TILLAGE EFFECTS ON COTTON AND FLAX

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ABSTRACT

The purpose of this study was to determine if various tillage and sub-soiling techniques were detrimental or beneficial to winter flax (*Linum usitatissimum L.*) yields under South Carolina conditions. Flax was double-cropped with cotton. Subsoiling increased the cotton and flax yield which is similar to findings for other crops on southeastern USA Coastal Plain soils. Cotton yields were not influenced by tillage treatment while flax dry plant matter yields were significantly greater for chisel and disk treatments than for no tillage. For the fiber properties studied, micronaire, fiber length, and fiber length uniformity of cotton along with flax fiber strength were impacted by the tillage management studied. Cotton fiber properties are such that conservation systems appear to be a viable option for growers due to fiber property improvements. Fiber flax yield and fiber properties indicate additional field preparation may be required to produce increased yields with improved fiber properties. Our results indicate that conservation tillage practices can be beneficial for cotton production under Florence, SC growing conditions but additional research on improved techniques is needed for the production of fiber flax with this management practice.

INTRODUCTION

Flax (*Linum usitatissimum L.*) is a dual purpose crop from which seed and fiber can be removed at varying degrees depending upon its agricultural production (Parks et al., 1993). Compared to flax grown for seed, fiber flax plants are taller, have fewer branches, produce more fiber, have lower oilseed content and produce less seed (Anonymous, 1992). Long growing seasons and production of flax as a winter crop allows the land to be utilized for cotton and flax fiber, thereby providing growers two fiber crops. There are limited studies, however, related to flax double-cropped with cotton (Bauer and Frederick, 1997) and physical properties of flax fiber related to soil conditions (Elhaak et al., 1999).

Soil nutrients are known to affect fiber quality (Mikhailova, 1975, Tarent'ev et al., 1976, and Hocking et al., 1987). Southeastern Coastal Plain soils typically have a shallow soil layer with coarse texture that limits root depth and lowers water storage so that deep tillage is recommended to boost available water and avoid yield reductions in drought (Camp et al., 1999).

Seed flax grows well in reduced tillage with flax yields equal or much higher than in conventional tilled plots (Gubbels and Kenaschuk, 1989, Brandt, 1992, Lafond, 1993). Tillage affects cotton fiber quality and yield inconsistently as an indirect response due to a shift in the growing season relative to conventional tillage (Pettigrew and Jones, 2001, Bauer and Frederick, 2005). No-till produces cotton fibers with higher fiber length uniformity and may help reduce cotton bale variability (Bauer and Frederick, 2005). Bauer and Frederick (2005) indicate that tillage management may control canopy position specific property distribution. Little is known about the impact of tillage or sub-soiling on the quality or variability of flax fiber quality.

The purpose of this study was to evaluate the production of cotton and flax in consecutive harvests under various tillage and subsoiling techniques. Further, yields and properties of cotton and winter flax fibers under South Carolina conditions were determined for the various tillage techniques.

MATERIALS AND METHODS

'Laura' flax was grown in northeastern South Carolina as a winter crop. Flax was planted at seeding rates of 100 lb ac^{-1}. This variety was selected for this study because of its potential as a dual crop for both seed and fiber. Plots were planted in the fall of 2001-2002 and 2002-2003 in Darlington County at the Pee Dee Research and Education Center located near Florence, SC (latitude 34^o 17' North and longitude 79^o 41' West). Soil was Eunola loamy sand (fine-loamy, siliceous, thermic Aquic Hapludult), and the previous summer crop was cotton. The sixteen plots were irrigated with subsurface alternate furrow drip irrigation (Geoflow Rootguard, Corte Madera, CA). Laterals had in-line labyrinth emitters 2 ft apart that delivered 0.45 gal hr^{-1} of water. Flax was planted using a John Deere 750 No-Till Drill (Deere & Company, Moline, IL). Treatments were arranged as a randomized complete block of sixteen plots with four replications. Plots were 50 ft long and 25 ft wide. Rows were spaced at 8 in.

The studies were carried out in plots located adjacent to each other, and each plot received different land preparation. Soil surface tillage treatments included: 1.) no tillage, 2.) disking the soil twice to a depth of 6 in then smoothed with a harrow equipped with s-shaped tines and rolling baskets, and 3.) chisel plowing with a 7 ft wide seven shank KMC chisel (Kelly Manufacturing Co., Tifton, GA) to a depth of 8 in, disked twice to a depth of 6 in and then smoothed with a harrow equipped with s-shaped tines and rolling basket. For each of these three techniques, sub-soiling was either not done or performed to a depth of 16 in with a KMC (Kelly Manufacturing Co., Tifton, GA) straight 45 degree forward angled subsoiler shanks spaced 3 ft apart.

Surface tillage and subsoiling treatments before planting cotton were performed on May 31 in 2001 and May 14 in 2002. Cotton (variety DP 458BRR) was planted in 38 in wide rows at 4 plants per ft on June 4, 2001 and May 15, 2002 using a 4 row Case-IH 900 series planter (Case IH, Racine, WI) equipped with Yetter wavy coulters (Yetter Manufacturing, Colchester, IL). A pre-plant fertilizer application (58 lb ac^{-1} P_2O_5, 100 lb ac^{-1} K_2O, 10 lb ac^{-1} S, and 0.5 lb ac^{-1} B was made on March 19, 2001. Nitrogen as ammonium nitrate (120 lb ac^{-1} in 2001 and 80 lb ac^{-1} in 2002) was applied in a split application each year with 40 lb ac^{-1} applied at planting and the rest about a month later when plant had their first flower buds. Each year weeds were controlled with hand weeding and a combination of herbicides (Pendimethalin [0.8 lb ac^{-1}], Fluometuron [1.0 lb ac^{-1}], Glyphosate [1.0 lb ac^{-1}], Prometryn [0.5 lb ac^{-1}], Sethoxydim [1.2 lb ac^{-1}], and Monosodium methyarsonate [2.0 lb ac^{-1}]). In mid to late October, cotton was chemically defoliated with thidiazuron (N-phenyl-N-1,2,3-thiadazol-5-urea) and S,S,S-tributyl phosphorotithioate, and bolls were opened with ethephon [(2-chloroethyl) phosphonic acid] at the recommended rates each year. Plots were harvested on November 7, 2001 and October 28, 2002. Two interior rows were harvested using a two-row spindle picker for seed cotton yield.

After harvest, plants located within interior rows were counted. Each harvest bag was sub-sampled and saw-ginned to determine lint yield. Fiber qualities were graded according to HVI techniques (ASTM International, 1993)

After cotton harvest, cotton stalks were shredded in the field. In 2001-2002, fertilizer (7-21-32) was applied on November 13 at a rate based upon soil test results and Clemson University Cooperative Extension Service recommendations for small-grain production, applying 20 lb nitrogen, 60 lb P_2O_5, and 90 lb K_2O per ac. Tillage treatments were performed before planting flax on November 19 with sub-soiling performed on November 20. Planting date was November 27. On February 15, all plots received 60 lb N ac^{-1} applied as ammonia nitrate. Bromxynil herbicide was applied at a rate of 0.5 lb a.i. ac^{-1} on March 8. Flax stands were drip irrigated with 0.25 in of water on April 19 and April 22. Flax stand was cut with a drum mower on May 1 at the onset of flowering for straw yield. Dried flax stalks were harvested on May 8 using a rectangle baler. Samples were bagged, dried at 160 ^{o}F for 48 hours, and weighed.

In 2002-2003, 1000 lb ac^{-1} of dolomitic limestone to reduce soil acidity along with fertilizer (7-21-32) was applied on October 30 at a rate based upon soil test results and Clemson University Cooperative Extension Service recommendations for small-grain production, applying 20 lb nitrogen, 60 lb potassium, and 90 lb phosphorous per ac. Tillage and sub-soiling treatments were performed on selected plots on October 31. Planting date was Nov 4. On February 15, all plots received 66 lb N ac^{-1} applied as ammonia nitrate. Bromxynil herbicide was applied at a rate of 0.5 lb a.i. ac^{-1} on March 5. Flax was harvested on May 7 at the onset of flowering for straw yield. Samples were bagged, dried at 160 ^{o}F for 48 hours, and weighed.

Flax stalks were collected and transported to the Cotton Quality Research Station, ARS-USDA, Clemson, SC, where the bast fibers were released from the stem by a process termed dew-retting in which indigenous fungi and bacteria colonize and partially decompose the plant stems of flax. Following dew-retting the plant stalks were processed through the typical set-up for the USDA Flax Fiber Pilot Plant (Flax-PP) according to Foulk et al. (2004). These modules are 32 in rather than 48 in (commercial line) and built under specifications of the commercial ‘Unified Line’, which was delivered by Czech Flax Machinery, Měřín, Czech Republic (Akin et al., 2004). The components comprising the USDA Flax Fiber Pilot Plant are the following: a 9-roller crushing calender, top shaker, scutching wheel, and 5-roller calender. Flax-PP fiber yield is the percent of fiber separated from the dew-retted flax stalks.

Flax-PP cleaned fibers maintain their length through processing and require cottonizing (fiber length and fineness comparable to cotton) for textile applications. The Shirley Analyzer (SDL America, Charlotte, NC) shortens flax fibers and separates foreign matter and coarse fibers from the finer fibers (Pfeiffenberger, 1944). Fine fiber yield is the percent of fine fiber separated from the Flax-PP cleaned fiber. Shirley-cleaned fibers were analyzed for strength and elongation using the Stelometer, based on the methods developed for cotton (ASTM International, 1999a), and for fineness using air flow, based on the micronaire (ASTM International, 1999b) that was modified to use 5.0 g fiber samples based on calibration with flax fineness standards from the Institut Textile de France, Lille, France (Akin et al., 1999).

RESULTS AND DISCUSSION

In the southeastern USA, conservation tillage systems are being widely used for cotton production and other crops. Subsoiling allows plants to more easily penetrate the soil and locate water as well as nutrients. Soil strength appears to limit rooting depth, development, and irrigation effects (Camp et al., 1999). In this study, differences for the fiber properties and yield existed between years. The yield and fiber quality responses to tillage were similar for both years as no year X tillage interactions were significant in any year of the study. Therefore, data presented are averaged over years. The effect of subsoiling, determined by combining the three tillage techniques for subsoiling or not, was to increase lint yields for cotton and plant yields for flax (Tables 1 and 3). Combining all tillage techniques, the only significant difference (at the 0.05 level) observed in subsoil treatments for cotton production was the cotton yield which was larger (967 vs. 850 lb lint/ac) with subsoiling. Combining all tillage techniques, at the 0.1 level, flax dry plant matter yields (Table 3) were significantly higher with subsoil treatment (1933 vs. 1534 lb plant matter/ac) as were the fiber yields from the Flax-PP (24 vs. 22%). Flax-PP yield is a percent of straw processed through Flax-PP and not based on straw per acre. These results indicate that we can extract the same amount of fiber from straw, regardless of tillage. Yearly subsoiling is typically recommended for Coastal Plain soils (Threadgill, 1982) and provides increased yields of corn, soybean, and wheat (Frederick et al., 1998 and Busscher et al., 2000). Busscher and Bauer (2003) note that omitting deep tillage from management for 2 years may be a viable wide row cotton production practice for fields with controlled traffic. Nevertheless, subsoiling continues to be an option that could increase cotton lint and dry fiber flax plant matter yields.

Cumulative water applied to cotton and fiber flax plants through irrigation plus rainfalls in both years were nearly the same. Equivalent water was applied to each crop but soil treatments varied the soil and surface residue on the soil which may have impacted the plant's rate of water and nutrient uptake and resultant fibers. However, cotton plant population, lint turnout, and lb of cotton per ac were not influenced by tillage treatment (Table 2). Flax dry plant matter yield was significantly larger for disk treatment than for no till treatment (Table 4). This difference in dry plant matter yield did not correlate to increased Flax-PP fiber yields nor increased fine fiber yields from passage through a Shirley Analyzer. Fine fiber yield is a percent of fine fiber separated from the Flax-PP cleaned fiber and not based on straw per acre. The no-tillage system produces a lower fiber flax stalk yield which may have been due to reduced plant populations because fiber flax prefers a good seedbed, weed control, and a flat, uniform, and firm seedbed for germination (Foulk et al., 2003). Reduced plant populations with no-tillage could also have been related to planting date, delayed emergence, and reduced fall growth under wet and cool conditions.

Many phenological models are based on the concept of degree day, which is the difference between daily mean temperature (maximum daily temperature + minimum daily temperature)/2 and a base temperature. Cotton heat units were calculated using a base temperature of 15 ^{o}C. Cotton fiber quality properties are affected by cumulative heat units (Bradow and Davidonis, 2000). Cotton growth and development are dependent upon many factors including early, medium, and full season varieties with cumulative heat unit approximations normally ranging from 1550 to 1850 (Norfleet et al., 1997). In this study, cotton cumulative heat units ranged from 1350 to 1641. Flax heat units were calculated using a base temperature of 5 ^{o}C. Flax yields and stem lengths are affected by cumulative heat units (Sultana, 1992). Sultana (1992) further states that with flax work performed in Europe, cumulative heat units typically fall around 900 for harvesting with 1400 cumulative heat units the optimal for seed, scutched flax, and tow. In this study, flax cumulative heat units ranged from 1161 to 1322. The two different years produced substantially different yields and physical properties for both crops. Cotton lint yield averaged 992 lb ac^{-1} in 2001 and 825 lb ac^{-1} in 2002 while flax stalk yield averaged 1321 lb ac^{-1} in 2001 and 2145 lb ac^{-1} in 2002. Straw yields were low compared to other data (Foulk et al., 2003 and Parks et al., 1993). Overall, cotton fiber in 2001 was significantly longer (1.14 in vs. 1.08 in), more uniform (84% vs. 82%), weaker (29.3 g/tex vs. 30.1 g/tex), and finer (3.9 vs. 5.0) than the cotton fiber in 2002 while flax fiber in 2001 was significantly finer (4.2 vs. 5.0) and weaker (30.9 g/tex vs. 38.5 g/tex) than the flax fiber in 2002. Dew-retting is inconsistent and any flax fiber quality variations could be due to differential retting.

The degree of soil loosening and soil surface characteristics differed among the three tillage systems. Cotton fiber physical properties of length, length uniformity, and micronaire significantly varied at the 0.05 level between the three surface tillage techniques (Table 2). Micronaire values were significantly lower for cotton produced with chisel (4.3) than with disk (4.5) or no-tillage (4.4) treatments. However, no differences were detected for reflectance, yellowness, elongation, or strength of cotton fibers. For cotton production, fiber length from no-till cotton was comparable to chisel plowing but was significantly longer than disk plowing. Disk plowing produced shorter cotton fibers with a significantly lower uniformity. For cotton, micronaire was significantly lower for chisel treatment. A higher fiber length uniformity result from no tillage systems agrees with work performed by Bauer and Frederick (2005). Longer fibers with no-till may be related to more surface residue and the reflected light from the soil surface environment. Kasperbauer (2000) demonstrated that cotton grown over far-red red light reflectors (green and red) were significantly longer and finer than cotton grown over high photosynthetic photon flux reflectors (aluminum and white). In this study, there was generally no effect of tillage treatment on strength suggesting that strength is likely not influenced by tillage practices under the soil and growing conditions tested.

The tillage systems affect on the flax fiber crop production and the physical properties of fibers are shown in Table 3. As indicated by Elhaak et al. (1999) increases in the percentages of α- and hemi-cellulose in flax fibers lead to improved spinnability and fiber strength, which is a function of soil texture and nutrient availability. Elhaak et al. (1999) further state that drought stress can lead to increased deposition of lignin and pectins in plant stems and reduced fiber strength. In this study, flax fiber strength was the only measured physical property that significantly varied at the 0.05 level between 3 tillage systems (Table 4). Flax fiber strength was significantly larger for chisel than no-till crop production systems. This increase in fiber strength may have been related to nutrient availability, moisture retention, and soil surface physical properties created by chisel plowing vs. no-till. Dew-retting is inconsistent and flax fiber quality variations could be due to differential retting. Additional field preparation better incorporates plant residue into the soil thus creating a less compacted surface for early growth.

Double-cropping winter small grains with summer crops and conservation tillage is common throughout the southeast USA. A possible problem for cotton in a flax double crop system is the late planting for cotton (especially if the crop is also harvested for seed). In some years with cool fall temperatures, late harvest of cotton may not allow for timely flax planting. Harvesting flax just for fiber before seeds mature will make this system more reliable for cotton production. Flax production problems may include low soil temperatures in the fall during crop establishment (especially for no tillage flax production) and damage from frost. The amount of foreign matter in flax straw was not evaluated in this study, but may be a concern with commercial flax straw harvesting equipment. More research is needed on many aspects of this system. Nevertheless, conservation tillage management has shown to increase soil organic matter and thereby may improve soil productivity while reducing erosion. Improved conservation tillage management techniques should be developed for successful establishment of a sustainable flax industry in the southeast.

The intention of this study was to determine if various tillage and sub-soiling techniques were detrimental or beneficial to cotton and winter flax yields under South Carolina conditions. As expected, subsoiling increased the cotton and flax yield response which is similar to findings for other crops. In this study, cotton yields were not influenced by tillage treatment while flax dry plant matter yields for disk treatment were significantly greater than no till treatments. For the fiber properties studied, micronaire, fiber length, and fiber length uniformity of cotton along with flax fiber strength were impacted by the tillage management studied. Dew-retting is inconsistent and any flax fiber quality variations could be due to differential retting. Cotton fiber properties are such that conservation systems appear to be a viable option for growers due to fiber property improvements. Fiber flax yield and fiber properties indicate additional field preparation may be required to produce increased yields with improved fiber properties. Increases in straw yield will clearly affect the total fiber yield per acre. Our results indicate that conservation tillage practices can be beneficial for cotton production under Florence, SC growing conditions but additional research is vital for reliable fiber flax production.

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Table 1.
Cotton yield and fiber quality on 64 cotton grid plot.*

Tillage	Subsoil	Lint turnout (%)	lb lint ac (lb/ac)	Plants per plant row (Plants/1 ft row)	Length [a] (in)	Uniformity [a] (%)	Strength [a] (grams/tex)	Micronaire [a]
Chisel	Yes	39.5a	955 a,b	3.2 a	1.12 a	83.5 a	29.4 a	4.2 b
Chisel	No	39.5 a	883 a,b	2.9 a	1.11 a,b	83.2 a,b	30.0 a	4.4 a
Disk	Yes	39.8 a	980 a	3.0 a	1.10 b	82.6 b	29.3 a	4.5 a
Disk	No	39.6 a	804 b	3.2 a	1.11 a,b	83.1 a,b	30.2 a	4.5 a
No-till	Yes	39.5 a	968 a	3.1 a	1.12 a	83.5 a	29.9 a	4.4 a
No-till	No	39.8 a	865 a,b	3.3 a	1.11 a,b	83.3 a	29.4 a	4.4 a

* Values followed by different letters within columns are significantly different, $P<0.05$, according to Duncan's New Multiple Range Test.
[a] Fiber properties determined using standard test methods (ASTM International, 1993)

Table 2.
Cotton yield and fiber quality on 64 cotton grid plot. Data are averaged over subsoiling*

Tillage	Lint turnout (%)	lb lint ac (lb/ac)	Plants per plant row (Plants/1 ft row)	Length [a] (in)	Uniformity [a] (%)	Strength [a] (grams/tex)	Micronaire [a]
Chisel	39.5 a	919 a	3.0 a	1.12 a,b	83.3 a	29.7 a	4.3 b
Disk	39.7 a	891 a	3.1 a	1.10 b	82.8 b	29.7 a	4.5 a
No-till	39.6 a	916 a	3.2 a	1.12 a	83.4 a	29.6 a	4.4 a

* Values followed by different letters within columns are significantly different, $P<0.05$, according to Duncan's New Multiple Range Test.
[a] Fiber properties determined using standard test methods (ASTM International, 1993).

Table 3.
Flax yield and fiber quality on 64 cotton grid plot.*

Tillage	Subsoil	Dry yield (lb/ac)	Flax Pilot Plant yield[a] (%)	Shirley Analyzer yield[b] (%)	Strength[c] (grams/tex)	Elongation[c] (%)	Micronaire[d]
Chisel	Yes	2127 a	23.5 a,b	21.0 a	36.8 a	1.4 a	4.7 a
Chisel	No	1374 a,b	22.5 a,b	23.0 a	35.7 a,b	1.5 a	4.7 a
Disk	Yes	2117 a	22.9 a,b	25.5 a	34.4 a,b	1.3 a	4.6 a,b
Disk	No	1998 a,b	21.4 a	23.7 a	35.0 a,b	1.3 a	4.6 a
No-till	Yes	1552 a,b	25.5 a	21.0 a	33.0 b	1.3 a	4.7 a
No-till	No	1230 b	22.1 a,b	23.8 a	33.3 b	1.3 a	4.4 b

* Values followed by different letters within columns are significantly different, P<0.05, according to Duncan's New Multiple Range Test.
[a] Flax-PP fiber yield is the percent of fiber separated from the dew-retted flax stalks.
[b] Shirley Analyzer yield is the percent of fine fiber separated from the Flax-PP cleaned fiber.
[c] Fibers properties determined using a modified test method (ASTM International, 1999a).
[d] Fibers properties determined using a modified test method (ASTM International, 1999b).

Table 4.
Flax yield and fiber quality on 64 cotton grid plot. Data are averaged over subsoiling *

Tillage	Dry yield (lb/ac)	Flax Pilot Plant yield[a] (%)	Shirley Analyzer yield[b] (%)	Strength[c] (grams/tex)	Elongation[c] (%)	Micronaire[d]
Chisel	1750 a,b	23.0 a	22.0 a	36.3 a	1.4 a	4.7 a
Disk	2057 a	22.1 a	24.6 a	34.7 a,b	1.3 a	4.6 a
No-till	1391 b	23.8 a	22.4 a	33.1 b	1.3 a	4.6 a

* Values followed by different letters within columns are significantly different, P<0.05, according to Duncan's New Multiple Range Test.
[a] Flax-PP fiber yield is the percent of fiber separated from the dew-retted flax stalks.
[b] Shirley Analyzer yield is the percent of fine fiber separated from the Flax-PP cleaned fiber.
[c] Fibers properties determined using a modified test method (ASTM International, 1999a).
[d] Fibers properties determined using a modified test method (ASTM International, 1999b).