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# ECONOMICS & MARKETING

## Profit-Maximizing Nitrogen Fertilization Rates for Alternative Tillage and Winter Cover Systems

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### INTERPRETIVE SUMMARY

Agronomic research has shown that no-tillage cotton production combined with winter cover crops can improve soil quality by reducing erosion, increasing organic matter, and improving water-holding capacity. Farmers interested in incorporating winter cover crops and no tillage into their production system need information about profit maximizing N fertilization rates.

Cotton yield data for 1984 through 1999 were obtained from a winter cover crop experiment at the West Tennessee Experiment Station, Jackson, TN, and were used to estimate N response functions. The experimental design was a randomized complete block with split-plots and four replications per year. Broadcast ammonium nitrate fertilizer was varied in the main plots, and winter cover and tillage were varied in the split-plots. N fertilizer rates applied to the plots were 0, 30, 60, and 90 lb N acre$^{-1}$. Conventional tillage and no tillage were the tillage treatments in the experiment. The cover crop treatments were winter wheat, hairy vetch, crimson clover, and no cover. The same plots received the same N fertilization rate, tillage, and cover crop treatment each year. Yield response functions estimated from the data were used to predict profit-maximizing N rates, yields, costs, and net revenues.


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**How do alternative winter cover crops and N fertilization rates influence lint yields for tillage and no-tillage cotton?**

When no N fertilizer is applied on conventional-tillage cotton, the vetch winter cover provides enough legume N to increase yields 135 lb acre$^{-1}$ from the 997 lb acre$^{-1}$ yield for no winter cover. No-tillage yield response to vetch N is larger than the yield response for tillage cotton. The vetch cover fixes enough legume N to increase lint yield 209 lb acre$^{-1}$ above the 884 lb acre-1 yield for no winter cover. Vetch and no cover provide the highest profit-maximizing yields, and clover produces the lowest profit-maximizing yields among winter covers. Yield gains for vetch and clover may have been hampered by pigweed problems in the experiment.

**What impacts do alternative winter cover crops have on the N fertilization rates required to maximize tillage and no-tillage cotton profits?**

Cotton following vetch requires no N fertilization to maximize profits. Conventional-tillage cotton following vetch requires 55 lb acre$^{-1}$ less N fertilizer to maximize profit than cotton following no cover. No-tillage cotton following vetch needs 68 lb acre$^{-1}$ less applied N to maximize profits when compared with no cover. These reductions in the N fertilizer requirement for vetch are considerably larger than the N savings estimated for corn production.

**How does the profitability of cotton following a winter cover compare with cotton following no winter cover?**

Net revenues are smaller for vetch than for no cover because the N cost savings are less than the expense of establishing the vetch cover at the prices assumed in this analysis. The profitability of no-tillage cotton following vetch is influenced

by the cost of vetch seed. A small reduction in the price of vetch seed from the price assumed in the analysis makes no-tillage cotton following vetch profitable relative to no cover. By contrast, an extremely low vetch seed price is required to make tillage cotton after vetch profitable. Increasing the cost of N fertilizer from the level assumed in this analysis did not make vetch more profitable than no cover for either tillage or no-tillage cotton.


## ABSTRACT

**Cotton (*Gossypium hirsutum* L.) producers interested in adopting winter cover crops need information about profit maximizing N fertilization rates. This study evaluated how alternative winter covers affect profit maximizing N rates and net revenues for tillage and no-tillage cotton. Data from a long-term experiment in Tennessee were used to estimate N response functions for tillage and no-tillage cotton following winter wheat (*Triticum aestivum* L.), hairy vetch (*Vicia villosa* L.), crimson clover (*Trifolium incarnatum* L.), and no cover. The response functions were used to predict profit-maximizing N rates and net revenues. Several important findings resulted. First, cotton following vetch requires no N fertilization to maximize profit. Conventional-tillage cotton following vetch requires 62 kg ha$^{-1}$ less N fertilizer to maximize profit than cotton following no cover. No-tillage cotton following vetch needs 76 kg ha$^{-1}$ less applied N to maximize profit when compared with no cover. Second, vetch provides profit-maximizing yields similar to cotton with no winter cover. Finally, even with the substantial reduction in fertilizer cost, maximum net revenues are smaller for vetch than for no cover, primarily due to the cost of establishing the vetch cover. However, a small reduction in the price of vetch seed or a small increase in lint yields from those estimated would make no-tillage cotton following vetch profitable relative to no cover.**


A U.S. Department of Agriculture study found that crop residue remaining after planting conventionally tilled cotton (*Gossypium hirsutum* L.) averages 3%, compared with 29% for corn (*Zea mays* L.) (USDA, 1997). Absence of cotton residues on the soil surface with tillage may exacerbate soil erosion problems and the runoff of chemicals and nutrients. Incorporating no-tillage practices into crop production can be an effective way to control erosion and runoff problems, but its value in cotton production is reduced by the relatively small amount of surface residue generated from cotton biomass. A survey of Tennessee cotton fields indicated that continuous no tillage on 1 to 4% slopes had average surface residue at planting that just met the 30% residue requirement for conservation compliance (Denton and Tyler, 1997). Planting a winter ground cover between cotton crops may provide another management tool for increasing protective surface residues in cotton production. Residues added with winter covers can improve soil quality over time by reducing soil erosion, increasing soil organic matter and nutrient availability, and conserving soil moisture (Bruce et al., 1987; Langdale et al., 1991; Meisinger et al., 1991; Sharpley and Smith, 1991; Bauer and Busscher, 1996; Daniel et al., 1999a, 1999b). These soil benefits are important in West Tennessee because the soils are often highly erodible and susceptible to nitrate runoff and leaching (Bradley and Tyler, 1996).

Notwithstanding the potential for soil benefits, profitability is an important consideration in farmer adoption of winter cover crops in cotton production. Prior economic analyses of winter legume cover crop systems for corn are encouraging in this regard. Frye et al. (1985) found that the net revenues for corn following hairy vetch (*Vicia villosa* L.) were larger than the net revenues for corn grown without a winter cover. The primary factor influencing profitability of the vetch system was the large increase in corn yields. The additional revenue from higher yields more than offset the seed, machinery, and labor expenses for establishment of the vetch cover. Lichtenberg et al. (1994) and Roberts et al. (1998) also found that profit-maximizing yields and net revenues for vetch were larger than for corn following no cover.

Besides yield benefits, legume winter covers provide N to the next crop that can reduce the costly application of N fertilizer. Economic considerations influence how much N fertilizer usage is curtailed in the presence of winter legumes (Lichtenberg et al., 1994). Improved soil quality with winter covers and conservation tillage may enhance the yield response to N fertilizer. Consequently, farmers may not have an economic incentive to substantially reduce or eliminate N fertilization with legume cover crops. For example, Lichtenberg et al. (1994) determined that the profit-maximizing applied N rate for corn after hairy vetch was 5% lower than the rate for corn without a winter cover. Yields for their study came from 3 yr of pooled data from experimental plots that were at different plot locations in each year. On the other hand, Roberts et al. (1998) estimated a larger reduction in the N fertilization rate required to maximize profit in the presence of legume. Their analysis of data from a long-term continuous no-tillage corn experiment indicated that corn following vetch required 16 to 26% less N fertilizer than corn following no cover.

Whether a winter cover system is profitable or not is influenced by the crop and the geographic location of production (Allison and Ott, 1987). Presently, there is little information on the profitability of conventional-tillage or no-tillage cotton grown after alternative winter covers. The objective of this study was to evaluate how alternative winter covers affect lint yield response and the profit-maximizing N fertilization rates, yields, production costs, and net revenues for tillage and no-tillage cotton production in west Tennessee.

## MATERIALS AND METHODS

### Yield Data

Cotton-yield data for 1981 through 1999 were obtained from a winter cover crop experiment at the West Tennessee Experiment Station, Jackson, TN. The soil type in the experimental plots was a Memphis (fine-silty, mixed, active, thermic Typic Hapluadalf) silt loam, the second most common in west Tennessee (Springer and Elder, 1980). N fertilizer and tillage were varied in the study. The experimental design was a randomized complete block with split-plots and four replications per year. N fertilizer was varied in the main plots, with winter cover and tillage being varied in the split-plots. The same plots received the same N fertilization rate, cover crop, and tillage treatment each year. Individual plot sizes were 4 m (4 rows) wide and 9.1 m long.

Cotton was planted on conventional-tillage and no-tillage plots after winter wheat (*Triticum aestivum* L.), hairy vetch, crimson clover (*Trifolium incarnatum* L.), and no winter cover crop alternatives. The cotton cv. Stoneville 825 was planted on the plots between 1984 and 1993. When this variety became less competitive in yield, compared with newer varieties in the early 1990s, it was replaced by newer varieties from the University of Tennessee Agricultural Extension Service recommended variety list. Cotton cv. Deltapine 50 was used in 1994, 1995, and 1997. In 1996, ‘Stoneville 132’ was sown on the plots. ‘Stoneville 474’ was planted in 1998 and ‘Deltapine 425’ in 1999. 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 before planting. Winter covers were re-established each season after cotton harvest with seeding rates of 100.8 kg $ha^{-1}$ for wheat, 22.4 kg $ha^{-1}$ for vetch, and 16.8 kg $ha^{-1}$ for clover. Broadcast ammonium nitrate was the N source applied at planting. Rates of N fertilizer applied to the plots were 0, 33.6, 67.2, and 100.8 kg $ha^{-1}$.

Researchers who managed the experiment had to learn to manage heavy crop residues with herbicides in cotton and discern which winter covers worked best from an agronomic standpoint. The experiment started with rye (*Secale cereale* L.) and vetch-rye covers that were switched to wheat and crimson clover in the fourth year of the experiment. Therefore, the experiment’s first three years of data (1981 through 1983) were excluded from the analysis.

Two important events in the experiment complicated the economic analysis of the yield data. Researchers experienced increasing difficulty with controlling weeds. Pigweed (*Amaranthus palmeria*, S. Wats) was especially prevalent in the no tillage and legume winter cover plots. Researchers were better able to control pigweed with the availability of pyrithiobac sodium [sodium 2-chloro-6-[(4,6-dimethoxy pyrimidin-2-yl)thio]benzoate](Staple, DuPont, Wilmington, DE) herbicide in 1995. Researchers also conducted a lime recommendation study in the latter years of the data period. They split the plots and applied different lime rates in spring 1995: the full extension service recommended rate and half the recommended rate. Declining soil pH in some of the plots before the application of lime in 1995 may have had a negative impact on yield over time. Plots receiving half the recommended lime rate were excluded from analysis.

### Lint Yield Response Model

The lint yield data were used to estimate a quadratic yield response function for each winter cover crop alternative as indicated in the following equation:

$$Y_t = a + bNF_t + cNF_t^2 + dTM_t + eT_t \times fNF_t \times TM_t + gNF_t \times T_t + hTM_t \times T_t + ipH_t + u_t \quad [1]$$

where Y is lint yield (kg ha$^{-1}$) for cotton following one of the winter cover crop treatments in the experiment; NF is the applied N fertilization rate (kg ha$^{-1}$); TM is a tillage binary variable (no tillage = 1, conventional tillage = 0); T is a time trend index (1 = 1984, 2 = 1985…, 16 = 1999); NF × TM, NF × T, and TM × T are linear interactions among the respective variables; pH is a soil pH experiment binary variable where pH = 1 for 1995 through 1999, 0 otherwise; t is a subscript indicating year of the experiment; a, b, c, d, e, f, g, h, and i are parameters to be estimated by regression; and u is a random error term.

Economic theory and agronomic considerations guided the specification of the yield response model presented in Eq. [1]. The quadratic functional form for N response (which allows for diminishing marginal productivity of an input) has been widely used to estimate N fertilizer response (Woodward, 1977). It is especially appropriate for cotton where N fertilization affects maturity, lint yield, and lint fiber quality. For cotton, inadequate or excessive N applications may reduce yields (Maples and Keogh, 1971). N deficiency in cotton causes premature senescence and reduces lint yields (McConnell et al., 1995). High N fertilization rates may cause excessive vegetative growth, thereby delaying maturity and harvest, which in turn may reduce lint yields in years with early frost or prolonged rainfall during autumn (Hutchinson et al., 1995; McConnell, 1995). Crop maturity is a critical issue for cotton growers in Tennessee, which is along the northern edge of the U.S. Cotton Belt (Gwathmey and Howard, 1998). Given the previous discussion, the expected signs for the N fertilizer coefficients b and c were hypothesized to be positive and negative, respectfully.

No tillage can improve soil physical properties by decreasing soil erosion, improving water infiltration, increasing organic matter, decreasing soil compaction, and enhancing soil tilth (Mutchler et al., 1985; Griffith et al., 1992; Stevens et al., 1992; Kovar et al., 1994). The expected improvements in soil quality suggest that lint yields will be higher with no tillage. However, the literature documenting the impact of no tillage on lint yields is mixed. Some researchers have reported similar or higher lint yields with no tillage compared with conventional-tillage yields (Stevens et al., 1992; Bloodworth and Johnson, 1995; Hutchinson et al., 1995; Triplet et al., 1996). Other studies have found that conventional-tillage cotton yields were higher than no-tillage cotton yields (Burmester et al., 1993; Bauer and Busscher, 1996). Inadequate cotton stands due to cool early-season conditions or poor weed control with no tillage are two reasons why no-tillage cotton yields may be lower than with conventional tillage (Touchton et al., 1988; Hutchinson, 1993; Hoskinson and Gwathmey, 1996). Given the conflicting results from these studies and the weed problems in the experiment previously described, the hypothesized sign for the TM coefficient was difficult to determine *a priori*.

As with no tillage, winter cover crops can improve soil physical properties over time (Bruce et al., 1987; Langdale et al., 1991; Meisinger et al., 1991; Sharpley and Smith, 1991; Bauer and Busscher, 1996; Daniel et al., 1999a, 1999b). These soil benefits are hypothesized to improve crop yields over time and enhance the productivity of N fertilizer (Lichtenberg et al., 1994; Roberts et al., 1998). Unfortunately, data measuring annual changes in soil quality attributes for each winter cover were not available from the experiment. Instead, the time trend index variable, T, was used to try to capture the expected long-term benefits of no tillage and winter covers on soil quality and lint yields. A time index in a production function is a standard method for modeling technical change (Chambers, 1988). Technical change refers to any kind of shift in the production function (Solow, 1957). In this specific case, technical change refers to the shift in the production function over time due to the cover crop and its positive impact on soil quality and yields. Therefore, the sign on the time index coefficient, e, is expected to be positive. However, the expected positive relationship for the time index may be confounded by the potential negative effects of weeds and decreasing pH on yields, as described previously.

Linear interaction terms in Eq. [1] were used to evaluate potential complimentary and competitive technical relationships among the NF, tillage, and time index variables (Debertin, 1986). The expected relationship for the NF × TM coefficient was difficult to determine a priori. Under no tillage, cotton stalks and plant material are not incorporated into the soil; therefore, they decay more slowly and release less N for use by the subsequent crop, when compared with conventional tillage. Less available soil N with no tillage suggests that more N fertilizer may be required to achieve the same yield as with conventional tillage. This relationship suggests that the coefficient for NF × TM should be positive under no tillage due to the larger marginal physical productivity of N fertilizer. By contrast, C sequestration and N immobilization under no tillage and winter covers may reduce the N availability to the crop (Mengel et al., 1992). This relationship suggests that the coefficient for NF × TM may be negative due to the lower marginal physical productivity of applied N under no tillage. The sign for NF × T was hypothesized to be positive due to the expected increase in the marginal physical product of N fertilizer as soil quality increases over time with no tillage and winter covers (Lichtenberg et al., 1994; Roberts et al., 1998). The coefficient for TM × T was expected to be positive because yields were expected to increase over time under no tillage relative to tillage as a result of improved soil quality (Triplet et al., 1996; Roberts et al., 1998).

Finally, the coefficient for the pH binary variable was expected to be positive after the application of lime in spring 1995. However, impact on pigweed control of using pyrithiobac sodium herbicide beginning in 1996 also may have confounded the pH variable.

### Profit-maximizing Net Revenues

The yield response functions were used to predict profit-maximizing N fertilization rates for each winter cover and tillage alternative. Using Eq. [1], the N fertilization rate that equates the value of the marginal product of N with its price is (Debertin, 1986):

$$NF^* = \frac{(P_N/P_L)\text{-b-fTM-gT}}{2c} \qquad [2]$$

where NF* is the profit-maximizing N fertilization rate (kg $ha^{-1}$); $P_N$ is the price of ammonium nitrate fertilizer ($ $kg^{-1}$); PL is lint price ($ $kg^{-1}$); and b, c, f, and g are estimated regression coefficients from Eq. [1]. In the analysis, revenues from cottonseed were assumed to equal the cost of ginning and bale handling.

NF* was used to calculate maximum net revenue for each winter cover and tillage alternative using the following formula:

$$NR^* = P_L \times Y^* - P_N \times NF^* - P_S \times WC_S - WC_{OC} - TM_{OC} \qquad [3]$$

where NF* is maximum net revenue ($ $ha^{-1}$); Y* is the profit-maximizing lint yield calculated using Eq. [1] and the profit-maximizing N fertilization rate NF* from Eq. [2]; $P_S$ is the winter cover crop seed price ($ $kg^{-1}$); $WC_S$ is the winter cover crop seeding rate (kg $ha^{-1}$); $WC_{OC}$ is the other estimated materials, labor, equipment, and interest costs to establish the winter cover crop ($ $ha^{-1}$); and $TM_{OC}$ is the other variable costs, fixed equipment expenses, and overhead costs for conventional-tillage or no-tillage cotton production that did not vary in this analysis ($ $ha^{-1}$). Eq. [3] was used to calculate break-even lint yields, N fertilizer prices, and winter cover seed prices that would make the net revenue for a winter cover alternative equal to no cover.

Prices and costs used to calculate profit-maximizing values were expressed in 1999 dollars so changes in net revenues would reflect changes in profit-maximizing yields rather than inflationary price changes. A lint price of $1.58 $kg^{-1}$ and N fertilizer price of $0.73 $kg^{-1}$ were used to calculate profit-maximizing values. Average prices for 1984 through 1999 were used in these calculations (TDA, 1985–2000). These prices were inflated to 1999 dollars by the Implicit Gross Domestic Product Price Deflator before averaging (USCCEA, 2000). Cover crop costs include cover seed cost and the costs of machinery, labor, and interest on the variable costs of cover establishment. Cover seed costs were 100.8 kg $ha^{-1}$ multiplied by $0.38 $kg^{-1}$ for wheat, 22.4 kg $ha^{-1}$

multiplied by \$2.69 $kg^{-1}$ for vetch, and 16.8 kg $ha^{-1}$ multiplied by \$2.34 $kg^{-1}$ for clover. The costs of seed for each of the winter covers were obtained from a 1999 Tennessee Farmers Cooperative retail price list. Machinery and labor costs to seed the winter covers assume a 150 hp tractor and a 6.38 m drill with 17.8 cm row spacing requiring 0.27 h $ha^{-1}$ plus labor at \$6.75 $h^{-1}$ for 0.35 h $ha^{-1}$ (Gerloff, 2000). An interest rate of 9% for 12 mo was charged on the variable costs of establishing the winter cover (Gerloff, 2000). Other costs of production that did not vary in this analysis were from extension service enterprise budgets for conventional-tillage and no-tillage cotton (Gerloff, 2000). The no-tillage budget assumes the application of a burn-down herbicide to kill the winter cover and weeds before planting. The tillage budget assumes two disking operations before planting to kill the winter cover and weeds and prepare the seedbed.

## RESULTS AND DISCUSSION

### Lint Yield Response

The estimated lint yield response functions for the four winter cover alternatives are presented in Table 1. Diagnostic procedures (SAS Institute, 1988) indicated that there were no collinearity problems that contributed to a lack of significance among the explanatory variables in each winter cover crop model (Belsley et al., 1980).

Several of the management variables are statistically significant in explaining lint yield response in each of the winter cover crop equations. N fertilizer coefficients NF and NF2 have the hypothesized signs and are significantly different from zero (P = 0.05) in the cotton following winter wheat and cotton following no cover equations. The estimated TM coefficients have negative signs that are significantly different from zero for cotton following no cover (P = 0.05),

**Table 1. Estimated cotton lint yield response functions from winter cover crops, Jackson, TN, 1984–1999.**

| | Winter cover crop alternative | | | |
|---|---|---|---|---|
| Variable† | No cover | Winter wheat | Hairy vetch | Crimson clover |
| Intercept | 1178.32***<br>(14.23)‡ | 1190.58***<br>(16.71) | 1319.53***<br>(14.47) | 1275.00***<br>(17.02) |
| NF | 4.34*<br>(2.23) | 4.23*<br>(2.53) | 0.41<br>(0.19) | -1.45 x $10^3$<br>(0.00) |
| $NF^2$ | -0.03*<br>(2.07) | -0.03*<br>(2.08) | -0.01<br>(0.82) | -0.01<br>(0.38) |
| TM | -183.01*<br>(2.05) | -264.76***<br>(3.45) | -144.52<br>(1.47) | -192.73*<br>(2.39) |
| T | -72.27***<br>(7.84) | -66.27***<br>(8.35) | -70.35***<br>(6.93) | -69.12***<br>(8.28) |
| NF x TM | 0.91<br>(0.96) | 1.51<br>(1.84) | -0.89<br>(0.84) | 0.23<br>(0.27) |
| NF x T | 0.03<br>(0.26) | -0.03<br>(0.28) | 0.07<br>(0.64) | 0.04<br>(0.41) |
| TM x T | 7.10<br>(0.91) | 17.11*<br>(2.56) | 12.76<br>(1.49) | 21.24***<br>(3.02) |
| pH | 515.75 ***<br>(7.93) | 412.97***<br>(7.38) | 509.47***<br>(7.11) | 424.71***<br>(7.22) |
| Adjusted $R^2$ | 0.49 | 0.53 | 0.37 | 0.42 |
| Model F-statistic | 16.26*** | 18.86*** | 10.17*** | 12.70*** |

**†Cotton lint yield (kg $ha^{-1}$) is the dependent variable, NF = applied ammonium nitrate (kg $ha^{-1}$), TM = tillage method binary variable (no tillage = 1, conventional tillage = 0), T = time-trend index (1 = 1984 to 16 = 1999), and pH = soil pH experiment binary variable where pH = 1 for 1995 through 1999, 0 otherwise.**

**‡ Numbers in parentheses are t-statistics.**

***,**, *** Significantly different from zero at the 0.05, 0.01, and 0.001 levels of significance, respectively.**

cotton following wheat (P = 0.001), and cotton following crimson clover (P = 0.05). Coefficients for the time-trend variables in all four winter cover equations have negative signs that are statistically significant (P = 0.001). The no tillage-time-trend interactions (TM × T) for cotton after wheat and cotton after clover have positive coefficients that are statistically significant at the 0.05 and 0.001 probability levels, respectively. As hypothesized, the signs on the estimated pH coefficients are positive and statistically significant (P = 0.001).

Although the estimated time-trend coefficient in each winter cover function has a statistically significant negative sign, the net impact of time on yields is not clear due to the interaction of time with other variables in the model. An evaluation of lint yield with respect to T and its interactions indicates that yields declined over time for all four cover crop scenarios. In addition, evaluation of the yield response equations with respect to TM and its interactions indicates that no-tillage yields are lower than conventional-tillage yields for all four cover crop alternatives. Difficulty controlling pigweed in the no-tillage plots may be an important factor in explaining the lower no-tillage yields and the overall downward trend in yields. These negative influences on yields more than offset any positive long-term benefits of winter covers and no tillage on soil quality.

To illustrate the economic consequences of winter covers on N response, the estimated regression model coefficients in Table 1 were used to predict the conventional-tillage yields depicted in Fig. 1 (with T held at its mean value of 8 and the pH binary variable set at 1). Even though the N fertilizer relationships for the two winter legume

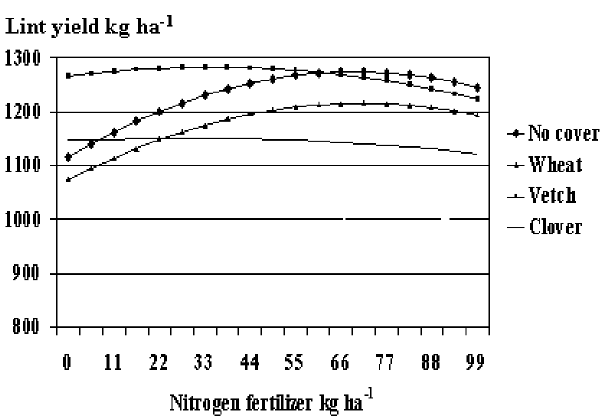


**Fig. 1. Conventional-tillage lint yield response to N fertilizer for alternative winter cover crops.**

equations are not statistically significant, several important economic implications can be derived from a careful evaluation of yield response for the alternative winter covers illustrated in Fig. 1. The important findings about conventional-tillage yield response to N fertilizer are as follows.

First, as indicated by their relatively flat (not statistically significant) response curves, yields for tillage cotton following vetch or clover are not responsive to N fertilizer. The marginal physical products of N fertilizer are driven down to zero by the presence of legume N. Consequently, additional yield cannot be gained by applying N fertilizer on cotton grown after a vetch or clover winter cover. The lack of a significant yield response with legumes suggests that N fertilizer is not required to maximize profit for cotton following a winter legume (profitability comparisons with other winter covers will be discussed in the next section). Legume winter covers fix sufficient N for the cotton crop such that the addition of N fertilizer does not increase yields. Thus, the most appropriate yield levels for legume covers in Fig. 1 that can be compared with the yields of the other winter covers are the intercept (no applied N fertilizer) yields of 1266 kg $ha^{-1}$ for vetch and 1147 kg $ha^{-1}$ for clover.

The second finding obtained from Fig. 1 is the level of the yield boost provided by legume N for tillage cotton. When no N fertilizer is applied, the vetch and clover winter covers, respectively, provide enough legume N to increase yields 151 kg $ha^{-1}$ and 31 kg $ha^{-1}$ from the 1116 kg $ha^{-1}$ yield for no winter cover. The winter wheat cover, which can immobilize N during decomposition after desiccation, lowers lint yield by 43 kg $ha^{-1}$ when compared with cotton after no winter cover.

Third, yields for tillage cotton following vetch with no N fertilization are higher than the yields for tillage cotton following no cover fertilized with up to 54 kg N $ha^{-1}$. In addition, vetch with no applied N provides a higher yield than the cotton following wheat maximum yield of 1216 kg $ha^{-1}$ produced with a N fertilization rate of 71 kg $ha^{-1}$. Yields for no cover are greater than the yields for winter wheat for all N fertilization levels. The results indicate that for conventional-tillage cotton, applying more N fertilizer after a wheat cover cannot give yields as high as the largest yields for cotton after vetch or no winter cover. For example, no amount of N can be applied to cotton following wheat that will give a lint yield equal to the vetch and no cover profit-maximizing yields (results to be described in the next section). Several factors may contribute to lower cotton following wheat yields. A large amount of biomass from the wheat cover can result in cold soils and slow early emergence and growth. In addition, large biomass production may cause immobilization of N as biomass is broken down in the soil.

Finally, yields for tillage cotton following clover are low, relative to the yields produced with the other winter covers. For example, clover provides smaller yields than vetch when no N fertilizer is applied. In addition, lint yields for clover are smaller than the yields for wheat or no cover, except at low-N fertilization levels. Cotton following clover with no applied N produces lower yields than no-cover cotton fertilized with more than 7 kg N ha$^{-1}$. Cotton following wheat fertilized with more than 22 kg N ha$^{-1}$ gives larger yields than cotton following clover with no applied N. The following agronomic factors may explain the smaller yield response for clover compared with vetch when no N fertilizer is applied. Clover tends to provide less N than vetch due to smaller dry matter production (Ebelhar et al., 1984; Hargrove, 1986; Frye et al., 1988). In addition, Sclerotinia crown rot (*Sclerotinia trifoliorum* Eriks) was present in some years and negatively affected the clover stand. Winter injury was also a problem in some years. However, it is uncertain why cotton following clover did not respond to N fertilizer if less legume N was available. As with vetch, the pigweed and soil pH problems that were particularly prevalent in the legume plots fertilized with higher N rates may have contributed to the absence of a yield response with clover.

Fig. 2 depicts the relationships among the estimated no-tillage lint yield response functions for winter cover crops and N fertilization rates (again with T held at its mean value of 8 and the pH variable set at 1). Several important findings can be drawn from this chart.

First, since the no tillage yield response for N fertilizer with winter legumes was not significant (Table 1), the zero-applied-N yields of 1224 kg ha$^{-1}$ for vetch and 1124 kg ha$^{-1}$ for clover can be compared with the no-tillage yields of the other winter covers (Fig. 2). The predicted yield for

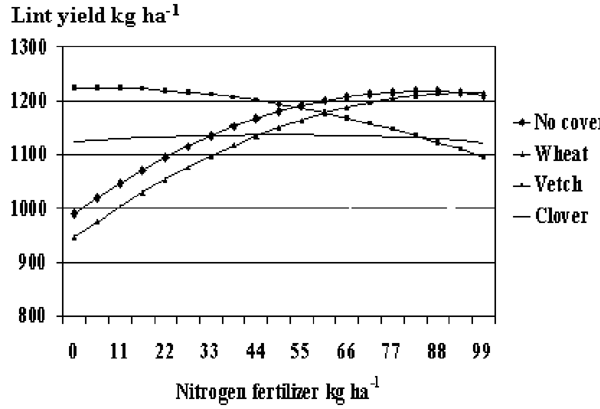


**Fig. 2. No-tillage lint yield response to N fertilizer for alternative winter cover crops.**

vetch with no applied N is larger than the predicted maximum yields for cotton following no cover or wheat fertilized with 83 kg N ha$^{-1}$ and 97 kg N ha$^{-1}$, respectively. As with the tillage system, the absence of a significant yield response for cotton following a legume when N fertilizer is applied could be due to excessive total N in the system.

Second, the yield boost from legume N when no N fertilizer is applied is larger for no-tillage cotton than it is for conventional-tillage cotton. The vetch and clover covers fixed enough N to increase lint yield 234 kg ha$^{-1}$ and 134 kg ha$^{-1}$, respectively, from the 990 kg ha$^{-1}$ yield for no winter cover. Lint yield for cotton following wheat is 54 kg ha$^{-1}$ lower than the yield for cotton grown without a winter cover.

Third, no-tillage cotton followed by wheat requires a higher N fertilization rate to achieve the same yield level as cotton grown without a winter cover, except at high N fertilization levels.

Finally, similar to the tillage results, no-tillage cotton following clover performed poorly relative to the other winter covers. Cotton following clover without N fertilizer provides smaller yields than no-cover cotton fertilized with more than 30 kg N ha$^{-1}$. In a comparison of clover versus wheat, clover with no N fertilization gives smaller yields than cotton after wheat that receives more than 45 kg ha$^{-1}$ N fertilizer. As stated earlier, clover with no N fertilization may have provided less N to the cotton crop than vetch.

## Profit-Maximizing Net Revenues

Table 2 provides estimates of profit-maximizing N fertilizer rates and lint yields.

Regression model coefficient estimates were used to predict profit-maximizing N fertilizer rates for no cover and wheat (with T held at its mean value of 8). Due to the lack of a significant yield response for N fertilizer in the presence of winter legumes, the intercept (no applied N fertilizer) yields for vetch and clover (Figs. 1, 2) were used to compare profitability among the winter cover alternatives.

First, tillage profit-maximizing yields are higher than no-tillage profit-maximizing yields for the no cover, vetch, and clover winter covers. One factor that may have contributed to lower no-tillage yields was the previously described pigweed problem prevalent in the legume plots. Pigweed may have been less of a problem for cotton following wheat. The profit-maximizing no-tillage cotton following wheat yield is identical to the profit-maximizing yield for tillage cotton following wheat. In addition, the optimal yield for no-tillage cotton following wheat is similar to the maximum yield for tillage cotton following no winter cover. For tillage cotton, no cover produces the largest profit-maximizing yield. By contrast, vetch provides the highest profit-maximizing yields for no-tillage cotton. However, the yield differences for cotton following vetch over cotton without a winter cover are very small for both tillage scenarios. Thus, any economic advantage for vetch must come from potential N fertilizer savings rather than yield gains. The lack of a yield gain for vetch, compared with no cover in cotton, is in contrast to the corn yield gains estimated by Lichtenberg et al. (1994) and Roberts et al. (1998).

Second, results indicate that cotton following vetch or clover requires no N fertilization to maximize profits. For conventional tillage, the predicted N fertilizer savings for cotton following vetch is 62 kg ha$^{-1}$ when compared with cotton following no cover, and 63 kg ha$^{-1}$ when compared with cotton following winter wheat (Table 2). For no-tillage, the estimated N savings are even larger for vetch. Total N savings amount to 76 kg ha$^{-1}$ for vetch versus no cover and 89 kg ha-1 for vetch versus wheat. These reductions in the N fertilizer requirement for vetch are considerably more than the 5 to 26% savings estimated for corn (Lichtenberg et al., 1994; Roberts et al., 1998). Thus, if West Tennessee cotton farmers switch from wheat or no cover to a vetch cover they may be able to eliminate N fertilization and maintain yield levels similar to no cover.

Finally, no-tillage cotton following wheat requires 41% (26 kg ha$^{-1}$) more N fertilizer to maximize profits even though maximum yields are identical for tillage and no-tillage. The additional N fertilizer requirement may be needed to help break down the large amount of non-incorporated biomass that may be produced by the winter wheat cover for no tillage.

The University of Tennessee N fertilizer recommendation for cotton production has been modified to reflect the profit-maximizing N rates for the cotton following legume findings in this study (UTEPSS, 2001). The previous guideline was to apply 34 to 67 kg N ha$^{-1}$ to alluvial soils and 67 to 90 kg N ha$^{-1}$ for upland soils regardless of tillage or winter cover crop. These ranges allow a grower to choose a N rate based on knowledge of cropping history and previous fertilization. The current guidelines provide for cotton following a winter legume by recommending the application of 0 to 34 kg N ha$^{-1}$ with legumes.

Estimated total production costs for each winter cover and tillage system are presented in Table 3. Costs of production for no-tillage cotton following no cover or wheat are lower than the costs for tillage, even though the predicted expenses for N fertilizer are larger. Winter cover establishment costs are calculated to be $57.41 ha$^{-1}$ for wheat, $81.91 ha$^{-1}$ for vetch, and $59.02 ha$^{-1}$ for clover. Cotton grown without a winter cover has the lowest production cost because the higher cost of N fertilizer compared with vetch or clover

**Table 2. Profit-maximizing N fertilization rates and lint yields for alternative winter cover crops.**

| | Winter cover crop alternative | | | |
|---|---|---|---|---|
| **Item** | **No cover** | **Wheat** | **Vetch** | **Clover** |
| | kg ha$^{-1}$ | | | |
| **Tillage** | | | | |
| **N fertilizer** | **62** | **63** | **0** | **0** |
| **Lint yields** | **1273** | **1214** | **1266** | **1147** |
| **No tillage** | | | | |
| **N fertilizer** | **76** | **89** | **0** | **0** |
| **Lint yields** | **1216** | **1214** | **1224** | **1124** |

**Table 3. Profit-maximizing costs of production for alternative winter cover crop and tillage systems.**

| | Winter cover crop alternative | | | |
|---|---|---|---|---|
| **Cost item** | **No cover** | **Wheat** | **Vetch** | **Clover** |
| | $ ha$^{-1}$ | | | |
| **Winter cover crop** | | | | |
| Seed† | 0.00 | 37.79 | 60.27 | 39.27 |
| Labor‡ | 0.00 | 2.33 | 2.33 | 2.33 |
| Tractor§ | 0.00 | 6.04 | 6.04 | 6.04 |
| Drill§ | 0.00 | 6.99 | 6.99 | 6.99 |
| Interest¶ | 0.00 | 4.25 | 6.28 | 4.39 |
| Total | 0.00 | 57.41 | 81.91 | 59.02 |
| **N fertilizer#** | | | | |
| Tillage | 45.55 | 45.80 | 0.00 | 0.00 |
| No tillage | 55.68 | 65.20 | 0.00 | 0.00 |
| **Other costs** | | | | |
| Tillage | 743.96 | 743.96 | 743.96 | 743.96 |
| No tillage | 723.91 | 723.91 | 723.91 | 723.91 |
| **Total costs** | | | | |
| Tillage | 789.51 | 847.17 | 825.87 | 802.98 |
| No tillage | 779.59 | 846.52 | 805.82 | 782.93 |

† Cover seed costs were 100.8 kg ha$^{-1}$ multiplied by $0.38 kg$^{-1}$ for wheat, 22.4 kg ha$^{-1}$ multiplied by $2.69 kg$^{-1}$ for vetch, and 16.8 kg ha$^{-1}$ multiplied by $2.34 kg$^{-1}$ for clover (Tennessee Farmer Cooperative, 1999).

‡ Labor costs were calculated using a wage rate of $6.75 h$^{-1}$.

§ Machinery and labor costs assume 0.27 h ha$^{-1}$ for a 150-hp tractor and a 6.38-m drill with 17.8-cm row spacing and 0.35 h ha$^{-1}$ for labor (Gerloff, 2000).

¶ An interest rate of 9% for 12 mo was charged on the variable costs of establishing the winter cover (Gerloff, 2000).

# The profit-maximizing N fertilizer rate multiplied by the 1984–1999 average real ammonium nitrate price of $0.73 kg$^{-1}$.

is more than offset by the lack of a cover crop establishment cost. The high N fertilizer rate and cover establishment cost give cotton following wheat the highest cost of production.

Profit-maximizing net revenues for the alternative winter cover crop and tillage systems are presented in Table 4. Because of high production costs for cotton grown with the alternative winter covers, conventional-tillage cotton grown after no winter cover produced the largest net revenue ($1221 ha$^{-1}$) among the eight winter cover and tillage alternatives. The next highest net revenue of $1175 ha$^{-1}$ was produced using a vetch cover followed by conventional-tillage cotton. Even with the larger reduction in N expense with vetch, the fertilizer cost savings did not offset the cost of establishing the vetch cover at the prices assumed in this analysis.

Sensitivity of net revenues to changes in prices and yields for tillage cotton following vetch is also presented in Table 4. The cost of vetch seed must drop from $2.69 kg$^{-1}$ to $0.62 kg$^{-1}$ before vetch revenues equal those for no cover. Vetch seed prices typically exhibit large fluctuations from year to year. For example, vetch seed prices in 1997 were $1.43 kg$^{-1}$ (Roberts et al., 1998) compared with $2.69 kg$^{-1}$ in 1999. Even with the lower 1997 vetch price, tillage cotton following vetch would still not be profitable relative to no cover. Looking at the impact of N prices on the profitability of vetch, the cost of ammonium nitrate fertilizer must double from $0.73 kg$^{-1}$ to $1.52 kg$^{-1}$ before vetch revenues match no-cover revenues. The highest ammonium nitrate price (expressed in 1999 dollars) since 1984 was $0.88 kg$^{-1}$ in 1985, suggesting a very small likelihood of observing this breakeven N price. Finally, a relatively modest 2% (29 kg ha$^{-1}$) increase in lint yields from those estimated would cause the revenues from vetch to equal the revenues from no cover.

Similar to tillage net revenue results, cotton following no cover produced the largest no-tillage net revenue ($1142 ha$^{-1}$). However, the net revenue difference between vetch and no cover is only $14 ha$^{-1}$ for no-tillage cotton. Consequently, a modest drop in vetch seed cost to $2.12 kg$^{-1}$ would cause net revenues from vetch to be competitive with no cover. By comparison, ammonium nitrate prices would have to rise to $0.91 kg$^{-1}$ for vetch revenues to match no-cover revenues. As indicated previously, a N price this high did not occur

**Table 4. Profit-maximizing net revenues and breakeven values for alternative winter cover crop and tillage systems.**

| | Winter cover crop | | | |
|---|---|---|---|---|
| **Item** | **No cover** | **Wheat** | **Vetch** | **Clover** |
| **Tillage** | | | | |
| **Net revenues($ ha$^{-1}$)** | **1221** | **1071** | **1175** | **1009** |
| **Net revenue difference ($ ha$^{-1}$)†** | — | **-150** | **-46** | **-212** |
| **Breakeven cover seed price ($ ha$^{-1}$)‡** | — | ¶ | **0.62** | ¶ |
| **Breakeven N price ($ ha$^{-1}$)§** | — | ¶ | **1.52** | ¶ |
| **Breakeven lint yield difference (kg ha$^{-1}$) #** | — | **95** | **29** | **134** |
| **No tillage** | | | | |
| **Net revenues ($ ha$^{-1}$)** | **1142** | **1071** | **1128** | **993** |
| **Net revenue difference ($ ha$^{-1}$)†** | — | **-71** | **-14** | **-148** |
| **Breakeven cover seed price ($ ha$^{-1}$)‡** | — | ¶ | **2.12** | ¶ |
| **Breakeven N price ($ ha$^{-1}$)§** | — | ¶ | **0.91** | ¶ |
| **Breakeven lint yield difference (kg ha$^{-1}$)#** | — | **45** | **9** | **94** |

**† Compared with the no winter cover profit-maximizing net revenue.**
**‡ Base cover seed costs were $0.38 kg$^{-1}$ for wheat, $2.69 kg$^{-1}$ for vetch, and $2.34 kg$^{-1}$ for clover (Tennessee Farmers Cooperative retail price list, 1999).**
**§ The base ammonium nitrate price was $0.73 kg$^{-1}$.**
**¶ The breakeven winter cover seed price is less than zero.**
**# Compared with the no winter cover profit-maximizing lint yield.**

between 1984 and 1999. Finally, lint yields would need to increase by only 9 kg ha$^{-1}$ from those estimated for vetch to be profitable relative to the no-cover system. These no-tillage results suggest relatively small reductions in vetch seed prices or increases in yields from those estimated would make vetch in a no-tillage cotton system profitable relative to the no-cover system.

## SUMMARY AND CONCLUSIONS

Research has shown that no-tillage cotton following a winter cover crop can positively impact soil productivity and reduce the adverse impacts of cotton production on the environment. Among the many soil quality benefits, a cover crop can positively impact organic matter, improve fertility, and increase water-holding capacity. Winter covers can have a positive impact on the environment by reducing soil erosion and preventing the runoff of chemicals and nutrients. Despite these potential soil productivity and environmental benefits, an important factor influencing a farmer's willingness to adopt winter cover crops in cotton production is the profitability of the practice. The objective of this study was to determine profit-maximizing N fertilization rates and net revenues for conventional-tillage and no-tillage cotton following alternative winter cover crops.

Cotton yield data from a long-term experiment at the West Tennessee Experiment Station, Jackson, TN, were used to estimate N fertilizer response functions for tillage and no-tillage cotton following winter wheat, hairy vetch, crimson clover, and no cover. The functions were used to predict profit-maximizing N rates, yields, costs, and net revenues.

The important findings from this analysis are as follows. First, N fertilizer is not required to maximize profit for cotton following a winter legume. When compared with no cover, the predicted N savings with vetch are 62 kg ha$^{-1}$ for tillage cotton and 76 kg ha$^{-1}$ for no-tillage cotton. The effects of this reduction in fertilizer N use for the vetch system on water quality are uncertain. Thus, whether nitrate leaching decreases with elimination of N fertilization with vetch is an empirical question that remains to be answered.

Second, cotton following vetch provides similar profit-maximizing yields to cotton grown with no winter cover. The lack of a yield gain for cotton following vetch is in contrast to the profit-maximizing yield gains estimated for corn following vetch in other economic studies. Problems controlling pigweed, particularly in the no-tillage legume cover plots, may have limited the potential yield gains for vetch in this experiment. With the availability of glyphosate [N-(phosphonomethyl) glycine]-tolerant cotton and pyrithiobac sodium (Staple) herbicide, weed control for no-tillage cotton following vetch may be much less of a problem for farmers.

Finally, even with the substantial reduction in fertilizer cost for cotton following vetch, its profit-maximizing net revenues are smaller than no cover because the N cost savings are less than the expense of establishing the vetch cover. Consequently, farmers may be reluctant to adopt winter covers for conservation purposes because net revenues are lower with winter cover crops. However, the profitability of no-tillage cotton following vetch is influenced by the cost of seed, which exhibits large fluctuations in price from year to year. For example, a small reduction in the price of vetch seed from the price assumed in the analysis makes no-tillage cotton following vetch profitable relative to no cover. On the other hand, an extremely low vetch seed price is required to make tillage cotton after vetch profitable. A large increase in the N fertilizer price does not make vetch more profitable than no cover for both tillage and no-tillage cotton. The availability of better weed control technologies for cotton may make vetch more profitable than no cover in a no-tillage system.

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