No-Till, Short- and Long-Run Economics

contains two papers prepared for an August 2005 no-till conference in Ukraine

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Authors:

Terry L. Kastens, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-5866 (office), 785-532-6925 (fax)
email: tkastens@ksu.edu web: www.agmanager.info
Kevin C. Dhuyvetter, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-3527 (office), 785-532-6925 (fax)
email: kcd@ksu.edu web: www.agmanager.info
Alan J. Schlegel, Agronomist-in-Charge, Kansas State University Southwest Research-Extension Center, Tribune, KS 67879
Phone: 620-376-4761 (office), 620-376-8114 (cell), 620-376-2278 (fax)
email: schlegel@ksu.edu web: http://www.wkarc.org/Swrec/tribune/tribune.htm
Troy J. Dumler, Agricultural Economist, Kansas State University Southwest Area Extension Office, Garden City, KS 67846
Phone: 620-275-9164 (office), 620-276-6028 (fax)
email: tdumler@ksu.edu web: www.agmanager.info

Abstract

In some places, for example the High Plains, no-till leads to immediate and obvious increases in crop yields due to immediate savings in water. In such areas, despite input costs rising with no-till, crop revenue tends to rise more, increasing profitability. But, no-till also changes crop production costs associated especially with labor and machinery management. Though such "reduced cost" features are harder to measure, they make no-till profitable even in areas where yields might be flat or even diminished due to no-till. It is in this second area where most Kansas no-tillers now find themselves from a decision-making standpoint. A third area of no-till economics, the idea that no-till induces changes to soils over time, likely will lead to differences in profitability among farmers according to their time and intensity of involvement in no-till. Important issues are changing surface residue and soil structure and related changes in water evaporation, infiltration, and storage, as well as changes in soil organic matter and related changes in optimal fertilizer requirements.

Economic Implications of Less-tillage:
a Kansas Perspective

NT CA 2005 Conference
Dnipropetrovsk, Ukraine
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Authors:

Kevin C. Dhuyvetter, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-3527 (office), 785-410-3244 (cell), 785-532-6925 (fax)
email: kcd@ksu.edu web: www.agmanager.info
Terry L. Kastens, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-5866 (office), 785-770-0295 (cell), 785-532-6925 (fax)
email: tkastens@ksu.edu web: www.agmanager.info

Kastens is a professor and crops production farm management specialist who works publicly and one-on-one with farms in terms of the economics of crop production, especially associated with land and machinery. He has been at his post since 1995 and was engaged full time in farming prior to that time. He maintains partnership involvement with the family farm in northwest Kansas, a farm that has adopted many no-till practices over the years and one which continues to be a pioneer in researching and adopting technologies such as no-till and precision agriculture.

Dhuyvetter is a professor and crops and livestock production farm management specialist who also works extensively with area farms. He has been at his current post since 1999 and occupied the Agricultural Economist position at Garden City Kansas from 1986-1995. During his Garden City assignment, Dhuyvetter was a leader in examining and educating around the economics of less tillage, especially associated with intensifying the predominant crop rotation in the area.

Economic Implications of Less-Tillage: A Kansas Perspective

Kevin C. Dhuyvetter and Terry L. Kastens

Introduction

Interest in reducing or eliminating tillage in crop production has been increasing in Kansas. This is based on the number of questions and requests for information and meetings received by Extension personnel, attendance at regional meetings (e.g., the annual *No-Till on the Plains Conference*), and trends in acreage of crops farmed with conservation-tillage practices.

The Conservation Technology Information Center (CTIC) regularly conducts a Crops Residue Management (CRM) survey to identify the number of acres of crops planted and tillage systems used by state. The CTIC defines conservation tillage as any tillage and planting system that maintains 30% or more residue on the soil surface after planting. Conservation tillage includes: no-till, ridge-till, and mulch-till. Reduced-till is defined as tillage that leaves 15-30% residue on the soil surface after planting. Conventional-till is defined as a tillage system that leaves less than 15% residue on the soil surface after planting. The percentages of acres farmed with the different tillage systems for the major crops in Kansas over the period 1989-2004, as reported by CTIC, are given in figures 1-3.[1]

Figure 1 shows the distribution of tillage systems for the primary row crops in Kansas, corn, grain sorghum (milo), and soybeans. Since 1989, the amount of conservation tillage (i.e., no-till, ridge-till, and mulch-till) has increased from slightly less than 30% of the acres to almost 50% of the acres in 2004. However, during this time period there has actually been a decrease in the amount of mulch till and a substantial increase in no-till acres (from less than 5% in 1989 to 33.7% in 2004). The percent of acres in a ridge-till system peaked in the mid to late 1990s and since has almost disappeared.

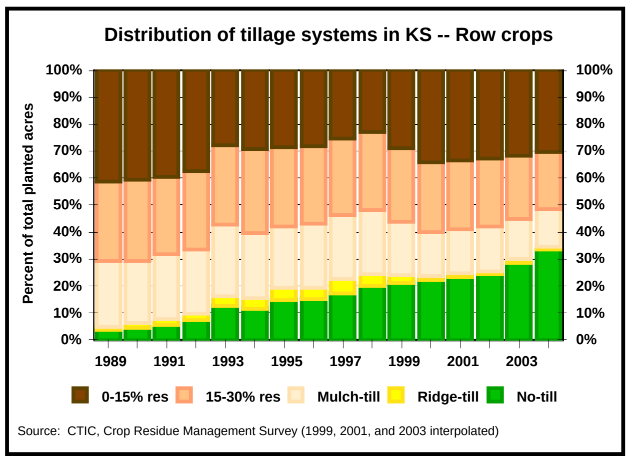

Figure 1

Figure 2 shows total acres of winter wheat by tillage system in Kansas. While there has been a slight upward trend in the amount of no-tilled acres (from 0.5% in 1989 to 9.4% in 2004), the vast majority of small grains acres continues to be farmed with either reduced or conventional tillage (i.e., 15-30% or 0-15% residue). An important reason for this is that, in areas of continuous wheat (central KS), cheat grass and other disease problems are recurrent issues with no-till. In wheat-fallow rotations in western KS, no-till historically has been cost prohibitive because of large amounts of herbicides required during the long summer-time fallow period.

[1] CTIC switched to conducting their survey on an every other year basis beginning in 1998 and thus they did not conduct surveys in 1999, 2001, and 2003. Data reported in the figures for these years are simply interpolated as the average between the preceding and following years.

Figure 3 shows the acres of the different crops in Kansas as reported by the CTIC (FS indicates full-season and DC indicates double-crop). It can be seen that, on an acre basis, wheat has been, and continues to be, the dominant crop in Kansas. However, row crops have been increasing their share of total acres. For example, early on in this time period wheat acres represented approximately 60% of the total crop acres, while in the later years wheat has accounted for only about 50% of the acres. While this changing crop mix likely is due to factors such as weather and government program provisions, the increased adoption of no-till likely also played a role.

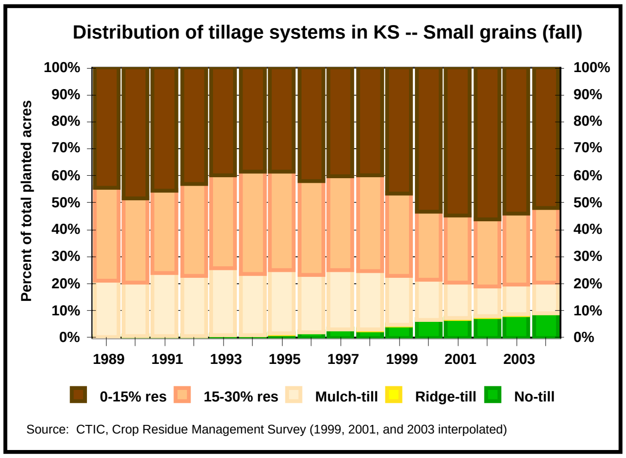

Figure 2

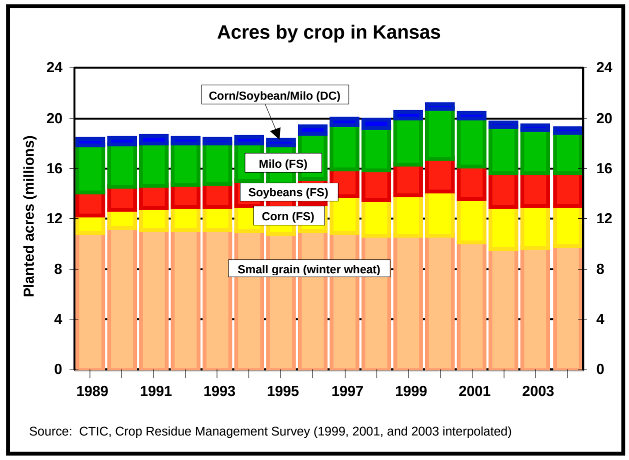

Figure 3

Figure 4 shows the distribution of tillage systems for all major crops in Kansas. In 1989, crops in a no-till system accounted for 2.1% of the total acres; by 2004 the share had grown to 21.2%. Whether this trend of increasing no-till acres in Kansas represents slow or fast adoption certainly can be debated. However, regardless of how one views it, at least two things are not debatable: (1) producers have been adopting no-till in Kansas, and (2) there is opportunity for considerably more acres of no-till in Kansas.

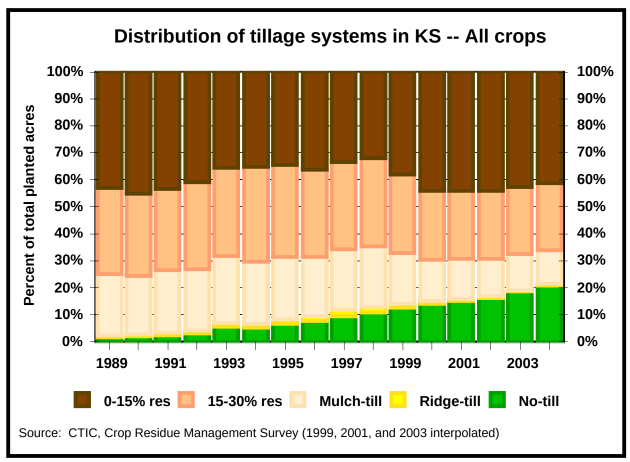

Figure 4

Figure 5 shows the distribution of tillage systems for the midwest region as reported by the CTIC, where the midwest region is defined as the following states: North Dakota (ND), South Dakota (SD), Nebraska (NE), Kansas (KS), Minnesota (MN), Iowa (IA), Missouri (MO), Wisconsin (WI), Michigan (MI), Illinois (IL), Indiana (IN), and Ohio (OH). With no-till acreage increasing from 4.8% of the total acres in 1989 to 24.8% in 2004, the midwest region has had basically the same percentage points increase in no-till adoption as Kansas (2.1% to 21.2%). Figure 6 shows a breakdown of the tillage systems by crop in the midwest. Similar to the pattern observed in Kansas, no-till systems are more common for row crops than cereal grains, and particularly for soybeans and milo (grain sorghum). Somewhat surprising, the greatest increase in no-till soybean acres occurred in the early 1990s, just prior to the introduction of herbicide tolerant soybeans (i.e., Roundup Ready soybeans).

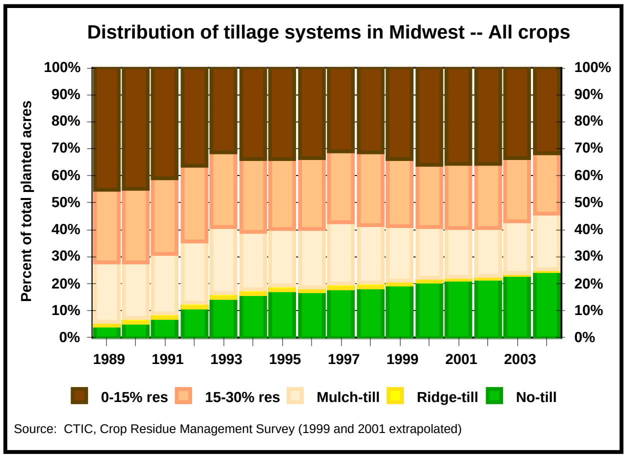

Figure 5

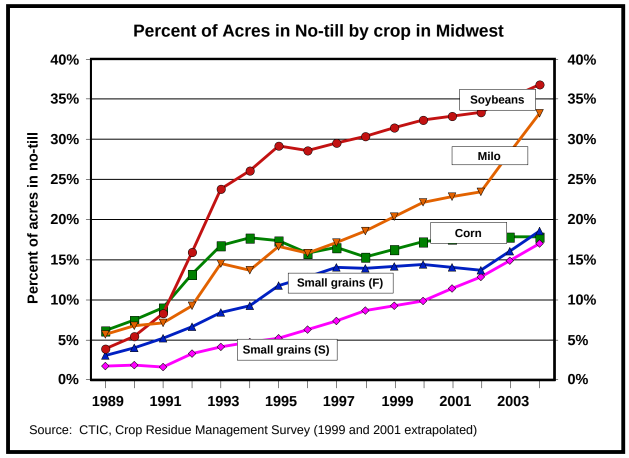

Figure 6

Based on the data presented in figures 1-6, it is apparent that, on average, conventional- and reduced-till cropping systems are still the prevalent systems in Kansas and the midwest (with the possible exception of some individual crops, e.g., soybeans and double-cropped acres). Wheat and other cereal grain crops continue to be farmed with predominately conventional- and reduced-tillage systems. However, the trend for row crops is that a larger percentage of acres is being farmed with no-till cropping practices.

Why switch to no-till?

Given the trend to more acres being farmed with less tillage, a logical question is, What is the driving force behind this? Some possible reasons why producers might consider reducing or eliminating tillage are the following:

- Increase profit potential
- Reduce labor requirements
- Reduce machinery investment
- Increase acres farmed
- Reduce moisture stress/increase yield
- Conservation compliance
- Other (e.g., increase wildlife habitat, carbon sequestration)

While all of these are possible reasons for switching to no-till, most of them are largely related to the first reason listed, increase profit potential. This begs the question, Does reducing or eliminating tillage actually increase profits?

Ignoring government program support payments and crop insurance, profitability is calculated in the following simple manner:

Revenue (yield x price)
! <u>Cost (variable and fixed)</u>
= Profit or net returns

Because there is no reason to believe that a producer's tillage method will impact the price he receives for his crop(s), profitability will depend on how yields and costs are affected by reducing tillage. Thus, a producer's expectations as to the effect reducing tillage has on both yields and costs will be important in determining whether reducing or eliminating tillage would be expected to be profitable.

Impact of tillage on yield

Because yields are heavily influenced by annual precipitation, it is important to recognize the variability that exists in Kansas. Figure 7 shows that 30-year average (1971-2000) annual precipitation in Kansas ranges from a low of 13-14 inches (330-356 mm) in the southwest region of the state to in excess of 45 inches (1143 mm) in the southeast corner of the state. Based on the wide variability that exists in annual precipitation across the state of Kansas, it seems logical that the impact tillage has on yield also might vary considerably for the different regions of the state.

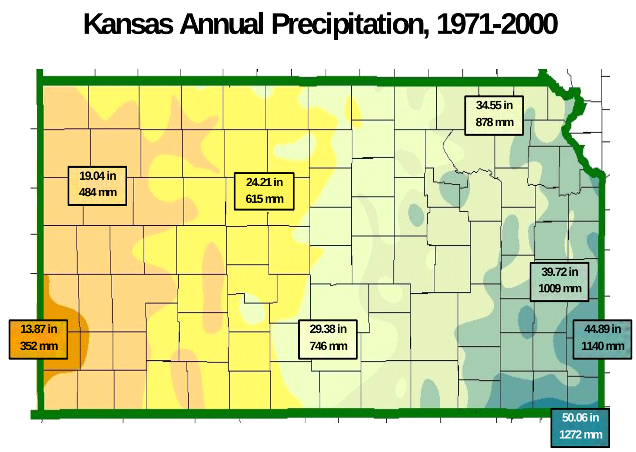

Figure 7

Figures 8 through 13 show the results of several University research studies examining the impact of tillage system on crop yield as well as some farm-level data from producers that participate in the Kansas Farm Management Association program for different regions of Kansas.

In a seven-year study in southwest Kansas, reducing tillage had a significant impact on yields of row crops grown in rotation with wheat (figure 8). Yields of corn, milo, soybeans, and sunflowers were highest with no-till (NT) and lowest under conventional tillage (CT).[2] NT yields were 26%, 11%, 13%, and 17% higher than CT yields for corn, milo, soybeans, and sunflowers, respectively. Where reduced tillage (RT) was considered, i.e., soybeans and sunflowers, RT yields were slightly higher than with CT but lower than with NT. In a 14-year study of a wheat-milo-fallow rotation in west central Kansas, reducing tillage significantly increased yields, with NT having larger increases than RT. Yields with RT were 15% and 60% higher than CT compared to NT yields being 60% and 93% higher than CT yields for wheat and milo, respectively (figure 9).

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[2] The definitions of conventional tillage (CT) and reduced till (RT) vary across studies and are not necessarily consistent with the CTIC definitions previously mentioned. The definition of no-till (NT) is less ambiguous and thus there is more consistency between NT research studies; however, small differences still may exist.

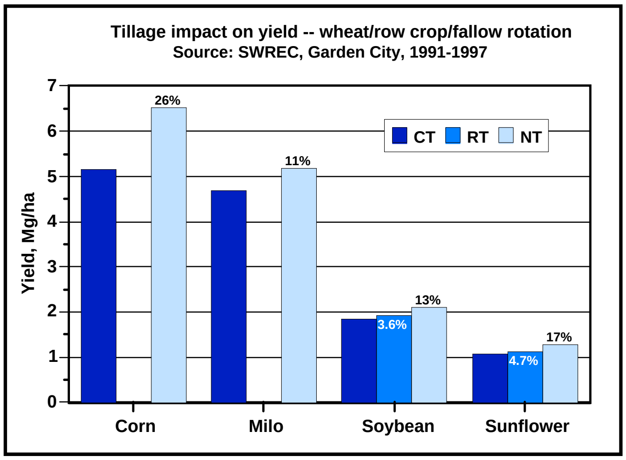

Figure 8

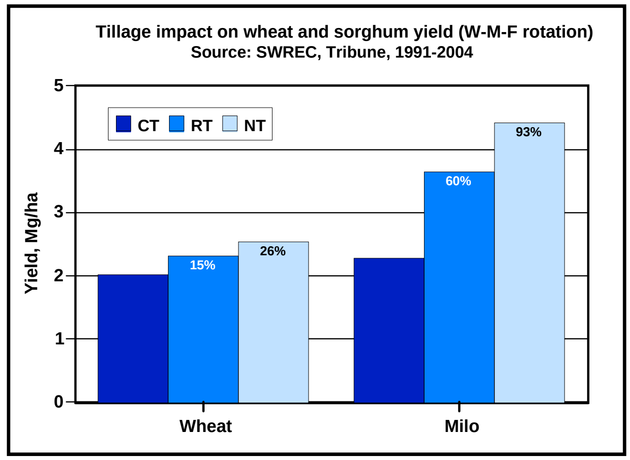

Figure 9

As reported by the Northwest Kansas Farm Management Association (NW FMA), Figure 10 shows summer crop yields (corn and milo) for producers in the northwest region of Kansas that use either NT or some tillage (CT/RT). The 10-year average yield advantage for NT corn is 15% and the 12-year advantage for NT milo is 22%. The reason there are only 10 years for corn is because very few producers plant corn under CT or RT anymore and thus 2001 was the last year an analysis of this enterprise was reported (NT corn enterprise continues to be reported).

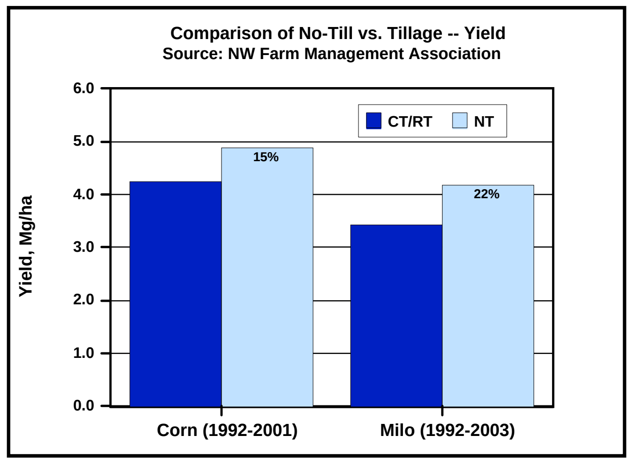

Figure 10

In a university study conducted from 1976-1981 in north central Kansas, yields of milo and soybeans were comparable for CT, RT, and NT (figure 11). No clear pattern emerged from this study as to what an optimal tillage system might be, as milo yields were greatest with RT (3% > CT) and soybean yields were greatest with NT (4% > CT). While the data reported in figure 11 are somewhat dated, farm-level data for NT versus "non-NT" (i.e., CT and RT) farmers in north central Kansas reinforce the similar yields (figure 12). In this case, NT soybean yields are somewhat lower than CT/RT soybean yields; however, this is due to the fact that NT farms plant both full season and double crop soybeans and thus their overall farm-level soybean yield is lower. More importantly, the wheat and milo yields suggest that in this region of the state the yield enhancing benefit of NT is much smaller than in the western regions of the state.

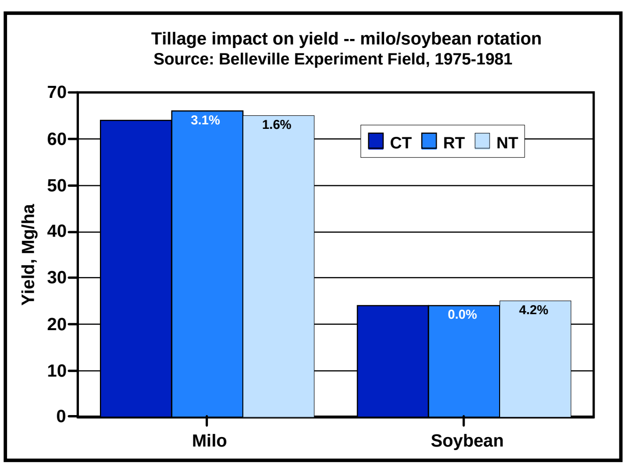

Figure 11

Research in south central Kansas comparing wheat and milo yields across various rotations and tillage systems reveals that there is a tillage by rotation effect (figure 13). NT yields were 13% lower than CT yields in a continuous wheat rotation. However, in a wheat-milo rotation, NT and CT yields were comparable. Similarly, NT and RT milo yields were lower than CT in a continuous milo rotation but greater than CT in a milo-wheat rotation. A second university trial in south central Kansas that included additional crops also provides some evidence that there is an interaction between tillage system and crop rotation (figure 14). More importantly, this second study reinforces that yield advantages with NT over tillage-based systems are much smaller than in the more arid regions of western Kansas.

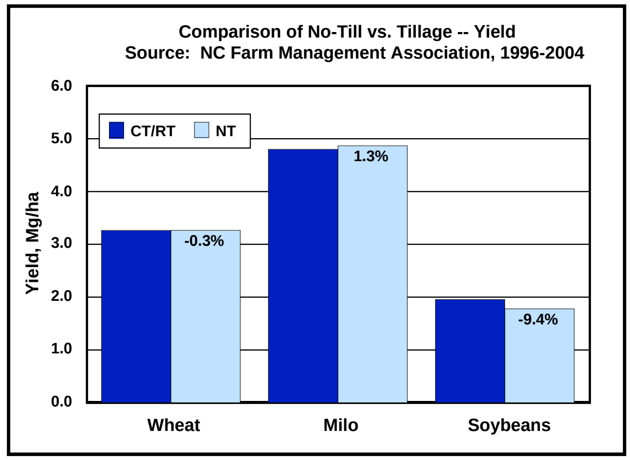

Figure 12

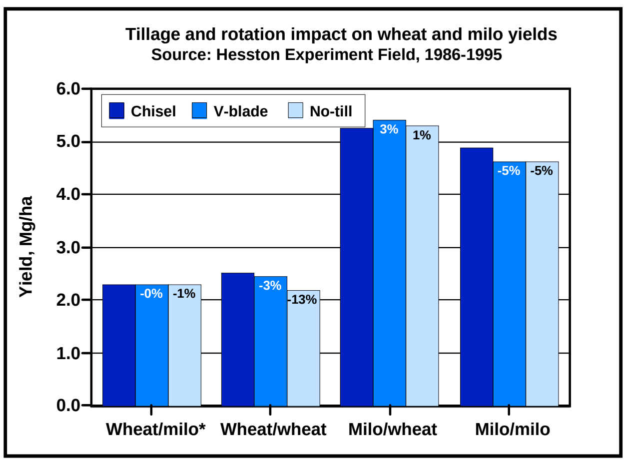

Figure 13

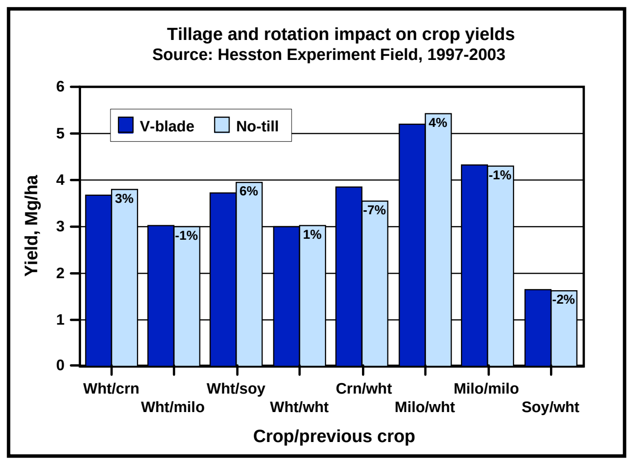

Figure 14

Corn, soybean, and milo yields in northeast Kansas were similar for NT and CT (figure 15). Similar to research findings in south central Kansas (figures 13 and 14), NT yields were slightly better than CT with a crop rotation compared to a monoculture system. However, even in this case, NT yields had only a small advantage over CT (3% or less). That is, in the case of corn yields, the rotation effect was much larger than the tillage effect.

Soybean yields, grown in rotation with milo, were approximately equal regardless of the tillage system in southeast Kansas (figure 16). However, milo yields in this rotation were significantly lower with NT than with CT. Yields with RT were less than with CT, but by only 4%; NT yields were 25% less.

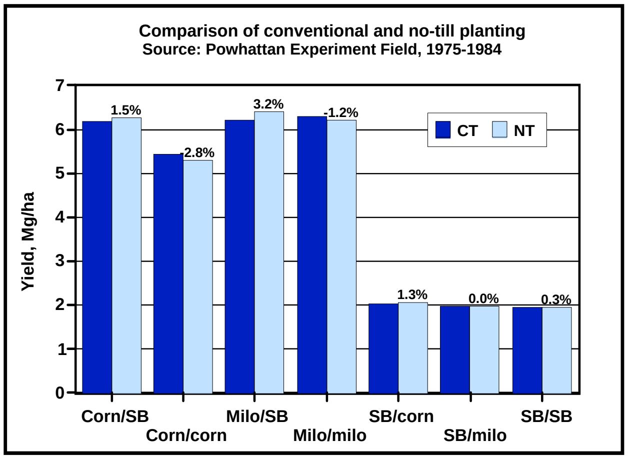

Figure 15

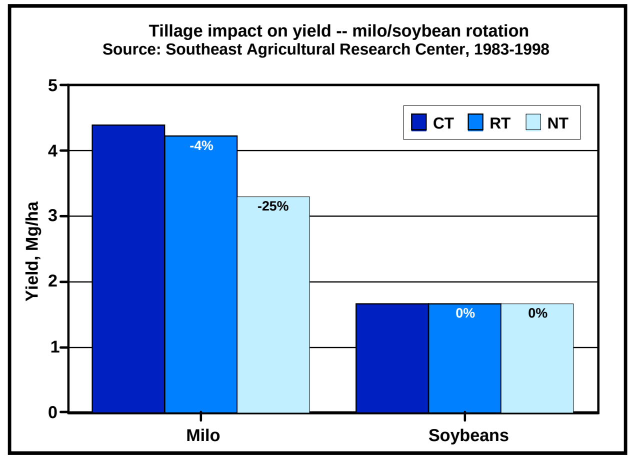

Figure 16

The research results shown in figures 8-16 are examples only and are not meant to be inclusive of all research at Kansas State University. However, some generalizations can be made from these results. First, it is apparent that RT and NT have a much greater yield impact in western Kansas than in central or eastern Kansas. This is not surprising given that precipitation levels in western Kansas are much lower and thus the benefit of conserving moisture is larger. Second, these results suggest that when considering the impact tillage will have on yield it is important to account for the rotation effect, as the two (tillage and rotation) are not necessarily independent.

Based on university research and limited farm-level data, it appears that revenue would be comparable for CT, RT, and NT in central and eastern Kansas because there is little yield benefit of reducing tillage. Furthermore, there is some evidence that in some locations (and some rotations) revenue might actually decrease with NT compared to CT. This suggests that, if profitability is to increase with NT, costs will have to decrease relative to CT.

On the other hand, research data from western Kansas indicate that yields, hence revenue, will increase as tillage is reduced. Therefore, in this region of the state the only requirement for NT to be more profitable than CT is that costs increase by less than revenue increases. Thus, based solely on yields, it is evident that if NT is going to "fit" in different regions of the state, it is likely for different reasons. For example, in western Kansas it may be more yield-driven but in central and eastern Kansas it is most likely to be cost-driven.

Impact of tillage on costs

When trying to estimate how different tillage systems might impact costs there basically are two approaches. One method is to project costs using simulated budgets. A second method is to use farm-level data to estimate actual historical costs. Each of these methods is useful but both have potential weaknesses.

With simulated budgets, costs are estimated based on expected tillage operations and herbicide applications. While these estimates might be reasonably accurate, they also can miss hidden costs or savings associated with reducing tillage. For example, a projected budget may overlook the possibility that machinery costs might actually increase in the short run. For example, tillage equipment is often maintained by farms when first adopting no-till. Likewise, if no-till allows additional acres to be farmed, there may be savings associated with spreading machinery fixed costs over more acres that are not captured in a projected budget. Thus, it is important to recognize that projected budgets are not perfect, but they serve as a starting point in evaluating the costs associated with alternative tillage systems.

Figure 17 shows the projected costs for wheat-fallow (WF) and wheat-milo-fallow (WMF) rotations in western Kansas with three different tillage systems based on costs in 1994. In these budgets, as herbicides are increasingly substituted for tillage (i.e., going from CT to RT to NT), total costs increase in both rotations. As cropping intensity increases (i.e., going from WF to the WMF rotation) costs per tillable acre increase due to planting more acres, but the differences between CT, RT, and NT are less pronounced in the more intensive rotation (WMF). This suggests that the relative differences in costs between the tillage systems are dependent on the length of the fallow period. Thus, based on projected budgets, reducing or eliminating tillage in western Kansas results in costs increasing. However, as with yields, there is a rotation by tillage effect. Furthermore, it is important to recognize that the tradeoff that existed between tillage and herbicide costs in the mid 1990s is different today (2005) due to the relative prices of steel, diesel fuel and herbicides. That is, eliminating tillage may not be associated with increasing costs today like it was in the past. Also, it is important to recognize that, when converting from WF-CT to WMF-NT, costs per *land* acre increase, requiring more cash outlay, but costs per *harvested* acre will actually be less. The WMF rotation, chiefly made possible because of NT, has 33% more acres harvested on an annual basis than the WF rotation.

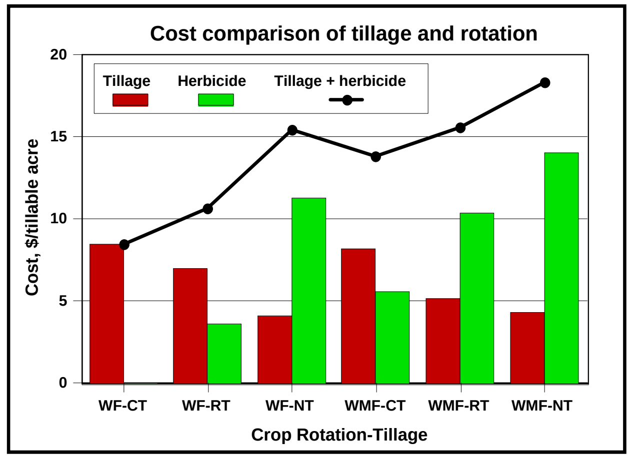

Figure 17

Figure 18 shows projected budgets for a corn, soybean, and wheat rotation in north central Kansas for CT and NT. While the NT system is exactly that (i.e., no tillage is used), the CT system reflects a reduced tillage system that relies on both herbicides and tillage for corn and soybeans. The total costs for the corn crop basically are equal for CT and NT, soybean costs are slightly less for NT, and wheat costs are slightly higher for NT. The tradeoff between decreasing tillage costs and increasing herbicide costs when going from CT to NT is readily apparent.

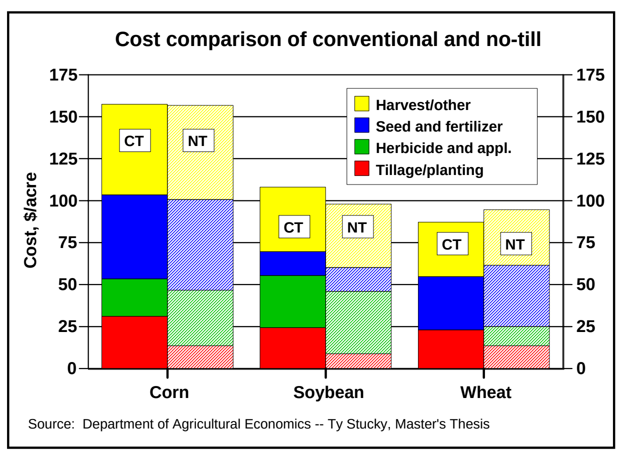

Figure 18

In figure 18, projected tillage costs were based on custom rates for machinery operations, which is consistent with long run machinery costs and holding acres constant. A potential problem with this approach is that it may not account for all costs or benefits that a producer actually realizes when going to no-till. Thus, actual farm-level data, if available, may be more appropriate. However, problems may also exist when analyzing actual farm-level data. First, if the farms considered are not representative, then actual cost data do not provide reliable inferences for other farms. Second, farms that are going through the transition phase of adopting no-till may have higher costs than would be expected in the long run. Third, if farms use multiple tillage systems, fixed costs need to be allocated to crops in the different tillage systems. In spite of these potential problems, an analysis of actual farm-level data is a useful starting point in estimating the impact no-till might have on costs.

The North Central Farm Management Association (NC FMA) has been analyzing and comparing the costs of no-till farms with all other farms in their association since 1996. No-till farms are defined as those farms that are strictly no-till. Farms that use reduced tillage or even no-till on only a portion of their acres are included with the "all other, or CT/RT" farms category. This definition minimizes problems associated with allocating fixed costs, but it also significantly reduces the number of no-till farms to the point where representation may be a problem.

Figure 19 shows the average costs for the strictly no-till farms compared to all other crop farms in the NC FMA from 1996 to 2004. As with the projected budgets (figures 17 and 18), the tradeoff between direct inputs (seed, fertilizer, chemicals) and tillage-related expenses (machinery and labor) is readily apparent. On a per land acre basis, the costs for the NT farms are a little over $2/acre higher than for CT/RT farms. This might lead one to believe that going to NT will increase costs slightly. However, the NT farms harvest a higher percent of acres. The NT farms harvest over 100% of their land acres (i.e., they double-crop some acres), compared to the other farms where less than 100% of land acres are harvested (i.e., some acres are fallowed). Thus, even though costs on a per *land* acre increase, increasing total cash outlay, costs on a per *harvested* acre basis decrease.

No-Till cost study - NC Farm Management Association, 1996-2004

	$/land acre		$/harvested acre	
EXPENSE ITEM, $/acre	CT/RT	NT	CT/RT	NT
Direct input (seed, fert, chem, etc)	$41.26	$55.41	$42.04	$53.37
Machinery cost	$39.44	$35.60	$40.24	$34.27
Labor	$28.35	$24.42	$28.95	$23.50
Total asset charge	$38.59	$38.03	$39.38	$36.63
Building and conservation	$2.99	$2.09	$3.06	$2.01
Other	$11.94	$9.09	$12.18	$8.75
Total expense	$162.58	$164.63	$165.84	$158.53
Total acres	938	1,212	908	1,256
Harvested acres/land acres	xxxxx	xxxxx	96.8%	103.6%

Figure 19

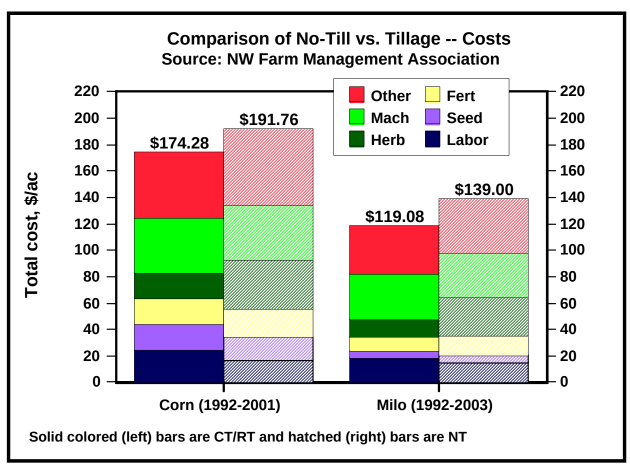

Figure 20

The Northwest Farm Management Association (NW FMA) has been tracking the costs of farms with NT corn and milo compared to farms that use some tillage. Figure 20 shows the breakdown of costs for the different crop enterprises. Similar to what was shown in Figure 17, the costs for both corn and milo are higher per acre with NT compared to CT/RT in western Kansas.

While the cost information shown in figures 17-20 may have some weaknesses as previously discussed, some generalizations can be made from these results. First, costs of reducing or eliminating tillage (i.e., RT and NT) increase compared to CT in western Kansas. However, as the fallow portion of the rotation is reduced (i.e., cropping intensity increases) the differences between CT, RT, and NT costs also become smaller. In north central Kansas (and other central and eastern regions), it appears that switching from CT to NT will have only marginal impacts on costs in the long run. Second, even though total costs may not change, at least in central and eastern Kansas, it is important to recognize that there is a tradeoff between certain inputs — herbicides are substituted for tillage-related expenses. Third, if reducing tillage allows a producer to increase cropping intensity and/or increase farm size, it is possible that NT may reduce costs on a per harvested acre even though total cash outlays may increase.

Impact of tillage on profitability

Based on the yield and cost information presented to this point, the following general conclusions can be made in regard to expected profitability of adopting no-till: (1) returns can be increased in western Kansas by adopting no-till for a spring crop grown in rotation with wheat because yields increase by more than costs increase (returns data are not shown); (2) in central and eastern Kansas, both yields and costs are comparable between tillage systems; so, there appears to be no huge economic incentive, or disincentive, to adopt no-till.

A study of economics using Farm Management data

This section reports the results of an economic analysis of Farm Management data. The analysis is based on approximately 900 producers continuously enrolled in the Kansas Farm Management Association Program for the ten-year period 1994 to 2003. For a detailed explanation of the research methods and results of earlier time periods see Kastens and Nivens and Nivens, Kastens, and Dhuyvetter.

This analysis determines the impact various management traits have in explaining differences in profitability between producers while accounting for geographical region, year, and crop mix. Specifically, the management traits examined are: profit, cost, yield, price, technology adoption, and planting intensity, where all variables are "relative to their neighbors." The reason for comparing each farm to its *neighbors* is because absolute values vary considerably from year to year due to external factors such as weather and general economic conditions. However, relative differences are still indicative of management abilities. Using yield as an example, "different from one's neighbors" simply considers how much better or worse an individual producer's yield is than the average yield for other producers in the same county in the same year. A producer that consistently has higher yields than his neighbors would be considered to be a better manager in that category. However, another question arises, Are yield differences largely driven by uncontrolled factors such as weather, so that few, if any, producers can actually be *consistently* better than their neighbors? Thus, it is important to determine which of these management traits tends to be the most persistent.

The technology adoption variable is based on an index that measures the rate at which producers substitute herbicide for tillage expenses (fuel, oil, labor, repairs, etc.). This variable, referred to as a "less-tillage" index, indicates if a producer is reducing his level of tillage relative to other producers within the region, but it does not distinguish between "less tillage" and no-till. Figures 21 and 22 show the average rates of less-tillage adoption for each of the six Farm Management regions for two different 10-year time periods, 1989-1998 (figure 21) and 1994-2003 (figure 22). Figure 21 displays two important points. First, the rate of adoption is increasing (i.e., upward sloping line) for all regions of Kansas and second, the rates of adoption are fastest in the western regions of the state (steeper-sloped lines). Differences in index values between regions reflect varying crop mixes. For example, the index value is generally higher in the NE region where corn and soybean crops are common, crops that traditionally depend on herbicides. In the SC region, where wheat is the dominant crop, the index is lower. However, that producers in both regions are increasing their rate of less-tillage adoption is noteworthy. In the more recent analysis (figure 22), many of the lines have less of an upward slope and the NE region is even downward sloping. Does this indicate a move away from less tillage adoption? While it is impossible to say with certainty, it is likely that this change has to do with the decreasing relative price of herbicides rather than a major change in production practices.

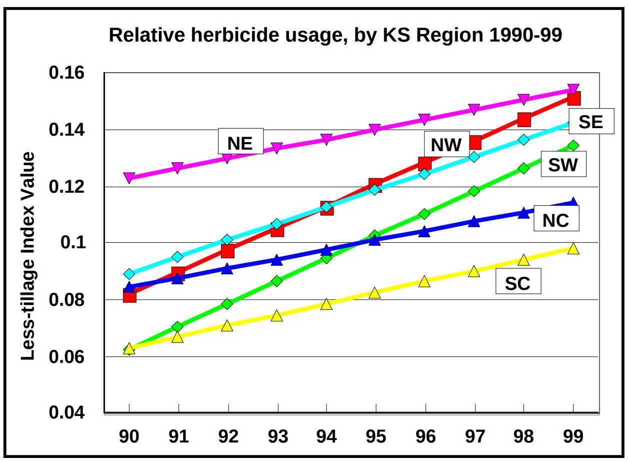

Figure 21

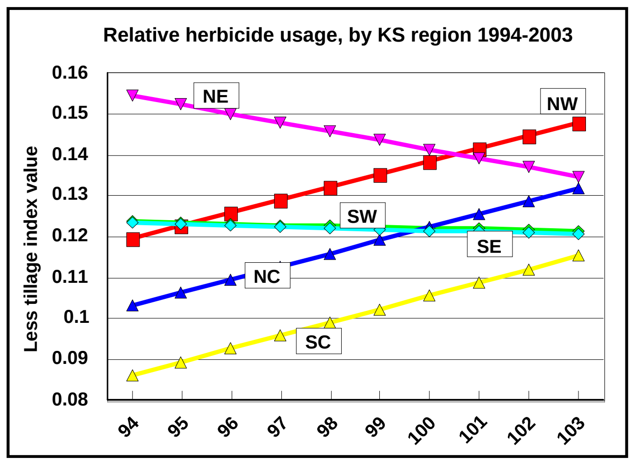

Figure 22

Persistence of management traits

As a reminder, index values were calculated for each farm (approximately 900 farms) for each year (10 years) for each management trait (profit, cost, yield, technology adoption, etc.), where the index is "different from one's neighbors."[3] The producer-specific 1994-2003 average value for each of the management traits is indicative of management superiority or inferiority. For example, a producer whose 10-year average yield index was greater than zero is said to be a better manager than his neighbors. However, we need to know if that producer is *consistently* better than his neighbors or if his yields "jump around" from year to year and it just happened to be that they were better than average. In other words, we want to be able to say with a certain amount of confidence that this producer is a good manager with regards to getting high yields as opposed to this being some random event.

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[3] Profit is in terms of $/acre and all other variables are percent greater or less than one's neighbors.

Once 10-year average "different from neighbors" index values are calculated for each management trait for each producer, it is possible to statistically test the 10-year average of these values against 0. This allows us to say with a certain level of confidence that an individual producer was better or worse than his neighbors (i.e., the average). Figure 23 shows the percent of producers (out of approximately 900 total) that are persistently better or worse than the average for each of the different management variables.[4] High values suggest that a trait is something producers can manage, whereas, low values are indicative of a trait that is much more difficult to manage.

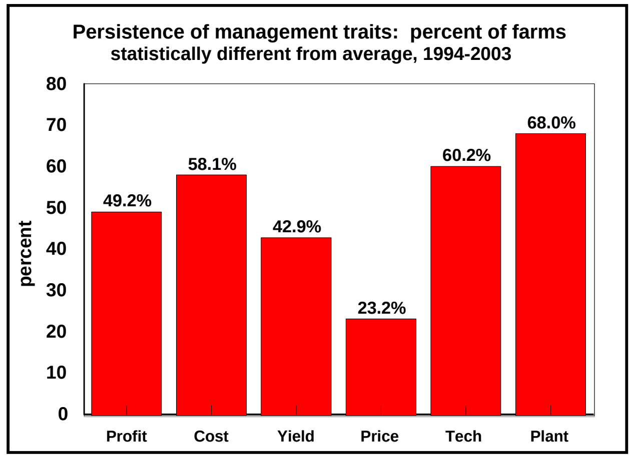

Figure 23

In figure 23, the most persistent trait is planting intensity (harvested acres as a percent of total land acres) and the least persistent trait is price. As already pointed out, planting intensity is often related to the adoption of no-till (e.g., reducing fallow acres in western Kansas or increasing double-crop acres in central and eastern Kansas). Of the management traits considered, technology adoption is the second-most persistent trait, with 60.2% of producers being statistically different from their neighbors. This value of 60.2% is interpreted as follows. Assuming a normal distribution, 30% of producers are consistently ahead of their neighbors in adopting less-tillage, 30% of producers are consistently slower at adopting less-tillage, and 40% of producers are somewhat random with regards to their adoption of less tillage (i.e., they are neither ahead nor behind their neighbors).

The persistence rankings of the different management traits are consistent with intuition. For example, the two most persistent traits, planting intensity and technology adoption, are controlled by the producer (e.g., you either decide to adopt this technology or you do not) and thus we would expect them to be quite persistent. On the other hand, yield and price are the two least persistent traits which also makes sense. While yield is managed somewhat by crop rotation, tillage, inputs, etc., it is still largely subject to factors uncontrolled by the producer, like weather. Likewise, given that considerable research has found grain markets to be efficient (i.e., it is difficult to "beat the market"), it is not surprising that this is the least persistent trait. That is, the prices most producers (77%) receive relative to their neighbors are basically random from year to year. Given that we now know which management traits are the most persistent (i.e., something I as a manager have some control over), the question is, How do these traits impact profitability?

Impact of management traits on profitability

Using the management traits displayed in figure 23 and adding variables for government payments (govt), farm size (acres), percent of acres rented (rent), and income variability over the 10-year period (risk) — where govt, acres, and rent are calculated as percent different from one's

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[4] Percent of producers classified as being persistently different from their neighbors is based on a 95% confidence level.

neighbors and risk is the standard deviation in income ($/acre) — the following relationship was estimated using statistical regression analysis:

(1) Profit = *f* (yield, cost, price, tech, intensity, govt, acres, rent, risk).

Farm size was included to capture economies of size and the possible adoption of technologies other than less tillage. Government payments, percent acres rented, and a risk measure were included in equation (1) as it was hypothesized they will impact profitability differences.[5] The results of estimating equation (1) are given in Table 1.

Table 1 shows the estimated coefficients for the profit equation, the standard deviation of the variables, and the impact changing each variable by one standard deviation has on profit. With the exception of price, all management traits as well as government payments, farm size, percent acres rented, and risk are statistically significant in explaining variation in profitability differences between producers and their neighbors. The signs on the coefficients indicate that having greater yields, adopting technology faster (relying more on herbicides than neighbors), planting more intensively, farming a larger portion of rented land, having a larger farm, and larger government payments relative to one's neighbors are associated with greater profitability. Likewise, producers that have lower costs than their neighbors have higher profits.

The risk variable is positive and significant, which indicates that those producers that are more profitable tend to have more variability in their income. It also should be noted that several of these variables somewhat go together. For example, producers that use less technology tend to plant more intensively. Likewise, producers that rent a higher percent of their acres tend to be larger farms.

Table 1. Impact on Profit per Acre of Management Traits.

Trait[a]	Estimated Coefficient	Std Dev	Profit, $/ac at 1 std dev
Cost	-0.9650*	26.7	-$25.78
Yield	0.2298*	15.0	$3.44
Price	0.0939	8.3	$0.77
Tech	0.1577*	50.6	$7.97
Plant	0.7152*	22.5	$16.06
Govt	0.0735*	65.1	$4.79
Acres	0.1384*	77.5	$10.72
Rent	0.4444*	44.8	$19.92
Risk	0.5565*	65.9	$36.70

[a] Unit for all traits is percent different from neighbors.
* Denotes significantly different than 0 at the 95% confidence level

While most of these results are as expected (i.e., higher yields, lower costs, higher government payments all lead to higher profits), the positive and significant coefficient on technology adoption implies that producers who have been substituting herbicide for tillage expenses at a rate

[5] While these variables were hypothesized to impact profitability differences, they often are not necessarily something that can easily be "managed" in the short run.

faster than their neighbors have been more profitable than producers who are slow to adopt this technology. Likewise, those producers who have been planting crops more intensively than their neighbors have been more profitable.

The interpretation of the technology adoption coefficient (Tech) is as follows. For every 1% increase in the percent herbicide is of herbicide plus machinery expense, a producer would expect to have an additional $0.158/acre greater profit than his neighbors. Similarly, a producer who has costs that are one percent lower than his neighbors would expect to have $0.965/acre greater profits (10% lower costs would imply $9.65/acre greater profits).

In order to compare the different traits, they need to be standardized in some manner because a one percent change may be easier to achieve with one trait than another. Thus, each variable is evaluated at a one standard deviation change because this change would be expected to have an approximately equal likelihood of occurring. For example, a producer would have an equal chance of consistently getting 15.0% higher yields than his neighbors as he would of consistently having 26.7% lower costs than his neighbors. That is, the data suggest that it should be "as easy" to increase yields by 15.0% over time as decrease costs by 26.7%. Comparing profits evaluated at one standard deviation (i.e., Estimated Coefficient x Std Dev) indicates that, of the management variables, cost is the most important variable, with planting intensity the next most important. The impact of technology adoption is not far behind, indicating that producers who have been greater adopters of less tillage have had significantly higher returns. Farm size (Acres) also is an important factor in explaining profitability differences between farmers and thus, to the extent that adopting no-till allows producers to increase their farm size and capture economies of size, this is an additional benefit of no-till.

With a normal distribution, 68% of the observations fall within a range of the mean +/! one standard deviation. This implies that 32% fall outside of this range (16% are better and 16% are worse). Thus, another way to think of the $7.97/acre less-tillage value in table 1 is that the 16% of the producers (those adopting less-tillage the fastest) had profits that were at least $7.97/acre greater than the average producer, while another 16% (those that were slow at adopting less-tillage) had profits at least $7.97/acre lower than the average.

A motivation for this study/analysis is that other methods of analysis often cannot separate management traits. For example, comparing the profitability of no-till farms to other farms using a budgeting approach may lead to erroneous conclusions if other management traits have not been accounted for. The method of analysis used here (statistical regression) estimates the impact of an individual variable while attempting to "hold all else constant." Thus, the impact of technology adoption is estimated while holding all other traits constant. For example, a producer who has costs 26.7% lower than his neighbors would be expected to have $25.78/acre greater profits, regardless of whether he is better or worse than his neighbors in terms of other traits. However, a question arises, What is the impact of being a better manager than one's neighbor in more than one category (i.e., all else is not constant)? With regression analysis, the results in table 1 are additive across all traits. For example, a producer who has 10% lower costs, has 10% greater reliance on less-tillage, and has a 20% greater planting intensity would have $25.53/acre greater profits than his neighbors [-0.9650(-10) + 0.1577(10) + 0.7152(20)].

This analysis provides strong support that reducing tillage leads to greater profitability, partly due to yields increasing and partly due to costs decreasing (impact less tillage has on yields and costs results not shown). While this analysis cannot distinguish between reduced- and no-till, it is superior to many other analyses because (1) it includes a large number of operations and thus should be representative and reliable for making inferences, (2) it implicitly accounts for crop rotation and less-tillage transition costs, (3) it covers a relatively long time period, and (4) other management factors have been accounted for when considering the impact less tillage has on profitability.

Impact of no-till on crop share leases

Crop share arrangements are the dominant form of leasing land in Kansas (Golden, Tsoodle, and Bigge). The concept of an equitable crop share arrangement is to identify all contributions made by the different parties (i.e., the landowner and the tenant) and then share any income in this same proportion. In other words, each party is compensated according to what he/she annually contributes to the production process. Defining a lease as “fair” and equitable in this manner implies that shares going to each party need to change as relative contributions change, if the lease is to remain equitable. Because switching to no-till changes the “cost structure” even though total costs may not change, it is possible that adopting no-till will impact the equitable crop share arrangement. In other words, the tradeoff between herbicide and tillage-related expenses that occurs when converting from conventional or reduced tillage to no-till may have an impact on crop share lease arrangements.

The impact of switching from conventional tillage (CT) to no-till (NT) on equitable crop share arrangements was analyzed using the costs from the budgets presented in figure 18, along with average land values for north central Kansas.[6] Figure 24 shows the equitable shares for a hypothetical landowner and producer given two scenarios of inputs that are shared (designated as Farm #1 and Farm #2) and assuming a crop rotation of 50% wheat, 25% corn, and 25% soybeans.[7]

The Farm #1 scenario represents a situation where the only shared expenses are fertilizer and insecticide. In this case, the equitable arrangement is basically a 1/3 - 2/3 regardless of

Conventional (CT) vs. No-tillage (NT) Effect on Equitable Shares (Rotation = 50% W, 25% C, 25% S)

	Farm #1		Farm #2	
Tillage system	CT	NT	CT	NT
Contribution	Contributor		Contributor	
Land	Landlord	Landlord	Landlord	Landlord
Machinery	Tenant	Tenant	Tenant	Tenant
Fertilizer/insect.	Shared	Shared	Shared	Shared
Herbicde	Tenant	Tenant	Shared	Shared
Herbicide appl.	Tenant	Tenant	Shared	Shared
Other	Tenant	Tenant	Tenant	Tenant
Contributions	32.5/67.5	33.1/66.9	36.3/63.7	40.6/59.4

Figure 24

[6] Equitable share lease percentages were calculated using the *KSU-Lease.xls* spreadsheet available at www.agmanager.info.

[7] It is important to recognize that numerous scenarios could be considered in addition to the two presented here. For example, equitable crop share arrangements could be determined for situations where some herbicides are shared (e.g., shared on row crops but not wheat) or when application charges are not shared.

whether or not the farm is CT or NT. The equitable share is approximately equal because the increased herbicide expense associated with NT principally is offset by the reduction in tillage-related expenses in the CT system. The recommendation for this scenario is that the crop share arrangement should not be changed when the farm adopts no-till.

Farm #2 is based on a scenario where fertilizer, insecticide, herbicides, and herbicide application are all shared in the same proportion as the crop. In this case, the equitable crop share arrangement with CT is 36% / 64% compared to 41% / 59% with NT.[8] The recommendation in this case would be that adopting no-till will require an adjustment to the equitable crop share arrangement. Most likely, if a producer converts to no-till his crop rotation will change. The equitable crop share arrangements also were calculated for Farm #1 and Farm #2 assuming the rotation changed to 20% wheat, 40% corn, and 40% soybeans. This alternative rotation with NT (the rotation with CT was held constant) changed the equitable arrangements slightly (data not shown) but the general conclusion did not change. That is, when converting from CT to NT, the equitable crop share percentages may or may not need to be adjusted depending on which inputs were shared prior to the conversion to no-till.

The point of the examples presented in figure 24 is not what the crop share percentages *should be* in north central Kansas for CT and NT farms. Rather, they are meant to illustrate that a general statement about how NT impacts crop share arrangements cannot be made. In the first example (Farm #1), a producer that decides to switch from CT to NT should be able to do so with little resistance from the landlord. However, in the second example (Farm #2), if a producer converts to NT and does not change the initial crop share arrangement (36% / 64%), the landowner will clearly be worse off. In this example, the landowner would be contributing 41% of the expenses but only receiving 36% of the income. Thus, it is important when adopting no-till that crop share rental arrangements are evaluated to make sure both the landowner and the tenant have an economic incentive to do so.

Summary and Conclusions

Interest in reduced- and no-till in Kansas has been increasing in recent years. Trends in acres farmed with conservation tillage practices confirm this interest, however, the majority of acres in 2004 still were farmed with systems involving considerable tillage. This implies there are still many acres in Kansas that could be converted to no-till if it is profitable to do so.
University trials in central and eastern Kansas comparing yields with different tillage systems generally have shown that yields are comparable for the different tillage systems. Research conducted in western Kansas shows that yields of crops grown in rotation with wheat increase as tillage is reduced. As expected, the results from a number of the research studies indicate that there is a tillage and rotation interaction. Thus, it is important to account for rotation when considering the impact tillage, or lack of tillage, has on yields.

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[8] In this NT example, when the herbicide application was paid by the producer rather than being a shared expense, the equitable percentages were 39/61 rather than 41/59. Given that both of these scenarios would likely be rounded to 40/60 in practice, this shows the importance of good communications and negotiations between landowners and tenants.

If acreage is held constant, projected budgets typically suggest total costs remain relatively constant as tillage is reduced — because herbicides are simply substitutes for tillage costs (i.e., labor, fuel, repairs). An exception to this is in western Kansas, where fallow acres are involved. Here, reducing tillage generally results in total costs increasing. It also should be pointed out that the projected budgets presented in this paper were developed prior to the current herbicide and fuel price situation (i.e., diesel prices very high relative to herbicide prices). Thus, even in central and eastern Kansas, there may be some economic incentives to convert to no-till with current prices that historically have not been observed.

Constant yields and constant costs imply that switching from conventional tillage to reduced- or no-till essentially would be a breakeven proposition. However, an analysis of data from approximately 900 farms over a 10-year period reveals that producers increasingly have been substituting herbicides for tillage over the last decade in all regions of Kansas, with the fastest rates of substitution occurring in western Kansas. These data also indicate that producers adopting this technology (i.e., less tillage) have been more profitable than producers not adopting the technology.

Because reducing or eliminating tillage changes the mix of costs (i.e., herbicides are substituted for tillage-related expenses), producers need to consider the impact this has on crop share rental arrangements. In some cases, converting to no-till has no effect on equitable crop share percentages but in other cases it does have an impact. Thus, it is important that landowners and producers evaluate their crop share arrangements and make adjustments if necessary so that both parties receive the proper economic signals to maximize a farm's profitability.

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No-till and Water Management in the High Plains:
a Kansas Perspective

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Authors:

Terry L. Kastens, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-5866 (office), 785-770-0295 (cell), 785-532-6925 (fax)
email: tkastens@ksu.edu web: www.agmanager.info
Kevin C. Dhuyvetter, Agricultural Economist, Kansas State University, Manhattan, KS 66506
Phone: 785-532-3527 (office), 785-410-3244 (cell), 785-532-6925 (fax)
email: kcd@ksu.edu web: www.agmanager.info
Alan J. Schlegel, Agronomist-in-Charge, Kansas State University Southwest Research-Extension Center, Tribune, KS 67879
Phone: 620-376-4761 (office), 620-376-8114 (cell), 620-376-2278 (fax)
email: schlegel@ksu.edu web: http://www.wkarc.org/Swrec/tribune/tribune.htm
Troy J. Dumler, Agricultural Economist, Kansas State University Southwest Area Extension Office, Garden City, KS 67846
Phone: 620-275-9164 (office), 620-276-6028 (fax)
email: tdumler@ksu.edu web: www.agmanager.info

Kastens is a professor and crops production farm management specialist who works publicly and one-on-one with farms in terms of the economics of crop production, especially associated with land and machinery. He has been at his post since 1995 and was engaged full time in farming prior to that time. He maintains partnership involvement with the family farm in northwest Kansas, a farm that has adopted many no-till practices over the years and one which continues to be a pioneer in researching and adopting technologies such as no-till and precision agriculture.

Dhuyvetter is a professor and crops and livestock production farm management specialist who also works extensively with area farms. He has been at his current post since 1999 and occupied the Agricultural Economist position at Garden City Kansas from 1986-1995. During his Garden City assignment, Dhuyvetter was a leader in examining and educating around the economics of less tillage, especially associated with intensifying the predominant crop rotation (wheat-fallow) in the area.

Schlegel is a professor stationed at an important research location for High Plains crop production. He has conducted considerable research and published extensively in the area of High Plains crop production practices and how they relate to viable crop production systems through better water use efficiencies.

Dumler has held the Agricultural Economist position at Garden City Kansas since 1998. Dumler is in the unique position to work directly with agronomists in western Kansas and eastern Colorado in terms of acquiring an excellent economic understanding of crop production in the area, especially associated with non-irrigated and limited-irrigation cropping systems. Besides the usual academic credentials, each of these four authors brings to the table considerable practical understanding of what can and cannot be done, and what might be most feasible when it comes to profitably raising crops in the low-rainfall High Plains.

No-till and Water Management in the High Plains:
a Kansas Perspective

Terry L. Kastens, Kevin C. Dhuyvetter, Alan J. Schlegel, and Troy J. Dumler

Benefits of less tillage arise from cost savings

Across broad geographical regions, ranging widely in climate and soils, technologies associated with reducing mechanical soil tillage have greatly changed agricultural production. In particular, substituting mechanical tillage with herbicides for weed control has allowed farmers to single-handedly operate more crop land acres and capture the associated economies of size along the way. For such farms, moving towards less tillage is all about lowering production costs, especially associated with machinery operations and management. Moreover, if recent trends of higher fuel prices and lower herbicide (especially glyphosate-based herbicides) prices continue, this signal to reduce tillage will become even stronger in the next decade (figure 1).

Machinery management associated with reducing soil tillage even further, say to no-till (NT), often allows for increased cropping intensity. That is, seedbed preparation time between the harvest of one crop and the planting of another crop essentially can be eliminated, allowing double-cropping where growing-season length normally would have prevented it. Double-cropped soybeans after wheat in the eastern Great Plains of the U.S. is an example. Again, for such farms, NT is all about reducing costs, in this case the opportunity cost of crop land. That is, land's annual charge (rent) can now be spread over more acres of crop.

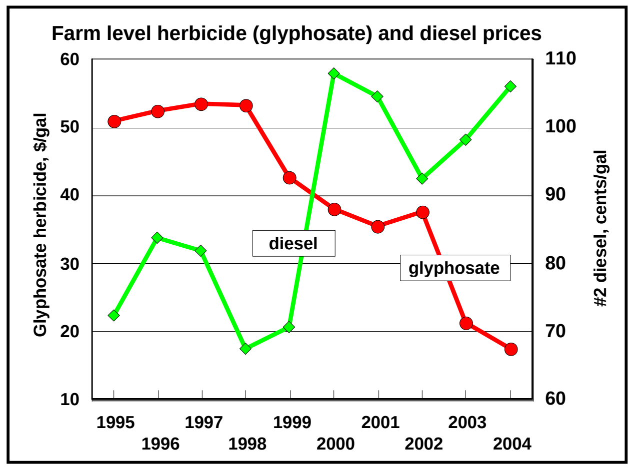

Figure 1

Benefits of less tillage arise from water savings, thus increased crop production

For drier crop producing areas, saving water typically is a strong motivating factor for switching crop production practices from conventional mechanical tillage (CT) towards NT. Indeed, even in areas not considered particularly dry, for example the eastern Great Plains, with 25-35 inches (635-889 mm) of annual rainfall, water savings associated with NT may be needed to make the increased cropping intensity noted above economically feasible. After all, eliminating seedbed preparation time is of little benefit if soil moisture is not adequate for seed germination.

For even drier crop producing areas, such as the western Great Plains areas of the U.S. and Canada (the High Plains; figure 2), with annual rainfall of 10-20 inches (254-508 mm), water savings associated with reduced or NT likely is the dominant factor causing farms to adopt production practices that depend less and less on mechanical tillage. To contain the discussion, the balance of this paper focuses on the High Plains, and the benefits associated with water savings induced by less tillage, with a special focus on eastern Colorado and Western Kansas.

Technology adoption

Throughout this discussion, it is important to note that farmers adopt technologies because they expect such technologies to increase their profits. The speed of technology adoption is determined by three factors. First, is the magnitude of the expected profit, with large expected profits inducing faster adoption. Second, is the farmer's confidence in the outcome. If the farmer is relatively sure of the outcome (i.e., the outcome does not vary a lot from year to year), he will adopt the technology quickly. Third, is the capital required of the technology's adoption. That is, technology investment is just one of many places farmers can spend their money. As examples, they might choose to spend it on farm expansion or personal consumption rather than new technologies. Hence, technologies that require large capital investments often are delayed.

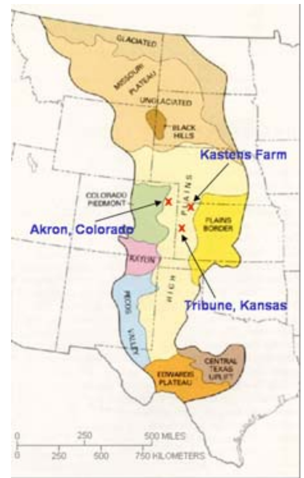

Figure 2. High Plains

Is NT black and white?

Farmers, researchers, and industry advocates of less tillage often are divided about whether they consider degrees of NT in their characterizations of the technology. Some consider NT to be only continuous no-till, with the only "allowed" soil disturbance being that of placing the seed underground. Others consider NT to allow the soil disturbance associated with placing fertilizer underground, perhaps even anhydrous ammonia, which typically involves considerable soil disruption. Still others consider NT to be crop-specific, for example CT wheat followed the next year by NT corn or grain sorghum (milo).

We have little reason to spend much time debating such classifications, yet we do recognize that certain aspects of NT might be more black and white than others. For example, an occasional year of soil tillage likely will destroy more than one year's worth of NT-induced soil improvement in a sequence of otherwise NT years. On the other hand, in our model of technology adoption, much can be gained from considering NT to be a continuum rather than black and white. After all, less tillage involves numerous technology stages. Early on, farmers will adopt certain stages (the more obviously beneficial ones) but not others. But, having benefitted from what was learned by those early adopters, latecomers might skip certain stages.

Some background: traditional wheat-fallow

In the late 1800s to early 1900s, settlers in the High Plains often continuously cropped land after it was broken out of native grass. Advancements in farm machinery, wheat cultivars, and crop production techniques eventually led to the adoption of summerfallow winter wheat (wheat-fallow, WF). Broadly speaking, WF likely was the area's dominant cropping regime from the 1930s to around the 1980s. With WF, a field was planted to wheat in September, harvested the next June or July, laid fallow for the next 14-15 months, whereupon it was again planted to wheat. Though weeds typically were not controlled during the post-harvest period (at least prior to the 1960s), during the May-September period ahead of planting, mechanical tillage was used to control weeds so that soil water could build to sufficient levels for ensuring success of the following wheat crop. The resultant soil accumulation of water during the fallow period, along with the nitrogen mineralized during especially the summer portion of the long fallow period, resulted in more profit than the continuous (wheat, corn) cropping systems WF replaced.

Despite WF being more profitable than the cropping systems it replaced, relatively inefficient water storage results from this technology. In fact, typically only 25% of the rain received during the fallow period ends up as plant-available water in the soil profile. This is due to several factors. First, weeds growing during the fallow period use soil water and hence provide the primary reason for tillage during the fallow period (kill the weeds in order to save the water). Yet, tillage regularly churns wet soil to the surface, increasing evaporation of water to the atmosphere. Also, tillage buries crop residue, which leads to greater soil erosion due to wind and to rainfall running off the land rather than soaking into the soil. This is compounded by the fact that area rainfall, though low annually, often comes in violent storms at much faster rates than the soil can take in. Finally, in years when rainfall during the 15-month fallow period is large, fallowed soils will be above their water holding capacity, meaning that substantial rain in such years will be lost either to run-off, evaporation, or percolation below the crop rooting depth.

Despite it being a successful cropping system overall, WF had other issues besides inefficient storage of water. First, the less frequent cropping in some cases lead to less total annual biomass production. More importantly, the associated practice of tilling during wetter and warmer time periods ensured that a large part of that biomass would end up as atmospheric CO_2 rather than soil carbon. This meant that the overall cropping system lead to a mining out of the soil organic matter and along with it the fertility required of crop production, especially nitrogen and phosphorus (N and P). Consequently, farmers and researchers eventually (generally around the 1960s-1970s) recognized that additions of commercial fertilizer were required to be profitable.

As noted, technologies often appear more evolutionary rather than revolutionary, though they might seem revolutionary to a newcomer who chooses to skip many of the smaller steps. The WF technology was no exception. Throughout the WF decades, marginal improvements in water storage efficiency were occurring due especially to improved farm machinery. The moldboard plow was replaced early on by the one-way disc plow (figure 3), which later was replaced by more residue-preserving machines such as the undercutter, also referred to as a sweep or v-blade (figure 4). Not only did the sweep preserve more residue on the soil surface, potentially reducing evaporation and increasing water infiltration, but it also more effectively allowed for tillage in the time period immediately following wheat harvest. That is, relative to the one-way, the sweep would leave wheat stubble standing upright, which meant that weeds could be killed in the after-harvest period and yet snowfall could be caught during the winter period thereafter, all the while preserving enough residue to keep wind from severely eroding the soil the following spring. Also, with commercial fertilization, residual soil N following harvest often induced greater weed growth during that after-harvest period, thus less soil water accumulation, and hence a greater need for weed control at this time. But, it is important to remember that, as with most technologies, each of these

Figure 3. One-way disk plow

Figure 4. V-blade plow

improvements was not particularly obvious to farmers at the time, as they regularly debated the economic merits of investing in such transitions.

Changing from WF to two crops in three years

The improvements in mechanical tillage, improved hybrids, increased commercial fertilization, and perhaps a series of wetter years or the cataclysmic spring-time wheat freeze of 1996, caused the WF system to begin to give way to a more intensive cropping system around the 1980s and 1990s. In particular, it was found that including corn or milo in the crop rotation increased profits over WF. Such rotations are referred to as WCF (wheat-corn-fallow) or WMF (wheat-milo-fallow). In these rotations, corn or milo is planted (typically in May) in the year after wheat harvest, with corn or milo harvest in October followed by a 10-month fallow period (say November to August), whereupon wheat is again planted in September. Relative to WF, a WCF or WMF rotation uses water more efficiently. That is, it involves less summer tillage, reducing the inefficiencies discussed earlier, and a shorter fallow period, reducing water losses in especially wet years.

Nearly simultaneously with the "discovery" of the WCF or WMF system, it was learned that using herbicides rather than tillage during the time period between wheat harvest and corn or milo planting resulted in even greater profit. Hence, the cropping system that became prevalent at the time was one involving wheat, followed by a fallow period (July to April) where weeds are controlled with herbicides and leading up to no-till-planted corn or milo, followed by a fallow period (November to August) where weeds are controlled using mechanical tillage. This cropping system in the area is still increasing in importance today (2005). But, recent droughts have caused some farms to wonder if they might be better off stepping back to WF.

Water especially drives crop yields in the High Plains

In most geographical areas, water, especially the timing and amounts of rainfall during the growing season, is an important driver of crop yields. But, in the semi-arid areas of the High Plains, water regularly is the most limiting factor in crop production. The fact that the sandy- and silt-loam soils in the area routinely have the ability to store substantial quantities of plant-available water, often up to around 2 inches of water per foot of soil depth (Wolf and Snyder 2003), makes water management even more complex and important for crop production success. In particular, in their cropping decisions, farmers must consider expected or known soil moisture at planting, along with expected in-season rainfall. Moreover, it is not unusual for a crop to acquire as much or more of its water needs from that stored in the soil ahead of planting than from that coming as in-season rainfall.

Today (2005), we believe that High Plains farmers generally have recognized the benefits associated with more intensive crop production such as WCF or WMF. Moreover, their routine use of herbicides rather than tillage in the corn or milo crop of such rotations indicates that they at least are becoming familiar with certain characteristics of a no-till system, for example the machinery management associated with owning, operating, or hiring crop sprayers and specialized no-till planting machinery. But, recent years have brought increasing amounts of no-till information from researchers, the agricultural media, and farmers themselves. So, High Plains farmers are now asking, What next? Should we use herbicides rather than tillage for our summer fallow periods, sometimes referred to as chem-fallow? Or, should we do away with the long fallow period all together, and instead try to raise at least one crop every calendar year? Alternatively, should we become more opportunistic in terms of water, planting crops only when sufficient soil water is present?

Today's High Plains cropping system decisions are complicated by the fact that an increasing amount of no-till information is related to its long-term characteristics, especially associated with soils. Questions arise such as, How fast does soil organic matter and soil structure build over time in a continuous NT cropping system? How deep in the soil are the changes? How will such dynamic changes impact crop yields, input costs, and profitability? Long-term crop rotations involving many different crops sometimes are recommended based on information discovered in one geographical area, with farmers in other areas left wondering whether similar results can be expected in their areas. Moreover, such complex trials are extremely difficult to assess in research settings, pointing to the importance of understanding basic agronomic/soil relationships.

Based on our understanding, we believe that long-term changes in soils due to continuous NT are most likely to benefit High Plains farming when understood in the context of the dynamics of water management. That is, we believe that NT benefits are more likely due to getting more of the rain that falls into the soil and to keeping less of the soil moisture from escaping through evaporation. This is not to say that the economics of change in the organic component of soil fertility is trivial, only that such features are dominated by changes in crop yields impacted by changes in water efficiencies. So, before we put forth a few numerical results and expectations for High Plains no-till management, we first offer a brief discussion of several water issues associated with tillage practices. The academic research described is not intended to be comprehensive, but is included only to provide examples and illustrations of issues we consider potentially important.

Crop residues on soil surfaces reduce evaporation

Evapotranspiration comprises transpiration (water consumed by the crop) and evaporation (water vaporized into the air from the soil). Hence, reducing evaporation without reducing transpiration should be the goal of more profitable water management. A potential benefit to no-till farming in dry areas is the potentially reduced levels of evaporation due to the presence of crop residue. In a 2003 study of irrigated soybeans in southwest Kansas, Klocke and Dumler (2004) report substantially reduced evaporation in the presence of either corn stover residue or wheat straw residue. During the growing season (11 Jun - 6 Sep), bare soil would have lost 7.2 inches (183 mm) of water from evaporation. Soils with corn stover lost 4.2 inches (107 mm) for a savings of 3 inches (76 mm) and soils with wheat straw lost 3.6 inches (92 mm) for a savings of 3.6 inches (91 mm). The authors were surprised that corn stover was as effective as it was (so close to wheat straw). 2004 results (see Klocke 2005) were similar to those of 2003. That is, across once- and twice-a-week irrigation, expected 2004 growing-season water savings in soybeans were 3.47 inches (88 mm) and 3.48 inches (88 mm) in the presence of corn stover and wheat straw residues, respectively. Their 2004 similar work in irrigated corn revealed water savings of 2.75 inches (70 mm) and 2.96 inches (75 mm) in the presence of corn stover and wheat straw residues, respectively.

Though the preceding information was for crops under irrigation, the concept that surface crop residue reduces evaporation losses holds for non-irrigated conditions as well. For example, Cahoon et al. (1996) report that "Weed-free wheat stubble in west central Nebraska can reduce evaporation by 2 inches (51 mm) compared to bare soil, from wheat harvest in July until row crop planting the following May." Note that this statement pertains to the evaporation savings associated with the NT corn or milo part of the WCF or WMF cropping system described earlier.

That High Plains farmers have adopted the WCF or WMF system (corn or milo, using no-till farming practices) indicates that they are well aware of the concept that residue reduces evaporation. But, the strength of that water savings impact across different residue situations likely is less well known. Consequently, Nielson et al. (2003) studied the impact of wheat stubble height on evaporation in eastern Colorado. At relatively high stem densities, say 40-60 stems per square foot (431 to 646 stems per square meter), which would correspond approximately to 40-60 bu/acre grain yield (2.69 to 4.03 Mg/ha) , cutting stubble at a height of 20 inches (508 mm) had little benefit over a 12-inch (305 mm) height. Though, at these stem densities, a 12- or 20-inch (305 or 508 mm) stubble height reduced relative evaporation potential from around 37% for a 4-inch (102 mm) height to 20% for a 12- or 20-inch (305 or 508 mm) height. But, at lower stem densities, say 10-20 stems per square foot (108 to 215 stems per square meter), expected relative evaporation was about 80%, 50%, and 38% for the 4-, 12-, and 20-inch cutting height (102, 305, and 508 mm), respectively. Clearly, with poor wheat yields (low stem densities), cutting height might especially impact the yield of crops that follow.

In a somewhat more practical setting than the Colorado study just discussed, Schlegel initiated a study in 2001 at Tribune Kansas comparing the impact of the previous year's wheat stubble height on the corn crop (milo instead of corn was grown in 2004). The high stubble height was as high as the combine could practically capture nearly all of the heads. The low stubble height was 50% of the high height. Somewhat shorter than typical wheat prevailed during the trial, so that the high height may have averaged only around 13 inches (330 mm). Though the 4-year study was plagued by a drought-induced crop failure in 2002, early results are at least encouraging. Across the 3 years and 3 different post-wheat-harvest weed control programs (starting in July, August, and only in the spring), the average benefit to higher wheat stubble height for the following crop was 8.2 bu/acre (0.55 Mg/ha). Given the wheat model to be described later, this would seem to imply an evaporation savings (or possibly a gain in water infiltration) due to cutting wheat higher that is greater than 1 inch (25 mm) of soil moisture.

Water infiltration in soils associated with soil structure

That crop residue reduces water runoff and thus increases soil infiltration has long been known. As one simple example of this, Croissant et al. (2004) report results of a water infiltration study performed in Colorado. The study used simulated rainfall on soil surfaces mimicking disced ground and NT. During the simulated rainstorm, runoff on the NT surface began after 15 minutes into the simulated rain event. By 20 minutes, runoff was occurring at 0.8 in/hr (20 mm/hr); by 25 minutes it had increased to a rate of 2.1 in/hr (53 mm/hr). It then leveled off at a rate of 2.4 in/hr (61 mm/hr) over the 30-40 minute period. On the disced surface, runoff began in 18 minutes, increased to a rate of 1.4 in/hr (36 mm/hr) in 20 minutes, to 3.0 in/hr (76 mm/hr) in 25 minutes, and then leveled off at 3.5 in/hr (89 mm/hr) from 30 to 40 minutes. In this simple 40 minute experiment, likely representing a 2.3-inch (58 mm) 40-minute rainstorm, 0.37 more inches (9.4 more mm) of water infiltrated the NT soil than the disced soil. Thus, in rainstorms like this, only 50% of the rain would get into the disced soil whereas 65% would get into the NT soil. Of course, depending on how long the NT soil had actually been in NT (not reported), part of the improved infiltration may have been from porosity changes in the soil rather than only the residue (see the following section).

Increased hydraulic conductivity and field capacity with NT

Conservation tillage has been shown to cause notable increases in saturated hydraulic conductivity in the topsoil layer within 3 years in soils in Germany (Horn, 2004). In that study, these changes become notably pronounced even to depths of 60 cm (2 feet) by about 7 years. On the other hand, a Japan study (Moroizumi and Horino, 2004) involving simulated shallow tillage (4.5 cm) suggests somewhat the opposite. Yet, that same research paper reported at least five studies where NT was shown to have equal to or greater hydraulic conductivity than conventional mechanical tillage systems. The cause was increased numbers of continuous macropores in NT soils. Apparently, the intuition that fluffed up soil from tillage should conduct water more rapidly than un-tilled soils is offset by the fact that large continuous soil pores with NT allow even faster percolation of water downwards through the soil, especially when the soil layer of transmission is saturated. Somewhat like the increased surface infiltration wrought by NT, this means that greater portions of rainfall events can be stored in the soil as available water with NT as compared to conventional tillage. Another way to view the situation is that higher organic matter soils with larger and more continuous macropores do not seal off as rapidly in rainstorms, which leads to greater infiltration of water (Lado, et al., 2004).

That NT increases total soil porosity and/or increases macropore size was confirmed with a unique procedure allowing calculation of soil water from the usual (disturbed; bulk density unknown) soil samples submitted to soil laboratories for soil fertility testing (Perfect et al., 2004). The study involved silt loam soils associated with a 35-year tillage study in Kentucky. More importantly, the study deduced that NT soils can provide 12.5% more plant available water than plowed and disced soils – at least in the portion of soil measured, which was the top 10 cm (4 inches). Importantly, the results were based on NT management combined with typical N fertilization rates. At 0 fertilizer N rates, the two tillage treatments were similar in terms of pore size and thus water providing capabilities. Interestingly, this was true despite the fact that the 0-N rate NT soils had substantially more total carbon (1.78% vs. 1.11%).

In a study comparing CT to NT (after being no-tilled for 27 years) to native pasture in the Palouse Region of Washington State, Fuentes et al. (2004) report the following. Pore spaces expand as soils become wetter, with native pasture's pores expanding more than those of NT which expand more than those of CT. Native prairie soils had around 10 times the hydraulic conductivity of CT and NT soils. Even after 27 years of NT, CT and NT soils did not differ much in terms of hydraulic conductivity at 0-10 cm depths, except at head levels near saturation, where NT had 73% greater conductivity (measured as cm/day) than CT at the 0-5 cm depth and 42% greater conductivity at the 5-10 cm depth. Moreover, across 6 measured points in time over 2001-2002, and across 3 sampling depths to 10 cm, saturated native prairie soils would contain approximately 21% more volumetric water than CT or NT according to the underlying models reported in this study. Notice that the issue of whether NT soils, *at saturation*, would contain more water than CT soils is a separate issue from whether or not NT soils tend *to be found* with higher amounts of water, as they might be with better infiltration and less evaporation.

Soil strength or structure improves with less tillage

There is substantial evidence that less tillage leads to stronger soils, those which have greater shear strength and which can thus support greater weight (for example, Horn 2004). Improving the strength of soils means that they will be harder to damage with wheel traffic later on. Thus, after sufficient years in a continuous NT system, reduced water infiltration in areas of machinery-induced compaction should become less of a problem.

Changes in soil organic carbon (SOC) and/or soil organic matter (SOM)

In recent years it has become popular to discuss changes in SOM over time due to the adoption of NT farming practices. Putting aside the broader related issues such as global warming and carbon sequestration, at the farm level one should ask, Why should I be interested in SOM changes over time? From our standpoint, our interest is more correlational than causal. That is, SOM often is highly correlated with other, more directly relevant, soil properties related to water and residue management. Consequently, it should be more useful to focus research directly on measures of interest, for example soil water and crop yields.

Not only is SOM an indirect measure of interest at the farm level, its changes over time tend to be small enough and variable enough that they are hard to detect except across very long time periods. But, to provide some information about what might be expected in terms of SOM changes over time, we recount information from Campbell et al. (2005), which reports various past studies on the topic. In Canadian semi-arid soils, across various cropping frequencies, NT was shown to increase SOC on average by 250 kg/ha/year in the 0-15 cm (0-6 inch) soil layer. Assuming that soils weigh 300,000 lb/acre/inch (132,000 kg/ha/cm) and that SOM is 58% SOC, this would imply an annual SOM increase of 0.02 percentage point. In a nearly continuously cropped system (1 fallow year followed by 5 wheat years), NT was shown to increase SOM about 0.05 percentage point annually.

Colorado research (3 stations in eastern Colorado) reported 1985-1997 changes in SOC in the top 20 cm of soil (0-8 inches) across different levels of cropping intensity and relative to a cropping system base of WF (50% cropping intensity). Assuming SOM is 58% SOC, on average, both the 66% cropping intensity (2 crops in 3 years) and the 75% cropping intensity (3 crops in 4 years) increased SOM by 0.009 percentage point annually. But, with the 100% cropping intensity, SOM increased by 0.017 percentage point annually. The authors concluded that soils likely need to be cropped annually before substantial changes in SOM will be detected. An 8-year study of SOM (Fabrizzi et al. 2003) was conducted in an Argentina area that receives 36 inches (914 mm) of annual rainfall and which has fairly high SOM soils to begin with (>4%). Results revealed that annual change in SOM of the 0-15 cm soil layer was 0.07 percentage point.

As one more point of reference for changes in SOM over time, figure 5 shows SOM measured at the 0-8 inch depth across several years on the Kastens farm in Rawlins County of Northwest Kansas. Cropping intensity on this farm likely varied from around 60% in 1994 to about 77% in 2004. During the time, about 60% of the crops were raised following a NT fallow period and 40% following a CT fallow period. Changes in SOM over the study period averaged 0.014 percentage point per year.

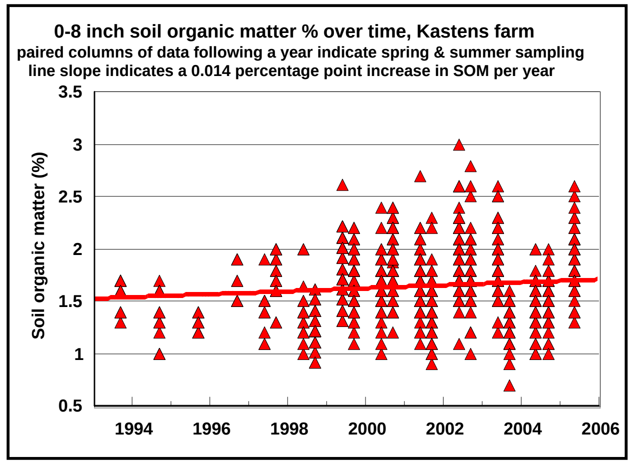

Figure 5

After noting the weaknesses of SOM, that associations with important measures of interest may be merely correlational and that changes in SOM over time due to NT likely will be small and hard to detect, a few positive words about SOM are in order. First, SOM information can be obtained from an inexpensive test that typically is run in routine soil testing to support fertilizer rates. Second, since it tends to be correlated with other soil properties more directly related to water efficiencies, such as porosity, it would provide a reasonable gauge of expected water efficiencies in the face of no better information. Third, as SOM builds over time with NT, the organic component of soil fertility, such as that of N and P, as well as the increased solubility of P (Wolf and Snyder 2003) will increase in importance. That means that using SOM information to help provide a better estimate of mineralized N and P, thus leading to fertilizer savings, will become a more profitable activity over time.

Soil changes with NT do not run deep but maybe they do not need to

If there is one common thread that runs through reported research regarding NT-induced changes in soils, it is that such soil changes are not observed particularly deep in the soil. Hence, it is unlikely that substantial profitability increases due to NT come from major changes in the rooting zone’s ability to hold water, give up water to crops, or release mineralized N or P to crops. On the other hand, it appears possible that small changes to soils just below the surface might be especially important in terms of allowing more water to get into the rooting zone. Consequently, even though characteristics at or above the soil surface (especially residue management and not repeatedly exposing wet soils to the atmosphere with tillage) likely dominate NT economics in the High Plains, changes in soils over time with NT might magnify the benefits of the water dynamics taking place at and above the soil surface.

Crop and water relationships at Tribune, Kansas

Based on information collected at Kansas State University’s Tribune Kansas Experiment Station over the last 31 years, about 30% of the variation in annual yields of winter wheat can be explained by only available soil water (ASW) at planting (figure 6). Practically, approximately one half of the water in soils of the area can be extracted by crops, which means that, though soils might contain as much as 4 inches of water per foot of depth at field capacity (333 mm of water per meter of depth), only about 2 inches per foot actually can be extracted by crops (Wolf and

Snyder 2003). Thus, at field capacity, we would say that the soil contains around 2 inches of ASW per foot (167 mm of ASW per meter). When in-season rainfall also is included to help explain wheat yield, the resultant statistical yield model has an R-squared value of 0.61 (figure 7), implying that 61% of the variation in annual winter wheat yields can be explained by these two aspects of water management alone.

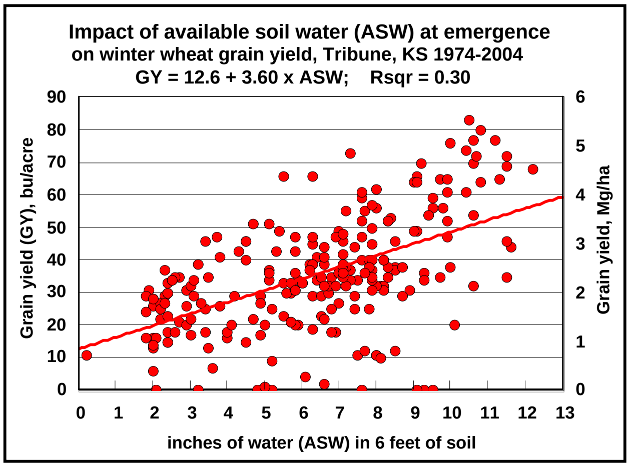

Figure 6

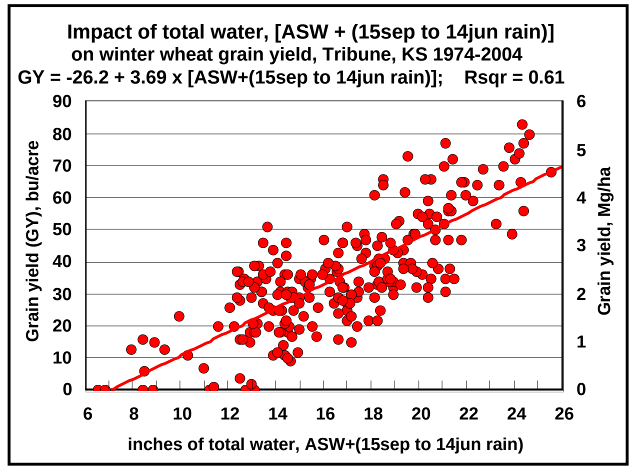

Figure 7

The model in figure 7 depicts water as simply the sum of ASW at planting and total in-season rainfall (15 Sep to 14 Jun). We have selected this single-variable treatment of water since, with these wheat data, the impact of an additional inch of water on crop yield was about the same whether it was an inch of soil water or an inch of rain during any of the in-season sub-time periods considered. Calculated from 26.2/3.69 in figure 7, the model suggests that it takes about 7.1 inches (180 mm) of water (either from the soil or rain) to get a positive wheat yield. Thereafter, each additional inch (25 mm) of water results in 3.69 additional bu/acre of wheat (0.25 additional Mg/ha). This impact of water on wheat yield observed in the Tribune Kansas area is similar to that observed in the Akron Colorado area, albeit over a shorter time period in Akron. In particular, the Akron study reports 5.3 bu/acre for each additional inch of water in wetter years (1993, 1995, 1996, 1997, and 1999) and only 1.7 bu/acre in drier years (1994, 1998, and 2000). The weighted average of these values is 3.95. The Akron study can be found online at http://www.colostate.edu/Depts/SoilCrop/ extension/ Newsletters/2003/Drought/stubble.html.

Figures 8 and 9 depict information comparable to figures 6 and 7, only for milo rather than wheat. Now, 56% of the annual variation in milo yields can be explained by only soil water (figure 8). Bringing into the model in-season rainfall increases the explanatory power marginally to 58% (figure 9). We should note that this statistical model would have been slightly better if we treated rainfall separately from soil water. In particular, in this study, the impact of an inch of rain on milo yield was only about half of the yield impact of an inch of soil water. But, in more recent (1991-2004) work discussed later, the impact of rain on milo yield can be shown to be much larger than the impact of soil water. Hence, for consistency with the wheat model, and to reduce the probability of reporting inappropriate inferences from limited data, we show in figure 9 the same type of model as in figure 7, where water is treated as simply the sum of soil water and in-season rainfall. The milo yield model suggests that it takes about 5.4 inches (137 mm) of water either from the soil or rain to get a positive milo yield. Thereafter, each additional inch of water results in 6.68 additional bu/acre of milo (0.42 additional Mg/ha of milo yield). Given the models, it appears milo is somewhat more efficient at turning water into grain than is wheat, at least in terms of grain yield.

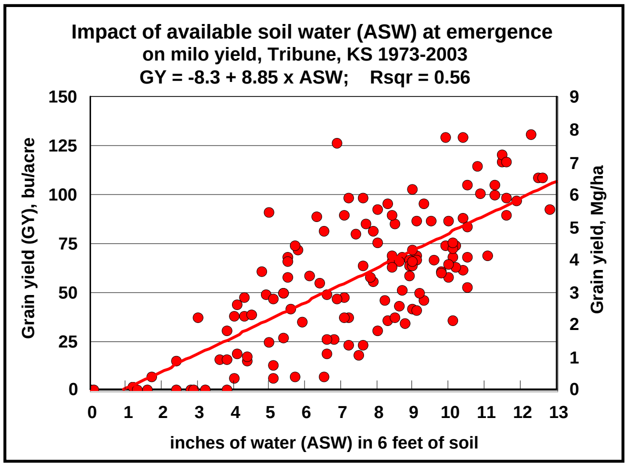

Figure 8

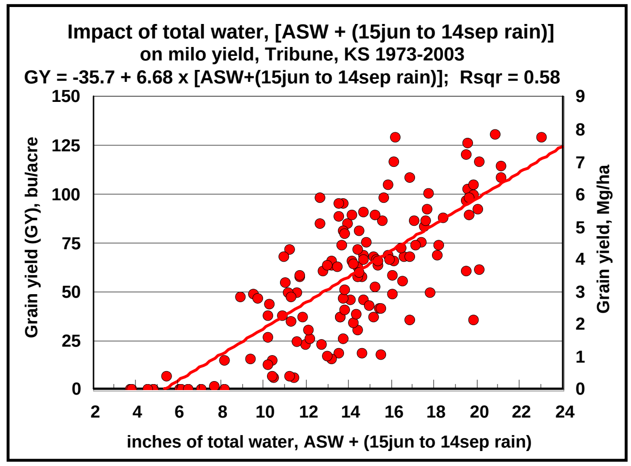

Figure 9

Less tillage means more available soil water at planting

A 14-year (1991-2004) study at Tribune Kansas compared tillage regimes of conventional tillage (CT), reduced tillage (RT), and no tillage (NT), for each of wheat and milo in a WMF rotation. CT involved 4 to 5 tillage operations during the fallow period. RT involved 2 to 3 tillage operations along with 1 to 2 herbicide applications. NT involved only herbicides (around 4 applications) for weed control. With this description, it is likely that most farmers during the time were using either CT or NT for a given crop and so that is our focus. Also, by most measures had we reported them, RT would come out somewhere between CT and NT.

Figures 10 and 11 compare CT to NT in terms of ASW at planting in 8 feet (2.4 m) of soil, for wheat and milo, respectively. It is easy to see in the figures that NT generally ends up with more water at planting than CT. For wheat (see figure 10), the annual savings is 1.51 inches (38 mm), or 20.9% when expressed as a percentage of average CT soil water at planting. For milo (see figure 11), the annual savings is 1.83 inches (46 mm), or 29.6% when expressed as a percentage of average CT soil water at planting.

In figures 10 and 11 it appears that not only is there generally a positive water savings associated with NT over CT, but that savings appears to start small or negative and possibly grow over time. Although the water savings have not been particularly large in the most recent 2 or 3 years, the data are consistent with a positive trend over time for the water savings. In particular, there is a statistically significant (p-value = 0.06) time trend for wheat equal to 0.29 in (7.5 mm) per year and a weakly significant (p-value = 0.22) trend for milo equal to 0.15 in (3.7 mm). Thus, insofar as it is appropriate to generalize from our inferences, we might expect ASW to grow over time with continued use of NT. This is consistent with some of the water dynamics concepts and research we reported earlier, namely, that NT's benefit in terms of water efficiencies is expected to grow over time as soils and/or residue characteristics change over time.

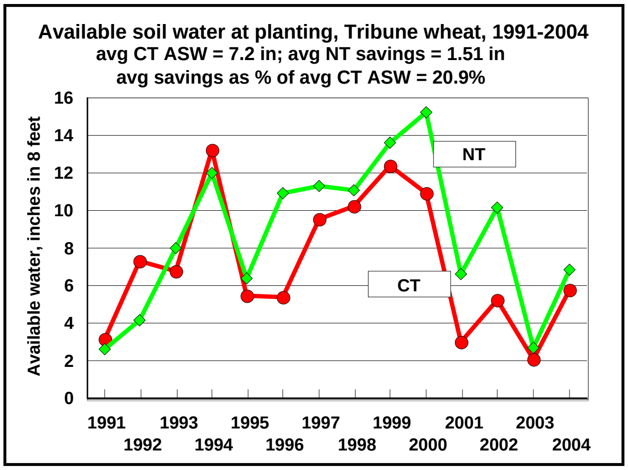

Figure 10

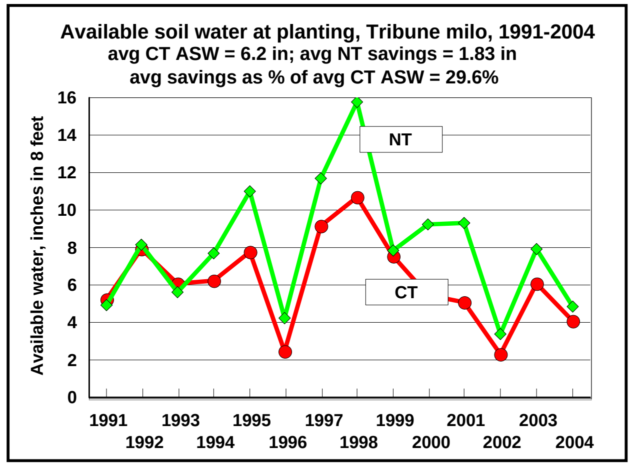

Figure 11

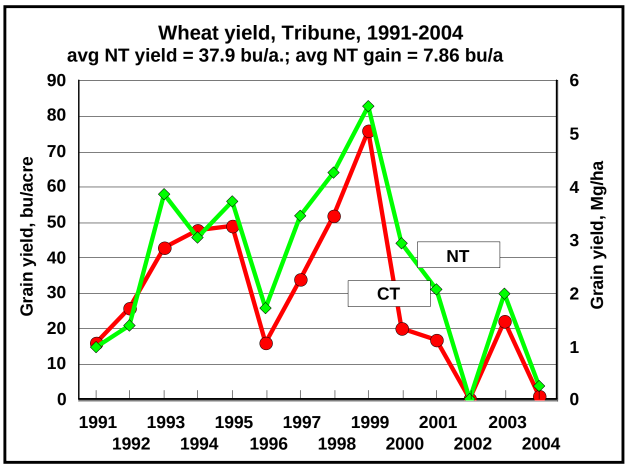

Figure 12

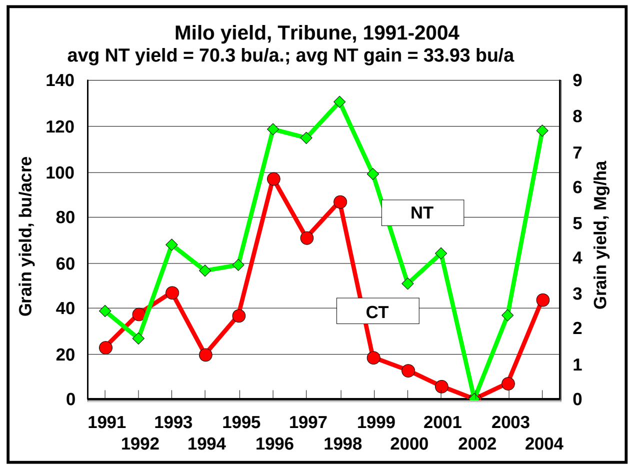

Figure 13

Less tillage means higher crop yields

Figures 12 and 13 depict the crop yields associated with the 1991-2004 Tribune study. The figures make it clear that the water savings associated with NT do become gains in crop yields. For wheat (figure 12), the annual NT yield advantage is 7.86 bu/acre (0.53 Mg/ha). For milo (figure 13), the annual NT yield advantage is 33.93 bu/acre (2.13 Mg/ha).

Less tillage means higher water use efficiency (WUE)

Figures 14 and 15 depict the water use efficiency (WUE) expressed as lb of grain per inch of water use associated with the 1991-2004 Tribune study. As used here, water use is inches of ASW at planting, plus in-season rainfall in inches, less inches of ASW remaining at harvest. Then, WUE is merely lb of grain production divided by water use. The figures make it clear that WUE is substantially higher for NT than for CT. For wheat, the average increase in NT WUE over that of CT is 21.21 lb/in (3.79 kg/cm), or 21.8% when expressed as a percentage of average CT WUE (figure 14). For milo, the average increase in NT WUE over that of CT is 129.8 lb/in

(23.2 kg/cm), or 96.6% when expressed as a percentage of average CT WUE (figure 15).

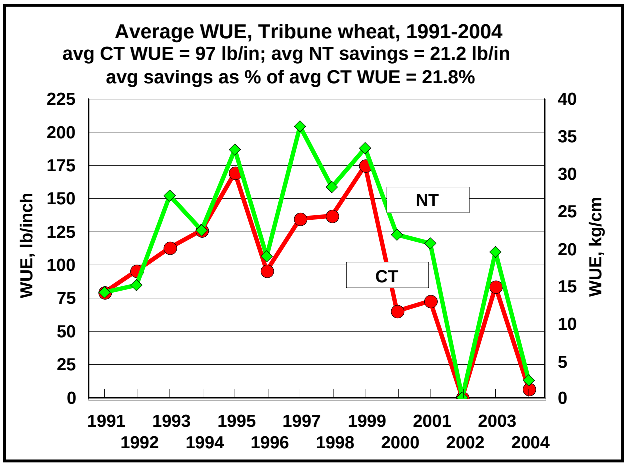

Figure 14

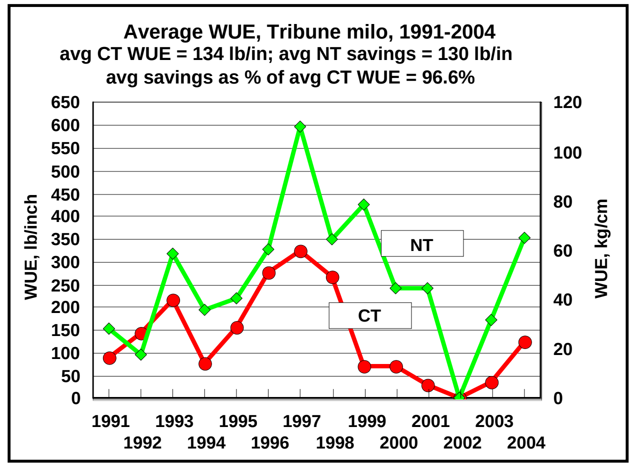

Figure 15

At least two reasons come to mind for the WUE increase associated with NT depicted in figures 14 and 15. First, the efficiency of getting rain into the soil in-season was not accounted for. That is, we merely added in-season rainfall to ASW at planting to determine total water available. Hence, insofar as in-season rain more effectively gets into the soil with NT, as is the case in the fallow period and shown in figures 10 and 11, this increase in effectiveness would be measured here as higher WUE. Secondly, it is likely that residue conditions reduce evaporation from the surface in-season, which would again show up as an increase in WUE in this study.

In figures 14 and 15 it appears that not only is NT WUE nearly always higher than that of CT, but the difference between NT and CT WUEs appears to be growing over time (similar to the ASW or yield difference in the associated figures), especially for milo. In particular, there is a time trend equal to about 1.34 lb/in (0.24 kg/cm) per year for wheat but that trend was not statistically significant (p-value = 0.41). But, for milo, the time trend indicated an annual improvement of around 11.41 lb/in (2.04 kg/cm) at a p-value of 0.12. Across wheat and milo, these trends are consistent with the expectation that NT WUE will grow over time as the NT cropping practice is continued.

Recapping the results of the Tribune study we offer the following. Relative to CT, NT is associated with storing substantially more water in the soil during the fallow period. This higher water savings induces higher yields for NT. Relative to CT, NT is associated with higher WUE, likely due to improved water efficiencies during the growing season. As with the soil water savings, the higher WUE with NT means higher yields for NT. There is some evidence that both available soil water at planting and water use efficiency might grow over time with continued use of NT. Applying the growth trends described earlier to the mathematical yield models also shown earlier (math not shown) would suggest that NT crop yields might increase as much as 1.49 bu/acre (0.10 Mg/ha) per year for wheat and 3.96 bu/acre (0.25 Mg/ha) per year for milo in systems with continued NT. The actual computed trend for NT crop yields over the study period was considerably lower for wheat (0.70 bu/acre or 0.05 Mg/ha per year) but similar for milo (3.84 bu/acre or 0.24 Mg/ha per year). Either way, these would be substantial gains to continued use of NT. But, we should keep in mind that this Tribune study includes only 14 years. Hence, even if it is appropriate to generalize about our inferences, it is likely that improved yields associated with NT eventually would grow at a slower rate than asserted here, or eventually quit growing all together. But, if the slowed growth comes about because of leaving water unused (tendency towards saturated soils during certain times in the crop rotation), the High Plains has a distinct advantage in that it simply can move to a higher level of cropping intensity. That is, fallow periods can be shortened and crops could be grown annually. So, all in all, we view these water-related findings quite positively in light of High Plains NT cropping systems.

A computer-based decision tool is next

Historical profits associated with different tillage and cropping systems can be acquired from accounting systems of farms and from readily accepted projected crop budgets. Unfortunately, such results often come too late for many decision makers. Competition is such that if a farm manager does not recognize beneficial technologies early on then he will find himself adopting such technologies only after they have already been adopted by many managers and only after the associated economic benefits have already been bid into land rents. That is, he will find himself adopting technologies only for survival. But, the most profitable manager looks to the future and is an astute assessor of new technologies so that he can benefit from them for a long time while other managers lag behind. The same is true for NT technologies. NT has many facets to explore, a number of which have been discussed in this paper. Forward-thinking farm managers seek to understand these facets well enough and early enough that they can profit from them. Based on our understanding, High Plains farm managers considering NT would benefit the most if they considered NT principally from a water management focus, collecting, storing, and using rainfall efficiently.

The information described in this paper provides a starting point for designing a computer spreadsheet decision tool for selecting tillage and cropping systems for the High Plains. Historical monthly rainfall amounts for locations of interest should be readily available and would provide the basis for the variability required of a simulation that examines both expected profit as well as risk. Suitable assumptions will need to be made regarding how effectively rainfall ends up in the soil profile. Yield response models where crop yield is considered to be a mathematical function of water already have been described and can be tailored as need be. Changes over time associated with improved water storage with NT can be considered along the lines described here, as can potential improvements in water use efficiency (thus crop yields) over time with NT. Finally, all of the necessary economics can be brought into the program that are relevant, for example expected machinery costs and crop input costs.

An early version of the decision tool just described has already been designed. We had hoped to have a number of economic results to report in this paper draft but have decided to wait until the various assumptions underlying the tool can be more thoroughly debated and verified. Nonetheless, we can say this. We have used this early version to assess cropping systems in the Tribune Kansas area, with 16.6 inches (422 mm) annual rainfall over the 1931-2004 period, and in the Rawlins County Kansas (location of Kastens farm) area, with 20.9 inches (531 mm) annual rainfall over the 1931-2004 period. From the early results it is quite clear that farms in both areas should consider NT over CT cropping systems since the simulated or expected profits are considerably higher. Thus, it is likely that even the somewhat well accepted cropping system of

WCF or WMF should be managed with NT, and not only the row crop part (corn or milo), but also the wheat crop in the system. Moreover, in both areas it appears that farm managers' NT programs might benefit from more intensive cropping than 2 crops in 3 years. Stay tuned to www.agmanager.info for further information on such cropping systems for the High Plains as it develops. Alternatively, any of the authors listed at the front of this paper can be contacted directly for an update on this project.

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