Effects of Alternative Lime Application Rates on Cotton Profitability with Varying Cover Crops, Nitrogen, and Tillage Methods

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Abstract: Soil acidity and cotton yields are influenced by cover crop, nitrogen, and tillage method. Applying half the recommended lime rate may be possible without reducing cotton yields. Using a nitrogen intensive cover crop and applying less nitrogen should mitigate the effects on soil acidity and yields.

Keywords: cover crops, cotton, lime, nitrogen, profitability, soil acidity, tillage.

JEL Classifications: Q12

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Introduction

Several West Tennessee soils used for cotton production are highly erodible and subject to surface water and groundwater pollution (Bradley and Tyler). To mitigate soil erosion and runoff problems, researchers at the University of Tennessee recommend farmers use winter cover crops and no-tillage practices (Duck and Tyler). Cover crops and no-tillage can benefit soils by reducing erosion, improving soil characteristics, and conserving soil nutrients (Meisinger et al.; Bauer and Busscher; Daniel et al., 1999a, 1999b). Grass covers can prevent nitrogen leaching into groundwater by immobilizing excess nitrogen in the soil during winter. Legumes are beneficial in providing nitrogen to the next crop while reducing the need for commercial nitrogen fertilizer (Larson et al., 2001a; Bauer and Roof; Hoyt and Hargrove; Reeves). Winter cover crops increase productions costs due to establishment costs combined with changes in nitrogen requirements (Meisinger et al.)

The build up of plant materials and surface placement of fertilizer can influence soil properties such as soil pH. Nitrogen is an important fertilizer input in cotton production. No tillage in combination with surface applied nitrogen can result in the top few inches of the soil becoming more acidic due to nitrification (Ismail, Blevins, and Frye; Blevins, Murdock, Thomas; Blevins et al.). As a result, low pH levels in the soil may affect the productivity of nitrogen fertilizers in no-tillage systems. Thus, the relationship between nitrogen fertilizer and soil acidity is particularly important in the no tillage production system. Howard et al. found that 60 lb N/A maximized lint yields on Loring and Lexington silt loams where no tillage cotton was produced was used with different winter covers. However, 90 lb N/A was necessary to optimize lint yields on a Memphis silt loam.

Profitability is important in a cotton farmer's decision to adopt winter cover crops (Larson et al., 2001b). Corn preceded by hairy vetch resulted in larger net revenues than corn grown without a prior cover crop (Frye et al.). Results suggest that establishment costs of the cover crop are more than offset by the increase in corn yield. Similar results were reported by Roberts et al. and Lichtenberg et al.

Liming to achieve a specific pH level has long been practiced by farmers in the United States. Most crops require lime when pH drops below 5.0 to reduce the level of harmful Aluminum and Manganese, increase uptake of beneficial nutrients such as Calcium, Magnesium, and others, and counteract the acidifying effect of ammoniacal nitrogen fertilizers (Bongiovanni and Lowenberg-DeBoer, Sumner and Yamada). On the other hand, if pH rises above 7.5, problems arise such as inadequate plant nutrient uptake, weed control deficiency, nutrient availability, and microorganism activity (Bongiovanni and Lowenberg-DeBoer). Research has shown that plants do not respond directly to H^+ activity, but benefit from the change in soil composition caused by the hydronium ion (Sumner and Yamada).

Lime has long been viewed as a crop production input providing certain benefits, but those benefits come with a cost (Bongiovanni and Lowenberg-DeBoer). If crop yields are increased with lime application and the cost of the lime and its application is less than the increase in total revenue from the additional yield, lime can be viewed as profitable. A profit-maximizing farmer will increase lime application so long as the value of the benefits exceeds the cost of the lime and its application (Hall).

Sumner and Yamada suggest the widespread use in early agricultural development of acid-sensitive legumes to supply nitrogen was a contributing factor to liming to achieve a target pH level. The increasing use of nitrogen fertilizers resulted in a reduction in the use of legume crops (Sumner and Yamada). Despite the decreasing presence of legumes in the crop rotation, target pH levels were never reevaluated. Introduction of the pH meter resulted in a focus on the level of soil acidity rather than the contributing factors of soil acidity such as nutrient deficiencies and high levels of exchangeable Aluminum and Manganese (Sumner and Yamada).

Woodruff states: "The actual soil pH requirements of crops, …, are not in close agreement with the soil pH recommendations that are made to farmers by the various advisory services." A long-term experiment was conducted at the West Tennessee Experiment Station, Jackson, TN to determine if one-half the University of Tennessee Extension recommended rate of lime would produce the same results as the full recommended rate of lime. Results of the study were expected to show no significant difference between the half and full rates of lime.

The objective of this research was to determine cotton profitability and lint yields for lime applied at the full University of Tennessee Extension recommended rate and half the recommended rate for various cover crop, nitrogen rate, and tillage alternatives.

Data and Methods

Yield Data

Cotton yield data for 1995 through 2001 were obtained from a long-term winter cover crop experiment at the West Tennessee Experiment Station, Jackson, TN conducted on a Lexington silt loam (fine-silty, mixed, thermic, Ultic Hapludalf). The experimental plots were established in 1981 and replicated four times in a split-split randomized complete block design. The experiment consisted of four blocks. Each block was split horizontally four times and randomly assigned four nitrogen rates. These blocks were further split into vertical blocks that consisted of randomly assigned cover crops. These blocks were again split into vertical blocks that were randomly assigned one of two tillage treatments, no tillage and conventional tillage. The plots received the same nitrogen fertilization rate, cover crop, and tillage treatment each year.

Cotton was planted on conventional tillage and no tillage plots after winter wheat, hairy vetch, crimson clover, and no winter cover crop alternatives. The cotton cultivar ‘Deltapine 50’ was used in 1995 and 1997. In 1996, ‘Stoneville 132’ was sowed on the plots. ‘Stoneville 474’ was planted in 1998. ‘Deltapine 425’ was used in 1999 and 2000. In 2001, ‘Deltapine 451’ was used on the plots. A burn-down herbicide was used to kill the cover crop before planting cotton in the no tillage plots. Conventional tillage plots were disked to destroy the cover crop prior to planting. Winter covers were reestablished each season after cotton harvest with seeding rates of 90 lb/A for winter wheat, 20 lb/A for hairy vetch, and 15 lb/A for crimson clover. Broadcast ammonium nitrate was the nitrogen source applied at planting. Rates of nitrogen fertilizer applied to the plots were 0, 30, 60, and 90 lb N/A.

After letting pH deteriorate by delaying the regular application of lime from 1981 to 1994, the cover crop, nitrogen fertilizer, and tillage plots were further split into blocks that were randomly assigned two lime rates—100% of the recommended University of Tennessee Extension lime rate and one-half the recommended lime rate. The full rates of applied lime included 1.5, 2, 2.5, 3, and 3.5 tons/A. Rates applied for one-half the recommended rate were 0.75, 1, 1.25, 1.5, and 1.75 tons/A. Lime was applied on May 10 and 11, 1995, according to the Adams and Evans buffer test for 0-6 inches soil depth. Individual plots received lime applications expected to increase pH to 6.5. Those plots recording a pH of 6.5 or higher in 1995, received no lime, thus becoming zero lime rate plots in the analysis. In this study, data from 1995 through 2001 were used to evaluate the impact of winter cover crop, nitrogen fertilization rate, tillage method, and lime rate on net revenue.

Lint Yield Response Function

A quadratic yield response function was estimated using the data for each winter cover alternative as follows:

$$Y_i = a + bN_i + cN_i^2 + dTM_i + eHRD_i + fZLD_i + gTM_i xHRD_i + hN_i xHRD_i + jN_i xZLD_i + kTM_i xZLD_i + mN_i xTM_i + u_i, \quad (1)$$

where Y is cotton lint yield (lb/A) for the i^{th} winter cover crop; N is the applied nitrogen rate (lb/A); TM is a dummy variable equal to one for no tillage and zero for conventional tillage; HRD is a dummy variable equal to one for half the recommended lime rate and zero otherwise; ZLD is a dummy variable equal to one for zero applied lime and zero otherwise; TM x HRD, N x HRD, N x ZLD, TM x ZLD, and N x TM are interactions between the respective variables; *a, b, c, d, e, f, g, h, j, k,* and *m* are parameters to be estimated by regression; and *u* is a random error term.

Quadratic yield response to *N* was assumed to account for expected diminishing marginal productivity due to excess applied nitrogen. The quadratic functional form has been widely used to estimate N fertilizer response (Woodward). The expected signs of *b* and *c* were positive and negative, respectively.

Documentation regarding the relationship between no tillage and lint yields is mixed. Several studies have reported similar or higher lint yields with no tillage compared to conventional tillage (Bloodworth and Johnson; Stevens et al.; Triplet, Dabney, and Siefker; and Hutchinson et al.). Other research has documented higher conventional tillage lint yields compared to no tillage (Bauer and Busscher; and Burmester, Patterson, and Reeves). The hypothesized sign of the *TM* coefficient was difficult to determine due to the conflicting results reported in the above studies.

The half rate of lime was hypothesized to positively influence yields by increasing the soil pH to a level where exchangeable Aluminum and Manganese are unavailable. Nonetheless, the half rate dummy variable (*HRD*) was not expected to be statistically significant given the hypothesis that the half rate and full rate of lime do not affect yields differently. *ZLD* was expected to have a negative coefficient. Though pH for the zero lime plots was at least 6.5 in 1995, it was expected to decline each year with the addition of nitrogen fertilizer and nitrogen available from the cover crop. Decreasing pH would then lead to declining marginal physical productivity of N causing a decrease in lint yields.

The coefficient for *N x HRD* was expected to be positive because of an expected increase in the marginal physical product of nitrogen fertilizer as soil pH increased over time. However, *N x HRD* was not expected to be statistically significant given the hypothesis that the half rate and full rate of lime do not affect yields differently. The coefficient for *N x ZLD* was expected to be negative because, with no lime application, the zero plots were expected to become increasingly acidic relative to the plots that received the full rate of lime, resulting in a decrease in the marginal physical product of nitrogen fertilizer.

Given the hypothesis that the half rate and full rate of lime do not affect yields differently, the coefficient for *TM x HRD* was expected to be positive but not statistically significant. *TM x ZLD* was expected to be negative but statistically insignificant. No lime was applied to plots with a pH of 6.5 or greater in 1995; therefore, pH for the zero lime plots would be decreasing each year. Plots receiving the full rate of lime in 1995 had acidic pH levels requiring a lime application. The full rate of lime plots would be expected to have increasing pH levels. Considering average yields over a 7-year period, the zero rate was not expected to be statistically different from the full rate of lime.

The expected relationship between yield and the *N x TM* interaction variable was expected to be negative. With no tillage, plant material is left on the surface to decay more slowly and release less N for crop use than with conventional tillage where it is incorporated into the soil. Mengal, Moncrief, and Schulte found available N for crop use was reduced in a no tillage and cover crop system due to C sequestration and N immobilization. This relationship implies a negative coefficient for the *N x TM* interaction resulting from a lower marginal physical product of N fertilizer under no tillage.

Profit Maximization

Estimated yield response functions were used to predict profit-maximizing nitrogen fertilizer rates, yields, costs, and net revenues above variable and fixed production costs. Net revenue was calculated using the following equation:

(2) $$NR_{i,j.k} = PY_{i,j,k} - RN_{i,j,k} - LC_{i,j,k} - CCE_{i,j,k} - OTE_{i,j,k} - OCE,$$

where NR is the net revenue (\$/A) for the i^{th} cover crop, j^{th} lime rate (half or full rate), and k^{th} tillage method (conventional or no tillage); P is the price of lint (\$/lb); Y is cotton lint yield (lb/A); R is the price of nitrogen (\$/lb); N is applied nitrogen (lb/A); LC is cost of applied lime (\$/ton), CCE is expenses associated with the winter cover crop; OTE is other production expenses related to tillage method; and OCE is other crop production expenses that remained constant.

Prices and costs used to calculate profit-maximizing values were expressed in 2004 dollars so changes in net revenues would reflect changes in profit-maximizing yields rather than inflationary price changes. A lint price of \$0.70/lb, a nitrogen fertilizer price of \$0.36/lb, and a lime price of \$24.36/ton were used to calculate net revenues. Average prices for 1984 through 2004 were used in these calculations (Tennessee Department of Agriculture). These prices were inflated to 2004 dollars by the Implicit Gross Domestic Product Price Deflator before averaging (Congress of the United States, Council of Economic Advisors). The cost of lime for each plot was amortized over $n = 7$ years using the capital recovery method and a real interest rate of $i = 6.6\%$.

(3) $$LIME = LMAC \times \left[\frac{i}{1-(1-i)^{-n}} \right],$$

where *LMAC* is the cost of lime materials, *n* is the amortization period in years, and *i* is the real rate of interest charged as a opportunity cost on the investment. Averages of the full and one-half recommended rates of lime multiplied by the price of lime per ton were used to estimate the lime costs presented in the net revenue analysis. The average cost for the full rate of lime (*LMAC*) was \$11.14 for 2.5 tons/A and the average cost for the half rate was estimated at \$5.57 for 1.25 tons/A.

The real rate of interest of 6.6% was calculated using nominal interest rates paid by farmers for capital from Farm Credit Services for 1984 through 2004 (U. S. Department of Agriculture, Economic Research Service) and the annual percentage change in inflation for that period as measured by the Implicit Gross Domestic Product Price Deflator (Congress of the United States, Council of Economic Advisors). Winter cover establishment costs were zero for no cover, \$25.00 for wheat, \$34.00 for vetch, and \$25.00 for clover. Other costs of production that remained constant were taken from the University of Tennessee Extension enterprise budgets for conventional tillage and no tillage Roundup Ready cotton (Gerloff). The no tillage budget assumes the application of a burn-down herbicide to kill the winter cover and weeds before planting at a cost of \$365.22/acre. The tillage budget assumes two disking operations before planting to kill the winter cover and weeds and prepare the seedbed at $388.86/acre. Statistical analyses were conducted using the Statistical Analysis System (SAS Institute).

Results

Lint Yield Response

Expected cotton lint yield response functions for the various winter cover crops are presented in Table 1. The N and N^2 variables had the expected signs and were significant at $\alpha = 0.01$ or 0.05 for no cover, winter wheat, and hairy vetch. Nitrogen fertilizer coefficients in the crimson clover equation were not responsive because the marginal physical product of nitrogen fertilizer was decreased in the presence of legume nitrogen. The coefficients of N and N^2 were not significantly different from zero for the crimson clover cover.

No tillage (*TM*) was significantly different from zero for hairy vetch ($\alpha = 0.10$) and crimson clover ($\alpha = 0.01$) covers and had a positive impact on lint yields. *ZLD* was significant at $\alpha = 0.10$ for the winter wheat cover and reduced lint yields as hypothesized. The *TM x ZLD* interaction term had the hypothesized negative sign and was significantly different from zero at $\alpha = 0.05$ for no cover crop.

An evaluation of F-statistics for the half rate of lime variable and its interactions (the linear combination of *HRD*, *N x HRD*, and *TM x HRD*) was not significantly different from zero for all four cover crops included in the study. Therefore, the hypothesis that no significant difference between the half and full rates of lime exists is upheld. F-statistics for the linear combination of *N x HRD*, *N x ZLD*, and *N x TM* were not statistically different from zero for all four cover options suggesting a consistent N response function. The F-statistic for the linear combination of the tillage interaction variables (*TM x HRD*, *TM x ZLD*, and *N x TM*) was significantly different from zero at $\alpha = 0.01$ for no cover crop, but was not significantly different from zero for the other three cover options. As shown in Table 1, the *TM x ZLD* interaction was statistically significant, suggesting that no tillage significantly lowered lint yields in no cover crop plots where no lime was applied compared to conventional tillage.

Profit Maximization

Profit-maximizing N rates, lint yields, costs, and net revenues for the full lime rate and half lime rate choices are presented in Table 2. Lint yields and net revenues were comparable for the half and full rates of lime. The slightly higher net revenues for one-half the recommended rate of lime were mostly due to lower lime costs. Profit-maximizing N rates among the half and full rates of lime were minimal among the no cover, winter wheat, and hairy vetch cover crops. The largest difference in profit-maximizing N for the half and full lime rates was observed for the crimson clover cover. No tillage consistently produced higher lint yields and net revenues compared to conventional tillage for all four cover crop options. However, profit-maximizing N rates were about the same among the two tillage methods.

Overall, the legume covers required the least amount of N fertilizer with crimson clover requiring no application of N in a no tillage system. Hairy vetch provided the largest lint yield and net revenue compared to the other winter cover options. The profitability of the half and full rates of lime were about the same based on the results presented in Table 2 for all the winter cover crop options.

Conclusions

Estimated cotton lint yield response functions for no cover, winter wheat, and hairy vetch winter cover alternatives suggest that the amount of applied nitrogen has a significant impact on lint yields. Applied nitrogen was less important when using crimson clover as a cover crop.

When using hairy vetch and crimson clover covers, no tillage was significant in increasing lint yields compared to conventional tillage.

Among the cover crop options, hairy vetch resulted in the largest net revenue of $233/A and a lint yield of 933 lb/A when using the half rate of lime and no tillage. Using a winter cover of crimson clover did not require nitrogen fertilizer, but resulted in the lowest net revenues and lint yields among the tillage methods and lime rates.

Cotton lint yields and net revenues achieved with one-half the University of Tennessee Extension recommended rate of lime were either comparable or greater than the full rate of lime for both tillage methods. Based on the findings of this study, cotton farmers may find it more profitable to apply one-half the University of Tennessee Extension recommended rate of lime. Especially cotton farmers leasing land may find it more practical to apply only the half rate of lime due to the uncertainty of lease agreements. Additional research including more than seven years of data would be needed to determine if farmers would benefit from the full rate of lime for a longer period of time than the half rate.

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Table 1. Estimated Cotton Lint Yield Response Functions for Various Winter Cover Crops.

	Cover Crop			
Variable†	No Cover	Winter Wheat	Hairy Vetch	Crimson Clover
Intercept	548.76	402.21	724.78	674.56
N	6.94***	11.06***	4.05***	0.19
N^2	-0.05**	-0.08***	-0.04***	0.01
TM	71.37	97.69	91.20*	130.27***
HRD	8.34	11.63	-50.22	18.24
ZLD	64.30	181.02*	61.96	110.43
N x HRD	0.14	-0.04	0.53	0.25
N x ZLD	0.48	-2.77	‡	‡
TM x HRD	-3.40	-18.39	60.89	-24.78
TM x ZLD	-164.68**	-85.09	‡	-4.85
N x TM	0.18	0.48	-0.82	0.10
Adj. R^2	0.1894	0.1927	0.0286	0.0653
F-statistic	11.44	11.67	2.64	4.47
Observations	448	448	448	448

†Cotton lint yield (lb/A) is the dependent variable, N = applied nitrogen (lb/A), TM = tillage method binary variable (no tillage = 1, conventional tillage = 0), HRD = one-half the University of TN Extension recommended rate of lime binary variable (one-half the recommended rate = 1, zero otherwise), ZLD = zero rate of applied lime binary variable (zero rate = 1, zero otherwise).

*, **, *** Significantly different from zero at the 0.10, 0.05, and 0.01 levels of significance, respectively.

‡Variables not included in analysis due to perfect collinearity.

Table 2. Profit-Maximizing N Rates, Lint Yields, Costs and Net Revenues for the Full Lime Rate and Half Lime Rate Choices.

Winter Cover Crop/Cost/ Revenue Item	Full Lime Rate		Half Lime Rate	
	No Till	Con Till	No Till	Con Till
No Winter Cover				
N-Rate (lb/acre)	70	68	72	70
Yield (lb/acre)	875	803	881	812
N-Cost ($/acre)	$25	$25	$26	$25
Lime Cost ($/acre)	$11	$11	$6	$6
Cover Cost ($/acre)	$0	$0	$0	$0
Other Production Costs ($/acre)[†]	$365	$389	$365	$389
Net Revenue ($/acre)	$211	$138	$220	$149
Winter Wheat				
N-Rate (lb/acre)	69	66	69	66
Yield (lb/acre)	884	786	878	797
N-Cost ($/acre)	$25	$24	$25	$24
Lime Cost ($/acre)	$11	$11	$6	$6
Cover Cost ($/acre)	$25	$25	$25	$25
Other Production Costs ($/acre)	$365	$389	$365	$389
Net Revenue ($/acre)	$193	$101	$194	$115
Hairy Vetch				
N-Rate (lb/acre)	37	48	44	55
Yield (lb/acre)	914	834	933	785
N-Cost ($/acre)	$13	$17	$16	$20
Lime Cost ($/acre)	$11	$11	$6	$6
Cover Cost ($/acre)	$34	$34	$34	$34
Other Production Costs ($/acre)	$365	$389	$365	$389
Net Revenue ($/acre)	$217	$132	$233	$102
Crimson Clover				
N-Rate (lb/acre)	22	31	0	8
Yield (lb/acre)	810	683	799	694
N-Cost ($/acre)	$8	$11	$0	$3
Lime Cost ($/acre)	$11	$11	$6	$6
Cover Cost ($/acre)	$25	$25	$25	$25
Other Production Costs ($/acre)	$365	$389	$365	$389
Net Revenue ($/acre)	$158	$42	$163	$63

[†] Includes change in costs among tillage methods and other production costs held constant.