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AGRONOMY AND SOILS

Development and Yields of Cotton under Two Tillage Systems and Nitrogen Application Following White Lupin Grain Crop

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ABSTRACT

Cotton (*Gosspium hirsutum* L.) growth and yield following a white lupin (*Lupinus albus* L.) grain crop may be influenced by tillage system and rate of N fertilizer application. Field studies were conducted on Dothan sandy loam from 1995 through 1997 to evaluate the influence of conventional (CT) and strip-tillage (ST) systems in combination with four rates (0, 67, 134, and 202 kg N ha^{-1}) of sidedress N on growth, development, and yield of 'Deltapine 5409' cotton following a white lupin grain crop. The 202 kg N ha^{-1} rate was split into two applications so that 134 kg ha^{-1} was applied 4 wks after planting and 68 kg ha^{-1} was applied 7 wks after planting. There were significant year by tillage by N rate interactions for lint yield, plant height, bolls plant^{-1}, and bolls meter^{-2}, and significant tillage by N rate interactions for boll weight and lint weight boll^{-1}. Because of higher bolls m^{-2}, lint yields were greater from cotton grown under ST than CT. For every 1 kg N ha^{-1} applied to cotton, lint yield increased by 2.49 kg ha^{-1} under ST in 1995, 1.07 and 1.69 kg ha^{-1} under CT and ST, respectively, in 1996, and 1.81 kg ha^{-1} for CT in 1997. Based on regression analysis, maximum lint yields were achieved with the application of 76 kg N ha^{-1} under CT in 1995, and 78 kg N ha^{-1} under ST in 1997. Plant height, bolls plant^{-1}, and bolls m^{-2}, and boll weight increased with increasing N rates. Lint yields were primarily correlated with bolls m^{-2}. Following a white lupin grain crop, cotton can be successfully grown in ST. Nitrogen application to cotton increased lint yields due to increased bolls m^{-2}. The optimal N rate for cotton following white lupin was 78 kg N ha^{-1}.

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One of the most important agronomic benefits of growing legumes is the contribution of biological N, which decreases the need for inorganic N fertilization of following crops (Brown et al., 1985). Growing legume crops reduces weed populations, soil erosion, and evaporation, and increases organic matter and N content in the soil (Touchton et al., 1984; Brown et al., 1985; Varco 1993; Boquet et al., 1994). Field studies have shown that growing legumes prior to cotton reduced the need of N application on cotton by 50% (Touchton and Reeves, 1988; Millhollon and Melville, 1991). Boquet et al. (1994) found growing *Vicia* increased subsequent cotton yields by 437 kg ha^{-1} compared with no legume crop. Leguminous crops, such as crimson clover (*Trifolium incarnatum* L.) and peas (*Pisum sativum* L.), may contribute up to 100 kg N ha^{-1} to the following crop (Hoyt and Hargrove, 1986). Using legume crops as the only source of nitrogen produced similar or greater cotton yields compared with applying 134 kg N ha^{-1} in monoculture (Touchton et al., 1984). Measurements of fixed nitrogen in the soil suggest that 90 to 168 kg N ha^{-1} is fixed by crimson clover and *Vicia* during the spring blooming period (Mitchell, 1996). According to Reeves et al. (1999), winter white lupin could also be used in rotation with summer annual crops to improve the long-term sustainability of cropping systems in the Southeast. In the 1940s, white lupin was grown as green manure for cotton (Reeves et al., 1990), which is an important summer crop in southeastern row crop production systems (Buntin et al., 2002). Consecutive hard freezes in the winters of 1950-51 and 1951-52, loss of government price supports, low cost of nitrogen fertilizer, disease susceptibility (Reeves, 1991), and high grain prices contributed to the regional decline of growing lupin (Van Santen and Reeves, 2003). In recent years, prices of grain have decreased greatly and cost of fertilizer N will eventually increase as resource reserves are depleted (Van Santen and Reeves, 2003). Mask et al. (1993) noted that the recent interest in sustainable agriculture and in double-cropping with winter grown lupin have generated renewed interest in winter-hardy white lupin for the South. Lupin is well adapted to relatively infertile and acidic soils, and not only reduces the nitrogen fertilizer needs for summer crops, but also replaces nitrogen fertilizer requirements of winter wheat, and produces quantities of high protein feed grain that could be used on-farm without processing (Mask et al., 1993). Research is also attempting to resolve problems related to insufficient disease resistance, cold hardiness, and tolerance to wet soils in order to develop the full potential of lupin.

Crop yield levels are highly dependent on proper management practices. Nitrogen deficiency reduces vegetative and reproductive growth (Gerik et al., 1994), but high N availability may lead to excessive vegetative development that delays crop maturity and reduces lint yield (Howard et al., 2001). It is important to provide the optimum rate, source, and application method of N for conservation tillage, partly due to the quality of plant residues of the previous crop (Touchton et al., 1995). Compared with conventional tillage, conservation tillage decreases input costs (Burte et al., 1992), traffic, soil compaction, labor, fuel, and equipment usage (Smart and Brandford, 1996), and therefore increases revenues (Harman et al., 1989). Strip-tillage, which is the most common conservation tillage system in the southeastern USA, uses a seed-bed preparation implement with in-row subsoil shanks, multiple coulters, and ground driven crumblers that till a band approximately 30 cm wide (Johnson et al., 2001). It is important to understand not only the process of plant development, but also the interaction between plant growth and crop management. The purpose of this research was to evaluate the influence of tillage and N fertilizer rates on cotton development and yields following a white lupin grain crop.

MATERIALS AND METHODS

Field trials with cotton following white lupin were conducted from 1995 through 1997 on a Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) at the University of Florida, North Florida Research and Education Center in Quincy, FL. The experiment consisted of two tillage systems, conventional (CT) and strip-till (ST), and four rates (0, 67, 134, and 202 kg ha^{-1}) of sidedress N.

Prior to planting, the white lupin (cv. Lunoble) was broadcast fertilized with 28, 24, and 70 kg ha^{-1} of N, P, K, respectively, to supply starter N for lupin and nutrients for the lupin and following cotton crops. The ST and CT sections of the field were seeded with white lupin at 174 kg ha^{-1} in double, 21.6-cm wide rows with 91 cm between double row centers using a modified KMC planter (Kelley Manufacturing Co.; Tifton, GA) in late November of 1994, 1995, and 1996. After mechanical harvest of white lupin for grain, residue was cut with a rotary-mower and left in the field. The plots with white lupin under ST and CT were followed by cotton plots under ST and CT, respectively.

Following white lupin harvest, the field was sprayed with glyphosate (Roundup Ultra 4L; Monsanto Co.; St. Louis, MO) at 1.7 kg a.i. ha^{-1} 2 wk prior to planting cotton. Three days prior to planting cotton, the CT plots were disked, sub-soiled, and s-tine harrowed. In ST, 18-cm wide rows were cultivated to a 40-cm depth using a Brown Ro-till implement (Brown Manufacturing Co.; Ozark, AL) with 91 cm between row centers.

Cotton was seeded in a 91-cm inter-row spacing at a seeding rate of 12 seeds per row-meter using a KMC 15 series planter (Kelly Manufacturing Co.; Tifton, GA) on 22 June, 25 May, and 16 June in 1995, 1996, and 1997, respectively. Late planting, due to lupin harvest for grain, had little impact on lint yields. Each plot was 3.7 m wide by 6.1 m long and consisted of four rows. Cotton was fertilized with ammonium nitrate (34-0-0) at 0, 67, 134, and 202 kg N ha^{-1}. The 0, 67, and 134 kg N ha^{-1} rates were applied 4 wk after planting. The 202 kg N ha^{-1} was divided so that 134 kg N ha^{-1} and 68 kg N ha^{-1} applied were 4 and 7 wk after planting, respectively. At first bloom, plants were broadcast sprayed with mepiquat chloride (Pix 0.35L; BASF Corp.; Research Triangle Park, NC) at 18.5 g ha^{-1} to control height. Other cultural practices, including irrigation, weed control, and defoliation, were implemented according to standard production practices. There was no need for irrigation in 1995 due to adequate rainfall. Lower rainfall in 1996 and 1997 was compensated with irrigation at 102 and 107 mm, respectively, using a lateral-moving sprinkler irrigation system. Cotton was harvested manually 3 wk after defoliation. Number of cotton bolls from the first to fifth lateral fruiting position on sympodial (fruiting) branches was recorded. Lint yield was calculated based on lint percentage of a ginned cotton sample from each plot (908 g).

The field experimental design was a split plot in a randomized complete block with four replications. Tillage practices were the main plots and N rates were the subplots. All data were analyzed using a PROC MIXED model (SAS Inst.; Cary, NC). Years, tillage systems, and N applications were considered fixed effects. Blocks and interactions including blocks were assumed to be random effects. The PROC MIXED procedure of SAS with the LSMEANS PDIFF option was used to compare tillage systems and N applications. The difference between means for tillage and N applications was considered significant at $P \leq 0.05$. Single degree-of-freedom contrasts were used to evaluate linear and quadratic effects of N applications on cotton. When a contrast indicated that there was a significant ($P \leq 0.05$) linear or quadratic response, then linear or quadratic regression models, respectively, were fit using PROC REG (SAS Inst.). Pearson correlation coefficients (*r*) were calculated between lint yield and plant stand, plant height, bolls plant^{-1}, bolls m^{-2}, boll weight, and lint weight boll^{-1}.

RESULTS AND DISCUSSION

Application of N rates from 0 to 202 kg ha^{-1} did not influence cotton stand, but plant stand was influenced by tillage (Table 1). Due to better plant emergence, plant stand averaged across years was significantly greater ($P \leq 0.01$) in ST than in CT (5.5 vs. 4.8 plants m^{-2}). Johnson et al. (2001) also noted that cotton stands following a legume crop were greater under ST than CT in some years. Similar cotton stands were obtained between tillage systems in a wheat-cotton rotation (Wiatrak et al., 2005). Gallaher (2002) observed greater cotton plant populations following small grains compared with cotton following legumes.

A significant year by tillage by N rate interaction was observed for cotton plant height (Table 1), which was reduced by the application of mepiquat chloride. For each kg ha^{-1} N of applied, plant height increased by 0.07 cm under CT in 1995, 0.065 cm under ST in 1996, and 0.09 cm under CT and ST in 1997 (Fig. 1). As estimated by regression equations, maximum plant height was attained with 103 kg N ha^{-1} for ST in 1995 and 109 kg N ha^{-1} for CT in 1996. Hutmacher et al. (1996) and Wiatrak et al. (2005) also observed taller plants with increased N application compared with no N or 60 kg N ha^{-1}. Cotton grown following lupin were taller at lower N rates than cotton following wheat (Wiatrak et al., 2005), presumably due to utilization of legume N in a lupin-cotton rotation.

The interaction for year by tillage by N rate was significant for bolls plant^{-1} (Table 1). With every 1 kg N ha^{-1} applied to cotton, bolls plant^{-1} increased by 0.035 for ST in 1995, 0.014 and 0.007 for CT and ST, respectively, in 1997 (Fig. 2). Based on regression equations, the greatest number of bolls plant^{-1} was estimated with the application of 74 kg N ha^{-1} under CT in 1995 and 121 kg N ha^{-1} under ST in 1996. Under CT in 1996, bolls plant^{-1} were not significantly affected by N application. These results are similar to previous studies (Wright et al., 1998; Wiatrak et al., 2005), but without N fertilization there were generally fewer bolls plant^{-1} for cotton following wheat than following lupin, presumably because legume N was utilized by the following cotton crop to produce more bolls (Wiatrak et al., 2005).

Table 1. Significance of experimental factors for plant stand, plant height, and yield characteristics, and Pearson correlation coefficients between lint yields and plant characteristics of cotton grown from 1995 through 1997

Factor	Plant characteristic[z]						
	Plant stand	Plant height	Bolls plant^{-1}	Bolls m^{-2}	Boll weight	Lint weight boll^{-1}	Lint yield
Year (Y)	*	***	***	***	**	**	***
Tillage (T)	**	**	**	***	NS	NS	***
Y x T	NS	**	**	NS	NS	NS	*
Nitrogen rate (N)	NS	***	***	***	NS	NS	***
Y x N	NS	***	NS	NS	NS	NS	***
T x N	NS	*	***	***	*	*	**
Y x T x N	NS	***	***	***	NS	NS	***
	Pearson correlation coefficient						
Lint yield	0.13	0.34***	0.52***	0.88***	NS	0.42***	-

[z]Plant characteristic followed by NS are not significant different ($P > 0.05$) or by *, **, *** are significantly different at $P \leq 0.05$, 0.01, and 0.001, respectively.

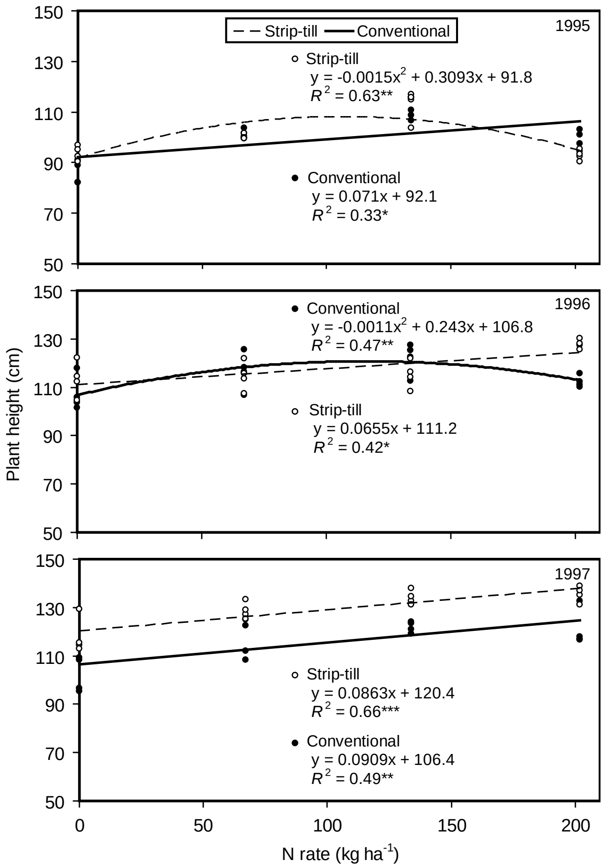

Figure 1. Influence of N application on cotton plant height under two tillage systems from 1995 through 1997. Regression coefficients (R^2) followed by *, **, * are significantly different at $P \leq 0.05$, 0.01, and 0.001, respectively.**

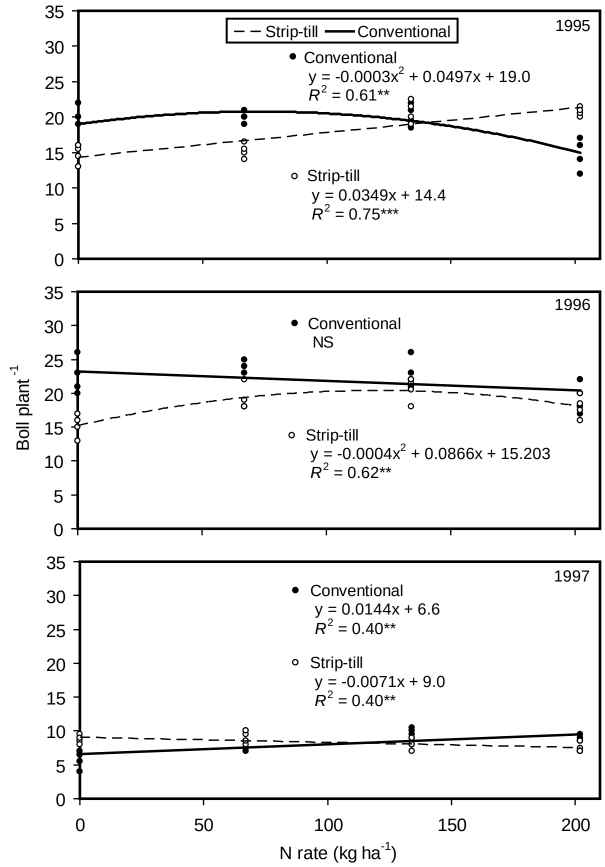

Figure 2. Influence of N application on bolls plant^{-1} under two tillage systems from 1995 through 1997. Regression coefficients (R^2) followed by NS are not significantly different ($P > 0.05$) or by *, **, * are significantly different at $P \leq 0.05$, 0.01, and 0.001, respectively.**

The year by tillage by N rate interaction was significant for bolls m^{-2} (Table 1). With every 1 kg N ha^{-1} applied to cotton, bolls m^{-2} increased by 0.13 for ST in 1995, 0.096 for ST in 1996, and 0.085 for CT in 1997 (Fig. 3). According to regression equation, the maximum bolls m^{-2} was expected with the application of 68 and 100 kg N ha^{-1} for CT in 1995 and ST in 1997, respectively. Under CT in 1996, bolls m^{-2} were not significantly increased by N application. Reddy and Rao (1970) and Wiatrak et al. (2005) also noted more bolls m^{-2} as N application increased on cotton, and Pettigrew and Jones (2001) observed more bolls m^{-2} for cotton grown in conservation tillage than in CT. In this study with low N rates, generally more bolls m^{-2} were observed for cotton following lupin than reported previously for cotton following wheat (Wiatrak et al., 2005).

An interaction of tillage by N rate was also significant for cotton boll weight and lint weight boll^{-1} (Table 2). Boll and lint weights were greater with the application of 202 kg N ha^{-1} than without N on cotton for CT, and there were no significant differences among N rates for boll and lint weights for ST (Table 2). Pettigrew and Jones (2001) observed greater boll weight for cotton grown in conservation tillage than in CT. Wright et al. (1998) and Wiatrak et al. (2005) also noted increased boll weight with increased N rate. Boll weight and lint weight boll^{-1} for cotton following lupin in the present study were generally similar to those obtained in a wheat-cotton rotation study (Wiatrak et al., 2005).

A year by tillage by N rate interaction was significant for lint yields (Table 1). With every 1 kg N ha^{-1} applied to cotton, lint yields increased by 2.49 kg ha^{-1} for ST in 1995, 1.07 and 1.69 kg ha^{-1} for CT and ST in 1996, respectively, and 1.81 kg ha^{-1} for CT in 1997 (Fig. 4). Based on regression equations, the maximum cotton yield was expected with 76 and 78 kg N ha^{-1} under CT in 1995 and ST in 1997, respectively. Wright et al. (1998) noted significantly higher lint yields with the application of 134 kg N ha^{-1} than 67 kg N ha^{-1}. Other researchers found that optimum N rate ranged from 35 to 135 kg N ha^{-1} (Touchton et al., 1981; Thom and Spurgeon, 1982; Maples and Frizzel, 1985; Howard and Hoskinson, 1986; Lutrick et al., 1986; and Phillips et al., 1987). Hartman (1989) and Ayisi (1992) noted that less of the legume N is available to the following crop when lupin is harvested for grain. Cotton yields following lupin in this study were greater at lower N rates that cotton following wheat (Wiatrak et al., 2005), possibly due to utilization of legume N. Maximum yields for cotton following lupin were obtained at 34 kg N ha^{-1}, but cotton following winter fallow required 102 kg N ha^{-1} for maximum production (Van Santen and Reeves, 2003). Legume cover crops provided 135 to 200 kg N ha^{-1} for corn (Van Santen and Reeves, 2003) and 61 to 97 kg N ha^{-1} for sorghum (Hargrove, 1986). The N contribution of lupin to cotton in this study was estimated to be 68 kg ha^{-1} when compared with cotton following winter fallow (Van Santen and Reeves, 2003) and about 60 kg ha^{-1} when compared with cotton following wheat (Wiatrak et al., 2005). Application of more than 78 kg N ha^{-1} did not significantly increase lint yield of cotton following a white lupin grain crop in this study. In general, the fertilizer N application to cotton can be reduced by at least 60 kg ha^{-1} in the lupin-cotton rotation because of legume N contribution.

Table 2. Influence of tillage and N application on boll weight and lint weight boll^{-1} of cotton grown from 1995 through 1997

N rate (kg ha^{-1})	Boll weight (g)^z		Lint boll^{-1} (g)^z	
	CT	ST	CT	ST
0	4.86 b	5.16 a	1.98 b	2.12 a
67	5.01 ab	5.07 a	2.06 ab	2.08 a
134	5.17 ab	5.12 a	2.08 ab	2.06 a
202	5.24 a	5.19 a	2.18 a	2.03 a

^{z} Means within a column followed by the same letter are not significantly different according to the Lsmeans Pdiff option of the Proc Mixed procedure (P = 0.05).

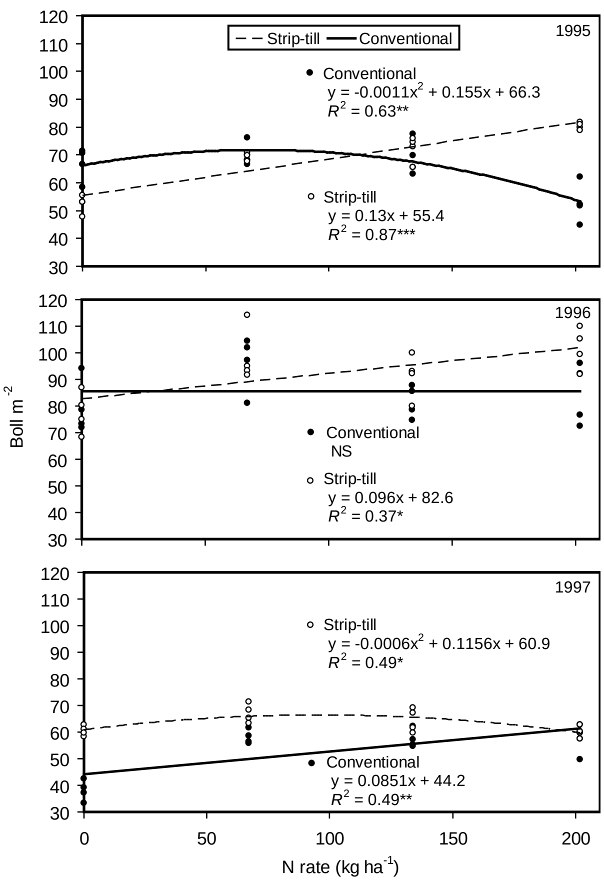

Figure 3. Influence of N application on bolls m^{-2} under two tillage systems from 1995 through 1997. Regression coefficients (R^2) followed by NS are not significantly different (P > 0.05) or by *, **, * are significantly different at $P \leq$ 0.05, 0.01, and 0.001, respectively.**

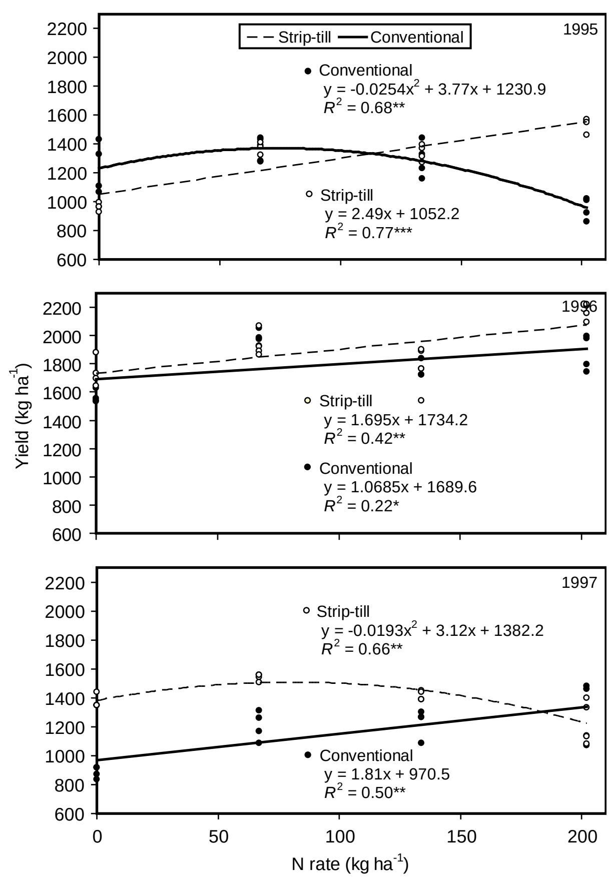

Figure 4. Influence of N application on cotton lint yield under two tillage systems from 1995 through 1997. Regression coefficients (R^2) followed by *, **, * are significantly different at $P \leq$ 0.05, 0.01, and 0.001, respectively.**

Based on these results, averaged across previous crops and N rates, greater cotton yields were obtained from ST than CT. Burmester et al. (1997) showed that cotton yields from conservation tillage and CT may vary across years. Matocha and Barber (1992) and Smart and Bradford (1996) noted that tillage and fertilization have a direct effect on cotton yield. Greater lint yields have been reported from conservation tillage than conventional tillage (Brown et al., 1985; Keeling et al., 1989; Delaney et al., 1996; and Vacek and Matocha, 1997) and similar cotton yields have been reported from conservation tillage and conventional tillage (Stevens et al., 1992; Hutchinson et al., 1993; Vacek and Matocha, 1997).

Lint yields were correlated with plant height ($r = 0.34$), bolls plant^{-1} ($r = 0.52$), bolls m^{-2} ($r = 0.88$), and lint weight boll^{-1} ($r = 0.42$) (Table 1). A high correlation between lint yields and bolls m^{-2} ($r = 0.94$) has been reported previously (Morrow and Krieg, 1990). Yield was increased with an increase in the number of bolls m^{-2} (Reddy and Rao, 1970). In this study, increase in lint yields was associated primarily with an increase in number of bolls m^{-2}.

CONCLUSIONS

Plant height, bolls plant^{-1}, bolls m^{-2}, boll weight, and lint yields were variable across years and generally increased with increase in N rate on cotton grown in both CT and ST. Application of N in ST did not increase boll weight or lint weight boll^{-1} in any year and decreased bolls plant^{-1} in one of three years. With increased N rate, greater lint yields were primarily due to increased bolls m^{-2}. Greater lint yields, due to mainly higher bolls m^{-2}, were greater from cotton grown under ST than CT. The results also indicate that applying more than 78 kg N ha^{-1} on cotton following a white lupin grain crop may not significantly increase lint yields. With development of adapted cultivars, white lupin may be an acceptable winter crop for rotation with cotton, because it does not require N fertilization, and the level of nitrate N in the soil may be lower. With the lower level of nitrate N, there are fewer nitrates to leach below the root zone on the sandy soils in Florida. More research is needed to evaluate the economics of lupin as an alternative to wheat or winter fallow.

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