Incentives for Switching Agricultural Land to Carbon Sequestering No-Tillage: What Duration are Incentives Necessary?

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Abstract

Fourteen long term side-by-side tillage practice experiments were studied to analyze if no-tillage yields improved through time allowing incentives to decline. In the majority of cases, no significant increase in no-till yield is evident. Incentives may need to be permanent if switched acres are to remain using no-tillage practices.

Introduction

The Kyoto Protocol to the United Nations Framework Convention on Climatic Change proposes to limit future greenhouse gas emissions (UNFCCC). Land-use can be a key determinate in atmospheric carbon flux (Houghton et al), which is the major contributor to greenhouse gas emissions. Agriculture has the potential to decrease the amount of carbon in the atmosphere by improving land use methods so as to sequester carbon in agricultural soil (Watson et al., 2000). Recent research on the net carbon sequestering ability of no-tillage has lead to a renewed interest in switching more acres from conventional tillage to no-tillage (Lal et al; West and Marland).

No-tillage acreage has risen from 16 million acres in 1990 to 55 million acres in 2002, and accounts for 19.6% of total US acreage in 2002 (CTIC). Previous economic modeling work on the role of agriculture as a carbon sink has proposed that an incentive level may be necessary to switch additional acreage to no-tillage practices (McCarl et al., 2000, 1997, 1998; Adams et al. 1999, 1993, 1992). Recent research has evaluated the farmer incentives based on risk preference that would be required to cause farmers to switch to no-tillage practices (De La Torre Ugarte et al.). De La Torre Ugarte et al. evaluated long term side-by-side experimental plot data combined with regionally specific rotation budgets to determine incentive levels unique to four regions and fourteen rotations. They concluded that future studies should evaluate the long-term tillage data to determine if the incentive level can be reduced or eliminated as yields respond to improved soil quality.

Farmers have switched from conventional tillage to no-tillage to take advantage of many agronomic benefits. Tilling the soil allows oxygen into the soil to increase microorganism decomposition of organic matter. This results in short-term benefits by freeing nutrients into the soil for crop uptake, but prolonged tillage leads to decreased organic matter and fewer micro-organisms (Rasmussen). This leads to further problems of soil compaction, low infiltration rates, increased overland runoff and soil erosion (Mueller). Alternatively, no-tillage allows soils to rebuild through the slow decomposition of crop residues and roots, which leads to increased micro-organisms, macro-pore development, greater infiltration and less erosion (Lindstrom). The agronomic advantages many not be apparent in the initial years after a switch from conventional tillage and may take several years before the full benefits of no-till are realized (Dick; Packer).

Our objective in the current study is to evaluate whether the necessary incentive level to switch acres to no-till can be reduced over time. Given the research showing the improved agronomic qualities of no-till systems, our hypothesis is that the yields of no-till, and therefore net-returns of no-till, will increase over time relative to conventional tillage, and the necessary incentive level can be decreased.

Data and Methods

Through a search of tillage literature and by directly contacting land-grant research scientists, we collected data from fourteen long term side-by-side experiments from nine research farm locations throughout the agricultural regions of the US. These experiments studied the effects of conventional tillage, conservation tillage and no-tillage upon yield. Earlier non-temporal analysis of the same data determined that conventional tillage was most profitable in all experiments (De La Torre Ugarte et al.). Because incentives were necessary over the duration of these studies, we do not test net returns directly. We assume that total costs of the practices do not change over time and that market prices are constant. The only factors that can change net returns are yields in this analysis. Therefore, our analysis concentrates on yields directly to determine whether no-tillage yields increase over time relative to conventional tillage. Conventional tillage is defined as a tillage regime which leaves less than 30% residue cover on the fields.

Corn/soybean and continuous corn rotations are evaluated at four locations. Study sites include three separate research farms in Iowa (Burlington, Crawfordsville, Nashua) which recorded alternative practices of corn/soybean rotation and continuous corn on both poorly drained and well drained soils over 10, 12, and 24 years (Brown; Brenneman et al.; Pecinovsky). Purdue University's Agricultural Research Center in West Lafayette, Indiana collected yield data on corn/soybean rotation over twenty four years on poorly drained soil (West and Steinhardt, 2001).

Besides the four soybean/corn and continuous corn rotations, crops from six other locations were evaluated in the analysis. Wheat/sorghum rotation data were collected at two western Kansas locations, Garden City and Fort Hays, over a 10 year period (Norwood,1990; Norwood, 1993). Continuous sorghum data is available from the Northern Agronomy Farm in Manhattan, Kansas over nine years (Lamond). Soybean/sorghum rotation data over 14 years comes from the Rogers Memorial Farm in Lincoln, Nebraska (Dickey et al.). Cotton data is also included from the University of Tennessee's Experiment station in Milan, TN, which collected yield levels over fourteen years of side by side continuous cotton planted into wheat stubble (Bradley).

The yield difference between conventional and no-till was calculated as in equation 1 for each year in each experiment. Next, ordinary least squares was used to explain the differences in

Equation 1.
$$YDF_{ij} = ConventionalYield_{ij} - NoTillYield_{ij}$$
$$where\ i = year \quad and \quad j = \text{exp}\,eriment$$

Equation 2: $$YDF_{ij} = b_o + b_1(Time)$$

yield as a function of time, as in equation 2, where time is a variable set to one for the first observation of each crop and increases by one for each additional observation. Our interest lies with the time parameter, ß$_1$. If ß$_1$ is significant, we can reject the null hypothesis that there is no significant change in yield over time, and affirm that there is a difference in yield between conventional and no-till over the duration of the experiment. We will test the null hypothesis that the time parameter, ß$_1$ in equation 2, is equal to zero. Significance is measured by the t-test statistic and will be tested at the 1%, 5% and 10% level. If the sign is positive, conventional till yield is increasing over no-till, but if our hypothesis is to be affirmed, the sign must be negative, indicating that no-till yield is increasing over conventional tillage. If both hold true, that 1) the time parameter ß$_1$ is significant and 2) the sign is negative, we can affirm that no-till yield is increasing relative to conventional tillage.

Results

The null hypothesis H_0, that there is no significant change in the difference between conventional and no-till, was refuted in only three of 22 cases. In the majority of cases, there was no significant improvement in no-till yield over conventional tillage. Estimated parameters, their standard errors, and relevant significance levels for each location crop and rotation are listed in Appendix A. For comparative purposes, the mean yields of both conventional and no-tillage, their differences and the significance of the differences are also reported.

In all three cases which showed significant change in yield differences, the sign of the time parameter (ß$_1$) is negative, therefore, in these cases, we can accept the hypothesis that no-tillage yields are improving over conventional tillage. No-till yield increased in two corn/soybean rotations, and one wheat/sorghum rotation. But, in all three cases, only one crop in each rotation showed significant no-till yield improvement. Corn yield improved in one corn/soybean rotation and soybeans improved in the other. Sorghum improved in a wheat/sorghum rotation.

No-till soybeans in rotation with corn grown at Purdue University's Agricultural Research Center in Lafayatte, Indiana improved at a rate of 0.25 bushes per acre above conventional tillage over 24 years. Soybean yield improvement was significant at the 5% level. Although soybean no-till yield started considerably lower than conventional, by the end of the experimental period, no-till soybean yield had caught up. No-till corn yield, in the same rotation, started significantly less than conventional and showed no significant gain through the experimental period. The experiment was conducted on flat poorly drained silty clay loam soils.

No-till corn in rotation with soybeans grown at the Southeast Research and Demonstration Farm in Crawfordsville, Iowa improved at a rate of 2.13 bushes per acre above conventional tillage over 12 years. Corn yield improvement was significant at the 1% level. At this location, no-till corn yield started significantly lower, with an estimated intercept of 19.32. This indicates that no-till corn yield started 19.32 bu/acre less than conventional, but gained over two bu/acre per year on conventional corn. In the rotation, no-till soybean yield did not improve significantly over conventional tillage. The experiment was conducted on poorly drained Kalona soils. Interestingly, the same experiment conducted on well drained Nira soils at the same research farm showed no improvement over time.

Although the difference in corn yields with respect to time were significant in rotation with soybeans at the Crawfordsville, Iowa location, continuous corn at the same location over the same number of years showed no improvement. There were also replications of corn/soybean and continuous corn on well drained soils at the same research farm. Neither corn nor soybeans showed significant improvement in either rotation on the well drained soils.

No-till sorghum in rotation with wheat grown at the Southwest Kansas Research Extension Center in Garden City, Kansas improved at a rate of 1.6 bushels per acre above conventional tillage over nine years. Sorghum yield improvement was significant at the 10% level. At this location no-till yield started higher than conventional and continued to improve over conventional through the experimental period. The experiment was conducted on fine-loamy soils. Although no-till wheat in the rotation had a higher average yield, there was no significant improvement over time relative to conventional tillage.

Mean analysis of yield over the duration of the experiments show that in the corn/soybeans and continuous corn rotations, no-till yields are significantly lower in eleven of 14 crops. The remaining three show no significant difference in yield between the practices. In the dryer mid-western research locations, no-tillage had higher mean yields in five of the seven crops. But in all crops except one, no-till did not improve over time relative to conventional till. This also holds true for cotton yields grown at the Milan experiment station in Tennessee. In these cases, the yield increase from no-tillage occurs immediately with no significant long-term incremental improvement.

Discussion

Surprisingly, in 19 out of the 22 long term crop yield data sets, no significant improvement in no-till yield with respect to time was found. In none of the three significant crops was the other rotation crop significant. The only similarity found within the three significant crops is that two were grown on poorly drained soils. Our results indicate that, if these research farms are representative of the un-switched acreage, incentives may need to be long-term in order to switch and keep land in no-till. An important question is whether these experiments and locations are, in fact, representative of the remaining conventional tillage acreage that an incentive would target.

An argument can be made that experiment station studies are very important indicators of the dynamics of current conventional tillage acres. 19.6% of all agricultural lands have already switched to no-till. The first acres to switch to no-tillage have been on well drained sloppier more erosive lands, where the soil saving and water retention benefits of no-tillage are more apparent. Land owners had physically verifiable incentives to switch. A large portion of the remaining 80% of agricultural lands which remain under some level of tillage management may be poorly drained, flatter and more fertile. Experiment stations are often located on similar land, with very good soil. If the experiment station is located along a river bed or alluvial plain, the top soil could be several feet deep, and years of intensive tillage may not have decreased the soil's health significantly. Therefore, the benefits of no-tillage would not be apparent. These experiment station lands may give important insight into the dynamics between soil quality, tillage system and yield response on the remaining un-switched conventional tillage acreage.

On corn/soybean land, our results indicate that incentive levels to switch acres to no-tillage may need to be consistent for the acres to remain in no-tillage. Corn/soybean and continuous corn were grown on flat land at four locations. Of the fourteen individual crop yield response sequences, only two showed significant no-tillage yield improvement. Therefore there is some evidence that yields will not improve on the remaining un-switched acres. To keep these acres in no-tillage, a permanent incentive may be necessary.

There are two exceptions in the corn/soybean rotations that must be examined. Are there any similarities in these two cases which showed no-till improvement? What may have caused no-tillage to show improvement in these when other similar rotations and locations showed no improvement? Although one crop was corn and the other was soybeans, the two significant crops where in a corn/soybean rotation on poorly drained soils. Soybean yield was significant in West Lafayatte and corn was significant in Crawfordsville, Iowa. Interestingly, in the other four soybean rotations examined, intensive tillage soybean yield increased over no-till, though not at significant levels. The one factor that is unique to the West Lafayatte site is that moldboard plow is considered as conventional tillage, while chisel/disk is considered conventional at the others. When moldboard plow is the conventional tillage system, yield of no-till soybeans may increase and therefore incentives may be able to decrease.

We have not identified any unique factors at the Crawfordsville, Iowa site that may have led to no-till corn improving over conventional tillage. Initially, no-till yielded 19.32 bu/ac less than no-till, which was the largest disparity of all sites and crops. From this lower level, no-till gained 2.13 bu/ac/yr over the duration of the experiment. It is commonly believed that corn does not do as well under no-till on poorly drained soils due to root rot. This may have been the reason for the initial yield decline, but through time, the soil quality benefits of increased macro-pore development associated with no-till may have led to improved drainage on these soils, and therefore increased no-till yields. If this is true, it is not clear why the improvement was not evident in corn yields at the other poorly drained sites. There were two other corn/soybean experiments on poorly drained soils, both of which showed no significant yield difference change. Additional long term studies evaluating other crops and rotations on poorly drained soils should be located and analyzed to see if the Crawfordsville results are repeatable.

The experiments in the dryer western region of the Midwest indicate that in many cases, no-till immediately out-yields conventional tillage. Five of the seven crops in sorghum/wheat, sorghum, and sorghum/soybean rotation showed higher average no-till yields over the duration of the experiments. Yet only one crop, sorghum in rotation with wheat in Garden City, Kansas, showed significant no-till yield improvement over time. The same rotation evaluated at Hays, Kansas showed no significant gain in no-till sorghum yield. In these western rotations, no-tillage practices immediately increased yields but, in most cases, there was no additional significant increase in yield over time. Possibly soil moisture is the constraining variable in these dryer regions and moisture retention from not turning the soil is enough to increase yields immediately. The gradual benefits of improved drainage and greater organic matter levels may be of less importance in these locations. Our results indicate that if an incentive is needed in the western rotations, it may also need to be permanent to keep the land in no-tillage.

No-tillage cotton planted into a wheat cover crop in Milan, Tennessee had a higher average yield over the duration of the experiment, but there was no significant yield improvement with no-till compared with conventional tillage through time. As in the western rotations, no-tillage yield gains occurred immediately. The lack of incremental improvement may be due to the small amount of biomass that is created in cotton production. With less biomass degrading into the soil, the benefits of increased organic matter levels, improved drainage and water retention may be less forthcoming. As in the other cases, if an incentive level is necessary to switch cotton to no-till, it may need to be permanent.

There are other possible reasons for the lack of significant no-tillage yield improvement over time in these experiments. The yield benefits of no-till may take more years than the study durations to realize. The significant yield increase of corn in W. Lafayette was over a 27 year study period. Yet there were an additional five other crops tested at three locations over 27 years, and none of these others showed significant yield improvements.

Prior land-use may be another explanation to our results. Possibly the plot ground was fallow for many years. Even if the land was tilled for many years, there may have been other good-management practices which stabilized soil quality. All experiments were conducted at experiment stations, which may have superior land management histories. They may have added organic matter frequently, rotated crops and used erosion control measures. The benefits of no-tillage assume that the micro-organism and organic matter levels have dropped after many years of prior tillage. If the experiments were planted on good soil, these benefits would not be as apparent and yield improvement may not be evident.

This study evaluated both the most common tillage practice in each experiment's region and no-till. The most common tillage method is often not moldboard plowing, which intensively turns the soil sub-surfaces. In all of the corn and corn/soybean study sites but one, chisel/disk tillage is considered "conventional" because less than 30% of the surface has residue cover. Possibly the conventional chisel/disk systems leave enough residue and keep the soil sub-surface undisturbed enough to reap benefits. In this case, the differences in soil management may not be enough to see noticeable differences in yield over time. Nonetheless, incentive levels will need to be permanent if yields of no-till are not improving over conventional chisel/disk. In the Indiana location, where moldboard plow was considered conventional, soybeans showed significant yield improvement. Possibly, by analyzing moldboard plow as conventional tillage in the other sites, we would have found more yield improvement for no-tillage. But for our purposes of investigating incentive levels to switch current acres to no-tillage, we needed to include the most common regional 'conventional' tillage system.

Conclusion

Long-term yield studies indicate that, in most cases, no-tillage yield did not improve over conventional tillage. These studies, conducted on good quality soils at experiment stations, may be representative of the remaining acres still using conventional tillage. Therefore there is evidence that incentive levels to switch additional acreage to no-till may need to be permanent to keep acres in no-till.

One exception is in the case of soybeans in rotation with corn using moldboard plowing as the conventional tillage. In regions where moldboard plow is still used as the conventional tillage system, there is evidence that no-till yields increase over moldboard plow. Therefore, incentives may not need to be permanent. Further studies should more closely investigate rotations and regions using moldboard plow.

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Appendix A. Regression and mean yield results.

		Regression Results		Mean Analysis		
Experiment	Crop	Intercept	Time Parameter	Conventional Mean	No-till Mean	Mean Difference
Corn/Soybean Rotation	Corn	3.76	0.05	177.2	172.6	4.41 ***
West Layfatte, Indiana		(3.01)	(0.19)			
1975-2001	Soybeans	6.23	-0.25 **	53.4	48.3	2.7 ***
Chalmers silty clay loam		(1.87)	(0.12)			
Continuous Corn	Corn	9.95	0.92	169	153.4	22.8 ***
West Layfatte, Indiana		(9.17)	(0.57)			
1975-2001						
Chalmers silty clay loam						
Corn/Soybean Rotation	Corn	12.24	-1.08	136.7	131	5.74 **
Burlington Iowa		(6.71)	(0.99)			
1980-1990	Soybeans	0.26	0.21	43.5	42	1.53 **
Taintor silty clay loam		(2.17)	(0.32)			
Corn/Soybean Rotation	Corn	5.28	-0.16	140.2	137.3	3.25 **
Nashua, Iowa		(4.73)	(0.33)			
1978-2001	Soybeans	0.58	0.03	39	38.5	1.01
Kenyon loam, tile drained		(2.05)	(0.14)			
Corn/Soybean Rotation	Corn	5.04	0.43	124.4	117.9	10.46 ***
Nashua, Iowa		(3.79)	(0.26)			
1978-2001						
Kenyon loam, tile drained						
Corn/Soybean Rotation	Corn	19.32	-2.13 ***	139.8	134.3	5.5 **
on Poorly Drained soil		(4.18)	(0.57)			
Crawfordsville, Iowa	Soybeans	0.6	0.06	47.1	46.1	0.967 **
1990-2001		(1.23)	(0.17)			
Kalona soil						
Continuous Corn	Corn	9.26	-0.56	121.3	115.6	5.67 ***
on Poorly Drained soil		(4.21)	(0.57)			
Crawfordsville, Iowa						
1990-2001						
Kalona soil						
Corn/Soybean Rotation	Corn	11.44	-1.31	151.2	148.3	2.92
on Well Drained soil		(6.28)	(0.85)			
Crawfordsville, Iowa	Soybeans	-1.09	0.2	48.6	48.4	0.2
1990-2001		(1.17)	(0.16)			
Nira soil						
Continuous Corn	Corn	4.04	-0.08	119.3	115.8	3.5 **
on Well Drained soil		(4.09)	(0.56)			
Crawfordsville, Iowa						
1990-2001						
Nira soil						

Cotton units are lbs/acre, all others are bu/acre
( ) Standard Error
* Significant at the 10% level
**Significant at the 5% level
***Significant at the 1% level

Experiment	Crop	Regression Results Intercept	Time Parameter	Mean Analysis Conventional Mean	No-till Mean	Mean Difference
Wheat/Sorghum Rotation	Wheat	-1.47	-0.41	29.2	33.1	-3.94 ***
For Hays, Kansas		(3.08)	(0.45)			
1976-1986	Sorghum	-10.33	0.59	62.8	69.6	-6.78 ***
		(4.35)	(0.64)			
Wheat/Sorghum Rotation	Wheat	10.9	-1.21	38.2	33.3	4.9 ***
Garden City, Kansas		(5.09)	(0.90)			
1979-1991	Sorghum	-1.9	-1.6 *	53.7	64.4	-10.68 ***
Satanta loam		(4.89)	(0.79)			
Continuous sorghum	Sorghum	1.12	0.238	80	77.3	2.67 ***
Manhattan, Kansas		(3.17)	(0.43)			
1982-1995						
Smolan silty clay loam						
Soybean/Sorghum Rotation	Soybeans	-1.3	-0.14	39.5	41.5	-1.94 ***
Lincoln, Nebraska		(1.74)	(0.34)			
1983-1990	Sorghum	-2.84	-0.77	117.1	123.4	-6.28 ***
Sharpsburg silty clay loam		(3.37)	(0.67)			
Cotton into wheat cover	Cotton	54.54	-10.33	895.7	913.3	-17.5
Milan, Tennessee		(89.44)	(12.15)			
1981-1994						
Grenada silt loam						

Cotton units are lbs/acre, all others are bu/acre
( ) Standard Error
* Significant at the 10% level
**Significant at the 5% level
***Significant at the 1% level