Economics of Irrigated Continuous Corn under Conventional-Till and No-Till in Northern Colorado

David W. Archer,* Ardell D. Halvorson, and Curtis A. Reule

ABSTRACT

Conversion of irrigated cropland from conventional tillage (CT) to no-till (NT) could have several environmental benefits including reduced erosion potential, reduction of greenhouse gas emissions, and conservation of water. However NT must be economically viable if it is to be adopted. Costs of production and economic returns were evaluated for an irrigated, continuous corn (Zea mays L.) system under CT and NT over 6 yr on a clay loam soil in northern Colorado. Yield responses to N fertilization were included to determine economic optimum fertilization rates under each tillage system. Corn grain yields at economic optimum N fertilizer rates were 1.1 to 1.4 Mg ha$^{-1}$ lower for NT than for CT. However, net returns were $46 to 74 ha$^{-1}$ higher for NT than for CT due to reductions in operating costs of $57 to 114 ha$^{-1}$ and reductions in machinery ownership costs of $87 to 90 ha$^{-1}$. Operating cost savings were realized largely due to fuel and labor reductions of 75% and 71 to 72%, respectively, and in spite of higher N fertilizer requirements of 16 to 55 kg ha$^{-1}$ for NT compared to CT. No-till, irrigated, continuous corn appears to be an economically viable option for replacing CT production systems in the central Great Plains, especially when combined with the environmental benefits of the NT system.

FARMERS IN THE SOUTH PLATTE RIVER VALLEY of northeastern Colorado predominantly use intensive tillage, including moldboard plow tillage, to prepare a seedbed and to manage the large quantities of crop residues returned to the soil surface in irrigated crop production. As a result, soil erosion due to wind and water is a serious problem in this area. Conversion of irrigated cropland from moldboard plow tillage to less intensive tillage systems would reduce the potential for soil erosion, and has been reported to increase C storage in soils, enhancing soil organic carbon (SOC) sequestration and reducing CO$_2$ emissions (Entry et al., 2002; Halvorson et al., 2008; Mosier et al., 2006). However, less intensive tillage systems, like NT, must provide adequate economic returns if they are to be adopted by producers.

Limited information is available on the use of NT systems on irrigated lands, and particularly on the economic performance of these systems. Norwood (2000) reported higher corn grain yields for NT than for CT with limited irrigation, and Wiese et al. (1998) reported that NT increased economic returns compared to CT in a limited irrigation system. One benefit of NT with limited irrigation is an increase in water availability compared to CT, but irrigation is used to minimize these differences under full irrigation (Sims et al., 1998). Tew et al. (1986) reported higher gross margins for irrigated, continuous corn under a minimum tillage system, which included tillage in a 10-cm planting strip, compared to CT. However, gross margins for minimum tillage were less than for a tillage system which created alternating 76-cm tilled strips. Cahoon et al. (1999) reported that use of conservation tillage on irrigated continuous corn increased corn grain yields and economic returns compared to conventional systems. Similarly, Smart and Bradford (1999) reported higher economic returns for corn in conservation tillage systems compared to CT systems due to greater yields in dry years and lower production costs.

An important consideration in tillage system decisions is the interaction of tillage system with N fertilizer needs. It has often been observed that economic optimum N fertilizer rates differ among tillage systems (Stecker et al., 1995; Kwaw-Mensah and Al Kaisi, 2006). In irrigated corn production, Sims et al. (1998) reported that increasing N fertilizer levels minimized potential yield reductions in implementing NT corn production. While N fertilizer may be needed to maintain yields, this may also increase production costs for NT systems, reducing the profitability of these systems compared to CT systems. This is particularly important in the face of rising fuel and N fertilizer costs. Farmers have not adopted NT irrigated corn production systems in the central Great Plains, in part due to lack of information on the economic performance of these systems. However, as a result, farm-level information on economic performance is not available. Consequently, it was necessary to conduct a field study to provide this information. This study fills the identified information gaps by providing information on the economic performance of NT corn production under full irrigation, and

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Abbreviations: CT, conventional plow tillage system; NT, no-till; SOC, soil organic carbon.
accounting for interactions with N fertilizer rates. Our objective was to determine the production costs and evaluate the profitability of NT compared to CT for irrigated continuous corn production in the central Great Plains. We compare the production costs and profitability of these systems at economically optimum fertilizer rates and conduct sensitivity analysis of the results to changing fuel, fertilizer, and corn prices.

**MATERIALS AND METHODS**

**Field Study**

This study was conducted on a Fort Collins clay loam soil (fine-loamy, mixed, superactive, mesic Aridic Haplustalfs) with a 1 to 2% slope at the Agricultural Research Development and Education Center (ARDEC) (40°39´6´´ N, 104°59´57´´ W; 1535 m above sea level) near Fort Collins, CO. The study was initiated in 1999 on a field that had previously been continually cropped to corn for 6 yr using a CT system. The CT system generally used the following sequence of operations to prepare a seedbed for the next year’s corn crop: in the fall, shredding of corn stalks was followed by tandem disking and then moldboard plowing to a depth of about 25 to 30 cm; in the spring, roller harrowing (two operations) and landplanning (two operations) were followed by cultivation, if needed, with a light-duty cultivator to reduce potential for wind erosion. In the CT system, herbicides were applied to control weeds during the growing season with no mechanical cultivation for weed control. In the NT system, corn was direct planted into the previous year’s corn stalks each spring without any other field operations for seedbed preparation, followed by application of herbicides for weed control and then harvest. The complete list of operations is listed in Table 1. During the growing season, the corn was fully irrigated with a linear-move sprinkler system and water was applied as needed (determined weekly by appearance and feel).

Six N rates (0, 34, 67, 101, 134, and 202 kg N ha⁻¹ referred to as N1, N2, N3, N4, N5, and N6, respectively) were established in 2000 in the NT system. The N rates were selected to facilitate estimation of yield response functions. In the CT system, only the N1, N3, N5, and N6 treatments were present in 2000 and 2001. In 2002, the N2 treatment was added, and in 2003 the N4 treatment was added to the CT system when plot area embedded within the existing plots but used for another experiment became available. Due to only a minimal grain yield response to N fertilization at the N6 rate in 2000, the fertilizer N rate was reduced to 168 kg N ha⁻¹ in 2001, increased back to 202 kg N ha⁻¹ in 2002, and then increased to 224 kg N ha⁻¹ in 2003 and 2004, and to 246 kg N ha⁻¹ in 2005 due to obvious N shortage in the NT system with each additional corn crop. The same rate of N was applied to the same plots each year with the exception of the N6 treatment. The N source was UAN (32–0–0), which was applied with a liquid fertilizer applicator that banded the N about 5 cm below the soil surface in bands spaced 33 cm apart (parallel to the corn row, but at varying distance from the corn row) the day before corn planting. However, for the economic analysis, it was assumed the N fertilizer was applied with the planting operation. In 2005, one-half of the N fertilizer was applied before planting as UAN, and one-half was applied on 9 June as a dry granular polymer-coated urea with a broadcast applicator. This second N fertilizer application was included as a separate operation for the economic analysis. Further details on the field study may be found in Halvorson et al. (2006).

**Economic and Statistical Analysis**

To evaluate the production costs and profitability of the NT system compared to the CT system, annual costs for each tillage system were estimated using the cost and returns estimator (CARE) (USDA-NRCS, 1993) based on the operations and inputs used in the field study each year, but using fixed input prices. Fixed prices were used to isolate production-related effects from market effects. However, it is not known if the prices chosen will be indicative of future prices and costs, thus price sensitivity analysis, as described below, was used to evaluate the sensitivity of the results to changing prices. Machinery costs were from University of Minnesota Extension Service (Lazarus and Selley, 2005), and using a labor cost of $11.00 h⁻¹. Irrigation costs and herbicide costs were from University of Nebraska Extension Service (Selley et al., 2006; Bernard et al., 2005). Fuel, fertilizer, and seed costs were the April 2006 costs from the USDA-National Agricultural Statistics...
Service (USDA-NASS, 2006). Diesel fuel cost was $0.60 L⁻¹, N, P, and K fertilizer costs were $0.88, $1.31, and $0.584 kg⁻¹, respectively; and corn seed cost was $1.71 per thousand seeds. Net returns were calculated using a corn price of $93.70 Mg⁻¹ which was calculated to include government loan deficiency payments using the 10-yr average of the higher of the 2005 commodity loan rate or the annual marketing year average corn prices for Colorado from 1997 to 2006 (USDA-NASS, 2007; USDA-FSA, 2005). Government payments of $152 ha⁻¹ were also included in calculating returns, based on typical direct payment and historical countercyclical payment rates that would occur with the farm program provisions that were in place in 2005. No land or management costs were included in the production costs, so net returns represent returns to land and management.

A logistic function, similar to that used by Overman and Brock (2003), was used to estimate yield response to N:

\[
Y_t = \frac{A_t}{1 + b e^{-k_t(N_t - \bar{N})}} \tag{1}
\]

where \(Y_t\) is corn grain yield in year \(t\), \(N_t\) is applied N fertilizer, \(S_t\) is soil NO₃−N in the 0- to 90-cm depth, \(A_t\) is the asymptotic maximum yield, \(b_t\) is a location parameter (that shifts the yield function but does not change its shape), and \(k_t\) is a shape parameter for each year. Parameter estimates were obtained using nonlinear regression with SAS software (SAS Institute, 2006). The model was estimated both with and without soil test \((S_t)\) information. We followed the recommendation of Bullock and Bullock (1994) and calculated economic optimum N rates by maximizing expected net returns:

\[
\max \frac{1}{T} \sum_{t=1}^{T} \pi_t = \frac{1}{T} \sum_{t=1}^{T} \left[ \left( \sum_{i=0}^{2} \left( P_{Y_t} - G + wN_t - c_i \right) \right) \right] \tag{2}
\]

where \(T\) is the number of years observed, \(\pi_t\) is net return, \(Y_{t}\) is the corn grain yield function from Eq. [1], \(P\) is corn price, \(G\) is the direct and counter-cyclical government payment, \(w\) is N fertilizer price, and \(c_i\) is production costs other than N fertilizer. Again, corn price and input prices are fixed in this specification to focus on production-related effects. As a result, \(G\) is also fixed, since it is based on the corn price and historical yields. However, \(c_i\) is not fixed, since production activities may change from year-to-year in response to changing conditions (e.g., different herbicide needs due to different weed pressures each year). Although the optimization is conducted on a per hectare basis for a single field, expected net returns include changes in machinery ownership, and thus reflect a long-term farm-level tillage system decision. Consistent with this assumption, the optimization is conducted separately for the NT and CT systems, and expected net returns for each system are compared, so the analysis does not include the possibility of switching between tillage systems from year to year. Note that, when soil test information is included, the optimum available N is determined by Eq. [2], and the optimum N fertilizer rate is a linear function of soil test N calculated as the difference between the optimum available N and soil test N. The optimization model could not be solved analytically, but was solved using nonlinear programming with LINGO software (LINGO Systems, 2001). The experimental design was a split-plot, randomized complete block with tillage main plots and N rate as subplots. There were four replications for the CT treatments and three replications for the NT treatments. Along with differences in the number of N rate treatments included each year, this resulted in different numbers of observations that could be used in the regression estimates for each tillage system and each year. Standard errors for expected yields and expected net returns were calculated analytically from the variance in yields across years and the N response function regression errors, while standard errors for costs were based on variability across years only. An alternative analytical approach would be to use stochastic simulation with random samples drawn from the errors associated with the N response function regressions. This would also allow risk analysis to be conducted with random price effects included through random samples drawn from price distributions. However, the optimization approach was chosen due to greater clarity of exposition in the stated objective of comparing profitability of the NT system to the CT system and concerns about the validity of risk analysis based on 6 yr of yield observations.

Price sensitivity analysis was conducted to evaluate how the results would be affected by different N fertilizer, diesel fuel, and corn prices. The price sensitivity analysis was conducted in two parts. In the first part, the optimization Eq. [2] was solved for each of the annual price combinations observed from 2000 to 2006 determining the economic optimum fertilizer rate, expected yield, and expected net returns for each price combination. The economic optimum fertilizer rate for each price combination was also used with the yield response equation for each of the corresponding years 2000 to 2005 to evaluate the yield and net returns that would have been realized in that year.

In the second part, the approach was to identify the price combinations where the expected net returns for the two tillage systems would be equal. Then the relative profitability of each system could be assessed graphically by comparing observed or anticipated prices to the breakeven price combinations. The breakeven price combinations were identified using nonlinear programming to determine the corn price at which expected net returns for the CT system were equivalent to those from the NT system over a range of N fertilizer prices and diesel fuel prices. This was done by numerically solving a system of three equations for corn price, optimum CT N fertilizer rate, and optimum NT N fertilizer rate. The first two equations were the optimality conditions for N rates, setting the marginal expected yield increase equal to the ratio of N fertilizer price to corn price for each tillage system:

\[
\frac{1}{T} \sum_{t=1}^{T} \frac{A_t b_t k_t e^{-k_t N_t}}{(1 + b_t e^{-k_t N_t})^2} = \frac{w}{P}. \tag{3}
\]

The third equation is the break-even equation, setting expected net returns for CT equal to expected net returns for NT:

\[
\frac{1}{T} \sum_{t=1}^{T} \left[ \sum_{i=0}^{2} \left( P Y_{CT,t} + G - w N_{CT,t} - c_{i,CT} \right) \right] = \frac{1}{T} \sum_{t=1}^{T} \left[ \sum_{i=0}^{2} \left( P Y_{NT,t} + G - w N_{NT,t} - c_{i,NT} \right) \right]. \tag{4}
\]

The set of equations was solved repeatedly for combinations of three diesel fuel prices: $0.40, $0.60 and $0.80 L⁻¹, and nine N prices ranging from $0.22 to 0.67 kg⁻¹.
RESULTS AND DISCUSSION

Corn yields generally increased with increasing N fertilizer application rates for both CT and NT (Fig. 1). Responses to applied N varied from year to year both in terms of the shape of the response and the maximum yield attained. Regression results for the logistic yield response functions are shown in Table 2. The logistic model generally fit the data quite well, with $R^2$ values ranging from 0.81 to 0.99, and the parameter estimates well-determined. An exception was the 2002 estimates for the NT system where the A and $k$ parameter estimates were poorly determined, as shown by the high approximate standard errors. The high uncertainties in the parameter estimates were due to the positive linear slope in yield response even at the highest N rate, so the maximum yield was not yet well-defined. Similar responses were found relating corn grain yield to available N [fertilizer N applied + soil NO$_3$–N (0- to 90-cm depth)] (data not shown). Maximum yields were higher for CT than for NT in 4 of the 6 yr. Excluding 2002, maximum yields ranged from 11.48 to 14.36 Mg ha$^{-1}$ for CT and from 9.61 to 12.53 Mg ha$^{-1}$ for NT. Similar to the results reported by Sims et al. (1998), yield reductions for NT relative to CT were minimized at higher N rates.

Because of the high uncertainties for the 2002 NT yield response parameters, expected net return estimates were calculated both with and without the 2002 observations (Table 3). Although optimum N fertilizer N rates were higher under NT than for CT both with and without the 2002 observations, the difference was much greater when the 2002 observations were included: 55 kg ha$^{-1}$ vs. 16 kg ha$^{-1}$ when 2002 was excluded. This represented an increase in N fertilizer costs (Table 3) of $15 to $48 ha$^{-1}$ for NT compared to CT. Average pesticide costs were also higher for NT than for CT. Fuel costs for NT were 75% lower than for CT. The CT required 96 to 98 L ha$^{-1}$ of diesel fuel on average while NT required 25 L ha$^{-1}$. Labor needs for NT were reduced by 71 to 72% on average compared to CT reducing hired labor requirements and allowing operator labor to be devoted to other activities. The estimated cost savings associated with this labor reduction assumes either that hired labor is reduced or that the farmer fully uses saved labor elsewhere to generate an income equal to the wage rate of $11.00 h$^{-1}$.

A potential benefit of NT in irrigated systems is a reduction in evapotranspiration (Todd et al., 1991) which could have productivity benefits as well as reducing irrigation costs (Harman et al., 1985). In this study, irrigation water applications were the same for NT and CT, due to droughty conditions, except in 2000 and 2005 when 72

### Table 2. Coefficients for regression equations of corn grain yield vs. N fertilizer application with standard errors shown in parentheses.

| Year | CT system | | NT system | |
|------|-----------|----------------|-----------|
|      | $A$       | $b$            | $k$       | $R^2$ | $n$ | $A$       | $b$            | $k$       | $R^2$ | $n$ |
| 2000 | 11.48 (0.602) | 1.187 (0.1261) | 0.0156 (0.00277) | 0.97 | 12 | 9.78 (0.336) | 0.760 (0.1274) | 0.0309 (0.00798) | 0.84 | 18 |
| 2001 | 14.24 (0.269) | 0.606 (0.0701) | 0.0262 (0.0027) | 0.98 | 16 | 12.53 (1.190) | 0.766 (0.1509) | 0.0145 (0.00516) | 0.87 | 18 |
| 2002 | 12.50 (0.293) | 0.870 (0.0999) | 0.0330 (0.00538) | 0.92 | 20 | 16.75 (0.8091) | 1.994 (1.3263) | 0.0077 (0.00409) | 0.85 | 18 |
| 2003 | 12.53 (0.797) | 0.831 (0.1125) | 0.0130 (0.00319) | 0.86 | 24 | 10.79 (0.715) | 1.130 (0.2026) | 0.0192 (0.00524) | 0.83 | 18 |
| 2004 | 12.01 (0.363) | 0.695 (0.1085) | 0.0310 (0.00756) | 0.81 | 24 | 12.13 (0.700) | 1.715 (0.1722) | 0.0154 (0.00236) | 0.95 | 18 |
| 2005 | 12.60 (0.222) | 1.136 (0.0726) | 0.0236 (0.00202) | 0.97 | 24 | 10.90 (0.463) | 0.921 (0.1048) | 0.0162 (0.00302) | 0.91 | 18 |

### Table 3. Average production costs, expected gross returns, and expected net returns at the economic optimum N fertilizer rate averaged over 2000 to 2005† with standard errors shown in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>CT‡</th>
<th>NT‡</th>
<th>CT‡</th>
<th>NT‡</th>
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<td>152</td>
<td>152</td>
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<td>155</td>
<td>174</td>
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<tr>
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<tr>
<td>Crop insurance</td>
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<td>Interest on operating capital</td>
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<td>18</td>
<td>22</td>
<td>17</td>
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<tr>
<td>Total operating costs</td>
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<td>870 (26.5)</td>
<td>923 (14.9)</td>
<td>819 (18.7)</td>
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<td>Machinery ownership costs</td>
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<td>250 (5.7)</td>
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<td>Total costs</td>
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<td>1030 (26.7)</td>
<td>1182 (18.0)</td>
<td>979 (19.0)</td>
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<tr>
<td>Expected gross returns</td>
<td>1266 (50.6)</td>
<td>1168 (28.7)</td>
<td>1264 (57.3)</td>
<td>1135 (39.7)</td>
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<tr>
<td>Expected net returns</td>
<td>92 (52.0)</td>
<td>138 (34.7)</td>
<td>82 (59.4)</td>
<td>156 (34.0)</td>
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<td>Optimum N fertilizer rate, kg ha$^{-1}$§</td>
<td>155</td>
<td>210</td>
<td>164</td>
<td>180</td>
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<tr>
<td>Expected yield at optimum N rate, Mg ha$^{-1}$</td>
<td>11.9 (0.54)</td>
<td>10.8 (0.41)</td>
<td>11.9 (0.61)</td>
<td>10.5 (0.42)</td>
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† Averages both including and excluding 2002.
‡ CT: conventional tillage; NT: no-till.
§ Economic optimum N fertilizer rate without credit for soil test N.

![Fig. 1. Annual (2000–2005) corn grain yields for conventional tillage (CT) and no-till (NT) treatments as a function of N fertilizer application rate.](image)
and 25 mm less water, respectively, were applied on NT than on CT. This resulted in NT irrigation cost savings (labor, fuel, and lubrication, repairs) of $8 to 10 ha$^{-1}$ (Table 3) on average compared to CT. Costs for repairs and maintenance, and interest on operating capital were also lower for NT than for CT. As a result, average total operating costs for NT were $57$ to $114$ ha$^{-1}$ lower than for CT. In addition, machinery ownership costs were $87$ to $90$ ha$^{-1}$ lower for NT on average, resulting in lower average total costs ($144$–$203$ ha$^{-1}$) for NT than for CT. Costs for NT were more variable from year to year than for CT largely due to greater variability in herbicide applications, and thus greater variability in herbicide costs. It should be noted that machinery ownership cost savings assume that producers only retain equipment needed for each system and may not be entirely realized by producers who keep CT equipment (e.g., moldboard plow) as they transition into a NT system.

Expected corn grain yields at the economic optimum fertilizer rates were $1.1$ to $1.4$ Mg ha$^{-1}$ higher for CT than for NT (Table 3). This resulted in expected gross returns $98$ to $130$ ha$^{-1}$ higher for CT than for NT. However, with the reduction in production costs, expected net returns for NT were $46$ to $74$ ha$^{-1}$ higher than for CT. Corn grain yields were more variable under CT than under NT, and consequently gross returns were also more variable. Despite lower variability in production costs for CT than for NT, expected net returns were more variable under CT than under NT, so CT may not only be less profitable than NT it may also be more risky.

While Cahoon et al. (1999) also reported increases in economic returns when reducing tillage on irrigated continuous corn, their findings were in part due to observed yield increases, in contrast to our results. Our results are similar to those reported by Tew et al. (1986), however their results showed economic benefits for a minimum tillage system compared to CT without including reductions in machinery ownership costs. Our results show that the reductions in machinery ownership costs are needed in order for NT to increase net returns compared to CT.

Expected net returns include direct payments and countercyclical payments which are a part of the current government program. Since these payments are not affected by current production levels, they would be equal for the CT and NT system, at least in the short-term. However, if future farm programs were to allow updating of payment yields, lower yields in the NT system could reduce future government payments. Also, crop insurance indemnity payments are based on a producer’s historical production, so lower yields in the NT system could affect future crop insurance payments. These potential effects are not included in this analysis.

Although the magnitudes of optimum N rates, expected yields, and expected net returns were sensitive to the inclusion or exclusion of the 2002 observations, the general conclusions that optimum N rates were higher, expected yields were lower, and expected net returns were higher for NT than for CT were consistent in both cases. All of the subsequent results are based on the complete set of observations, including 2002.

Expected net returns as a function of N fertilizer rates are shown in Fig. 2. As has been often noted in other studies (Doll, 1972; Sawyer et al., 2006), the expected net return response function was relatively flat in the range of the economic optimum N rates. As a result, a wide range of N rates produce expected net returns near the economic optimum. For NT, N fertilizer rates of 139 to 303 kg ha$^{-1}$ and for CT 104 to 226 kg ha$^{-1}$ resulted in expected net returns within $10$ ha$^{-1}$ of the economic optimum. As a result, even if no adjustment was made to the N fertilizer rate in switching from CT to NT, and the economic optimum N rate for CT of 155 kg ha$^{-1}$ was applied under NT, expected net returns for NT would be $124$ ha$^{-1}$, exceeding CT net returns by $32$ ha$^{-1}$.

Since N fertilizer responses differ under the two tillage systems, it is important to consider how soil test information may affect expected net return comparisons. When soil test information was included in the yield response equations, the optimum available N (soil N + fertilizer N) rates were $194$ kg ha$^{-1}$ for CT and $216$ kg ha$^{-1}$ for NT (Fig. 3). Note that the optimum available N is constant for a given corn price and N fertilizer price regardless of the soil N level. However, expected net returns are not constant since soil N is a direct substitute for fertilizer N in the yield response model, so higher soil N reduces the optimum fertilizer N rate, reducing fertilizer cost and increasing expected net returns (Fig. 4). When amounts of soil test N in the two tillage systems were equal (and less than the total needed to maximize expected net returns), expected net returns for NT exceeded those for CT by $42$ ha$^{-1}$ (Fig. 3 and 4). However, Halvorson et al. (2006) reported that soil test
N tended to be slightly higher at the highest N rate in the CT system than in the NT system. If soil test N is higher under CT than under NT, then the expected net return advantage of NT compared to CT is decreased (Fig. 4). As an example, in Fig. 4, if soil test N is 100 kg ha\(^{-1}\) under each tillage system (points 'a' and 'b'), expected net returns are $141 and $183 ha\(^{-1}\) for CT and NT, respectively. However, if soil test N is lower under NT, say 80 kg ha\(^{-1}\) (point 'c'), expected net returns are $165 ha\(^{-1}\), reducing the expected net return advantage of NT from $42 to $24 ha\(^{-1}\).

Expected net return comparisons can be affected by changes in input costs and crop prices. This is particularly important with recent rapid changes in corn prices, N fertilizer prices and diesel fuel prices. Table 4 shows the differences between the NT and CT economic optimum N fertilizer rates given the annual N fertilizer, diesel fuel, and corn prices observed in 2000 to 2006. The economic optimum fertilizer N rates were 56 to 91 kg ha\(^{-1}\) higher under NT than under CT for the observed prices. Expected yield differences at the optimum N rate, also shown in Table 4, showed expected yields were always lower under NT than under CT, ranging from 0.8 to 1.0 Mg ha\(^{-1}\) lower. Based on the annual fertilizer response functions, realized yields (Table 4) were lower for NT than for CT at the economic optimum N rates in 5 of the 6 yr of the field study. The NT realized yield was 0.7 Mg ha\(^{-1}\) higher than CT in 2002 and was 1.9 Mg ha\(^{-1}\) lower than CT in 2001. Expected net returns (Table 4) were always higher for NT than for CT ranging from $15 to $64 ha\(^{-1}\) higher. Note that the lowest expected net return advantage for NT occurred with the prices observed in 2006 when diesel fuel, fertilizer N, and corn prices were all substantially higher than had been observed in previous years. This contrasts with the results reported by Nail et al. (2007) that recent changes in diesel and glyphosate prices have favored the profitability of conservation tillage vs. conventional tillage in wheat (Triticum aestivum L.)-fallow systems in Washington. Again, based on the annual fertilizer response functions, realized net returns (Table 4) were higher for NT than for CT in 5 of the 6 yr of the field study ranging from as much as $164 ha\(^{-1}\) higher in 2004 to $102 ha\(^{-1}\) lower than CT in 2001.

Because our findings showed higher optimum fertilizer N rates and lower expected yields for NT compared to CT, increases in corn prices and N fertilizer prices tend to reduce profitability of NT relative to CT. However, because diesel fuel use is higher in CT than in NT, increases in diesel fuel prices tend to increase profitability of NT relative to CT. Figure 5 shows the breakeven corn and N fertilizer price relationships, where expected net returns for NT equal expected net returns for CT, for three different diesel fuel prices. For corn and N fertilizer prices below and to the left of the breakeven curve, the NT system has higher expected net returns than CT. For corn and fertilizer N prices above and to the right of the breakeven curve, CT expected net returns exceed NT expected net returns. Increases in diesel fuel prices shift the breakeven curve upward and to the right. Annual average corn versus fertilizer N price points are also shown in Fig. 5 for 2000 to 2006. As was noted in Table 4, each year, prices were such that NT expected net returns exceeded CT net returns. Corn and

### Table 4. Differences between NT and CT† economic optimum N fertilizer rates, expected yields, realized yields, expected net returns, and realized net returns based on annual diesel fuel price, fertilizer N price, and corn price observations and annual corn yield response as a function of fertilizer N applied.

<table>
<thead>
<tr>
<th>Year</th>
<th>Diesel Price ($ L(^{-1}))</th>
<th>Fertilizer Price ($ kg(^{-1}))</th>
<th>N Price ($ Mg(^{-1}))</th>
<th>Economic Optimum N ($ Mg ha(^{-1}))</th>
<th>Yield ($ Mg ha(^{-1}))</th>
<th>Net Returns ($ ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.29</td>
<td>0.47</td>
<td>81.89</td>
<td>85</td>
<td>-0.8</td>
<td>64</td>
</tr>
<tr>
<td>2001</td>
<td>0.30</td>
<td>0.77</td>
<td>83.85</td>
<td>58</td>
<td>-1.0</td>
<td>43</td>
</tr>
<tr>
<td>2002</td>
<td>0.25</td>
<td>0.52</td>
<td>99.60</td>
<td>91</td>
<td>-0.8</td>
<td>44</td>
</tr>
<tr>
<td>2003</td>
<td>0.36</td>
<td>0.63</td>
<td>98.03</td>
<td>78</td>
<td>-0.9</td>
<td>44</td>
</tr>
<tr>
<td>2004</td>
<td>0.36</td>
<td>0.69</td>
<td>87.79</td>
<td>67</td>
<td>-0.9</td>
<td>49</td>
</tr>
<tr>
<td>2005</td>
<td>0.54</td>
<td>0.84</td>
<td>87.79</td>
<td>56</td>
<td>-1.0</td>
<td>52</td>
</tr>
<tr>
<td>2006</td>
<td>0.60</td>
<td>0.88</td>
<td>127.95</td>
<td>74</td>
<td>-0.9</td>
<td>15</td>
</tr>
</tbody>
</table>

† CT: conventional tillage; NT: no-till.

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Fig. 4. Expected (2000–2005) net returns for conventional tillage (CT) and no-till (NT) treatments at the economic optimum N fertilizer application rate as a function of soil N (0–90 cm depth). Labeled points show the effect of soil N levels on expected net returns under the two tillage systems with: a = CT, 100 kg ha\(^{-1}\) soil N; b = NT, 100 kg ha\(^{-1}\) soil N; c = NT, 80 kg ha\(^{-1}\) soil N.

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Fig. 5. Corn and N fertilizer price functions denoting prices where expected net returns for conventional tillage (CT) are equal to expected net returns for no-till (NT) at three diesel fuel price levels. For corn and N fertilizer prices below (above) the breakeven curves, expected net returns for NT exceed (are exceeded by) those for CT. Annual labeled price points (*) indicate annual average corn and N fertilizer price observations for 2000 to 2006.
N prices in 2006 moved dramatically upward and to the right, closer to the breakeven curves. However, the breakeven curve also shifted upward as diesel fuel prices increased during this period, and NT maintained a narrow advantage in expected net returns over CT.

CONCLUSIONS

Although expected corn grain yields at economic optimum N fertilizer rates were 1.1 to 1.4 Mg ha$^{-1}$ lower for NT than for CT, net returns were $\$46$ to $74$ ha$^{-1}$ higher. This was due to reductions in operating costs of $\$57$ to $114$ ha$^{-1}$ and reductions in machinery ownership costs of $\$87$ to $90$ ha$^{-1}$. Operating cost saving were realized largely due to fuel and labor reductions of $75\%$ and $71$ to $72\%$, respectively, and in spite of higher N fertilizer requirements of $16$ to $55$ kg ha$^{-1}$ for NT compared to CT. No-till also reduced irrigation costs compared to CT, although the savings were relatively small over the study period.

The estimated cost advantage for the NT system over the CT system includes machinery ownership cost savings that may not be realized by all producers during the transition as new equipment is acquired and unneeded equipment is sold. This may represent a barrier to the adoption of the NT system even if it is more profitable in the long-run. Longer-term research will be needed to determine whether the higher N requirements under NT continuous corn are a short-term increase needed only during the transition to NT or whether higher N rates will be needed over an extended period. If higher N rates are only needed during the transition to the NT system, this would increase the economic advantage of NT over CT in the long-term. The analysis assumed an expected profit maximizing producer, and did not include potential effects of risk aversion which might affect both optimum N fertilizer decisions and tillage system preferences.

The NT system had higher expected net returns over a wide range of corn prices, N fertilizer costs, and fuel costs. However, increases in corn prices and N fertilizer costs reduce the economic advantage of NT over CT. This analysis shows that NT, irrigated, continuous corn appears to be an economically viable alternative tillage system preferences. The NT system had higher expected net returns over a wide range of corn prices, N fertilizer costs, and fuel costs. However, increases in corn prices and N fertilizer costs reduce the economic advantage of NT over CT. This analysis shows that NT, irrigation, continuous corn appears to be an economically viable alternative for replacing CT production systems in the central Great Plains, especially when combined with the environmental benefits of the NT system.

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