The *Journal of Cotton Science* 3:84-91 (1999)
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AGRONOMY

Winter Annual Cover Crops in a Virginia No-till Cotton Production System: II. Cover Crop and Tillage Effects on Soil Moisture, Cotton Yield, and Cotton Quality

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INTERPRETIVE SUMMARY

Although cotton (*Gossypium hirsutum* L.) is taprooted and considered drought tolerant, a certain amount of moisture is critical for producing high yielding, good quality cotton. Cotton stressed by drought can result in yield decreases due to reduced size and production of sympodial leaves. Conservation tillage leaves a significant amount of surface residue which can conserve soil moisture. Several studies have shown that the different plant residue physical characteristics, such as thickness and surface coverage, can result in differences in water conserving ability of the plant residue.

A field study was conducted during the 1995, 1996, and 1997 growing seasons at the Southern Piedmont Agricultural Research and Extension Center, in Blackstone, VA, to determine the effects of cover crops and tillage systems on soil moisture, cotton yield, and cotton quality under central Virginia Piedmont soil and climate conditions. Due to delayed cotton maturity in 1997, data for yield and quality was not reported. Two tillage practices (conventional and no-till) and six cover crop treatments (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.) were used. 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 The cotton cultivar Deltapine 50 was planted using a four-row no-till planter equipped with fluted coulters to cut through surface residue followed by double disk openers to make a furrow for the seed, and press wheels to firmly cover the seed. Volumetric soil moisture was measured in each plot of the first two experimental replications in 1996 and 1997, to monitor differences in soil moisture under tillage systems (conventional vs. no-till) and cover crop treatments.

Did tillage and cover crop help conserve soil moisture throughout the cotton growing season?

Results from the 1996 growing season indicated no difference in soil moisture by tillage or cover crop treatment, on any given date or soil depth. Treatment effects may have been minimized by low biomass production of cover crops and greater-than-average rainfall early in the growing season. In 1997 however, at the 6, 12, and 24 inch depths soil moisture was higher under no-till compared with conventional tillage. The no-till system had 2.0, 2.4, and 1.9 % higher soil moisture compared with conventional tillage at the 6, 12, and 24 inch depths, respectively. The rye treatment had higher soil moisture compared with crimson clover, wheat, and lupin. Furthermore, the no-till rye cover crop treatment had the highest soil moisture of all other cover crop treatments from pinhead square through the first 3 wk of the cotton flowering period . The rye cover crop treatment produced more biomass than all the other cover crop treatments with the exception of hairy vetch + rye.

Did cover crop and tillage affect the yield and quality of cotton?

Cotton lint yield was not affected by tillage system in 1995 or 1996. The cotton yield following hairy vetch + rye, a small grain/legume cover crop mixture, was higher than the wheat treatment in 1995. The increase in cotton lint yield, following a small grain/legume mixture may be attributed to increased N availability to the following cotton crop. In 1996 cotton lint yields were not different by cover crop treatment. The cover crop effects

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were minimized due to low biomass production for all cover crops over the winter of 1995–1996. Tillage system had no effect on cotton fiber quality in 1995 or 1996. Although differences occurred in length and uniformity for certain cover crops, the measured values for each of these parameters did not affect market price.

ABSTRACT

Winter annual cover crops could help control soil erosion problems on sloping Piedmont soils in a no-till cotton (*Gossypium hirsutum* L.) production system. Field experiments were conducted from 1995 to 1997 to monitor the effects of winter annual cover crops in a no-till cotton production system on soil moisture, cotton yield, and cotton quality using the variety Deltapine 50. 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. Volumetric soil moisture was measured at 15, 30, 61, and 92 cm depths every 7 to 10 days during the 1996 and 1997 cotton growing seasons. Cotton was hand picked, weighed, and ginned for lint yield determination. Sub-samples of the ginned cotton from each plot were analyzed for quality (length, uniformity, strength, and micronaire). Soil moisture results indicated that no-till plots had higher soil moisture compared with conventional tillage during periods of drought in 1997. The no-till rye treatment conserved more soil moisture than any other cover crop treatment from pinhead square through the first three weeks of cotton flowering at the 15 cm depth. Cotton yield and quality were not affected by tillage system. However, the hairy vetch + rye cover crop treatment had higher cotton lint yields during 1995, compared with the wheat cover crop treatment, probably due to N immobilization by the wheat residue. Although differences occurred between cover crop treatments for the different quality parameters during 1995 and 1996, the market value of lint was only affected by micronaire in the 1995 growing season. High micronaire measurement for cover crop treatments in 1995 resulted from unseasonable heat unit accumulation in October and over maturity of the cotton fiber. Using winter annual cover crops in a no-till cotton production system provides greater soil moisture conservation during periods of drought, while producing lint fiber of similar yield and quality compared with a conventional tillage system.

Although cotton is taprooted and considered drought tolerant, an adequate supply of soil water is still critical for producing high yielding, good quality cotton. Stored soil moisture often limits yield of dryland cotton (Azevedo et al., 1996). Drought stress on cotton has been linked to yield decreases due to reduced size and production of sympodial leaves, in addition to reduced photosynthetic rates. Drought stress limits the amount of photosynthetic assimilate available for plant growth (Krieg, 1997). By using a no-till system, surface residue can be managed to better conserve soil water for greater use efficiency by the cotton plant (Hill and Blevins, 1973).

Water withdrawal is different under a no-till system, compared with a conventional tillage system (Blevins et al., 1971). Naderman (1991) reported that surface residue potentially increases infiltration of water into the soil by 25 to 50% under no-till compared with a conventional tillage system. In addition, cover crop surface residue decreases the effect of wind and temperature on soil water evaporation and increases water storage in the soil profile (Brun et al., 1986; Smart and Bradford, 1996).

Unger and Parker (1976) concluded that wheat straw was four times better than cotton residue for decreasing evaporation from the soil. The different physical characteristics of the wheat straw including specific gravity, thickness, and surface coverage were given as the reasons for the differences in the water conserving ability of the residues (Unger and Parker, 1976).

Burnett and Fisher (1954) reported that moisture is needed in the top 30 cm of soil for crop establishment, but cotton yields are more directly correlated with moisture stored between 30 and 90 cm below the soil surface. Water availability between pin head square and first flower (FF) influences the maximum boll load capacity of the cotton crop (Lawlor et al., 1992). With conventional tillage, the soil surface is unprotected and vulnerable to moisture evaporation from the beginning of the growing season until the cotton canopy closes the rows. By using cover crops to maximize ground cover, the ratio of soil water evaporation to crop transpiration decreases. With increased soil moisture reserve, cotton may endure short-term, low-rainfall conditions without detrimental effects (Blevins et al., 1971). Previous research concluded that use of cover crops in a reduced tillage production system increased available soil water and led to higher lint yields compared with conventional tillage systems (Lawlor et al., 1992). Regardless of moisture conservation other researchers have continually found that the combined effect of cover crops and conservation tillage maintains or increases cotton yields compared with conventional tillage (Bloodworth and Johnson, 1995; Boquet et al., 1994). In addition, Bauer and Busscher (1996) found that cotton lint quality was not affected by tillage system or winter cover, but a 0.1 decrease in micronaire was observed in cotton following rye compared with legumes.

The objectives of this study were to determine the effects of cover crops and tillage systems on soil moisture, cotton yield, and lint quality under central Virginia piedmont soil and climate conditions.

MATERIALS AND METHODS

A field study was conducted during the 1995, 1996, and 1997 growing seasons at the Southern Piedmont Agricultural Research and Extension Center, in Blackstone, VA. We had emergence problems in 1997, and an adequate cotton stand was obtained only after the third planting. This delayed maturity to the point where the cotton bolls failed to open, reducing yield. Thus, data for yield and quality will be reported only for 1995 and 1996, while soil moisture data will be reported for the 1996 and 1997 growing seasons. 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, kaolinitic, thermic Plinthic and Typic Kandiudults) 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 and 1.1 m between the rows. The cover crop treatments were crimson clover, hairy vetch, hairy vetch and rye, rye, wheat, and white lupin.

About 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 2.24 kg ha^{-1} glyphosate. The no-till plots received an additional burndown herbicide application when it was needed (Daniel et al., 1999). The cotton cultivar Deltapine 50 was planted 1 wk after the second burndown application, at the rate of 16.4 seeds m^{-1} of row. Cotton was planted using a 4-row no-till planter equipped with fluted coulters to cut through surface residue followed by double disk openers to make a furrow for the seed, and press wheels to firmly cover the seed.

At planting, aldicarb (granular insecticide) and metalaxyl (granular fungicide) were applied in-furrow at 5.6 and 11.2 kg ha^{-1}, respectively. Fertilizer N, P, K, and B according to soil test recommendations was broadcast on no-till plots and disked into conventional tillage plots. Standard production management practices were conducted throughout the cotton growing season each year.

Volumetric soil moisture was measured in each plot of the first two experimental replications in 1996 and 1997, to monitor differences in soil moisture under the two tillage systems and the cover crop treatments. The measurements were taken with the Troxler Sentry 200-AP soil moisture probe, operated from a permanent access tube (Troxler Electronic Laboratories Inc., 1991). Access tubes were constructed from Schedule 40 PVC pipe that had an inside diameter of 5.22 cm and an outside diameter of 6.03 cm. Access tubes were cut 1.22 m long, and sealed on the bottom with an inside-diameter plastic plug and PVC glue. The access tubes were inserted tightly into a newly augured hole, with 15 cm of the tube extending from the soil surface. Once all the access tubes had been installed, volumetric soil moisture measurements were taken at the 15, 30, 61, and 92 cm depths every 7 to 10 d from the day of cotton planting until the middle of the cotton flowering period.

For reliable soil moisture readings the Sentry 200-AP moisture probe was calibrated to the specific soils in the experiment area using a procedure was based the technique of Khosla and Persaud (1997). The probe was calibrated to within 2.56% accuracy for 1996 and 0.37 % accuracy for 1997. Reproducibility of the instrument was high based on repeated measurements at the same depth that showed little or no drift in the measurement.

Data will be presented for all the measurements and three moisture measurement dates chosen to match critical periods in the growth stage of the cotton plant when moisture availability could affect stand establishment, fruit development, maturity, and overall cotton yield. The dates analyzed in 1996 were 20 May, 1 July, 5 August. In 1997 those dates were 27 May, 2 July, and 7 August. Each year the moisture data were analyzed separately by depth (15, 30, 61, and 92 cm), on each date to determine the effect of tillage and cover crop treatment on soil moisture.

About 2 wk prior to the estimated harvest date the cotton was defoliated each year (Tables 3, 4, and 5). On 12 Oct. 1995 and 14 Nov. 1996, a 2.43 m length of row was harvested by hand from one of the middle rows in each plot. The number of plants and open bolls were counted in each section of row harvested. Subsamples of the harvested cotton were ginned for lint yield determination and analyzed for quality. The cotton fiber quality (length, uniformity, strength, and micronaire) was analyzed by the USDA laboratory in Florence, SC. (USDA, 1995).

Data analysis

Analysis of variance was calculated using the SAS software package (SAS Institute, 1993). Effects of treatment (cover crops and tillage), depth, field block, date (when needed), year, and all 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

Soil Moisture

Results from the 1996 growing season indicated no difference in soil moisture by tillage or cover crop treatment on any given date or soil depth. Treatment effects may have been minimized by low biomass production of cover crops (319–968 kg ha^{-1}) in 1996. Also, higher-than-average rainfall during May, and July (Fig. 1) likely reduced the differences in soil moisture between conventional and no-tillage systems.

Similarly to 1996 data, in 1997 tillage did not have an effect on soil moisture (Fig. 2 [May] and 3 [July]) with the exception of the period prior to cotton flowering (Fig. 4 [August]). Tillage system affected soil moisture 1 wk after first flower (7 Aug) in 1997. At the 15, 30, and 61 cm depths, soil moisture was higher under no-till compared with conventional tillage (Fig. 4). The no-till system had 2.0, 2.4, and 1.9 % higher soil moisture compared with conventional tillage at the 15, 30, and 61 cm depths, respectively (Fig. 4). Similar results were obtained by Lawlor et al. (1992) who reported higher soil moisture under conservation tillage

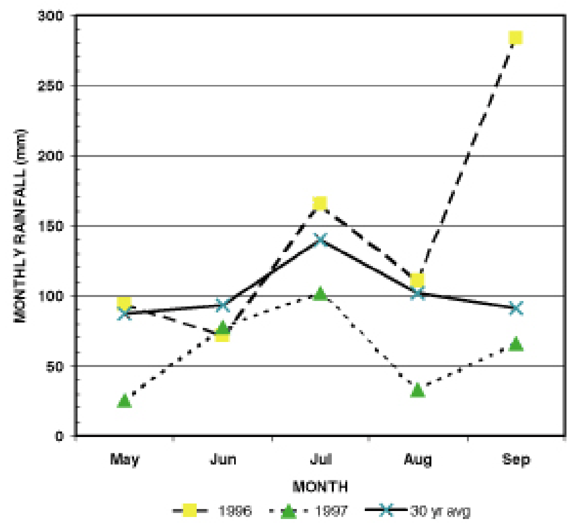

Fig. 1. Monthly rainfall totals for May through September during the 1996 and 1997 growing seasons, and the 30-yr average.

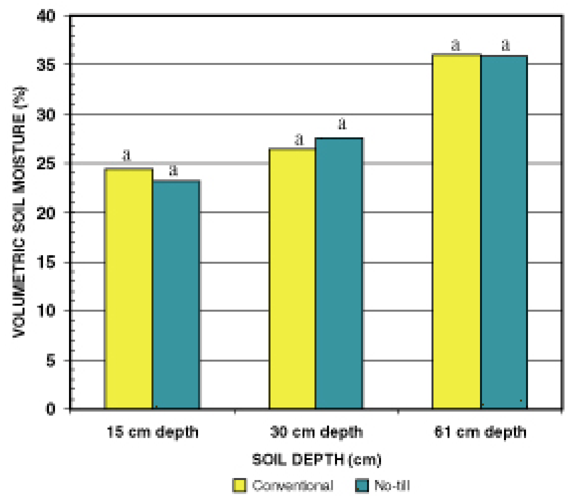

Fig. 2. Soil moisture percent under conventional tillage and no-tillage at the 15, 30, and 61 cm depth 2 d before planting (27 May) during the 1997 growing season. Means for bars within depths followed by the same letter are not significantly different *P* = 0.05 (Duncan's multiple range test).

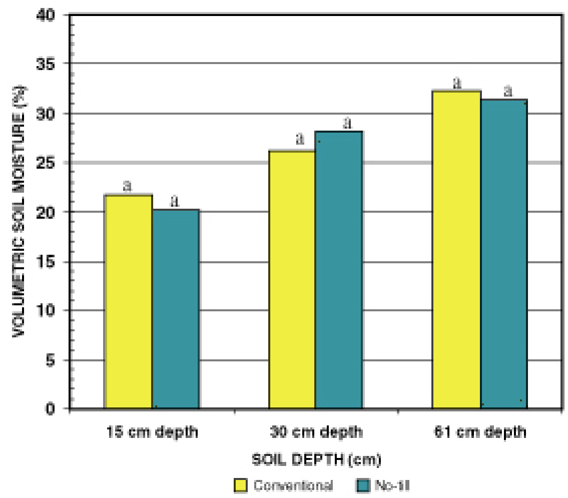

Fig. 3. Soil moisture percent under conventional tillage and no-tillage at the 15, 30, and 61 cm depth at cotton square (2 July) during the 1997 growing season. Means for bars within depths followed by the same letter are not significantly different *P* = 0.05 (Duncan's multiple range test).

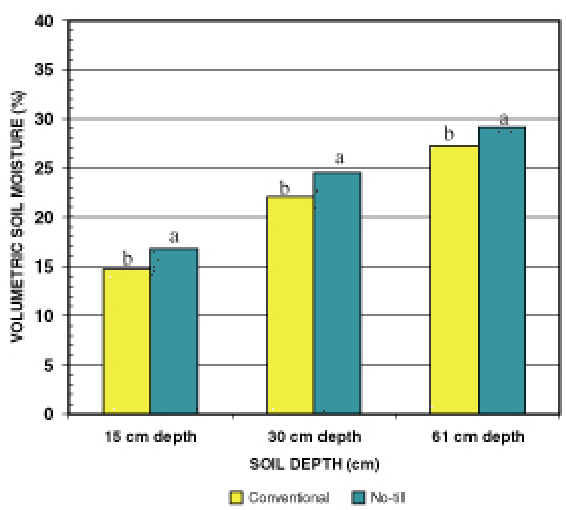

Fig. 4. Soil moisture percent under conventional tillage and no-tillage at the 15, 30, and 61 cm depth 1 wk after first flower (7 Aug) during the 1997 growing season. Means for bars within depths followed by the same letter are not significantly different *P* = 0.05 (Duncan's multiple range test).

compared with conventional tillage. The high percentage soil moisture reported in this study for the no-till system could be attributed to the presence of a surface residue that probably resulted in higher rainfall infiltration and decreased soil water evaporation.

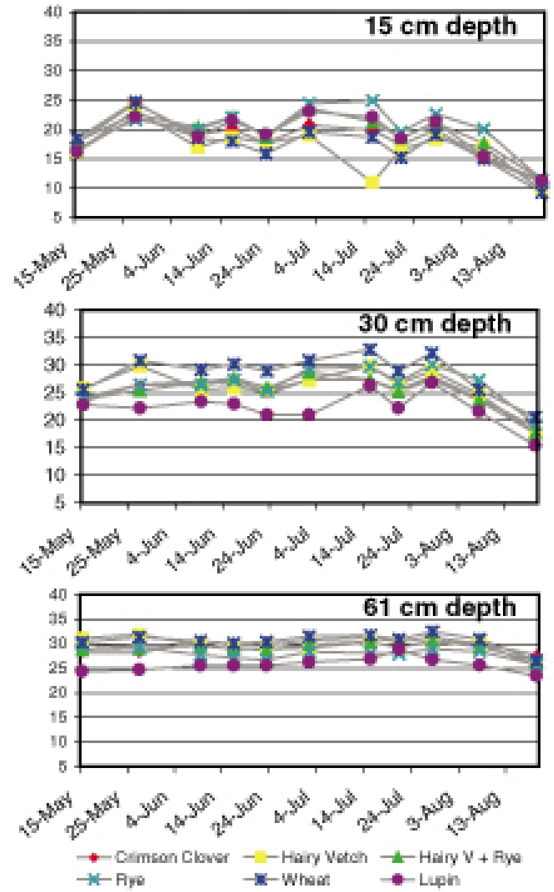

Fig. 5. Soil moisture percent measured between 15 May and 19 August during the 1997 cotton growing season at the 15, 30 and 61 cm depth under no-tillage for all cover crop treatments.

In 1997, where significantly more cover crop biomass was produced compared with 1996, effect of cover crops on soil moisture was evident. Figure 5 shows the effect of cover crops under no tillage system at the 15, 30 and 61 cm depths.

Soil moisture was higher by cover crop treatment under no-tillage at the 15 and 30 cm depth (Fig. 5). The rye treatment had higher soil moisture compared with crimson clover, wheat, and lupin. Furthermore, the no-till rye cover crop treatment had the highest soil moisture of all other cover crop treatments from pin head square (2 July) through the first 3 wk of the cotton flowering period (19 Aug) at the 15 cm depth (Fig. 5). Wheat had a similar effect on moisture at the 30 cm depth. No effect of cover on moisture was observed at 61 cm depth.

Table 1. Split block analysis of variance(ANOVA) from 1995 and 1996 for cotton lint yield.

Source of Variation	df	Mean squares Lint yield
Year (Y)	1	3 308 522.7**
Replication (R) (year)	6	1 999 427.4**
Treatment (T)	5	48 148.6
Y × T	5	58 527.0**
R × T (year) (Error a)	30	75 631.0
Till	1	106 071
Y × till	1	1 933.8
R × till (year) (Error b)	6	132 626.9
T × till	5	23 294.5
Y × T × till	5	27 724.9

*, ** Significant at $P = 0.05$ and 0.01, respectively.

Although the cotton plant needs adequate moisture throughout the growing season, drought can affect the cotton yield and quality negatively if it occurs during the fruiting period. It has been reported that drought following bloom has the greatest affect on cotton yield and quality more than any other time during cotton growth and development.

The greater moisture-conserving ability of rye, compared with the other cover crop treatments, could be due to the amount and physical characteristics of the residue. The rye cover crop treatment produced more biomass than all the other cover crop treatments with the exception of hairy vetch + rye. In addition, the rye cover crop treatment reached a mature growth stage, which may have resulted in a high C:N ratio of the straw residue.

Unger and Parker (1976) explain that residue specific gravity, thickness, and surface coverage differ by type of residue, which alters the potential moisture evaporation from the soil. The conserved soil moisture in the no-till system throughout the cotton fruiting and flowering period could have potentially increased cotton yield in 1997. However, due to the late planting date and delayed cotton maturity in 1997 we were not able to obtain yield for the 1997 growing season.

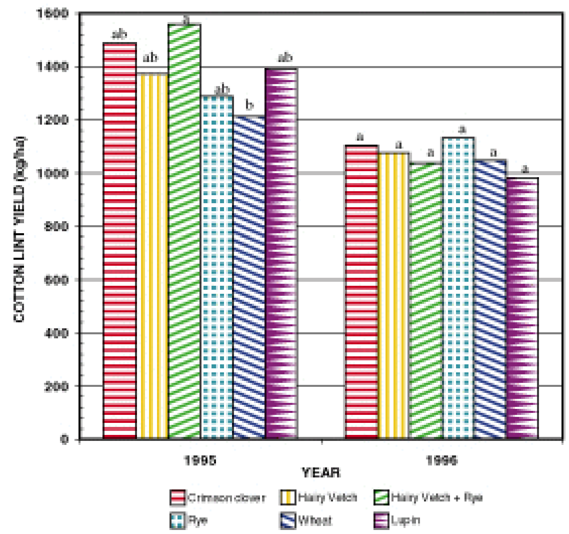

Fig. 6. Cotton lint yield by cover crop treatment for the 1995 and 1996 growing seasons. Means for bars within years followed by the same letter are not significantly different *P* = 0.05 (Duncan's multiple range test).

Cotton Yield

Although no year-by-treatment interaction was observed (Table 1) in the cotton yield analysis, due to extreme yield differences between the two years (1995 and 1996) data is shown separately by year. Since no tillage-by-cover crop treatment interaction was observed for 1995 and 1996, cotton lint yield was averaged across tillage systems. Lint yield differed among cover crop treatments in 1995, but in 1996 no cover crop treatment effects were observed (Fig. 6).

The cotton yield following hairy vetch + rye, a

Table 2. Cotton lint quality (length, uniformity strength and micronaire) by cover crop treatment for the 1995 and 1996 growing seasons.

	HVI							
	------------------ 1995 --------------------				-----------------1996 --------------------			
Cover Crops	Length, in.	Uniformity	Strength	Micronaire	Length	Uniformity	Strength	Micronaire
			g/tex		1/100 of in.		g/tex	
Crimson clover	112.6a†	83.8ab	30.9a	5.2a	112.6b	83.3a	27.1a	4.2a
Hairy vetch	114.5a	83.6b	31.2a	5.0ab	115.3a	83.5a	26.7a	4.0a
Hairy vetch + rye	115.4a	84.0ab	30.9a	4.9b	115.8a	83.8a	26.8a	3.9a
Rye	115.3a	84.4a	31.1a	5.2ab	114.0ab	82.9a	26.3a	3.9a
Wheat	114.9a	84.3ab	30.9a	5.2a	114.1ab	83.0a	26.8a	4.0a
Lupin	114.5a	83.8ab	30.7a	5.2ab	114.8ab	83.3a	26.9a	3.8a

† Means in a column within years followed by the same letter are not significantly different P = 0.05 (Duncan's multiple range test).

small grain/legume cover crop mixture, was higher than the wheat treatment in 1995 (Fig. 6). The increase in cotton lint yield, following a small grain/legume mixture may be attributed to increased N availability to the following cotton crop. For maximum utilization of legume N by the cotton crop, mineralization of legume N must occur at the same time or prior to crop N uptake. The timing of N mineralization by the hairy vetch + rye mixture may differ from the other cover crop treatments, and correspond better to the uptake of N by the cotton. Ranells and Wagger (1997) researched the use of a small grain/legume cover crop combination and reported that the C:N ratio of <30 allowed for N additions to the following summer annual crop. Sullivan et al. (1991) stated that small grain cover crops have higher C:N ratios leading to persistent surface residues potentially immobilizing soil N. The findings by Ranells and Wagger (1997) and Sullivan et al. (1991) help to explain the decrease in cotton lint yield under the wheat cover crop treatment compared with the hairy vetch + rye cover crop treatment in 1995.

In 1996 cotton lint yields were not influenced by cover crop treatment. The cover crop effects were minimized due to low biomass production for all cover crops over the winter of 1995/1996. Furthermore, above average rainfall during May, July, and August (during the periods of cotton planting, fruiting, and flowering) provided abundant moisture for the entire test site.

Cotton Quality

Cotton quality data from the 1995 and 1996 growing seasons are reported separately by year due to year-by-treatment interactions for some of the fiber quality parameters. Cover crop treatments did not affect fiber length in 1995 (Table 2). However in 1996, the fiber length in the hairy vetch + rye and hairy vetch cover crop treatments were higher than the crimson clover treatment. Similarly, fiber strength and uniformity were not affected by cover crops for both 1995 and 1996 growing season. (Table 2).

Fiber micronaire measurements of less than 3.5 or more than 5.0 units are discounted in value. In 1995, cotton produced on all cover crop treatments except hairy vetch + rye had micronaire values between 5.0 and 5.2 units (Table 2). These high micronaire measurements resulted in a price deduction of 1.4 cents per kilogram of lint. In 1996, micronaire was not different across cover crop treatments (Table 2) and all micronaire values were in the premium range (3.7 to 4.2 units).

CONCLUSIONS

Many factors contributed to the effects of cover crop treatments and tillage systems on soil moisture throughout the cotton growing season. Yearly differences in soil moisture were dependent on cover crop growth over the winter and rainfall throughout the cotton growing season. In 1996, cover crops and tillage systems had no effect on soil moisture at any given date or soil depth. Low biomass production of all cover crop treatments and above average rainfall during the cotton growing season, contributed to minimal soil moisture differences between cover crop treatments and tillage systems. Soil moisture in the no-till system was higher compared with the conventional tillage system at the 15, 30, and 61 cm depth 1 wk after first flower. As the season progressed and the soil became increasingly droughty, the no-till rye cover crop treatment conserved more soil moisture at the 15 cm depth compared with all the other treatments until 19 August.

Cotton lint yield was not affected by tillage system in 1995 or 1996. However, in 1995 cotton lint yield was affected by cover crop treatments. In 1995, cotton grown in the hairy vetch + rye treatment had greater lint yield compared with cotton grown in the wheat cover crop treatment. The difference in lint yield was possibly related to the wheat cover crop treatment immobilizing soil N.

Tillage system had no effect on cotton fiber quality in 1995 or 1996. Although differences occurred in length and uniformity for certain cover crops, the measured values for each of these parameters did not affect market price. Micronaire measurements in 1995 for cotton grown in crimson clover and wheat residue were higher than cotton grown in hairy vetch + rye residue. The hairy vetch, rye, and lupin treatments did not differ. All treatments except hairy vetch + rye had cotton fiber micronaire readings between 5.0 and 5.2, which resulted in a market price reduction of 1.4 cents per kilogram of lint. However, unseasonably high heat unit accumulation in October of 1995 may have contributed more to the over maturity of cotton fiber and high micronaire measurements than did the cover crop treatments.

In conclusion, the presence of a cover crop residue in a no-till cotton production system provides greater soil moisture conservation, compared with a conventional tillage system, during seasons of low rainfall. In addition, the no-till rye cover crop treatment conserves more soil moisture at the 15-cm depth during periods of short-term drought, compared with the other cover crop treatments. Cotton lint yield and quality was not affected by tillage system. Cotton lint yield was affected by cover crop treatment in 1995 when the cover crop treatments produced large amounts of biomass. Cover crop treatments caused minor differences in cotton quality, however the differences were not enough to result in a market price deductions. The market price deduction in micronaire for 1995 may be more related to climate than cover crop treatment.

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