected percentage ground cover and biomass are closely related. Those cover crops producing the best covers also produced higher biomass. Lupin which produced lowest cover also produced lowest biomass (Fig. 1 and 2). The best ground cover performers in all years were the small grains by themselves or in a mix (hairy vetch + rye,

Table 3. Summary of average monthly temperature, rainfall and number of sub-zero temperature days from planting through desiccation of winter annual cover crops for the 1994-1995, 1995-1996, 1996-1997 growing seasons and the 30-yr average.

Month	1994-1995	1995-1996	1996-1997	30-yr Avg.	1994-1996	1995-1996	1996-1997	30-yr Avg.	1994-1995	1995-1996	1996-1997
	Average temperature (°C)				Total rainfall (mm)				Number of days with min. temp. below 0 °C		
Oct.	**14.8**	**16.9**	**15.3**	**15.2**	**72.4**	**176.5**	**162.6**	**68.8**	**0**	**0**	**0**
Nov.	**11.8**	**6.7**	**6.1**	**9.6**	**86.5**	**58.4**	**120.7**	**74.2**	**4**	**19**	**17**
Dec.	**8.2**	**2.8**	**6.2**	**4.3**	**17.8**	**35.6**	**92.7**	**79.8**	**12**	**23**	**14**
Jan.	**4.5**	**1.1**	**3.0**	**3.5**	**108.0**	**130.8**	**55.9**	**71.6**	**21**	**24**	**23**
Feb.	**3.6**	**3.7**	**6.7**	**3.8**	**40.6**	**81.3**	**91.4**	**83.1**	**18**	**15**	**12**
Mar.	**10.4**	**6.2**	**11.1**	**8.6**	**73.4**	**90.2**	**76.2**	**88.1**	**8**	**14**	**5**
Apr.	**14.6**	**14.7**	**14.3**	**14.4**	**52.1**	**91.4**	**16.5**	**79.8**	**4**	**3**	**2**

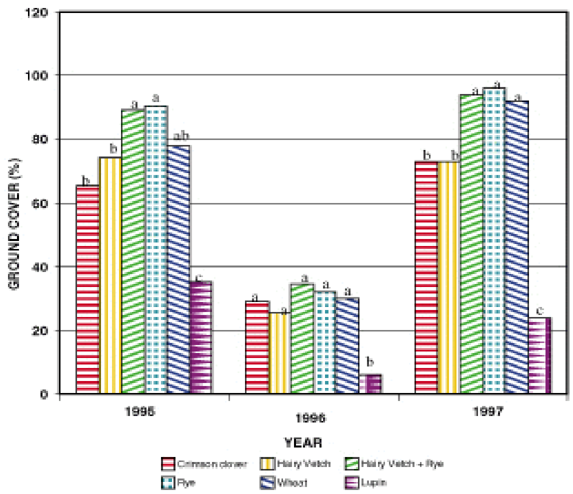

Fig. 2. Percentage ground cover provided by cover crop treatments after cotton planting for the 1995, 1996, and 1997 growing seasons. Means for bars within years followed by the same letter are not significantly different *P* = 0.05 (Duncan's Multiple Range Test).

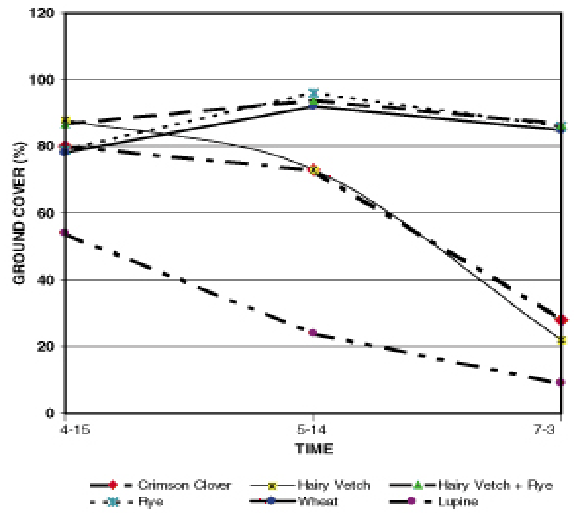

Fig. 3. Percentage ground cover by cover crop residue before dessication (4–15), immediately after cotton planting (5–14) and 50 d later (7–3) for 1997 growing season

rye, and wheat (Fig. 2). Lupin produced the lowest ground cover. Using NRCS guidelines of 30% ground cover as the minimum for no-till shows that in 1995 all cover crops provided acceptable cover but lupin was marginally acceptable. The small grains by themselves or mixed provided 75% or greater ground cover (Fig. 2). In 1996 all cover crops provided much lower cover. Only the small grains provided at least 30% or greater cover (Fig. 2). In 1997 however, only lupin provided less than 30% cover. The small grains provided 90% or greater cover.

Though it was not an explicit objective of our study, in 1997 we also measured the changes in cover crops over time for the various crops (Fig. 3). Similar to results of Munawar et al. (1990) the small grains by themselves or in a mix were the most persistent providing at least 35% cover 50 d after cotton planting. Legume cover crops decomposed rapidly and produced less than 30% cover 50 d after cotton planting.

Weather conditions were an important factor in cover crop success. The 1994-1995 growing season produced the best cover crop. The 1996-1997 season produced a smaller but comparable cover crop. The 1995-1996 season however, produced a much smaller cover crop. The 1994-1995 season rainfall and temperature were average or slightly above for October and November (Table 3). The cover crops have two environmentally favorable months in which to establish before a drier December. Though spring rains were light (about 75% of normal) moisture was adequate and temperatures were average or slightly above. These spring conditions permitted the well established cover crop to increase biomass. The 1996-1997 growing season had good moisture during fall establishment and average temperature for October. Through November temperatures were colder than average with many below zero days, the coldest temperatures did not come till the end of the month when the cover crops were established and hardened (Fig. 4). The 1996-1997 spring season was dry, March had 86% of the normal rainfall and April had only 21% of the normal rainfall. This dry period occurred when greatest biomass accumulations would occur and may be the reason for reduced production compared with the 1994-1995 cover crop.

In contrast, the 1995-1996 cover crop was exposed to extremes in both moisture and temperature. October of the 1995-1996 growing season rainfall was 176 mm (256% of average). Then November and December were dry (79% and 49% of normal precipitation, respectively). Starting in November, temperatures were below normal for every month except April (Table 3 and Fig. 4). The 1994-1995 and 1996-1997 growing seasons had

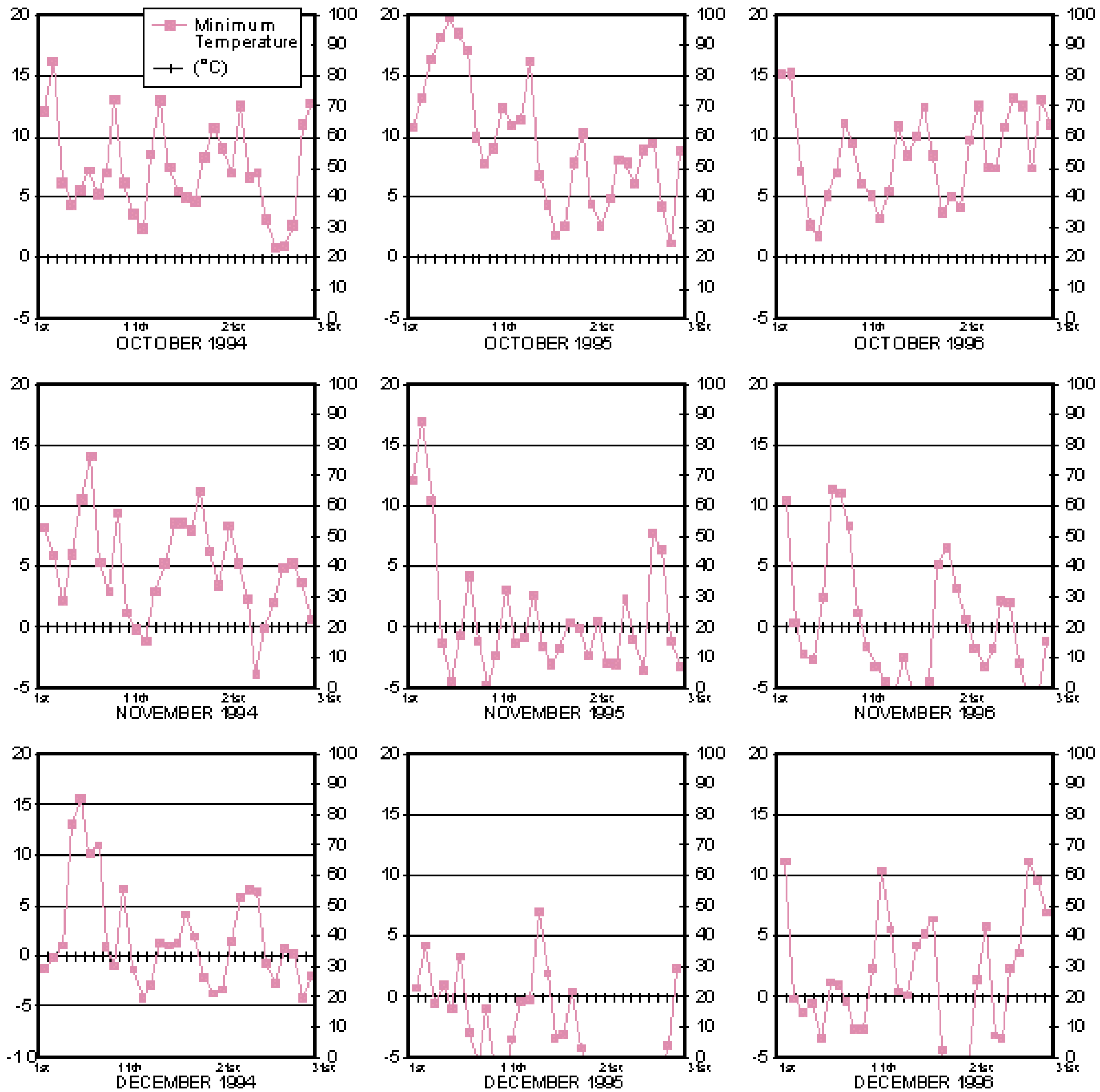

Fig. 4a. Minimum temperature and daily rainfall from planting through desiccation of winter annual cover crops for the 1994–1995, and 1995–1996 growing seasons.

some very low temperatures (6 and 5 d below -10°C, respectively compared with 7 d below -10°C for the 1995-1996 growing season), however, these occurred in December, January and February. None occurred in March. In March 1996, there were 2 d below -10°C and about half the days were below 0°C. The sustained and extreme cold, specially in the spring, and the moisture extremes during establishment apparently damaged the cover crops in the 1995-1996 growing season.

Nitrogen assimilation by cover crops

Total above ground N assimilated by the cover crops was determined by multiplying the biomass yield with the N content of the cover crop (Table 4). As might be expected, the legumes (crimson clover, vetch and lupin) had greater percent N content than the small grains. For small grains total N assimilated by the cover crop is a function of biomass production and the amount of N derived

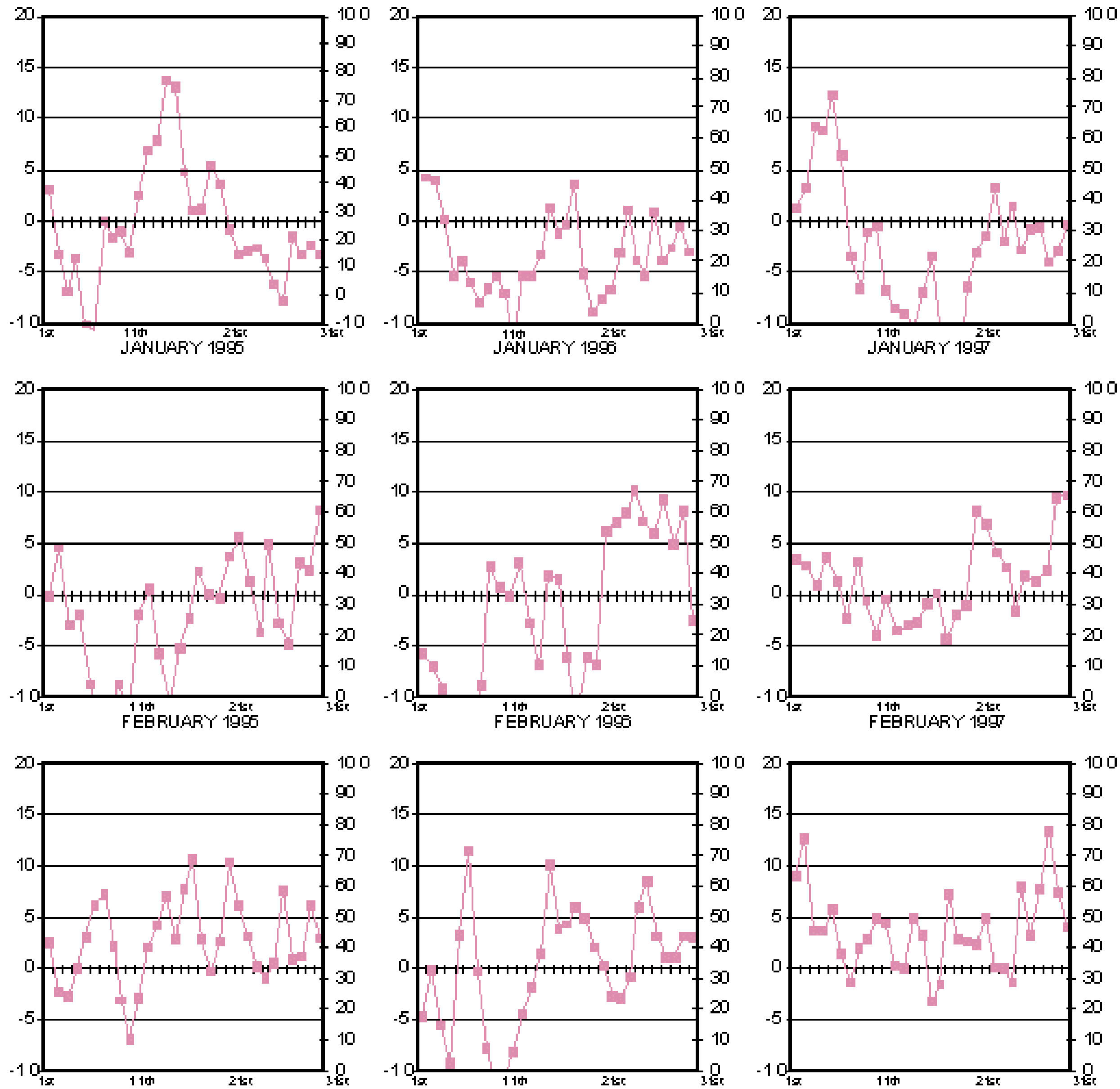

Fig. 4b. Minimum temperature and daily rainfall from planting through desiccation of winter annual cover crops for the 1995–1996, and 1996–1997 growing seasons.

from the soil. In the case of legumes however, an additional amount of N is presumed to come from N fixed by rhizobia.

Lupin always showed lowest assimilation due to low biomass production. Wheat always showed next lowest N assimilation due to lower N concentration. Rye alone showed comparable N assimilation to crimson clover, hairy vetch, or vetch + rye in the 1995 and 1997 seasons. Clover and vetch showed higher N assimilation levels in the 1996 season. Because a percentage of assimilated N in the crimson clover and hairy vetch is from rhizobia fixed N, then the fact that rye assimilated a comparable amount of N in two growing seasons indicates that rye may remove more N from the soil. The soil N assimilated by cover crops should be less susceptible to leaching and runoff losses than if it had remained in the soil (Clark et al., 1994; Moseley et al., 1996). Furthermore, once the cover crop is killed in the spring, decomposition of the

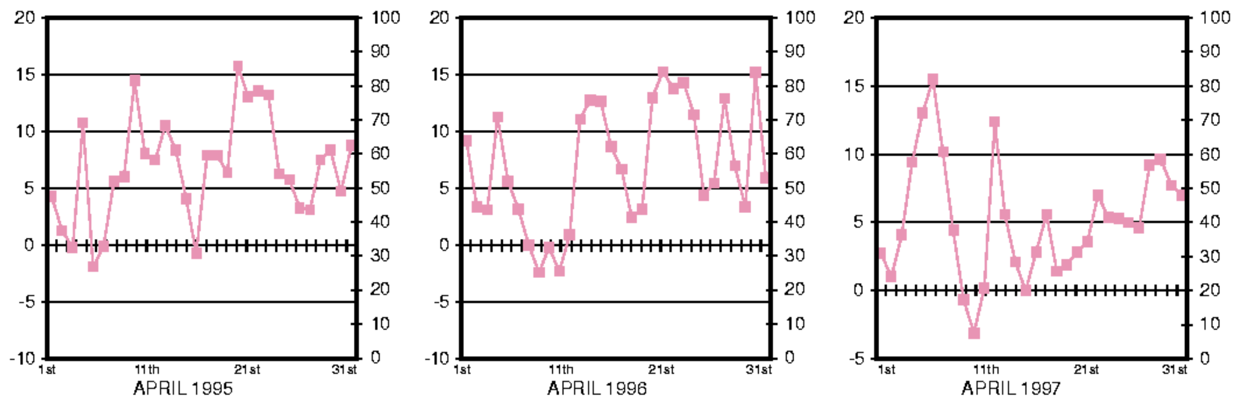

Fig. 4c. Minimum temperature and daily rainfall from planting through desiccation of winter annual cover crops for the 1995-1996, and 1996-1997 growing seasons.

Table 4. Average cover crop biomass yield, nitrogen concentration, and nitrogen assimilation for 1995, 1996, 1997 and the three year average.

Treatment	Avg. biomass			Avg. N concentration			Assimilated N			3-yr average	
	1995	1996	1997	1995	1996	1997	1995	1996	1997	Biomass	Assm. N
	----------- kg ha^{-1} -----------			---------- % ---------			------- kg ha^{-1} --------			-------- kg ha^{-1} ---------	
Crimson clover	4270	968	2094	3.04	3.16	3.51	130	31	74	2444	78
Hairy vetch	2890	738	1631	4.04	3.92	4.36	117	29	71	1753	72
Hairy vetch + rye	3650	605	3547	2.78	2.70	2.15	102	16	76	2600	65
Rye	4600	528	4015	2.78	1.91	2.06	128	10	83	3047	74
Wheat	4060	451	2766	2.32	1.99	2.37	94	9	66	2426	56
Lupin	1900	319	619	3.94	2.46	2.16	75	8	13	946	32
LSD (0.05)	1701	164	724	0.75	0.41	0.39			22		24

biomass releases N for potential uptake by the summer annual crop. Differential decomposition rates of the cover crops (Fig. 3) suggests that rye which may assimilate a comparable amount of N to cover and vetch, will release the N slower due to slower decomposition.

CONCLUSIONS

All cover crops with the exception of lupin produced large amounts of biomass providing surface residue and aboveground N assimilation for a no-till cotton production system. Cover crop biomass production varied by year and treatment. Yearly differences in biomass production depended on temperature and rainfall conditions during the growing seasons. Average rainfall during establishment, and adequate rainfall during spring growth resulted in high biomass yields for 1995. The 1997 cover crop had above normal temperatures in the spring and produced a good but smaller crop compared with 1995, most likely due to a dry spring. Below average monthly temperatures for the 1995-1996 winter, and spring, especially in March, resulted in extremely low biomass yields. Percentage ground cover and above ground N assimilated by cover crops were positively correlated with the amount of biomass produced. Within a range of near average winter temperatures all cover crop treatments with the exception of lupin provided enough surface residue after cotton planting to meet NRCS conservation tillage standards. Additional observations of surface residue showed that small grain cover crops apparently decomposed slower and provided erosion control further into the cotton growing season than the legumes used in this study.

Based on our research in cover crop biomass production, ground cover percent, and aboveground N assimilation, rye performed best compared with the other cover crop treatments used in this study. Rye was established in October, persisted throughout cold winter temperatures, and grew rapidly in the spring. Rye produced large amounts of biomass, provided the highest percent ground cover after cotton planting, and assimilated an average of 74 kg N ha^{-1} which is comparable to the legumes in the study. Rye may extract greater amounts of N from the soil. Rye was less expensive to establish, easier to chemically desiccate, and provided surface residue further into the cotton growing season compared with leguminous cover crops. Overall, rye worked well as a cover crop in a no-till cotton production system under the soil and climate conditions in the southern Piedmont region of central Virginia.

Although rye performed best, the hairy vetch + rye and the wheat treatments were comparable to rye for biomass production, percent ground cover, and N assimilation. Because there is additional cost involved with planting the hairy vetch + rye mixture, there does not appear to be any advantage to this mix over the rye alone cover crop. Crimson clover and hairy vetch were more expensive to establish, produced less biomass, provided less ground cover, were more difficult to kill, but assimilated comparable amounts of N in relation to rye. The legume cover crop residue disappeared quickly after it was killed in the spring, potentially releasing the assimilated N to the summer annual crop quicker than rye.

The unpredictable amount and timing of N release from the legumes may risk late season rank growth in cotton, but it might work well with a different summer annual crop. Lupin performed poorly for each year of the study and is not recommended for use as a winter annual cover crop in this region. The data from this study show that fall cover crop establishment in the Piedmont region's of Virginia is practical and that rye should be a good choice as a cover crop.

ACKNOWLEDGMENTS

We are grateful to W. Wilkinson, research associate at the Southern Piedmont Agric. Research & Extension Center, for his help with this trial and Mr. Robert Freyman for his help on the statistical analysis. This research was funded by a grant from the Virginia Agricultural Council.

REFERENCES

Bauer, P.J., and W.J. Busscher. 1996. Winter cover and tillage influences on coastal plain cotton production. J. Prod. Agric. 9:50-54.

Bradley, J.F. 1995. Overview of conservation tillage on cotton production in the mid-south. p. 200-203. *In* D.A. Richter and J. Armour (ed.) Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Breitenbeck, G.A., and R.L. Hutchinson. 1994. Influence of tillage and winter cover crops on nitrogen status of cotton. p.50-55. *In* P.J. Bauer and W.J. Busscher (ed.) Proc. Southern conservation tillage conference for sustainable agriculture. Columbia, SC. 7-9 June 1994. Coastal Plains Soil, Water, and Plant Research Center, Florence, SC.

Clark, A.J., A.M. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. Agron. J. 86:1065-1070.

Denton, P., and D.D. Tyler. 1994. Surface residue cover in no-till cotton. p. 40-44. *In* P.J. Bauer and W.J. Busscher (ed.) Proc. Southern conservation tillage conference for sustainable agriculture. Columbia, SC. 7-9 June 1994. Coastal Plains Soil, Water, and Plant Research Center, Florence, SC.

Holderbaum, J.F., A.M. Decker, J.J. Meisinger, F.R. Mulford, and L.R. Vough. 1990. Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron. J. 82:117-124.

Meisinger, J.J., W.L. Hargrove, R.L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. p. 57-68. *In* W. L. Hargrove (ed.) Cover crops for clean water. Jackson, TN. 9-11 Apr. 1991. Soil Water Conserv. Soc., Ankeny, IA.

Moseley, D.W., D. Azevedo, J.A. Landivar, and R. Vieira. 1996. The effect of cover crop and crop rotation on cotton: plant growth and yield. p. 1410-1414. *In* P. Dugger and D.A. Richter (ed.) Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Munawar, A., R.L. Blevins, W.W. Frye, and M.R. Saul. 1990. Tillage and cover crop management for soil water conservation. Agron. J. 82:773-777.

Natural Resource Conservation Service. 1992a. Practice standard. Conservation tillage. Code 329. NRCS Field Office Technical Guide, November 1992. Natural Resource Conservation Service. Virginia.

Natural Resource Conservation Service. 1992b. Practice standard. Crop residue use. Code 344. NRCS Field Office Technical Guide, November 1992. Natural Resource Conservation Service. Virginia.

SAS, 1993. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

Smart, J.R., and J.M. Bradford. 1996. No-tillage and reduced tillage cotton production in south Texas. p. 1397-1401. *In* P. Dugger and D.A. Richter (ed.) Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Stevens, G., B. Phipps, and J. Mobley. 1996. Managing cotton for reduced wind damage with ridge till systems. p. 1403-1405. *In* P. Dugger and D.A. Richter (ed.) Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Thompson, J.M., and J.J. Varco. 1996. Fertilizer N and legume cover crop management effects on no-till cotton production. 1996. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Council, Memphis, TN.