ECONOMIC ANALYSIS OF ALTERNATIVE TILLAGE YIELDS: A MONTE CARLO ANALYSIS OF ARLINGTON FIELD TRIALS

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Introduction

Recent increases crop acres managed by individual producers, rising fuel and equipment costs, the desire to plant crops in a timely manner, and catastrophic erosion events have renewed interest in conservation tillage systems. Historically, no-till management has been a challenge for corn production in Wisconsin because residue has slowed the warming of the soil in the spring. Residue can also physically impair planting by plugging within the planting unit and "hair-pinning" in the seed slot. Therefore most no-till corn planters have been modified to include some type of in-row residue management attachment, either as finger coulters or disks that are designed to move some residue from the row, without substantial contact with the soil. Many producers are now considering more aggressive attachments or separate tillage operations that not only address residue concerns, but till the soil to some degree with the goal of capturing the production advantages of full-width tillage, while offering the soil conservation benefits of no-till. This practice has come to be known as strip-tillage.

1997-2007 field trials from the Arlington Research Station comparing yield differences under a traditional conservation tillage (fall chisel (CH), strip till (ST) and no-till (NT)) for 3 cropping systems (continuous corn (CC), corn following soybeans (SBC), and soybeans following corn (CSB)) are summarized by Wolkowski, et al[2]. Wolkowski et al. discuss the environmental, management, yield and economic dimensions of these alternative tillage field trial results. The current manuscript focuses more narrowly on the economic analysis of these results using Monte Carlo simulation techniques to better measure the impacts of relative yield variability across the 12 years of these alternative tillage field trails.

Clearly, some years are better/worse for these tillages and/or rotations than others, a crucial dimension of the yield/production risk essential to the economic evaluation of alternative farming systems. Wolkowski et al. evaluated the cost or production (COP) of the alternative tillages on a per acre and per bushel basis, using average yields across the 12 years of trials. Generally, less tillage incurs lower costs/acre due to lower labor, machinery, and fuel expenses using the same or fewer trips across the fields with equipment requiring less horsepower. However, these lower costs/acre can be offset by lower yields/acre due to reduced tillage systems as found in the Arlington field trials (see Table 1). Comparison of COP/bu corrects for the trade-off in lower COP/acre versus lower yields/acre. If cost reductions are sufficient to offset lower yields, then potential economic gains (lower COP/bu) due to reduced tillage systems will further complement their environmental benefits (reduced soil and nutrient loss; improved soil quality, structure and tilth, organic matter, carbon sequestration, etc).

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[2] Wolkowski, Richard, Tom Cox, and Jim Leverich. "Using Strip-tillage as an Option for Row Crop Production in Wisconsin". ***New Horizons in Soil Science***, (2)2008, November, 9 pages.

Relative Yield Variability

Table 1 provides an annual yield summary of these Arlington tillage trials for each cropping system. The "% of CH (Relative Yield)" data highlight the annual variability in both ST and NT yields relative to CH (the BASE tillage for comparison purposes). Since these are location specific (Arlington) field trials, annual tillage yields across the three crop rotations essentially hold annual weather related variability relatively constant across the tillage/cropping systems at the annual level (i.e., they experience the same weather annually). Annual relative yield variability measures the yield difference in ST and NT compared to CH (the BASE tillage system) holding weather (and, field trial management) constant across these tillage and cropping systems. Values greater (less) than 100% indicate those years when the alternative tillage yields were higher (lower) than CH.

On average over 1997-2007, ST and NT yields were 96% and 91% of CH, respectively for the CC rotation. Similarly, ST and NT yields were 99% and 95% of CH, respectively for the SBC rotation (99% and 95% for the CSB rotation). Hence, as discussed in Wolkowski et al, the reduced tillage systems, on average over the 1997-2007 Arlington field trials, produced less yield than CH. These reduced yield impacts were strongest for CC (where ST had higher yields than CH in only 2 of 10 years (1998, 2005) as did NT (2 years: 1998, 1999)). The reduced tillage systems were more yield competitive under both SBC (ST had higher yields than CH in 5 of 10 years; NT in 3 years) and CSB (ST out yielded CH in 4 of 9 years; NT in 3 of 9).

TABLE 1. Dick Wolkowski's 1997-2007 Arlington Tillage/Rotation/Fertility Study: Plot Summary.

CC	1997	1998	1999	2001	2002	2003	2004	2005	2006	2007	AVG
CH	190	160	147	189	181	161	187	182	211	212	182.0
ST	178	160	135	182	175	157	178	187	188	204	174.4
NT	176	164	147	151	174	149	159	176	166	205	166.7
% of CH (Relative Yield)											
ST	93.7%	100.0%	91.8%	96.3%	96.7%	97.5%	95.2%	102.7%	89.1%	96.2%	95.7%
NT	92.6%	102.5%	100.0%	79.9%	96.1%	92.5%	85.0%	96.7%	78.7%	96.7%	90.9%
SBC	**1997**	**1998**	**1999**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**AVG**
CH	172	181	172	192	209	186	206	187	205	231	194.1
ST	181	175	174	204	206	184	194	191	205	228	194.2
NT	180	160	158	194	199	181	180	189	193	220	185.4
% of CH (Relative Yield)											
ST	105.2%	96.7%	101.2%	106.3%	98.6%	98.9%	94.2%	102.1%	100.0%	98.7%	99.4%
NT	104.7%	88.4%	91.9%	101.0%	95.2%	97.3%	87.4%	101.1%	94.1%	95.2%	94.7%
CSB	**1997**	**1998**	**1999**	**2002**	**2001**	**2003**	**2004**	**2006**	**2005**	**2007**	**AVG**
CH	--	46	51	51	56	32	57	57	57	61	52.0
ST	--	49	49	51	59	31	53	55	55	63	51.7
NT	--	44	47	49	53	32	52	54	57	62	50.0
% of CH (Relative Yield)											
ST	--	106.5%	96.1%	100.0%	105.4%	96.9%	93.0%	96.5%	96.5%	103.3%	98.9%
NT	--	95.7%	92.2%	96.1%	94.6%	100.0%	91.2%	94.7%	100.0%	101.6%	95.1%

1997 - 2007 (Yield not collected in 2000 because of combine malfunction)
Split-split plot, four replications
Main plot = rotation: Continuous corn (CC), corn/soybean (CSB), soybean/corn (SBC).
Subplot = tillage: Fall chisel/spring field cultivator, fall strip-tillage (aggressive residue mgr. 97-99; mole-knife type unit 01-08, no-till (w/o residue managers)
Sub-subplot = fertility: Nothing, fall broadcast or spring row starter 18+46+60 (treatment started in 2001)
Yields are bu/a @ 15.5 % and 13.0 % moisture for corn and soybean, respectively.

Table 2 provides additional summary statistics highlighting the year to year relative yield variability across the tillage and cropping systems. While on average ST (NT) yields are 96% (91%) of CH in the CC field trials, NT yields show more than twice the variability (standard deviation (STD) = 8.7, coefficient of variation (CV) = 9.5%) of relative to ST yields (STD = 3.8%, CV = 4%). While observed maximum (MAX) relative yields are quite similar for ST and NT (~103%), NT shows sharply lower minimum (MIN) relative yields (~79%) than ST (89%). The associated range of relative yields (Range = Max – Min) are 13.6% (ST) and 23.8% (NT). Lastly, note that the yield correlations indicate that ST yields are much more strongly correlated with CH (0.93) than are NT yields (0.60), while ST and NT yields correlate 0.72. These summary statistics indicate that NT yields demonstrate higher relative yield variability (hence, relative production risk[3]) compared to ST over the 1997-2007 Arlington CC field trials.

TABLE 2. 1997-2007 Arlington Tillage Field Trials Summary Statistics.

AVG	Std Dev	Coeff Var	Min	Max	Range	Lower 99%	Upper 99%
182.0	21.2	11.6%	147	212	65	118.5	245.5
174.4	19.3	11.1%	135	204	69	116.4	232.4
166.7	17.3	10.4%	147	205	58	114.7	218.7
% of CH (Relative Yield)							
95.7%	3.8%	4.0%	89.1%	102.7%	13.6%	84.3%	107.0%
90.9%	8.7%	9.5%	78.7%	102.5%	23.8%	64.9%	117.0%

	Correlations		
CC	CH	ST	NT
CH	1.000	0.931	0.601
ST	0.931	1.000	0.715
NT	0.601	0.715	1.000

AVG	Std Dev	Coeff Var	Min	Max	Range	Lower 99%	Upper 99%
194.1	18.6	9.6%	172	231	59	138.3	249.9
194.2	16.9	8.7%	174	228	54	143.6	244.8
185.4	18.3	9.8%	158	220	62	130.6	240.2
% of CH (Relative Yield)							
99.4%	4.3%	4.3%	91.9%	106.3%	14.4%	86.5%	112.3%
94.7%	6.1%	6.4%	85.6%	104.7%	19.0%	76.5%	113.0%

	Correlations		
SBC	CH	ST	NT
CH	1.000	0.886	0.776
ST	0.886	1.000	0.952
NT	0.776	0.952	1.000

AVG	Std Dev	Coeff Var	Min	Max	Range	Lower 99%	Upper 99%
52.0	8.7	16.8%	32	61	29	25.8	78.2
51.7	9.0	17.4%	31	63	32	24.7	78.7
50.0	8.6	17.2%	32	62	30	24.2	75.8
% of CH (Relative Yield)							
98.9%	4.7%	4.7%	93.0%	106.5%	13.5%	84.9%	112.9%
95.1%	5.0%	5.2%	84.7%	101.6%	16.9%	80.1%	110.0%

	Correlations		
CSB	CH	ST	NT
CH	1.000	0.957	0.940
ST	0.957	1.000	0.947
NT	0.940	0.947	1.000

Similar, but generally smaller, impacts are found in the SBC and CSB rotations. In contrast to the CC results (NT more than twice ST), SBC relative yield variability in NT versus ST is roughly 50% higher (STD: 6.1% versus 4.3%; CV: 6.4% versus 4.3%). SBC correlations of ST and CH yields fall compared to CC (0.89 versus 0.93) while NT and CH yield correlations improve (0.78 versus 0.60). ST and NT yield correlations for SBC improve slightly over the CC results (0.78 versus 0.72). CSB results show the least relative yield variability across tillages: NT is roughly 10% higher than ST (STD: 5.0% versus 4.7%; CV: 5.2% versus 4.7%). SBC correlations of ST and CH yields increase compared to CC (0.96 versus 0.93) and SBC (0.89) while NT and CH yield correlations improve (0.94 versus 0.60 (CH) and 0.78(SBC)).

[3] Note that there are multiple sources of variability that influence the economic and environmental efficiency of cropping systems: those related to production (weather, soils/slopes, timing of operations) and those related to markets (input and output prices). Management is the crucial farmer controlled dimension of this inherent cropping systems variability. Here we focus on yield variability due to tillage and cropping system under field trial conditions (holding management and annual weather impacts constant), under fixed (2007 WI custom hire) COP, and ignore output price variability.

Across the 3 cropping systems in these field trials, ST showed less relative yield variability compared to CH than NT. These impacts were most pronounced in the CC rotation (~ NT twice as much relative yield variability as ST), and less so under SBC (50% more) and CSB (10% more). Similarly, ST and NT correlations increase under CSB (0.95) compared to CC (0.72) and are roughly equal under SBC (0.95).

Cost of Production @ 1997-2007 Average Yields

In addition to yield and environmental performance differences across tillage systems, economic costs of production (COPs) must be considered. Reduced tillage systems commonly generate fewer trips across the fields using the same or less horsepower to accomplish more tasks (e.g., tillage and fertilization in one pass). Hence, reduced tillage systems should lower costs of production as well as increase environmental performance (via decreased soil and nutrient losses, improved organic matter and water holding capacity, etc). Measuring these potential reduced costs on a $/bushel (versus $/acre) basis provides an adjustment for the possibility of lower yields under the reduced tillage.

Appendix Tables 1 and 2 provide corn and soybean COP/acre estimates using 2007 WI custom hire rates for the alternative tillage systems in these field trials: CH: fall chisel/spring cultivator, assumed as the BASE or reference tillage; ST: fall strip-tillage; NT: no-till without residue managers). Two N fertilizer options were also evaluated: applied with an applicator or applied with the planter. While the assumed custom hire rates are likely higher than those faced by individual farmers owning older machinery and/or who do not fully account for labor and capital costs, custom hire rates do provide a consistent, market-based estimate of the full economic costs of the alternative tillage systems. These full economic costs include competitive labor rates as well as the depreciation, repairs and the opportunity costs of machinery that are often not included in "back of the envelope" cost calculations. Therefore, these estimates provide somewhat conservative, "upper bounds" to the actual cost of production faced by farmers.

Table 3 indicates that under the 2007 COP/acre assumptions, reduced tillage systems were less costly compared to CH across all cropping systems, with NT generating more cost savings than ST, as expected. For the CC portion of these field trial 1997-2007 average yields, ST and NT respectively averaged 7.6 and 15.3 bushels/acre less than CH (182 bu/acre). However, the estimated cost/acre are also lower than CH for both reduced tillage system: ST, -$23.20/acre to -$11.20/acre; NT -$25.90/acre. Comparison of these tillage systems on a per bushel basis adjusts for the yield as well as cost differences. For continuous corn, this comparison is not favorable to the reduced tillage systems as their reduced costs/bushel are overshadowed by the associated reduced yields. Hence, only ST with applicator (versus planter) N has marginally lower cost/bu compared to CH.

The situation changes in the SBC and CSB rotations. In contrast to the CC results, the first-year corn following soybean (SBC) under ST yields are virtually identical to CH (+0.1 bu/acre) while yield under NT is reduced -8.7 bu/acre compared to CH. Given that COP are identical to the CC results above (i.e., planting corn under the alternative tillage systems), these more competitive yield differences generate more competitive cost/bu returns to reduced tillage. Under ST costs/bu range from -$0.06 to -$0.12/bu lower than CH while NT ranges -$0.02 to -$0.03/bu, depending on the N delivery system. This suggests than both cost savings and improved environmental performance are possible with these reduced tillage SBC systems compared to CH, with ST providing stronger economic gains compared to NT.

Table 3: Comparison of 1997-2007 Average Yields and 2007 Costs of Production by Crop and Tillage System: Arlington Field Trials

Crop/ System	Average	2007 COP/acre		COP/bushel	
CC	YIELD	N w/ App	N w/ Planter	N w/ App	N w/ Planter
CH	182.0	$463.85	$492.35	$2.55	$2.71
ST	174.4	$440.65	$481.15	$2.53	$2.76
NT	166.7	$437.95	$466.45	$2.63	$2.80
Change from Chisel Plow Average 1997-2008					
ST	-7.6	-$23.20	-$11.20	-$0.02	$0.05
NT	-15.3	-$25.90	-$25.90	$0.08	$0.09
Probabilty < Chisel Plow Average 1997-2008					
ST	66.7%	--	--	54.7%	42.6%
NT	97.0%	--	--	22.7%	21.9%
SBC	YIELD	N w/ App	N w/ Planter	N w/ App	N w/ Planter
CH	194.1	$463.85	$492.35	$2.39	$2.54
ST	194.2	$440.65	$481.15	$2.27	$2.48
NT	185.4	$437.95	$466.45	$2.36	$2.52
Change from Chisel Plow Average 1997-2008					
ST	0.1	-$23.20	-$11.20	-$0.12	-$0.06
NT	-8.7	-$25.90	-$25.90	-$0.03	-$0.02
Probabilty < Chisel Plow Average 1997-2008					
ST	49.6%	--	--	87.6%	69.6%
NT	76.3%	--	--	56.8%	56.1%
CSB	YIELD	N w/ App	N w/ Planter	N w/ App	N w/ Planter
CH	52.0	$333.30	--	$6.41	--
ST	51.7	$322.10	--	$6.23	--
NT	50.0	$307.40	--	$6.15	--
Change from Chisel Plow Average 1997-2008					
ST	-0.3	-$11.20	--	-$0.18	--
NT	-2.0	-$25.90	--	-$0.26	--
Probabilty < Chisel Plow Average 1997-2008					
ST	55.3%	--	--	71.3%	--
NT	75.4%	--	--	76.4%	--

CC = continuous corn; SBC = corn following soybeans; CSB = soybeans following corn. The year 2000 is not included due to a combine malfunction.

CH: Fall chisel/spring field cultivator.
ST: fall strip-tillage: aggressive residue mgr. 97-99; mole-knife type unit 01-08.
NT: no-till (w/o residue managers).

The situation changes in the SBC and CSB rotations. In contrast to the CC results, the first-year corn following soybean (SBC) under ST yields are virtually identical to CH (+0.1 bu/acre) while yield under NT is reduced -8.7 bu/acre compared to CH. Given that COP are identical to the CC results above (i.e., planting corn under the alternative tillage systems), these more competitive yield differences generate more competitive cost/bu returns to reduced tillage. Under ST costs/bu range from -$0.06 to -$0.12/bu lower than CH while NT ranges -$0.02 to -$0.03/bu, depending on the N delivery system. This suggests than both cost savings and improved environmental performance are possible with these reduced tillage SBC systems compared to CH, with ST providing stronger economic gains compared to NT.

The soybean (CSB) results are similar to the corn (SBC) results, except that reduced tillage yield differences compared to CH narrow further: ST, -0.3 bu/acre and NT, -2.0 bu/acre. In addition, the estimated COP for NT is almost 2.5 times less than ST, generating substantive COP reductions compared to CH: ST, -$11.20/acre and NT, -$25.90/acre. On a per bushel basis, these yield and COP differences translate to -$0.18/bu (ST) and -$0.26/bu (NT) cost savings over CH.

Economic analysis of this field trial suggests that, on average, the economic benefits (defined as reduced COP/bu) to reduced tillage are likely to be stronger under SBC and CSB rotations than CC. For SBC and CSB rotations, reduced (1997-2007) average trial yields compared to CH under the alternative reduced tillage systems evaluated, are likely to be offset by the reduced costs associated with reduced tillage systems. This suggests that both increase economic ($/bu) as well as environmental performance are likely to be attainable under these rotations with reduced tillage systems.

Annual Cost of Production Comparison

Following up on the discussion of Tables 1 and 2, economic analysis at average relative yields (Table 3) can be deepened by evaluating the variability of annual COP/bu (Table 4, annual results; Table 5, summary statistics) across tillage and cropping systems. This comparison provides additional insight into the expected variability of relative yields and COP/bu under the alternative tillage and cropping systems, an important aspect of their production uncertainty

TABLE 4. 1997-2007 Arlington Tillage Field Trials: Annual COP/bu Comparison (N w/ APP).

CC	1997	1998	1999	2001	2002	2003	2004	2005	2006	2007	AVG
CH	$2.44	$2.90	$3.16	$2.45	$2.56	$2.88	$2.48	$2.55	$2.20	$2.19	$2.58
ST	$2.48	$2.75	$3.26	$2.42	$2.52	$2.81	$2.48	$2.36	$2.34	$2.16	$2.56
NT	$2.49	$2.67	$2.98	$2.90	$2.52	$2.94	$2.75	$2.49	$2.64	$2.14	$2.65
% of CH (Relative COP/bu)											
ST	101.4%	95.0%	103.4%	98.7%	98.3%	97.4%	99.8%	92.5%	106.6%	98.7%	98.6%
NT	101.9%	92.1%	94.4%	118.2%	98.2%	102.0%	111.0%	97.6%	120.0%	97.6%	101.2%
SBC	1997	1998	1999	2001	2002	2003	2004	2005	2006	2007	AVG
CH	$2.70	$2.56	$2.70	$2.42	$2.22	$2.49	$2.25	$2.48	$2.26	$2.01	$2.41
ST	$2.43	$2.52	$2.53	$2.16	$2.14	$2.39	$2.27	$2.31	$2.15	$1.93	$2.28
NT	$2.43	$2.74	$2.77	$2.26	$2.20	$2.42	$2.43	$2.32	$2.27	$1.99	$2.38
% of CH (Relative COP/bu)											
ST	90.3%	98.3%	93.9%	89.4%	96.4%	96.0%	100.9%	93.0%	95.0%	96.2%	94.7%
NT	90.2%	106.8%	102.8%	93.4%	99.2%	97.0%	108.1%	93.4%	100.3%	99.1%	97.8%
CSB	1997	1998	1999	2002	2001	2003	2004	2006	2005	2007	AVG
CH	--	$7.25	$6.54	$6.54	$5.95	$10.42	$5.85	$5.85	$5.85	$5.46	$6.63
ST	--	$6.57	$6.57	$6.32	$5.46	$10.39	$6.08	$5.86	$5.86	$5.11	$6.47
NT	--	$6.99	$6.54	$6.27	$5.80	$9.61	$5.91	$5.69	$5.39	$4.96	$6.35
% of CH (Relative COP/bu)											
ST	--	90.7%	100.6%	96.6%	91.7%	99.8%	103.9%	100.2%	100.2%	93.6%	97.2%
NT	--	96.4%	100.1%	96.0%	97.4%	92.2%	101.1%	97.4%	92.2%	90.7%	94.8%

Similar to the results from Tables 1 and 2, Tables 4 and 5 indicate that there is substantive annual variability in COP/bu across tillage and cropping systems. Adding COP/acre differences to the relative yield variability from Tables 1 and 2 increase relative variability in the COP/bu results. Under CC, ST and NT have lower COP/bu in 8 and 5 out of 10 years, respectively (Table 4) and ST COP/bu averages 98.6% (-$0.02) of CH (NT: 101.2%, +$0.08). NT variability compared to ST is roughly 2.5 times higher (Std Dev 11.7 versus 4.3, CV 11.6% versus 4.3% and range 40.6% versus 14.2%). This indicates that adding COP/bu differences and aggregating over annual results (versus evaluating at average results) increased the relative variability in NT versus ST. ST and NT average 94.7% (-$0.12) and 97.8% (-$0.03) lower COP/bu than CH under SBC (CSB: 97.2% or -$0.18 for ST and 94.8% or -$0.26 for NT).

SBC and CSB results are similar, with ST and NT having lower COP/bu than CH in 9 and 6 years out of 10, respectively, for SBC (and, 5 and 7 years out of 9 for CSB). NT relative COP/bu variability is roughly twice that of ST for the SBC rotation (~15% higher for CSB).

TABLE 5. 1997-2007 Arlington Tillage Field Trials: Annual COP/bu Comparison (N w/ APP) Summary Statistics.

CC	AVG	Std Dev	Coeff Var	MIN	MAX	Range	Lower 99%	Upper 99%
CH	$2.58	$0.31	12.0%	$2.19	$3.16	$0.97	$1.65	$3.51
ST	$2.56	$0.31	12.2%	$2.16	$3.26	$1.10	$1.62	$3.49
NT	$2.65	$0.26	9.7%	$2.14	$2.98	$0.84	$1.88	$3.43
% of CH (Relative COP/bu)								
ST	98.6%	4.3%	4.3%	92.5%	106.6%	14.2%	85.9%	111.4%
NT	101.2%	11.7%	11.6%	79.5%	120.0%	40.6%	66.0%	136.3%
SBC	AVG	Std Dev	Coeff Var	MIN	MAX	Range	Lower 99%	Upper 99%
CH	$2.41	0.2	9.2%	$2.01	$2.70	$0.69	$1.74	$3.08
ST	$2.28	0.2	8.4%	$1.93	$2.53	$0.60	$1.71	$2.86
NT	$2.38	0.2	9.9%	$1.99	$2.77	$0.78	$1.67	$3.09
% of CH (Relative COP/bu)								
ST	94.7%	3.4%	3.6%	89.4%	100.9%	11.5%	84.4%	104.9%
NT	97.8%	6.8%	7.0%	85.6%	108.1%	22.4%	77.4%	118.3%
CSB	AVG	Std Dev	Coeff Var	MIN	MAX	Range	Lower 99%	Upper 99%
CH	$6.63	1.5	22.9%	$5.46	$10.42	$4.95	$2.08	$11.18
ST	$6.47	1.5	23.9%	$5.11	$10.39	$5.28	$1.82	$11.11
NT	$6.35	1.4	21.4%	$4.96	$9.61	$4.65	$2.27	$10.44
% of CH (Relative COP/bu)								
ST	97.2%	4.4%	4.5%	90.7%	103.9%	13.2%	84.1%	110.3%
NT	94.8%	4.9%	5.2%	84.7%	101.1%	16.4%	80.1%	109.5%

Annual Cost of Production: Monte Carlo Analysis

To further develop and analyze the observed relative yield and COP/bu variability from these Arlington field trials, Monte Carlo simulation was used to more fully characterize these results. Monte Carlo techniques basically use estimated probability distributions (in this case based on annual tillage yields for each cropping systems) to draw a large sample (10,000 replications here) of representative observations that more fully characterize the distribution of relative yields and COP/bu across the tillage and cropping systems. While the number of annual observations from the field trials (10 and 9 years for the CC/SBC and CSB, respectively) are a bit "light" (15 to 30 base observations are preferable), the field trial (experimental control) nature of these data provide a reasonable basis for characterizing their underlying distributions (especially means and standard deviations). A "best fit" distribution estimation routine was used to fit 30+ statistical distributions to the yields from the 3 tillages for each cropping system. The "best fit" distributions (those with the highest predictive power) revealed that all yield distributions except for CSB NT (which was a uniform distribution: all values between the high and low are equally likely to occur) were approximately normally distributed (very little skewness: i.e., means approximately equal to the median and mode). The virtue of the normal distribution for Monte Carlo analysis is that it always generates values close to the observed mean and standard deviation, hence will replicate the observed data quite closely (if there is not much skewness). For these reasons, normal distributions evaluated at observed yield means and standard deviations were used to characterize the randomness of tillage. Simulated tillage yields for each cropping system were assumed to be correlated at the observed yield correlations from Table 1. This multivariate simulation procedure forces the simulated yields to correspond to observed yield correlations and limits the individual tillage yields for each cropping system from being too extreme relative to observed interrelationships. Lastly, to approximate large sample properties for the simulation, 10,000 replications were generated and summarized (take a random draw for each tillage yield, compute the results in Table 3, store and repeat 10,000 times, then generate the summary statistics similar to Table 4). Table 6 summarizes the results of this Monte Carlo analysis.

If the base data provide a good basis for characterizing the underlying variability in tillage yields, the key source of variability in COP/bu, then Monte Carlo procedures provide a means to more fully sample from the range of feasible, interrelated (by cropping system) yields, hence the COP/bu of the alternative tillages. In addition, the estimated "empirical distributions" provide estimated probabilities that yields (or COP/bu) are at or below particular threshold values (in this case, those for the BASE tillage CH). These probabilities provide a useful characterization for how likely the alternative tillages are to perform relative to CH. In addition, the "best fit" distributions to these simulation forecasts are estimated. These provide a powerful prediction tool for summarizing the field trials that can be used in further economic and/or environmental simulations.

Table 6. Summary Statistics for Monte Carlo Simulations (10,000 replications).

Statistics	Mean	Standard Deviation	Coeff. of Variability	Minimum	Maximum	Range Width	Median	Variance	Skewness	Kurtosis
CC CH: YIELD	182.0	21.1	0.1162	108.6	258.2	149.6	166.7	447.2	0.00	2.97
CC ST: YIELD	174.4	19.3	0.1109	93.4	248.6	155.2	174.4	374.0	0.00	2.99
CC NT: YIELD	166.7	17.3	0.1040	99.9	230.5	130.6	166.7	300.7	0.0011	2.99
CC CH - ST: Yield Difference	-7.6	18.1	-2.38	-75.4	67.8	143.3	-7.5	325.8	0.00	3.10
CC CH - NT: Yield Difference	-15.3	8.2	-0.5364	-56.2	27.2	83.4	-15.4	67.4	0.0304	3.56
CC CH - ST: COP/bu (N w/ APP) Difference	-$0.03	$0.27	-10.69	-$1.53	$1.70	$3.23	-$0.02	$0.07	-0.0869	4.02
CC CH - ST: COP/bu (N w/ Planter) Difference	$0.05	$0.29	5.79	-$1.55	$1.95	$3.49	$0.05	$0.09	-0.0422	4.02
CC CH - NT: COP/bu (N w/ APP) Difference	$0.07	$0.12	1.67	-$0.82	$0.93	$1.75	$0.08	$0.01	-0.5151	5.97
CC CH - NT: COP/bu (N w/ Planter) Difference	$0.09	$0.13	1.48	-$0.86	$1.00	$1.86	$0.09	$0.02	-0.5015	5.95
SBC CH: YIELD	194.1	18.6	0.0959	121.7	267.7	146.0	194.1	346.3	0.0086	3.02
SBC ST: YIELD	194.2	16.9	0.0868	131.2	257.2	126.0	194.2	284.2	0.0047	2.99
SBC NT: YIELD	185.4	18.3	0.0985	115.1	255.0	139.9	185.4	333.2	0.0012	2.99
SBC CH - ST: YIELD Difference	0.1	8.8	88.79	-39.0	43.1	82.1	0.1	77.3	0.0298	3.35
SBC CH - NT: YIELD Difference	-8.7	12.3	-1.42	-56.6	36.6	93.2	-8.6	152.4	-0.0013	3.11
SBC CH - ST: COP/bu (N w/ APP) Difference	-$0.13	$0.11	-0.9017	-$0.80	$0.41	$1.21	-$0.12	$0.01	-0.4187	4.10
SBC CH - ST: COP/bu (N w/ Planter) Difference	-$0.06	$0.12	-1.88	-$0.78	$0.54	$1.32	-$0.06	$0.01	-0.3630	4.07
SBC CH - NT: COP/bu (N w/ APP) Difference	-$0.03	$0.16	-6.12	-$0.72	$0.77	$1.49	-$0.03	$0.03	0.0499	3.65
SBC CH - NT: COP/bu (N w/ Planter) Difference	-$0.02	$0.17	-8.86	-$0.75	$0.83	$1.58	-$0.02	$0.03	0.0561	3.66
CSB CH: YIELD	52.0	8.7	0.1680	20.0	87.2	67.2	52.0	76.3	0.00	3.00
CSB ST: YIELD	51.7	9.0	0.1743	17.2	87.3	70.1	51.7	81.1	-0.0011	3.01
CSB NT: YIELD	50.0	8.6	0.1720	18.9	82.4	63.5	50.0	74.0	0.0058	2.99
CSB CH - ST: YIELD Difference	-0.3	2.7	-8.12	-18.4	15.6	34.0	-0.4	7.3	0.0224	4.00
CSB CH - NT: YIELD Difference	-2.0	3.0	-1.52	-16.6	12.1	28.7	-2.0	9.2	0.0471	3.54
CSB CH - ST: COP/bu (N w/ APP) Difference	-$0.16	$0.41	-2.50	-$4.19	$9.34	$13.53	-$0.17	$0.17	1.37	38.15
CSB CH - NT: COP/bu (N w/ APP) Difference	-$0.26	$0.45	-1.74	-$4.46	$4.23	$8.70	-$0.26	$0.21	-0.0396	10.55

Lastly, the probabilities that the relative ST and NT yields and COP/bu relative to CH from this Monte Carlo exercise are summarized in Table 7 (as well as at the bottom of Table 3).

This table summarizes the probability that the corresponding ST or NT value (relative yield or COP/bu) is less than CH (i.e., that the change from CH is less than zero). These are computed from the empirical (frequency) distribution function generated by the Monte Carlo simulation. Probabilities near 50% indicated that the 2 values (ST or NT in comparison to CH) are equally likely. For CC, these probabilities indicate that NT yields are very likely to be less than CH based these data (97% chance). Similarly, the NT COP/bu are very unlikely to be greater than those for

CH (~22%-23% chance). ST yields are predicted to be less than CH in 2 out of 3 cases (67%) with COP/bu (N w/ APP) less than CH 55% of the time (N w/ Planter, 43%).

Under the SBC cropping results, ST yields are predicted to be greater than CHabout ½ the time (50%), with COP/bu less than CH 88% (N w/ APP) and 70% (N w/ Planter) of the time. Clearly these "stronger" probabilities are "better bets" than probabilities less than ½ (50%) of the time. NT is a bit less strong probabilistically than ST, with yields consistently less than CH (76% of the time) offset by COP/bu less than CH about 56%-57% of the time (both fertilizations). NT really shines under CSB, where highly likely lower yields (75%) are offset by equally likely lower COP/bu (76%). ST is expected to yield similar to CH (55%) and generated COP/bu savings over CH 71% of the time.

Table 7. Comparison of Probability ST or NT < CH.

		COP/bushel	
Crop/ System	YIELD	N w/ App	N w/ Planter
CC			
ST	66.7%	54.7%	42.6%
NT	97.0%	22.7%	21.9%
SBC			
ST	49.6%	87.6%	69.6%
NT	76.3%	56.8%	56.1%
CSB			
ST	55.3%	71.3%	
NT	75.4%	76.4%	

Summary/Conclusions

Clearly, the environmental, COP/acre and COP/bu benefits of reduced tillage systems are compelling but likely require adjustments to management as well as current machinery complements. Increased adoption of these reduced tillage systems requires a more thorough understanding of their relative environmental and economic dimensions, as well as opportunities (and willingness) to acquire different management skills. More research/outreach of alternative tillages along these dimensions is clearly warranted. For example, characterization of key weather related factors (wet/dry spring or pollination period, degree days, good/bad year, etc) across the years of these trials may provide for more general conclusions as to the likelihood that one tillage will outperform another. Similarly, observation across more soils, locations, and under different management (e.g., NT with row cleaners) would add more robustness to the current estimates. These provide rich opportunities for additional on-farm research.

Evaluating the economics of tillage systems is very complex. Consideration must be given to the initial and maintenance costs of equipment, the size of tractor needed to pull the tool, equipment depreciation, labor and opportunity costs, conservation program incentives, and increased management costs related to fertilizer and pest management. Producers will have to determine if it is cost effective to strip-till all row crops, as opposed only strip-tilling first-year corn into soybean stubble or fall-killed alfalfa, no-till planting soybean into corn or small grain stubble, and using chisel plowing or similar full-width systems for growing continuous corn. Growers are encouraged to set up simple side-by-side comparisons of different tillage systems to evaluate response on their own soils. Evaluation of economic COP/acre and COP/bu are also encouraged, as these Arlington field trials indicated that potentially lower yields under reduced tillage can be offset by gains in lower COP. Use of WI custom hire rates for field operations likely provide upper bounds on these COP, as they reflect market rates of return for the labor, machinery and capital involved in these alternative tillage systems. In many instances, both economic and environmental performance may be enhanced by wider adoption of reduced tillage systems.

Experienced no-tillers will likely take exception to the relative NT yields and COP estimates found in these field trials. NT systems often require increased management (planting, spraying and fertilization) and several years to achieve their full yield potential. In particular, the "soil equilibrium" (improved organic matter, soil structure, water absorption capacity, soil biotics, etc) under NT takes several years to develop and mature. These more "mature" NT systems are likely to generate yields quite competitive with the CH yields observed in these field trials. In this context, the relatively poor performance of NT relative to ST and CH may indicate the expected short run yields for a NT cropping system that is early in the adoption/adaptation stage. The ST results suggest a hybrid/transition cropping system that reaps much of the best of both NT and CH tillage systems while providing an opportunity to acquire the management skills and machinery complement to move towards even less tillage, improved yields, lower costs and improved environmental performance found by seasoned no-tillers.

Appendix Table 1. Corn Costs Per Acre @ 2007 WI Custom Hire Rates.								
	Nitrogen Applied With Applicator				Nitrogen Applied With Planter			
Implement	No-Till	Planter Strip Till	Pre-Strip Till	Chisel	No-Till	Planter Strip Till	Pre-Strip Till	Chisel
Chisel Plow				$14.70				$14.70
Field Cultivator				$11.50				$11.50
Strip Till Tool			$15.00				$15.00	
Dry Fertilizer Application	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
Nitrogen Applicator	$12.00	$12.00		$12.00				
Planter	$16.10	$16.10	$15.80	$15.80	$16.10	$16.10	$15.80	$15.80
Sprayer Pass I	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50
Sprayer Pass II	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50
Combining	$26.40	$26.40	$26.40	$26.40	$26.40	$26.40	$26.40	$26.40
Machinery Costs Subtotal	$74.50	$74.50	$77.20	$100.40	$62.50	$62.50	$77.20	$88.40
Nitrogen Fertilizer	$87.75	$87.75	$87.75	$87.75	$128.25	$128.25	$128.25	$128.25
P and K Fertilier	$65.70	$65.70	$65.70	$65.70	$65.70	$65.70	$65.70	$65.70
Herbicide	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00	$35.00
Seed	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00
Variable Costs Subtotal	$263.45	$263.45	$263.45	$263.45	$303.95	$303.95	$303.95	$303.95
Land/Rental Costs	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00
Total Costs: CORN	$437.95	$437.95	$440.65	$463.85	$466.45	$466.45	$481.15	$492.35
Change from Chisel	-$25.90	-$25.90	-$23.20	--	-$25.90	-$25.90	-$11.20	--
Breakeven Cost/Yield Difference	-8.4	-8.4	-7.5	--	-7.9	-7.9	-3.4	--
Cost/Bushel (= Breakeven Price)	$2.92	$2.92	$2.94	$3.09	$3.11	$3.11	$3.21	$3.28

Appendix Table 2. Soybean Costs Per Acre @ 2007 WI Custom Hire Rates.								
	Nitrogen Applied With Applicator				Nitrogen Applied With Planter			
Implement	No-Till	Planter Strip Till	Pre-Strip Till	Chisel	No-Till	Planter Strip Till	Pre-Strip Till	Chisel
Chisel Plow				$14.70				$14.70
Field Cultivator				$11.50				$11.50
Strip Till Tool			$15.00				$15.00	
Dry Fertilizer Application	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
Planter	$16.10	$16.10	$15.80	$15.80	$16.10	$16.10	$15.80	$15.80
Sprayer Pass I	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50
Sprayer Pass II	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50	$7.50
Combining	$26.10	$26.10	$26.10	$26.10	$26.10	$26.10	$26.10	$26.10
Machinery Cost Subtotal	$62.20	$62.20	$76.90	$88.10	$62.20	$62.20	$76.90	$88.10
P and K Fertilier	$70.20	$70.20	$70.20	$70.20	$70.20	$70.20	$70.20	$70.20
Herbicide	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00	$25.00
Seed	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00
Variable Cost Subtotal	$145.20	$145.20	$145.20	$145.20	$145.20	$145.20	$145.20	$145.20
Land/Rental Cost	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00
Total Costs: BEANS	$307.40	$307.40	$322.10	$333.30	$307.40	$307.40	$322.10	$333.30
Change from Chisel	-$25.90	-$25.90	-$11.20	--	-$25.90	-$25.90	-$11.20	--
Breakeven Cost/Yield Difference	-3.5	-3.5	-1.5	--	-3.5	-3.5	-1.5	--
Cost/Bushel (= Breakeven Price)	$6.83	$6.83	$7.16	$7.41	$6.83	$6.83	$7.16	$7.41