Income Risk Analysis of Alternative Tillage Systems for Corn and Soybean Production on Clay Soils

Emmanuel K. Yiridoe[1], Alfons Weersink[2], David C. Hooker[3], Tony J. Vyn[4] and Clarence Swanton[5]

[1] *Assistant professor, Department of Economics and Business Management, Nova Scotia Agricultural College, P.O. Box 550, Truro, NS B2N 5E3.*
[2] *Professor, Department of Agricultural Economics and Business, University of Guelph, Guelph, ON N1G 2W1.*
[3] *Research associate, Ridgetown College Campus, University of Guelph, Ridgetown, ON N0P 2C0.*
[4] *Associate professor, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150.*
[5] *Professor, Department of Plant Agriculture, University of Guelph, Guelph, ON N1G 2W1.*

Received February 1999, accepted March 2000

*Conservation tillage systems have not been widely adopted on clay soils. There are few empirical studies on the production potential and economic feasibility of conservation tillage systems for corn (*Zea mays *L.) and soybean (*Glycine max *L.) production on clay soils. On some soils in some regions, crop yields and possibly profitability can be increased, and yield and net farm returns risks may be reduced through the use of conservation tillage systems. Stochastic dominance efficiency criteria are used to rank net return distributions for one conventional tillage (CT) and seven conservation tillage (including five reduced tillage and two no-till) systems, conducted for corn and soybean cropping systems on two clay soils located in the 3050 to 3100 Corn Heat Unit areas of Ontario. Average yields are similar under conventional tillage and reduced tillage systems, although actual corn and soybean yield response to tillage treatment is affected by drought (year). Average net returns differ among tillage treatments due to two factors. First, actual corn and soybean yields vary among tillage systems for each soil type, depending on weather (i.e., year) effects. In addition, machinery costs that are crop-specific increase costs of production and therefore reduce net returns. In general, CT systems dominate both reduced tillage and no-till systems for almost all risk intervals for both clay soils, except for slightly high-risk-preferring intervals.*

*L'adoption des régimes de travail de conservation du sol a été plutôt restreinte sur les terres argileuses. Il n'y a d'ailleurs que peu d'études expérimentales sur les potentialités des productions et sur la faisabilité économique de ces régimes pour la culture du maïs (*Zea mays *L.) et du soja (*Glycine max *L.) dans ces types de sols. Dans quelques régions du pays, leur utilisation dans certains sols peut donner lieu à un accroissement des rendements culturaux et éventuellement de la rentabilité, en plus de réduire les risques afférents aux rendements et aux revenus nets de l'exploitation. Nous avons utilisé des critères d'efficience à dominance stochastique pour classer les niceaux de répartition de la rémunération nette obtenue dans régime de travail classique du sol (TC) et de sept régimes de travail de conservation du sol, soit cinq en travail réduit et deux en semis direct, conduits en culture de maïs et de soja sur des sols argileux situés dans les régions agroclimatiques de 3 050 à 3 100 unités thermiques maïs. Les rendements moyens étaient comparables en régime de travail classique et dans les régimes de travail réduit, bien que les rendements actuels des deux cultures sous les divers régimes étaient déprimés en année de sécheresse. La rémunération nette moyenne différait selon les régimes de travail du sol, et cela pour deux raisons : d'abord une variation des rendements réels de maïs et de soja entre* *régimes de travail pour chaque type de sol selon les conditions météorologiques de l'année, ensuite l'augmentation des coûts de production résultant de celle des coûts d'utilisation de matériels de culture spécialisés, tout cela se soldant par une baisse de la rémunération nette. Dans l'ensemble, les régimes TC l'emportaient dans les sols argileux pour la quasi-totalité des niveaux d'attitudes envers les risques, sauf dans le cas des attitudes La gestion de la logistique dans le commerce des céréales a acquis une grande importance maintenant que ce secteur a atteint la maturité. C'est particulièrement important dans le système canadien de mise en marché des céréales lequel, pour diverses raisons, a essuyé bien des perturbations ces dernières années. Les problèmes en cause ont fait l'objet de nombreuses évaluations du secteur. Ils ont même abouti au dépôt d'une plainte sur les obligations de service dans la campagne agricole 1996-1997 et ont été étudiés par la Commission Estey. Dans la présente communication nous avons construit un modèle détaillé du système canadien de logistique du marché des céréales ainsi que de l'effet de plusieurs stratégies importantes de logistique et de commercialisation sur la performance du système. Les résultats obtenus montrent qu'il y a suffisamment d'aléatoire dans les diverses fonctions du système pour conclure que les frais de séjour à quai sur la côte ouest seraient périodiquement un important poste de dépense. La fréquence des perturbations des services et les coûts à quai sont associés à plusieurs facteurs dont la livraison de grain gourd et humide, de grain mal classé et le niveau des disponibilités exportables. Plusieurs variables stratégiques influent sur le fonctionnement du système, notamment l'agressivité manifestée dans la vente par rapport aux stocks disponibles et le niveau des stocks disponibles dans les ports au début de la campagne d'exportation, de recherche prudentes des risques.*

INTRODUCTION

Conservation tillage systems are increasingly being promoted in response to a need to minimize the problem of soil erosion and soil degradation. Reduced soil erosion and sedimentation from conservation tillage can improve drainage of watersheds, quality and recreational value of water systems, and can reduce treatment and maintenance costs of water-using machinery and equipment (Clark et al 1985). In addition to off-farm benefits, on-farm benefits to farmers from conservation tillage may be generated from savings in labor and energy costs due to a reduction in frequency of field equipment operations (Burgess et al 1996). However, farmers have been reluctant to adopt conservation tillage systems that reduce farm profitability (Fox and Dickson 1988) or that expose producers to unreasonable risk (Hardaker et al 1997). Increased herbicide use and investment in equipment may offset some of the benefits of conservation tillage systems. On the other hand, financial and business risk may increase if there is increased yield variability from the adoption of conservation tillage systems (Weersink et al 1992). Thus, the expected profitability (i.e., on-farm net benefits) and level of risk associated with conservation tillage ultimately determine whether an individual farmer will adopt such systems and, consequently, whether any off-farm benefits will be generated.

Studies analyzing the profitability of alternative tillage systems for light-textured soils in Ontario (e.g., Baffoe et al 1986; Henderson and Stonehouse 1988; Weersink et al 1992; Yiridoe et al 1994) indicate that the financial feasibility of conservation tillage systems depend largely on the managerial ability of the farmer to produce yields that are similar to conventional tillage (CT) systems. Improvements in technology have allowed reduced tillage systems to generate similar yields to conventional tillage systems on these sandy soils. On these soils, significant adoption of conservation tillage systems has taken place. However, the diffusion rate has reached a plateau due to the perceived low yields and high risks of conservation tillage systems on other soils in the province. One reason for the limited adoption of conservation tillage on fine-textured clay soils is inconsistencies in seedbed quality and problems with crop establishment and crop growth, which may translate into lower net returns (Vyn et al 1994). In addition, there is little empirical research and farmer experience on the production potential and economic feasibility of conservation tillage systems for corn (*Zea mays* L.) and soybean (*Glycine max* L.) cropping systems on such clay soils in the region (Vyn and Swanton 1997).

The purpose of this study is to compare the income-risk efficiency of a corn-soybean rotation for seven conservation tillage systems with a conventional moldboard plow tillage system for two clay soils in southern Ontario, using generalized stochastic dominance. The conservation tillage systems analyzed consist of five reduced tillage systems and two no-till systems. Corn and soybean yields are generated from field experiments conducted from 1994 to 1996 at Alvinston, Lambton County, and at Fingal, Elgin County, both in the 3050 to 3100 Corn Heat Unit areas of Ontario.

METHODS

Cropping Systems and Cultural Practices

The site at Fingal, Elgin County, is a Toledo silty clay loam with 30% clay, 52% silt, 18% sand, and 3.8% organic matter. The soil at Alvinston, Lambton County, is a Brookston clay with 44% clay, 42% silt, 14% sand and 3.9% organic matter. For each site, the land was planted half to soybeans and half to corn, with an alternating corn/soybean rotation in three successive years. The experimental design was a randomized complete block, with each tillage treatment replicated four times. Tillage treatments were maintained on the same plots during the study period. Prior to conducting the study, both sites were under a corn-soybean-wheat rotation for at least five years. The experimental plots were established with tillage treatments initiated in the fall of 1993.

The alternative tillage systems studied are summarized in Tables 1 and 2. Tillage treatment 1 was a conventional tillage system, which consisted of a fall moldboard plow operation followed by seedbed preparation in the spring. Tillage treatment 2 was a fall chisel plow operation followed by two spring cultivator passes for both corn and soybeans. Tillage system 3 involved a single pass with a tandem disc in the fall. For corn, spring tillage was restricted to the immediate row area using a single planter-mounted 5 cm fluted coulter positioned directly in line with the seed disc openers, along with a fertilizer opener positioned to the side of the row. No spring tillage was performed for soybeans. A spring tillage only (treatment 4) for soybeans consisted of one pass with a tandem disc followed by a single pass with a field cultivator and packer. For corn, tillage consisted of two passes with a field cultivator. Zone-tillage system 5 for corn was restricted to the immediate row area, zone-tilled using a Trans- till in the fall, in addition to spring no-till with coulters. Zone-till involved tillage within the row area while the inter-row spaces were not tilled. The Trans-till implement consisted of a toolbar with an angled shank between two fluted coulters spaced 25 cm apart. For this study, the angled shank was set to operate at a depth of 17 cm, and tilled a zone 25 cm wide for each row. For soybeans, fall tillage involved an AerWay operation, with no additional tillage in the spring. AerWay is the trade name of an implement consisting of a rotating drum of spikes that provides minimal soil disturbance and maintains most of the surface residue. AerWay tillage treatment 6 consisted of a single pass in the spring, prior to planting soybeans, or a no-tillage coulter operation before planting corn.

Two no-till systems were studied. Tillage treatment 7 consisted of no-till (coulters) system in which tillage was restricted to the immediate row area using a planter-mounted 5 cm fluted coulter positioned directly in line with the seed disc openers with unit-mounted tined row cleaners, along with a fertilizer opener positioned 5 cm to the side of the row (for corn only). Tillage system 8 was a no-till (slot) treatment, which minimized soil disturbance.

In this study, tillage systems 2 through 8 are regarded as conservation tillage systems, of which tillage treatments 2 through 6 are described as reduced tillage systems. The Ontario

Table 1. Alternative tillage treatments and actual field operations for corn production

	Scheduling		
		Spring	
Operation/system	Fall[a]	Alvinston	Fingal
Tillage system:			
Moldboard plow	moldboard plow	cultivate (2×)	cultivate (2×)
Chisel plow	chisel plow	cultivate (2×)	cultivate (2×)
Fall disc	tandem disc	zone (2 coulters per row)	zone (2 coulters per row)
Spring tillage only	—	cultivate (2×)	cultivate (2×)
Fall zone-till/AerWay	zone-till for corn	zone (2 coulters per row)	zone (2 coulters per row)
Spring AerWay	—	AerWay plus zone-tillage	AerWay plus zone-tillage
No-till (coulter)	—	zone (2 coulters per row)	zone (2 coulters per row)
No-till (slot)	—	slot plant (fertilizer coulter only)	slot plant (fertilizer coulter only)
Seeding rate (seeds/ha)	—	74000	74000
Fertilizer application (kg/ha)			
Urea Ammonia Nitrate (28-0-0)	—	150	150
NPK starter fertilizer (11-52-0)	—	125	125
Herbicide application (kg a.i./ha)			
1994 and 1995			
Glyphosate	—	0.89	0.89
Dicamba	—	0.6	0.6
Metolachor	—	2.25	2.25
1996			
Glyphosate	—	0.89	0.89
Linuron	—	4.4	—
Metolachor	—	2.25	2.25

[a]Field operations in the fall were the same at both Alvinston and Fingal.

Land Stewardship Program defines conservation tillage as any rotation-tillage combination that leaves at least 20% of crop residue on the surface after seeding (OMAF 1987). A conservation tillage system minimizes soil and/or water loss relative to conventional tillage, and is usually a "noninversion tillage that retains protective amounts of residue mulch on the soil surface" (Soil Conservation Society of America 1982).

The cultural practices for corn, including the herbicides and fertilizers used and the rates applied, are summarized in Table 1. Pioneer 3960 corn hybrid was planted in 76 cm wide

Table 2. Alternative tillage treatments and actual field operations for soybeans production

	Scheduling		
		Spring	
Operation/system	Fall[a]	Alvinston	Fingal
Tillage system:			
Moldboard plow	moldboard plow	cultivate (2×)	cultivate (2×)
Chisel plow	chisel plow	cultivate (2×)	cultivate (2×)
Fall disc	tandem disc	slot plant only	slot plant only
Spring tillage only	—	disc (1×) plus cultivate (1×)	disc (1×) plus cultivate (1×)
Fall zone-till/AerWay	AerWay for soybeans	slot plant only	slot plant only
Spring AerWay	—	AerWay plus slot plant	AerWay plus slot plant
No-till (coulter)	—	zone (coulter drill)	zone (coulter drill)
No-till (slot)	—	slot plant only	slot plant only
Seeding rate (seed m^{-2})	—	52	52
Fertilizer application (kg/ha)			
Urea ammonia nitrate (28-0-0)	—	—	—
NPK starter fertilizer (11-52-0)	—	—	—
Herbicide application (kg a.i./ha)			
1994 and 1995			
Glyphosate	—	0.89	0.89
Metolachor	—	2.25	2.25
Imazethapyr	—	0.1	0.1
1996			
Glyphosate	—	0.89	0.89
Linuron	—	4.4	—
Metolachor	—	2.25	2.25
Bentazon	—	—	1

[a]Field operations in the fall were the same at both Alvinston and Fingal.

rows during 1994 and 1995, but was replaced with Pioneer 3769 during 1996 because Pioneer 3960 was commercially discontinued. Urea ammonium nitrate (U.A.N.) fertilizer was applied in subsurface bands 8 cm deep and between the crop rows, in addition to a starter fertilizer (11-52-0). Weed control during 1994 and 1995, at both the Fingal and Alvinston sites, involved a burndown herbicide (glyphosate), along with broadcast application of dicamba and metolachor. In 1996, glyphosate and metolachor were broadcast at Fingal, while at Alvinston a tank-mix of metolachor, linuron and glyphosate was broadcast-applied immediately after planting.

Soybeans were planted in 38 cm wide rows, except Fingal no-till (coulter) treatment in 1996 (Table 2). Due to drill constraints, the 1996 Fingal no-till (coulter) treatment plots were planted in 15 cm wide rows at the same rate of 52 seeds per square metre. All herbicides were applied to both corn and soybeans in every tillage system except glyphosate, which was used mainly as a burndown in the two no-till systems. Further details about the agronomic practices are described in Yiridoe et al (2000).

Net Farm Returns

Total net returns to land and labor were determined for each of the eight tillage systems based on actual corn and soybean yields, along with field operations from the experiments conducted on the two clay soils. Given that land and labor costs differed by farm, it was found more appropriate to calculate net returns to land and labor (revenues – direct costs), so that each farm could determine its individual profitability. The sizing of farm machinery complements were based on a representative 80 ha (200 acre) farm, being the average farm size for a corn-soybean operation in southern Ontario (OMAF 1989). Half the land was assumed planted to corn and the remaining half was allocated to soybeans. Machinery fixed costs including annual depreciation, interest on investment, and equipment housing and insurance were allocated to each crop in the rotation based on usage. For example, where the same equipment was used for both corn and soybean production, the associated annual fixed cost was split between the two crops. The declining balance method of calculating depreciation was used, with a rate of 15% applied to powered machines and 10% to nonpowered equipment. All equipment was assumed to be five years old, with the current values estimated by using the associated depreciation rates and the 1997 list prices for each equipment. Machinery insurance and storage were based on 1.5% of the purchase price.

Variable costs included farm input costs and variable machinery costs. Farm input costs such as seed and seed treatment, and fertilizer costs were assumed to be similar for each tillage system. Variable machinery costs were based on equipment usage and include oil and lubrication, fuel consumption and repair and maintenance. Oil and lubrication costs were estimated at 15% of total fuel costs. Further details on the total cost of production for each tillage system are described in Yiridoe et al (2000).

Total net returns to land and labor for each of the eight tillage systems were calculated by subtracting the production cost from the corresponding gross returns. Farm gross returns were obtained by multiplying the paired corn and soybean yields from the field experiments by the 1995 average market prices received by southern Ontario farmers for each crop and then by the assumed acreage of 40 ha allocated to corn and soybeans. The corn and soybean yield data for the alternative tillage systems studied are summarized in Table 3. Moment ratio analysis and Shapiro-Wilk tests, jointly, rejected normality of the yield distributions, except for soybean yield distributions under no-till, moldboard plow and spring AerWay tillage systems. Consequently, a distribution-free statistical test, the Wilcoxon Rank Sum Test, was used to test for significant differences between sample locations for all tillage treatments.

Risk Analysis

Yield variability of the alternative cropping systems generated a distribution of net returns for each tillage system. A farmer's choice of tillage system depends not only on the average level of returns, but also on the variability in net returns and risk attitude. The optimal tillage system choice, taking risk into consideration, was analyzed using stochastic dominance.

Table 3. Effect of cropping systems on average corn and soybean yields for alternative tillage systems, 1994–96[a]

	Tillage system							
Crop	Moldboard plow	Chisel plow	Fall disc	Spring tillage only	Fall zone-till/ AerWay	Spring AerWay	No-till (coulter)	No-till (slot)
Corn								
Alvinston site								
Mean (kg/ha)	5961a[b]	5432bc	5688b	5985a	5947a	5665b	5311c	5690b
Standard deviation	793	842	455	497	613	776	467	285
Fingal site								
Mean (kg/ha)	9975a	9691b	9696b	9833ab	9774ab	9461c	9696b	9270c
Standard deviation	738	898	882	806	850	965	727	408
Soybeans								
Alvinston site								
Mean (kg/ha)	2628a	2481ab	2437b	2406b	2344b	2435b	2343b	2451b
Standard deviation	376	345	526	368	462	407	366	520
Fingal site								
Mean (kg/ha)	3646a	3658a	3523ab	3613a	3493b	3736a	3765a	3622a
Standard deviation	427	282	356	387	391	213	200	351

[a]Actual yields for individual replications from the experimental test plots are available from the authors.

[b]Yield distributions for each site are compared separately. Within each site, yield locations with the same letter are not significantly different from each other according to the Wilcoxon rank sum test, for $\alpha = 0.05$.

This analysis was motivated by the need to determine risk efficient tillage systems for fine-textured clay soils. Stochastic dominance was used to differentiate alternative tillage systems, analyzed for two different soil types, into income-risk efficient and inefficient sets for a range of risk attitudes. This approach of ordering choices for various risk preferences is more flexible than alternative risk analysis procedures (such as MOTAD), which reduce the choices to a single optimum plan. The study used the generalized stochastic dominance (GSD) or stochastic dominance with respect to a function (Meyer 1977), which has more discriminatory power than first and second degree stochastic dominance (FSD and SSD) because GSD permits greater flexibility in defining individual preferences. GSD ranks choices for decision makers based on their risk attitudes, whose absolute risk aversion functions lie between specified lower and upper bounds. Risk aversion coefficients (RACs) permit interpersonal comparison of risk attitude at various net returns levels. The RAC bounds contain possible risk attitudes of all individuals, including risk aversion (positive), risk neutrality (zero) and risk preference (negative).

Accuracy in estimating the risk aversion coefficient bounds relative to the set of net returns distributions is important in generating accurate results (McCarl 1989). As a result, McCarl and Bessler's (1989) nonnegative certainty equivalent procedure was used to set approximate upper bounds. Net returns per hectare were multiplied by the assumed farm size for each crop (40 ha) to allow proper transformation of scale of the outcome distributions to maintain correct ranking by GSD (Raskin and Cochran 1986).

The income distributions from the treatments (eight tillage systems for two soil types) were ranked using Meyeroot software (McCarl 1989), which is a version of the optimal control algorithm for GSD. In this study, yields from the four replications were averaged for each treatment before conducting the pairwise comparison of the distributions. In addition, breakeven risk aversion coefficients (BRACs) for which dominance between a pair of treatments changed were determined. In interpreting the results, it is important for the reader to note that the three years of experimental data used provide a limited representation of the entire distribution. Yet, limited research resources constrain the ability to obtain an appropriate sequence of actual data from field experiments over a time span of sufficient length to indicate full yield variability. The following section presents a discussion of the risk- efficient actions, based on the yield distributions generated from the field experiments.

RESULTS AND DISCUSSION

Average Yield Comparison

Average yields were similar under moldboard plow tillage and several conservation tillage systems (Table 3), although actual corn and soybean yield response to tillage treatment was affected by drought (year) and soil type. Drought at Alvinston partly accounted for the generally higher corn and soybean yields at Fingal. As was hypothesized by Brown et al (1989), the higher clay fraction of the soil at Alvinston (44%) relative to that at Fingal (30%) resulted in a greater drought effect on yields. In addition, intensity and timing of rainfall during the first week of planting at both Fingal and Alvinston caused soil crusting and seed emergence problems for corn in 1994 and for both corn and soybeans at Alvinston in 1995. In general, drought stress affected the two no-till systems more than the moldboard plow tillage and reduced tillage systems.

Actual corn yields at both Alvinston and Fingal were higher under the moldboard plow tillage and spring tillage only treatments than under the remaining treatments. In contrast, Alvinston corn yield was lowest with the no-till (coulter) system (5311 kg/ha), while at Fingal average yield was lowest for the no-till (slot) treatment (9270 kg/ha). Alvinston site average soybean yields were not different among the conservation tillage systems (2 through 8).

Across years, variability in Alvinston corn yield, as measured by the coefficient of variation, was lowest for the no-till (slot) system, followed by the fall disc tillage systems. In contrast, the chisel plow tillage system generated the highest variability in yield. In addition, variability in corn yield at Fingal was lowest for the no-till (slot) treatment and highest for the chisel plow system, as was found for Alvinston. These results have important implications regarding the general perception about no-till yields among farmers in the study area. First, in general, statistical variance is greater with treatments that have higher average yields, consistent with the results in Table 3: the expected yield of the no-till treatments was significantly lower than the expected yield of the CT treatment, except soybeans at Fingal. Second, the general perception among farmers is that no-till systems are more "risky" than CT for these crops grown in such clay soils. The finding in the study is not inconsistent with this perception by farmers in the area in that most farmers are less worried about yield variation above the mean and often do not consider yields in excess of the expected yield to be "risk." Thus, the perception among farmers is consistent with the hypothesis that the expected yield of no-till is less than the expected yield of CT treatments for these crops, grown in such heavy clay soils. Hence farmers conclude that it would be more risky to use no-till.

In general, no particular tillage system consistently outperformed the other systems during all three years that the study was conducted. Under favorable growing conditions, both corn and soybean yields can be as competitive (or even higher in some cases) for conservation tillage as for conventional tillage management. Thus, based on crop yields alone, the choice of best tillage system depends on the year and soil type on which the study was conducted.

Average Net Returns Comparison

Average net returns and the corresponding income variability (as measured by the standard deviation) for the 80 ha corn-soybean enterprise were higher at Fingal than at Alvinston (Table 4). Average net farm returns were higher at Fingal than at Alvinston because Fingal generated both lower total costs of production and higher corn and soybean yields. Total production costs were higher at Alvinston largely due to higher costs for herbicides applied. For both corn and soybeans, total variable costs were lowest with the reduced tillage systems (2 through 6) and highest with no-till systems 7 and 8. At each site, total production costs were generally higher for corn than for soybeans, reflecting the characteristics of these crop production systems.

At each site, there were no differences in average returns between the conventional tillage system and the five reduced tillage systems ($\alpha = 0.05$), but actual net returns for corn-soybean production were higher for the conventional tillage treatment than the reduced tillage systems. Across sites, no-till systems generated the lowest net revenues largely because no-till machinery was more expensive, with higher variable and fixed machinery costs. Thus, higher machinery-related costs and lower yields jointly resulted in no-till systems generating the lowest net returns.

There were no significant differences in average net farm returns among the five reduced tillage systems (2 through 6) as a group, but relative ranking depended on the soil type. For example, at Alvinston, the spring tillage only treatment ranked first due to savings in machinery costs, followed by the chisel plow tillage system. In contrast, the ranking of the chisel plow tillage and spring tillage only treatments were reversed at Fingal.

Table 4. Production costs and average net returns for alternative tillage systems on an 80 ha farm ($)

Tillage system	Treatment notation	Gross return			Cost of production			Net returns
		Corn	Soybeans	Total	Corn	Soybeans	Total	
Alvinston site:								
Moldboard plow	A_1	40257	33218	73475	26234	21011	47245	13141*A*[b]
		(5724)[a]	(5826)	(8977)				(5820)
Chisel plow	A_2	36617	31237	67853	25919	20704	46623	10756*A*
		(7535)	(5251)	(10538)				(6701)
Fall disc	A_3	37969	30458	68426	27097	20725	47822	10312*AB*
		(5259)	(8559)	(12301)				(7010)
Spring tillage only	A_4	39991	30274	70265	25519	21504	47023	11904*A*
		(5283)	(7055)	(11219)				(7001)
Fall zone-till/AerWay	A_5	39647	29278	68925	27536	21128	48664	10024*AB*
		(6376)	(6741)	(11095)				(6932)
Spring AerWay	A_6	37957	30538	68494	26864	20629	47493	10614*AB*
		(6298)	(6242)	(11719)				(6304)
No-till (coulter)	A_7	35452	29541	64993	27133	27713	49846	7015*C*
		(5669)	(5744)	(10741)				(5636)
No-till (slot)	A_8	37788	30504	68291	26666	21523	48189	9401*BC*
		(5440)	(7741)	(11200)				(6725)
Fingal site:								
Moldboard plow	F_1	66234	45875	112109	22107	17781	40576	36010*A*
		(7019)	(6022)	(6289)				(10236)
Chisel Plow	F_2	64347	46085	110432	21800	17474	39955	35569*A*
		(9019)	(4758)	(8827)				(10003)
Fall disc	F_3	64380	44394	108774	22975	17496	41155	34001*A*
		(6541)	(6233)	(8372)				(9602)
Spring tillage only	F_4	65288	45518	110805	21402	18281	40362	35500*A*
		(8625)	(6503)	(8453)				(11164)
Fall zone-till/AerWay	F_5	64900	44006	108906	23414	17899	41997	33291*AB*
		(6972)	(7987)	(11823)				(10651)
Spring AerWay	F_6	62820	47072	109891	22722	17399	40824	34215*A*
		(8237)	(6136)	(9968)				(8905)
No-till (coulter)	F_7	64380	47439	111819	23984	19394	43089	33406*AB*
		(7052)	(3606)	(6690)				(8492)
No-till (slot)	F_8	61553	45633	107186	23114	18203	41430	31601*AB*
		(4957)	(5906)	(74960)				(8654)

[a]Figures in parentheses are standard deviations.
[b]Yield distributions for each site are compared separately. Within each site, values within this column followed by the same letter are not significantly different according to Wilcoxon rank sum test, for $\alpha = 0.05$.

Risk Efficient Tillage Choice

The GSD pairwise comparison of net returns among the eight tillage systems are summarized in Table 5. Across soil types, risk-averse individuals would least prefer no-till treatments compared with the reduced tillage and CT systems, because net income from the no-till systems were the lowest and with considerable income variability. However, there were differences in the relative risk efficiency ranking of the reduced tillage systems, depending on soil type and risk attitude. Stochastic dominance ranking of tillage systems were also analyzed for various risk aversion intervals, determined by the breakeven risk aversion coefficient (BRAC) values for which dominance switches between tillage systems.

Tillage Systems across Soil Types

Given that relative ranking of risky prospects is important to risk analysts (Kramer and Pope 1986), the GSD pairwise comparisons summarized in Table 5 were further analyzed to better determine the rankings of the tillage treatments at each site, for various risk aversion intervals. Results of the stochastic dominance rankings for the two soils are presented in Table 6.

In general, the moldboard plow systems dominated both the reduced tillage and no-till systems for almost all risk intervals for both soil types, except among slightly high-risk-preferring individuals. At Alvinston, the conventional tillage system dominated the other tillage treatments for RACs above –0.00013. However, for high- risk-preferring individuals with risk aversion intervals between –0.00013 and –0.0003, fall zone-till/AerWay and fall disc tillage systems dominated the conventional tillage system. On the other hand, no-till (slot) tillage system 8 was dominated by all the reduced tillage and CT systems for both soil types. This finding for no-till (slot) tillage is consistent with the net farm returns results in Table 4, where tillage system 8 generated the lowest returns at Fingal and the second lowest returns at Alvinston. Although net returns at Alvinston for no-till (slot) tillage ranked seventh (better than only no-till (coulter) system 7), variability of returns was higher for no-till (slot) than the no- till (coulter) system. Relative ranking of the reduced tillage systems (2 through 6) depended on the risk interval considered.

Tillage Systems within Soil Type

Among the reduced tillage treatments, the chisel plow tillage treatment ranked highest, followed by the fall disc tillage system for RACs above 0.00022, at Alvinston. In contrast, the spring AerWay tillage treatment had the lowest ranking among the reduced tillage treatments for risk-averse individuals. At slightly risk-preferring intervals (RAC = –0.000013), fall zone-till/AerWay ranked first, followed by the conventional tillage treatment. As the risk preference attitude increased further to BRAC = –0.0002, both fall zone-till/AerWay and fall disc tillage treatments ranked higher than the CT treatment. Thus, the risk efficiency of the fall zone-till/AerWay tillage treatment improved as risk attitude changed from risk-averse through risk neutrality to risk-preferring behavior.

At the Fingal site, CT dominated the conservation tillage systems for nearly all risk aversion intervals, as was found for the Alvinston site. However, in contrast to the results for Alvinston, CT dominance changed at BRAC = –0.000041, where spring AerWay tillage was the most risk-efficient. Among the reduced tillage systems, chisel plow dominated the remaining treatments for slightly risk-preferring to slightly risk-averse intervals, similar to the ranking for Alvinston. In addition, no-till (slot) treatment ranked the lowest among the eight tillage treatments for all risk intervals.

SUMMARY AND CONCLUSION

Although choice of tillage system is important in soil conservation policy, farmers are reluctant to adopt conservation tillage systems, particularly on clay soils. Adoption of newer tillage systems require managerial and potential economic adjustments. Increased variability associated with expected yields and the associated net returns make risk attitude an important consideration in the adoption of such new tillage systems.

Table 5. Generalized stochastic dominance pairwise comparison and breakeven risk aversion coefficients for the 16 tillage treatments

Treatments[a]	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Alvinston site:								
A_1	—							
A_2	-D[b]	—						
A_3	(–0.00001)[c]	(–0.000031)	—					
A_4	-D	(–0.00004)	(–0.00034)	—				
A_5	(–0.000011)	–0.000014	0.00021	–0.000029	—			
A_6	-D	–0.000022	(–0.00011)	–0.00024	–0.000023	—		
A_7	-D	-D	(–0.00001)	-D	-D	-D	—	
A_8	-D	(–0.000043)	(–0.000035)	(–0.00011)	(–4.5E-06)	(–3.5E-05)	(–0.00017)	—

Treatments[a]	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
Fingal site:								
F_1	—							
F_2	(–0.00011)	—						
F_3	(–0.000044)	(–0.000032)	—					
F_4	(–0.000024)	(–0.000027)	0.000012	—				
F_5	-D	-D	(–0.000013)	(–2..3E-05	—			
F_6	(–0.00004)	(–0.000032)	–0.000004	–0.000004	(–0.000033)	—		
F_7	-D	-D	-D	(–0.000037)	0.000036	(–0.00002)	—	
F_8	-D	-D	-D	-D	(–0.0004)	(–0.00003)	(–0.00004)	—

[a]Notation for each treatment is defined in Table 4.

[b]D = Row strategy dominates column strategy; -D = column strategy dominates row strategy.

[c]Figures are breakeven risk aversion coefficient (BRAC) values; values without parentheses are RACs below which row strategy dominates column strategy while those in parentheses are RAC above which column strategy dominates row strategy.

Table 6. GSD rankings and breakeven risk aversion coefficient values of alternative tillage systems for two clay soils

Risk attitudes	BRAC[a]	Tillage system rankings[b] 1	2	3	4	5	6	7	8
Alvinston site:									
Risk seeking	–0.0002	A_5[c]	A_3	A_1	A_6	A_4	A_2	A_8	A_7
↑	–0.000013	A_5	A_1	A_2	A_3	A_4	A_6	A_7	A_8
Risk neutral	0.00022	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
↓									
Risk averse	0.0004	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Fingal site:									
Risk seeking	–0.000041	F_6	F_4	F_1	F_3	F_2	F_7	F_5	F_8
↑	–0.000027	F_1	F_2	F_6	F_4	F_3	F_7	F_5	F_8
Risk neutral	0.000004	F_1	F_2	F_4	F_3	F_6	F_7	F_5	F_8
↓									
Risk averse	0.000027	F_1	F_2	F_4	F_3	F_5	F_6	F_7	F_8

[a]BRAC denotes breakeven risk aversion coefficient at which relative ranking between tillage systems switches in dominance.
[b]Ranking implies 1 dominates 2, etc.
[c]Notation for tillage systems are described in Table 4.

Stochastic dominance efficiency criteria are used to analyze net returns distributions generated from actual corn and soybean yields for a moldboard plow tillage system and seven conservation tillage systems. The field experiments were conducted on two clay soils, located in the 3050 to 3100 Corn Heat Unit areas of Ontario during 1994 to 1996.

A key limitation of the study is the limited number of years over which the field experiments were conducted and used in the stochastic dominance analysis. The three years of field dataset used provide a limited representation of the entire distribution and yield variability. It is therefore important for readers to recognize this in interpreting the results of this study.

Differences in average net returns among tillage systems were due to two factors. First, actual yields varied, depending on weather (year) and soil type. In addition, machinery costs that are crop-specific increased costs of production and therefore reduced net returns to the producer. It was also found that tillage systems that use a common (as opposed to a separate) set of machinery for both corn and soybean production saved on annual average machinery cost to each crop.

The moldboard plow systems generally dominated both reduced tillage and no-till systems for almost all risk intervals for both clay soil types, except among slightly high-risk-preferring intervals. The risk efficiency ranking for fall zone-till/AerWay tillage improved at the Alvinston site as risk attitude changed from risk-averse to risk- preferring behavior. Thus, overall, high risk of lower crop yields makes conservation tillage less attractive when risk attitudes are considered.

It is important to note that dynamic effects such as farmers' learning (from previous experience) curves are not considered in the study. In addition, Lockwood (1987) noted that farmers are usually not able to adapt newer technologies to farm-specific conditions until after a considerable part of the cash obligations on new farm equipment have been completed. Under such circumstances, the initial risk associated with adopting conservation tillage systems may be even greater than accounted for using the average net returns analyzed in this study.

REFERENCES

Baffoe, J. K., D. P. Stonehouse and B. D. Kay. 1986. A methodology for farm-level economic analysis of soil erosion under alternative crop rotational systems in Ontario. *Canadian Journal of Agricultural Economics* 34: 55–73.

Brown, H. J., R. M. Cruse and T. S. Colvin. 1989. Tillage system effects on crop growth and production costs for a corn and soybean rotation. *Journal of Production Agriculture* 2: 273–79.

Burgess, M. S., G. R. Mehuys and C. A. Madramootoo. 1996. Tillage and crop residue effects on corn production in Quebec. *Agronomy Journal* 88: 792–97.

Clark, E. H. II, J. A. Haverkamp and W. Chapman. 1985. *Eroding Soils: The Off-Farm Impacts*. Washington, DC: The Conservation Foundation.

Fox, G. and E. J. Dickson. 1988. What's economic about the economic costs of soil erosion and sedimentation control? Discussion Paper DP88/3. Guelph: University of Guelph, Department of Agricultural Economics and Business, September.

Hardaker, J. B., R. B. M. Huirine and J. R. Anderson. 1997. *Coping with Risk in Agriculture*. Wallingford, UK: CAB International.

Henderson, J. S. and D. P. Stonehouse. 1988. Effects of soil tillage and time of planting on corn yields and farm profits in southern Ontario. *Canadian Journal of Agricultural Economics* 36: 127–11.

Kramer, R. A. and R. D. Pope. 1986. Participation in farm commodity programs: A stochastic dominance analysis: Reply. *American Journal of Agricultural Economics* 68: 189–90.

Lockwood, R. C. 1987. Diffusion and adoption of new technology at the farm level. *Canadian Journal of Agricultural Economics* 34: 147–50.

McCarl, B. A. 1989. Meyeroot program documentation. Computer documentation. College Station, TX: Texas A & M University, Department of Agricultural Economics.

McCarl, B. A. and D. A. Bessler. 1989. Estimating the upper bound on the Pratt risk aversion coefficient when the utility function is unknown. *Australian Journal of Agricultural Economics* 33: 56–63.

Meyer, J. 1977. Choice among distributions. *Journal of Economic Theory* 14: 326–36.

Ontario. Ministry of Agriculture and Food. 1987. *Land Stewardship Program*. Toronto, ON: OMAF.

Ontario. Ministry of Agriculture and Food. 1989. Grain and forage crops: Estimated production costs. Report 89-05. Toronto, ON: OMAF.

Raskin, R. and M. J. Cochran. 1986. Interpretations and transformations of scale for the Pratt-Arrow absolute risk aversion coefficient: Implications for stochastic dominance. *Western Journal of Agricultural Economics* 11: 204–10.

Soil Conservation Society of America. 1982. *Resource Conservation Glossary*. Ankeny, IA.

Vyn, T. J., J. Janovicek and M. R. Carter. 1994. Tillage requirements for annual crop production in eastern Canada. In *Conservation Tillage in Agroecosystems,* edited by M. R. Carter. Boca Raton, FL: CRC Press.

Vyn, T. J. and C. J. Swanton. 1997. Determining the factors responsible for and methods to overcome the limitations of conservation cropping systems on clay soils. Final Report to Canada-Ontario Green Plan. Ottawa, ON: Agriculture Canada.

Weersink, A., M. Walker, C. Swanton and J. E. Shaw. 1992. Economic comparison of alternative tillage systems under risk. *Canadian Journal of Agricultural Economics* 40: 199–217.

Yiridoe, E. K., A. Weersink, C. J. Swanton and R. C. Roy. 1994. Risk efficient choice of bean-winter wheat rotation, cover crop and tillage system on light-textured soils. *Journal of Production Agriculture* 7: 374–80.

Yiridoe, E. K., T. J. Vyn, A. Weersink, D. C. Hooker and C. J. Swanton. 2000. Farm-level profitability analysis of alternative tillage systems on clays soils. *Canadian Journal of Plant Science* 80: 65–73.