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ECONOMIC AND STOCHASTIC EFFICIENCY COMPARISON OF EXPERIMENTAL TILLAGE SYSTEMS IN CORN AND SOYABEAN UNDER RISK

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SUMMARY

There are many reasons why agricultural researchers carefully evaluate approaches to experimental data analysis. Agricultural experiments are typically highly complex, with many types of variables often collected at a wide range of temporal and spatial scales. Furthermore, research in the developing world is often conducted on-farm where simple and conventional experimental designs are often unsuitable. Recently, a variant of stochastic dominance called stochastic efficiency with respect to a function (SERF) has been developed and used to analyse long-term experimental data. Unlike traditional stochastic dominance approaches, SERF uses the concept of certainty equivalents (CEs) to rank a set of risk-efficient alternatives instead of finding a subset of dominated alternatives. This study evaluates the efficacy of the SERF methodology for analysing conventional and conservation tillage systems using 14 years (1990–2003) of economic budget data collected from 36 experimental plots at the Iowa State University Northeast Research Station near Nashua, IA, USA. Specifically, the SERF approach is used to examine which of two different tillage systems (chisel plough and no-till) on continuous corn (*Zea mays*) and corn/soyabean (*Glycine max*) rotation cropping systems are the most risk-efficient in terms of maximizing economic profitability (gross margin and net return) by crop across a range of risk aversion preferences. In addition to the SERF analysis, we also conduct an economic analysis of the tillage system alternatives using mean-standard deviation and coefficient of variation for ranking purposes. Decision criteria analysis of the economic measures alone provided somewhat contradictive and non-conclusive rankings, e.g. examination of the decision criteria results for gross margin and net return showed that different tillage system alternatives were the highest ranked depending on the criterion and the cropping system (e.g. individual or rotation). SERF analysis results for the tillage systems were also dependent on the cropping system (individual, rotation or whole-farm combined) and economic outcome of interest (gross margin or net return) but only marginally on the level of risk aversion. For the individual cropping systems (continuous corn, rotation corn and rotation soyabean), the no-till tillage and rotation soyabean system was the most preferred and the chisel plough tillage and continuous corn system the least preferred across the entire range of risk aversion for both gross margin and net return. The no-till tillage system was preferred to the chisel plough tillage system when ranking within the continuous corn and the corn-soyabean rotation cropping systems for both gross margin and net return. Finally, when analysing the tillage system alternatives on a whole-farm basis (i.e. combined

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continuous corn and corn-soybean rotation), the no-till tillage system was clearly preferred to the chisel plough tillage system for both gross margin and net return. This study indicates that the SERF method appears to be a useful and easily understood tool to assist farm managers, experimental researchers and, potentially, policy makers and advisers on problems involving agricultural risk.

INTRODUCTION

At the national level, one of the major challenges to agriculture in the USA during the coming decades will be to produce sufficient food and fibre for a growing world population while maintaining environmentally acceptable farming practices. At the farm level, farmers face various decision-making challenges to reach these national goals. One of the major decisions farmers face is tillage system selection, either across the whole farm or for a specific crop. This decision usually has significant implications for the farm enterprise, both economically and environmentally. Reduced tillage or no-tillage (hereafter referred to as no-till) are considered to be conservation tillage practices that assist in maintaining acceptable environmental goals at potentially lower economic costs; however, the decision to invest in conservation tillage systems also involves risk. Despite clear benefits, farmers are still reluctant to adopt reduced tillage or no-till systems due to a lack of information about the consequences involved, including a lack of understanding concerning potential economic (e.g. purchase of new equipment) and environmental (e.g. potential increased herbicide use under no-till) impacts. More specifically, farmers lack knowledge about risks related to trade-offs between the upfront (or short-term) costs of implementing conservation management practices compared to expected long-term economic benefits in the future.

Under conditions of risk, mean-variance/mean-standard deviation (*s.d.*) analyses and stochastic dominance approaches (e.g. Hadar and Russell, 1969; Hanoch and Levy, 1969) have frequently been used to provide for risk aversion behaviour under general assumptions concerning farmer's utility functions and cumulative distribution functions (CDFs) of returns. For economic analyses, this normally involves comparison of cumulative income (e.g. gross margin or net return) probability distributions from a set of agricultural management alternatives (e.g. tillage or cropping systems). Stochastic dominance approaches to analyse farm tillage systems have steadily evolved since the mid-1980s. Klemme (1985) used first and second-degree stochastic dominance techniques to rank tillage systems on a net return basis to examine assumptions concerning various levels of risk avoidance. Lee *et al.* (1985) compared mean-variance and stochastic dominance techniques for farmer adoption of reduced tillage practices in a central Indiana watershed. Williams *et al.* (1987) used second-degree stochastic dominance to compare reduced tillage systems with conventional tillage systems for wheat and sorghum in western Kansas. Larson *et al.* (1998) used first-degree and second-degree stochastic dominance techniques to evaluate how using cover crops with various applied nitrogen rates affected net revenue from no-till corn production in western Tennessee. De Vuyst and Halverson (2004) used first and second-degree stochastic dominance to rank the economics of 18 continuous cropping/crop-fallow experimental treatments in the Northern

Great Plains as influenced by tillage system and nutrient management. Pendell *et al.* (2006) used stochastic dominance to examine the net return of continuous corn production using conventional and no-till tillage systems to quantify the value of carbon sequestration credits needed to encourage farmer adoption of carbon sequestration programmes.

In recent years, a method of stochastic dominance called stochastic efficiency with respect to a function (SERF) has been developed (Hardaker *et al.*, 2004b). Unlike the previously discussed stochastic dominance criterion, SERF orders a set of risk-efficient alternatives instead of finding a subset of dominated alternatives (Hardaker *et al.*, 2004a). It uses the concept of certainty equivalents (CEs) instead of CDFs for each alternative, and has stronger discriminating power than conventional stochastic dominance techniques. Grove (2006) and Grove *et al.* (2006) conducted a stochastic efficiency analysis and optimization of alternative agricultural water use and conservation strategies. Results showed that the portfolio of irrigation schedules for a risk averse farmer may include those with high production risk, due to the interaction of resource use between deficit irrigation alternatives when water is limited. Lien *et al.* (2007a) used SERF within a whole-farm stochastic modelling framework to analyse organic and conventional cropping systems in eastern Norway. SERF methodology was also applied by Lien *et al.* (2007b) to analyse optimal tree replanting on an area of recently harvested forestland. Pendell *et al.* (2007) examined the economic potential of using no-till and conventional tillage with both commercial nitrogen and cattle manure to sequester soil carbon in continuous corn production in northeastern Kansas. SERF was employed to determine preferred production systems under various risk preferences and to calculate utility-weighted CE risk premiums for estimating carbon credit values needed to motivate adoption of systems that sequester higher levels of carbon. Watkins *et al.* (2008) used SERF to evaluate the profitability and risk efficiency of Arkansas rice production management under no-till from the perspective of both the tenant and the landlord. Results indicated that risk-neutral and risk-averse tenants would benefit from no-till management, and that risk-neutral landlords would be indifferent between either no-till or conventional till. Archer and Reicosky (2009) evaluated the effects of no-till and five tillage system alternatives: fall residue management (Fall RM), Fall RM + strip-tillage (ST), spring residue management (Spring RM), Spring RM + ST, and Fall RM + Subsoil, relative to conventional mouldboard plough and chisel plough tillage systems on corn and soyabean yields and economic risks and returns. SERF risk analysis showed tillage system preferences ranked as: Fall RM > no-till > Fall RM + ST > Spring RM + ST, Spring RM > chisel plough > Fall RM + Subsoil > mouldboard plough for risk neutral or risk averse producers facing uncertain yield, crop price and input price conditions. Archer and Reicosky (2009) concluded that ST and no-till might be economically viable alternatives to conventional tillage systems for corn and soyabean production in the northern Corn Belt. Grove and Oosthuizen (2010) used an expected utility optimization model and SERF to evaluate deficit irrigation economics within a multi-crop setting while taking into account the increasing production risk of deficit irrigation. They concluded that although deficit irrigation was stochastically more efficient than full irrigation under limited water supply conditions, irrigation farmers would not voluntarily choose to conserve water through deficit irrigation and would require compensation to do so. Finally, Williams *et al.* (2010) examined the economic potential of producing a wheat and grain sorghum rotation with three different tillage strategies (conventional, reduced and no-till) compared with the Conservation Reserve Program (CRP) in a semiarid region. They used enterprise budgeting and SERF to determine the preferred management strategies under various risk preferences. Results indicated that CRP would be the preferred strategy for more risk-averse managers, i.e. only individuals who were risk-neutral or slightly risk-averse would prefer crop production to continued CRP enrolment.

There are many reasons why agricultural researchers carefully evaluate approaches to experimental data analysis. Agricultural experiments are typically highly complex, with many types of variables often collected at a wide range of temporal and spatial scales. Furthermore, research in the developing world is often conducted on-farm where simple and conventional experimental designs are often unsuitable. The above review of literature indicates that the SERF methodology may hold promise as a tool for analysis of long-term experimental data (in addition to traditional statistical approaches) when consideration of risk is involved. This study evaluates the efficacy of the SERF methodology for analysing conventional and conservation tillage systems using 14 years (1990–2003) of economic budget data collected from 35 treatments on 36 plots with continuous corn (*Zea mays*) and corn-soyabean (*Glycine max*) rotation cropping systems at the Iowa State University Northeast Research Station near Nashua, IA, USA. The field research experimental study was initiated in 1977; Chase and Duffy (1991) previously analysed economic data (net return) for the years 1978–1987. The primary objective of this research is to utilize the SERF approach in order to stochastically evaluate which of two different tillage system alternatives (chisel plough and no-till) maximize economic profitability (gross margin and net return) across individual (continuous corn, rotation corn and rotation soyabean), corn-soyabean rotation, and combined (continuous corn and corn-soyabean rotation) cropping systems over a range of risk aversion preferences. We analyse the tillage system alternatives across a continuum of risk since the risk aversion level of the decision maker is typically unknown; therefore, risk efficiency of the tillage alternatives is calculated using a range of assumed risk aversion levels. It is important to note that farmers balance tradeoffs between risk and profitability in their own personal way (i.e. attitudes towards risk depend on being a risk taker, risk neutral, risk avoider, or somewhere in between these three levels). Stochastic methods such as SERF allow a non-biased comparison of risk and return trade-offs with reasonable assumptions about how a farmer might value them, thereby avoiding having to directly ask individuals about their specific risk choices. In addition to the SERF analysis, we also conduct an economic analysis (gross margin and net return) of the tillage system alternatives using mean-*s.d.* and coefficient of variation (CV) decision criteria approaches. The primary purpose of the economic analysis is to illustrate that applying traditional decision criteria or simple statistical analysis to economic measures like gross margin or net return may be inconclusive and inadequate for ranking risky alternatives.

MATERIALS AND METHODS

Experimental design and economic budget data

Data for our study were obtained from 35 treatments on 36 plots (0.4 ha each) located at the Iowa State University Northeast Research Station near Nashua, IA, USA (43.0°N, 92.5°W). The experimental plots were established to quantify the impact of management practices on crop production and water quality (Bakhsh *et al.*, 2000; Karlen *et al.*, 1991). The soils are predominantly Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon silty-clay loam (fine-loamy, mixed, mesic Typic Hapludolls) and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls) with 30–40 g kg^{-1} (3–4%) organic matter (Voy, 1995). These soils are moderately well to poorly drained, lie over loamy glacial till and belong to the Kenyon-Clyde-Floyd soil association. Soil slopes varied from 1 to 3% among the various plots. The field experiments were established on a 15 ha research site in 1977 using a randomized complete block design with three replications. The seasonal water table at the site fluctuates from 20 to 160 cm and subsurface drainage tubes/pipes (10 cm diameter) were installed in the fall of 1979 at 120 cm depth and 29 m apart. Three experimental phases were conducted from 1978 to 1992, 1993 to 1998 and 1999 to 2003. From 1978 to 1992, there were four tillage treatments (chisel plough, mouldboard plough, no-till, ridge-till) under two different cropping sequences (continuous corn and both phases of a corn-soyabean rotation). Crop yield was the primary measurement from 1978 to 1989. Experimental data collected from 1990 included tile drain flow, nitrate concentration in tile drain flow, residual nitrogen (N) in soil, and crop yield, biomass and plant N uptake. From 1993 to 1998, there were two tillage treatments (chisel plough and no-till), with eight N management treatments (e.g. different rates, times of application, fertilizer type and/or swine manure) for chisel plough and four N treatments for no-till with no change in the number of crop sequences. The experimental data collected remained essentially the same as from 1990 to 1992 with the addition of runoff. Continuous corn was replaced with both phases of the corn-soyabean rotation in 1999, and the experiments were continued along with 10 fertilizer and swine manure treatments in the chisel plough system and two swine manure treatments in the no-till system. All plots received swine manure and/or urea-ammonium-nitrate (UAN) fertilizer each cropping season, with the swine manure applied in either fall or spring using application rates based on N or phosphorus (P) needs for the corn-soyabean/soyabean-corn rotations. Experimental measurements from 1999 to 2003 again focused on tile drain flow, nitrate concentration in drain flow, soil N, and crop yield, biomass and N uptake. Table 1 lists the major management practices for each of the 35 treatments (i.e. tillage and cropping systems) from 1990 to 2003 for the Nashua, IA, experiment. The major management practices for each of the 36 plots from 1990 to 2003 are listed in Table 2. Treatment IDs (Table 1) and plot IDs (Table 2) listed in bold contain mouldboard plough and ridge-till alternative tillage systems that were discontinued from the experiment in 1992 and were thus excluded from the economic and SERF analyses.

Economic budgets for 1990 to 2003 were developed as part of the web-based USDA Natural Resources Conservation Service (NRCS) – EconDoc exchange tool.

Table 1. Major management practices by treatment at the Northeastern Research and Demonstration Farm, Nashua, IA from 1990–2003.

Treatment ID	Treatment period	Cropping system	Tillage system	No. of treatment observations	Treatment ID	Treatment period	Cropping system	Tillage system	No. of treatment observations
1	1990–1992	CC	NT	9	19	1993–1998	CC	CP	18
2	1990–1993	CS	NT	15	20	1994–2003	CS	CP	30
3	1990–1992	SC	NT	9	21	1993–2003	SC	CP	27
4	1990–1992	CC	CP	9	22	2000–2003	CS	CP	12
5	1990–1993	CS	CP	18	23	2001–2003	SC	CP	9
6	1990–1992	SC	CP	9	24	1993–1998	CC	CP	18
7	1990–1992	CC	MP	9	25	1994–2003	CS	CP	30
8	1990–1992	CS	MP	9	26	1993–2003	SC	CP	33
9	1990–1992	SC	MP	9	27	1999	CC	CP	6
10	1990–1992	CC	RT	9	28	2000–2003	CS	CP	12
11	1990–1992	CS	RT	9	29	2000–2003	SC	CP	12
12	1990–1992	SC	RT	9	30	2000	CC	CP	3
13	1994–1998	CS	NT	15	31	2001–2003	CS	CP	9
14	1993–2000	SC	NT	27	32	2001–2003	SC	CP	9
15	1994–1999	CS	CP	21	33	2000–2003	CS	NT	12
16	1993–2000	SC	CP	27	34	2001–2003	SC	NT	9
17	1994–1999	CS	NT	18	35	1999–2000	SC	CP	6
18	1993–1998	SC	NT	18					

CS: corn-soyabean rotation with corn during even years; SC: soyabean-corn rotation with corn during odd years; CC: continuous corn; CP: chisel plough; RT: ridge-till; MP: mouldboard plough; NT: no-till.

Note: Treatment IDs listed in bold contain mouldboard plough and ridge-till alternative tillage systems that were discontinued from the experiment in 1992. These observations (54) were excluded from the economic and SERF analyses.

Table 2. Major management practices by plot at the Northeastern Research and Demonstration Farm, Nashua, IA from 1990–2003.

		Cropping system			Tillage system			
Plot ID	Dominant soil type	1978–1992	1993–1998	1998–2003	1978–1992	1993–1998	1998–2003	No. of plot observations
1, 7, 30	Readlyn, Kenyon	CS	CS	CS	CP	CP	CP	42
2 , 16 , 20	Readlyn, Kenyon	CS	CS	CS	MP	NT	NT	42
3, 24, 28	Readlyn, Kenyon	SC	SC	SC	NT	NT	CP	42
4, 18, 33	Kenyon	SC	CS	CS	CP	CP	CP	42
5, 21, 26	Readlyn, Kenyon	CC	CC	SC	CP	CP	CP	42
6 , 32 , 36	Readlyn, Kenyon	CC	SC	SC	RT	CP	CP	42
8 , 9 , 19	Readlyn, Floyd	CS	CS	CS	RT	CP	CP	42
10, 15, 29	Kenyon	CS	CS	CS	NT	NT	CP	42
11 , 23 , 27	Kenyon	SC	SC	SC	RT	CP	CP	42
12 , 17 , 34	Kenyon, Floyd	SC	SC	SC	MP	CP	CP	42
13 , 22 , 35	Readlyn, Floyd	CC	CC	CS	MP	CP	CP	42
14, 25, 31	Readlyn, Kenyon	CC	SC	SC	NT	NT	NT	42

CS: corn-soyabean rotation with corn during even years; SC: soyabean-corn rotation with corn during odd years; CC: continuous corn; CP: chisel plough; RT: ridge-till; MP: mouldboard plough; NT: no-till.

Note: Plot IDs listed in bold contain mouldboard plough and ridge-till alternative tillage systems that were discontinued from the experiment in 1992. These observations (54) were excluded from the economic and SERF analyses.

Primary data sources for the study included both Nashua experimental records and USDA National Agricultural Statistical Services (NASS) published data. The economic budget approach was used to summarize the per unit (hectare) revenue, gross margin (revenue – operational costs), and net return (revenue – total costs). This resulted in 450 treatment (tillage and cropping system) data observations (504 total observations minus 54 observations where mouldboard plough or ridge-till alternative tillage systems were used, Table 1) of enterprise budget data with detailed information about revenue, operational costs, overhead costs, total costs, gross margin and net return stored in the EconDocs economics information network. Historical market prices for commercial brands of each input (e.g. seeds, fuels, fertilizer, pesticides and herbicides, hours of machinery used and labour hours used) were calculated to determine the input operational costs for each plot in each specific year during the 1990–2003 period. Total net return to management for the chisel plough and no-till tillage systems were calculated for the Nashua experimental plots by subtracting the total production costs (including overhead costs) from the corresponding gross margin. Overhead cost is the part of the production cost allocated to each plot based on the overall farm expenses rather than those of the specific plot, such as machinery not specialized for a certain crop. Examples of overhead costs are the interest paid on an equipment loan or management costs directly related to production. To determine gross margin, we used average annual prices for corn and soyabeans from NASS county data records and annual yields reported by the Nashua experiment station. The gross margin and net return data were discounted to reflect the net present values.

Economic analysis with decision criteria

Although examining mean values for gross margin and net returns is useful, it is also important to examine variation in these economic measures to determine if risk affects the decision to use one system or another. Nearly all farm managers are risk averse, i.e. most will accept fewer dollars of return for fewer dollars of variability or loss. Each decision maker trades off risk and return at their own rate so it is difficult to prescribe a specific strategy for any one manager; however, some initial conclusions can be made with the use of decision criteria such as mean-*s.d.* and CV analyses. Risk-averse farm managers generally prefer systems that have both the largest mean gross margin or net return and smallest *s.d.* For example, given alternative A and baseline B farm management systems with two distributions of gross margin A_{gm} and B_{gm}, the mean-*s.d.* criterion predicts A_{gm} is preferred to B_{gm} if the mean of A_{gm} is larger than the mean of B_{gm} and the *s.d.* of A_{gm} is less than or equal to the *s.d.* of B_{gm}. If the mean and *s.d.* of A_{gm} are both larger than the mean and *s.d.* of B_{gm}, the mean-*s.d.* criterion cannot predict which distribution will be preferred without making additional assumptions about the farmer's risk preferences. The CV criterion (i.e. selecting the alternative with the lowest CV) measures risk (as measured by *s.d.* since the CV is simply the *s.d.* of a distribution divided by its mean) relative to mean gross margin and net return. The advantage of the CV criterion over the mean-*s.d.* criterion is that it simplifies the criteria to one value (CV) for each alternative and eliminates ambiguity. The CV criterion works well if the means of all the alternatives are similar and not close to zero. A disadvantage of both the CV and mean-*s.d.* criteria is that they ignore the skewness and extreme downside risks associated with some system alternatives.

Stochastic efficiency with respect to a function

Unlike stochastic dominance techniques (e.g. stochastic dominance with respect to a function) which typically find a set or subset of dominated alternatives, SERF identifies and orders utility efficient alternatives in terms of CEs for a specified risk preference. Hardaker *et al.* (2004a) state that the SERF procedure can potentially find a smaller set of preferred strategies (i.e. has stronger discriminating power) compared to stochastic dominance approaches, in addition to being more transparent and easier to implement. The CE of a risky alternative (in this study the type of tillage system) is the amount of money at which the decision maker is indifferent between the certain dollar value and the risky alternative. That is, the CE is the sure amount of money with the same utility as the expected utility of a risky alternative (e.g. Keeney and Raiffa, 1976). Strategies with higher CEs are preferred to those with lower CEs, and interpretation of the CEs is straightforward because, unlike utility values, they may be expressed in monetary terms (Lien *et al.*, 2007b). To calculate the CEs using SERF, various types of utility functions can be used (e.g. power, negative exponential, quadratic, log-log). In this study, similar to that of Lien *et al.* (2007b), we assume that farmers prefer more wealth to less and are risk-averse and thus we use a monotonic concave (i.e. $U' > 0$ and $U'' < 0$) power form for the utility function:

$$U(w) = \frac{w^{(1-r_r(w))}}{1 - r_r(w)} \tag{1}$$

where w is the initial wealth and r_r represents the coefficient of relative risk aversion with respect to wealth. The CEs can easily be determined by taking the inverse of the utility function:

$$CE(w, r_r) = U^{-1}(w, r_r) \tag{2}$$

The power utility function in Eq. (1) has the properties of constant relative risk aversion and decreasing absolute risk aversion, and in general can be used as a reasonable approximation of risk averting behaviour. Lien *et al.* (2007a) used a modified form (to account for wealth not at risk) of the power function for sustainable farm planning analysis, while other researchers (e.g. Pendell *et al.*, 2007) have used a negative exponential function to analyse farm decisions under risk. Schumann *et al.* (2004) demonstrated the SERF methodology using several types of utility functions. Results using the power and other functions (e.g. negative exponential, expo-power and log utility functions) with different underlying assumptions about absolute and relative risk aversion were very similar with the exception that the log utility function was not effective at discriminating between strategies over a wide range of risk aversion levels. The work of Schumann *et al.* (2004) shows that alternatives may change in rank at somewhat higher or lower levels as risk aversion is increased (depending on the type of utility function employed), but the general order of rankings for different utility functions over a range of risk aversion levels is similar.

As noted above, SERF analyses are dependent on the range of risk aversion coefficients used. The decision rule for SERF is to rank the risky alternatives (within the decision makers specified risk aversion coefficient) from the most preferred (i.e. the highest CEs at specified levels of risk aversion) to the least preferred (i.e. the lowest CEs at specified levels of risk aversion). Hardaker *et al.* (2004b) point out that another advantage of the SERF method is its ability to produce ranking of alternatives for any utility function with risk attitudes defined by corresponding ranges of absolute, relative or partial risk aversion coefficients. According to Arrow (1965), the relative risk aversion coefficient $r_r(w)$ is typically around 1. Anderson and Dillon (1992) proposed a rough categorization of degrees of risk aversion, based on the relative risk aversion with respect to wealth $r_r(w)$ in the range 0.5 (hardly risk averse) to approximately 4.0 (extremely risk averse). This range was used in this study for SERF analysis of the tillage system alternatives as well as including the situation where $r_r(w) = 0.0$, i.e. a risk neutral condition.

For a rational decision maker who is risk averse (the representative case for farm planning), the estimated CE is less than the expected monetary value (EV) of the risky strategy. The difference between the EV and the CE is called the risk premium (RP) (Hardaker *et al.*, 2004b), indicating the effect of the decision maker's risk aversion. Richardson *et al.* (2006) presents a utility-weighted RP that can be calculated once the strategies are ranked using the CE results (the RP changes as the degree of risk aversion increases). This is accomplished in Eq. (3) by subtracting the CE of a baseline (often a less preferred) strategy (B) from the CE of an alternative (often a preferred) strategy (A) where:

$$\mathrm{RP}(\mathrm{A}, \mathrm{B}, r_r) = \mathrm{CE}(\mathrm{A}, r_r) - \mathrm{CE}(\mathrm{B}, r_r) \tag{3}$$

The RP for a risk-averse decision maker reflects the minimum amount ($\$\ \mathrm{ha}^{-1}$ for the tillage systems considered in this study) that would have to be paid to a decision maker to justify a switch from alternative A to B (Hardaker *et al.*, 2004b).

SERF application

The SERF model utilizing the power utility function was programmed in Microsoft Excel™ and calculations verified against examples presented in the Simetar© 2006 User Manual (Richardson *et al.*, 2006). Statistical analyses were performed using SigmaStat 3.11 (Systat, 2006) to determine if significant tillage × rotational effects existed in the Nashua, IA data set. Holm-Sidak tests for multiple comparisons at the $\alpha = 0.05$ level showed statistically significant differences ($p \leq 0.001$) between the individual (continuous corn, rotation corn and rotation soyabean) cropping systems for both gross margin and net return across the chisel plough and no-till tillage system alternatives. In addition, student t-tests at the $\alpha = 0.05$ level showed statistically significant differences ($p \leq 0.001$) between continuous corn and corn-soyabean rotation cropping systems for both gross margin and net return across the chisel plough and no-till tillage system alternatives (indicating that significant rotational effects did indeed exist). For many SERF analyses in the literature (e.g. Archer and Reicosky, 2009), net return or gross margin distributions are simulated using multivariate empirical distributions (MVEs) of different variables including crop yields, crop prices and other input prices (e.g. fuel). The MVE distribution avoids imposing an explicit distribution on the variables and is suggested in situations where a limited number of observations precludes evaluating the fit of standardized probability distributions (Richardson *et al.*, 2000). That was not the case in this study; therefore, actual gross margin and net return distributions were used. Based on the statistical analyses, CE curves for both the individual (continuous corn, rotation corn and rotation soyabean) and corn-soyabean rotation cropping systems were calculated for the chisel plough and no-till tillage system alternatives. However, farm managers often analyse their production systems on a whole-farm basis when considering major changes in management such as the adoption of no-till. Therefore, CE curves were also calculated for combined (both continuous corn and corn-soyabean rotation) cropping systems for the chisel plough and no-till tillage system alternatives. All CE curves were produced by calculating 25 discrete CE values for each curve over the entire range of relative risk aversion (i.e. r_r between 0 and 4) using an initial wealth value of \$250 ha^{-1} (the mean net return for the 450 treatment observations).

RESULTS

Economic analysis with decision criteria

Individual and rotation cropping system economic data for Nashua, IA are shown primarily to give an indication of the underlying yield and total revenue (Table 3), and the operational and total costs (Table 4) used in calculating gross margins and net returns (Table 5). A simple examination of the mean-*s.d.* decision criteria for total revenue (the starting point for the economic budget analysis) in Table 3 shows that the chisel plough tillage system for rotation corn had the highest means across the individual cropping systems; however, the no-till tillage system for continuous corn had the lowest *s.d.*, CV and range. In general, the no-till tillage system had higher mean total revenues across the individual cropping systems whereas the chisel plough tillage system had lower *s.d.*s. A comparison of continuous corn versus the corn-soyabean rotation shows that the rotation cropping system had higher mean total revenues for both tillage system alternatives, but the continuous corn cropping system had lower *s.d.*s (Table 3). The results for total cost in Table 4 were similar to the total revenue results in Table 3 with the exceptions that: (1) the chisel plough tillage system for continuous corn had the highest mean total cost and (2) for both tillage system alternatives, the continuous corn mean total cost was higher than the corn-soyabean rotation mean total cost.

Examining the mean-*s.d.* decision criteria for gross margins in Table 5 shows that the results were somewhat more variable than the total revenue/costs results. The no-till tillage system for rotation soyabean had the highest means across the individual cropping systems; however, the no-till tillage system for continuous corn had the lowest

Table 3. Individual (continuous corn, rotation corn, rotation soyabean) and rotation (corn-soyabean) yield and total revenue for the Nashua, IA tillage system alternatives.

	Yield (t ha^{-1})			Total revenue (\$ ha^{-1})	
	Chisel plough	No-till		Chisel plough	No-till
Corn (continuous)			Corn (continuous)		
Mean	6.25	7.19	Mean	544.73	612.37
s.d.	1.71	0.82	*s.d.*	132.86	64.49
Coefficient of variation	0.27	0.11	Coefficient of variation	0.24	0.11
Maximum	9.64	8.12	Maximum	390.23	706.70
Minimum	2.47	5.97	Minimum	−261.14	535.59
Range	7.17	2.15	Range	651.37	171.11
Corn (rotation)			Corn (rotation)		
Mean	8.71	7.40	Mean	683.30	636.92
s.d.	7.02	1.72	*s.d.*	111.70	129.71
Coefficient of variation	0.81	0.23	Coefficient of variation	0.16	0.20
Maximum	86.22	10.42	Maximum	906.95	910.97
Minimum	4.00	3.35	Minimum	383.76	321.70
Range	82.22	7.07	Range	523.19	589.27
Soyabean (rotation)			Soyabean (rotation)		
Mean	2.93	2.93	Mean	589.21	622.98
s.d.	0.55	0.49	*s.d.*	140.44	145.47
Coefficient of variation	0.19	0.17	Coefficient of variation	0.24	0.23
Maximum	4.17	3.71	Maximum	995.77	991.17
Minimum	1.55	1.49	Minimum	347.37	332.39
Range	2.62	2.22	Range	648.40	658.78
Corn-soyabean (rotation)			Corn-soyabean (rotation)		
Mean	5.75	5.25	Mean	635.18	630.23
s.d.	5.71	2.58	*s.d.*	135.43	137.10
Coefficient of variation	0.99	0.49	Coefficient of variation	0.21	0.22
Maximum	86.22	10.42	Maximum	995.77	991.17
Minimum	1.55	1.49	Minimum	347.37	321.70
Range	84.67	8.93	Range	648.40	669.47

s.d./range and the no-till tillage system for rotation corn had the lowest CV. The no-till tillage system had higher means and lower *s.d.*s, CVs and ranges for corn (both continuous and rotation) while the opposite was true for rotation soyabean where the chisel plough tillage system performed better. Similar to total revenue results in Table 3, a comparison of continuous corn versus the corn-soyabean rotation in Table 5 shows that the rotation cropping system had higher mean gross margins for both tillage system alternatives but the continuous corn cropping system had lower *s.d.*s. Table 5 also shows that net return results followed the identical pattern as the gross margin results for the individual and rotation cropping systems.

There was no tillage system alternative that had the highest mean and lowest *s.d.*, CV and range across the gross margin and net return combinations for the individual and rotation cropping systems. For both gross margin and net return, the rotation cropping system had higher means and *s.d.*s compared to continuous corn for the tillage system alternatives (Table 5). This indicates a larger degree of risk relative to the expected return, i.e. there would be some amount of net income given up to

Table 4. Individual (continuous corn, rotation corn, rotation soyabean) and rotation (corn-soyabean) operational and total cost for the Nashua, IA tillage system alternatives.

	Operational cost ($ ha^{-1})			Total cost ($ ha^{-1})	
	Chisel plough	No-till		Chisel plough	No-till
Corn (continuous)			Corn (continuous)		
Mean	355.41	342.38	Mean	458.20	443.99
s.d.	58.44	37.70	*s.d.*	63.70	43.81
Coefficient of variation	0.16	0.11	Coefficient of variation	0.14	0.10
Maximum	446.79	393.38	Maximum	559.13	503.08
Minimum	254.45	315.29	Minimum	339.30	409.97
Range	192.34	78.09	Range	219.83	93.11
Corn (rotation)			Corn (rotation)		
Mean	337.15	321.08	Mean	435.25	412.27
s.d.	55.05	46.89	*s.d.*	55.00	50.62
Coefficient of variation	0.16	0.15	Coefficient of variation	0.13	0.12
Maximum	457.99	415.01	Maximum	573.94	518.46
Minimum	98.08	227.24	Minimum	326.84	320.06
Range	359.91	187.77	Range	247.10	198.40
Soyabean (Rotation)			*Soyabean (Rotation)*		
Mean	224.73	195.65	Mean	295.77	255.20
s.d.	48.44	48.48	*s.d.*	53.54	51.63
Coefficient of variation	0.22	0.25	Coefficient of variation	0.18	0.20
Maximum	352.44	283.43	Maximum	430.65	350.14
Minimum	140.48	113.86	Minimum	206.90	171.18
Range	211.96	169.57	Range	223.75	178.96
Corn-soyabean (rotation)			Corn-soyabean (rotation)		
Mean	279.65	260.91	Mean	363.92	336.92
s.d.	76.42	78.81	*s.d.*	88.39	93.80
Coefficient of variation	0.27	0.30	Coefficient of variation	0.24	0.28
Maximum	457.99	415.01	Maximum	573.94	518.46
Minimum	98.08	113.86	Minimum	206.90	171.18
Range	359.91	301.15	Range	367.04	347.28

reduce risk with the rotation cropping system. Based on the mean-*s.d.* decision criteria, Table 5 shows that there would probably be less motivation for a farm manager to use the chisel plough tillage system as in general it had lower mean gross margins and net returns with higher *s.d.*s than the no-till tillage system. However, it is worth reiterating that this result did not universally hold, i.e. for rotation corn the no-till tillage system had significantly higher *s.d.*s than the chisel plough tillage system for both gross margin and net return (this undoubtedly contributed to the higher *s.d.*s for the no-till tillage system in the corn-soyabean rotation). As indicated previously, farm managers will generally give up income for reduced variability. If the manager accepts a dollar less of return for a dollar less of risk (*s.d.*) at a one-to-one ratio, the CV can be used as a reasonable decision criterion. For both gross margin and net return, the CV results across the individual and rotation cropping systems were nearly identical to the mean-*s.d.* criteria results (Table 5). No-till tillage system CVs for gross margin and net return ranged from 0.32 to 0.54, which indicated that the *s.d.* was consistently near one-half of the mean or less for the individual and rotation cropping systems. Chisel

Table 5. Individual (continuous corn, rotation corn, rotation soyabean) and rotation (corn-soyabean) gross margin and net return for the Nashua, IA tillage system alternatives.

	Gross margin ($ha^{-1})			Net return ($ha^{-1})	
	Chisel plough	No-till		Chisel plough	No-till
Corn (continuous)			Corn (continuous)		
Mean	189.32	269.99	Mean	86.53	168.38
s.d.	134.34	86.29	*s.d.*	134.42	89.46
Coefficient of variation	0.71	0.32	Coefficient of variation	1.55	0.53
Maximum	493.50	389.97	Maximum	390.23	288.52
Minimum	−73.15	148.46	Minimum	−165.35	38.76
Range	566.65	241.51	Range	558.58	249.76
Corn (rotation)			Corn (rotation)		
Mean	346.15	315.84	Mean	248.05	224.65
s.d.	99.33	117.74	*s.d.*	101.52	116.07
Coefficient of variation	0.29	0.37	Coefficient of variation	0.41	0.52
Maximum	563.27	562.78	Maximum	478.42	465.12
Minimum	102.42	69.46	Minimum	2.95	−30.14
Range	460.85	493.32	Range	475.47	495.26
Soyabean (rotation)			Soyabean (rotation)		
Mean	364.48	427.33	Mean	293.44	367.78
s.d.	165.86	164.04	*s.d.*	170.44	165.67
Coefficient of variation	0.46	0.38	Coefficient of variation	0.58	0.45
Maximum	845.93	801.74	Maximum	780.30	738.02
Minimum	92.10	102.57	Minimum	11.67	38.49
Range	753.83	699.17	Range	768.63	699.53
Corn-soyabean (rotation)			Corn-soyabean (rotation)		
Mean	355.53	369.32	Mean	271.26	293.31
s.d.	137.60	152.39	*s.d.*	142.71	159.02
Coefficient of variation	0.39	0.41	Coefficient of variation	0.53	0.54
Maximum	845.93	801.74	Maximum	780.30	738.02
Minimum	92.10	69.46	Minimum	2.95	−30.14
Range	753.83	732.28	Range	777.35	768.16

plough tillage system CVs were fairly high for the continuous corn cropping system, 0.71 and 1.55 for gross margin and net return, respectively. It is interesting to note that the gross margin and net return CVs in Table 5 were substantially higher than the CVs for total revenue and total cost in Tables 3 and 4, respectively.

Table 5 clearly illustrates that applying traditional decision criteria or simple statistical analyses to economic measures like gross margin or net return may be inadequate and unsatisfactory for ranking risky alternatives, and may depend highly on the overall management goals and objectives of the decision maker. For example, Table 5 shows the benefits (e.g. higher mean gross margin and net return) of the corn-soyabean rotation compared to the continuous corn cropping system; however, the rotation cropping system has a somewhat larger degree of risk (e.g. higher *s.d.*s for both tillage system alternatives) relative to the expected return. In summary, application of decision criteria and statistical analysis alone to the economic measures can result in contradictory and inconclusive rankings, i.e. if the farm manager is interested in ranking tillage system alternatives over a range of risk then the type of analyses described above may not be sufficient. Furthermore, the high variability of decision criteria such as CV for the chisel plough tillage system (particularly for continuous corn) also indicates that further analysis should be performed. In the next section, we demonstrate the use of stochastic efficiency to overcome the shortcomings of the various decision criteria and statistical analysis approaches. The SERF method considers the entire gross margin and net return distribution, not simply one point of measurement, as does the mean-*s.d.* analysis.

SERF analysis

To further understand SERF methodology advantages over traditional (e.g. stochastic dominance) methods, gross margin and net return CDFs for the Nashua, IA individual cropping systems and tillage system alternatives are shown in Figures 1 and 2, respectively. First-degree stochastic dominance (FSD) can be implemented by simply observing the position of the CDF curves for all alternatives under consideration. In order for FSD to be valid, the CDF curve of one alternative must be entirely to the right of another alternative (i.e. the curves must be non-intersecting). Obviously, FSD is inconclusive since the gross margin (Figure 1) and net return (Figure 2) CDFs for the individual cropping systems intersect each other at several points including intersection on the negative tail of the CDFs. Therefore, the decision maker would require additional information (based on the area underneath each CDF), which means ranking the tillage system alternatives based on second-degree stochastic dominance (SSD). However, SSD also may not hold for the tillage system alternatives, especially where there are complex interactions in the tails of the CDFs. For example, in Figures 1 and 2 no-till rotation soyabean is the principally dominant tillage and cropping system; however, other tillage and cropping system CDFs cross the no-till gross margin and net return CDFs at the lower tail (representing the risk below the 0.25 CDF level). In addition, SSD considers only risk averse and not risk preferring behaviour.

For ease in interpreting the SERF results, the CEs of the tillage system alternatives can be graphed on the vertical axis against risk aversion on the horizontal axis over the range of the relative risk aversion coefficients (RRACs). Where the lines intersect, the strategies are equivalent to each other in terms of risk preferences. SERF gross margin and net return results for the individual, rotation, and combined (i.e. all crops) cropping systems using an initial wealth (w in Eq. (1)) of \$250 ha^{-1} are shown in Figures 2–4. SERF gross margin and net return CEs for the Nashua, IA individual cropping systems and chisel plough/no-till tillage system alternatives are shown in Figure 2a and 2b, respectively. The gross margin results in Figure 2a show that the no-till tillage and rotation soyabean system was the most preferred and the chisel plough tillage and continuous corn system the least preferred across the entire range of risk aversion. The chisel plough tillage rotation soyabean and chisel plough tillage rotation corn systems switch between the second and third most preferred system, respectively, at a fairly high level of risk aversion (i.e. RRAC > 3.0). For a risk neutral decision maker, the overall difference between the gross margin of

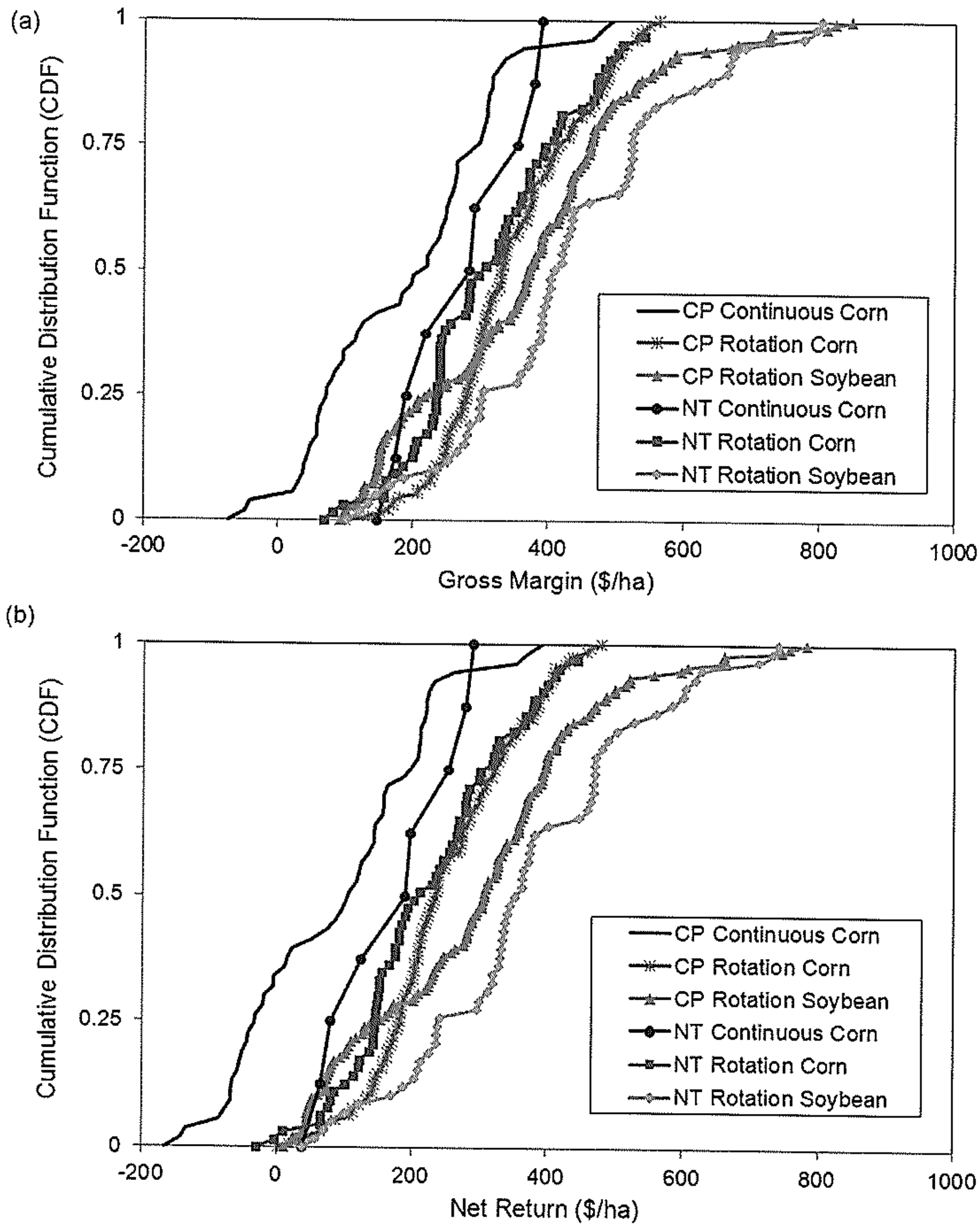

Figure 1. Gross margin (a) and net return (b) cumulative distribution functions for the Nashua, IA individual cropping systems (continuous corn, rotation corn and rotation soyabean) and chisel plough (CP) and no-till (NT) tillage system alternatives.

the tillage and cropping system alternatives was ~ $240 ha^{-1}. This indicates a risk neutral farm manager would need to receive ~ $240ha^{-1} to be indifferent between the no-till tillage and rotation soyabean system (highest ranked) and the chisel plough tillage and continuous corn system (lowest ranked). The difference in gross margin

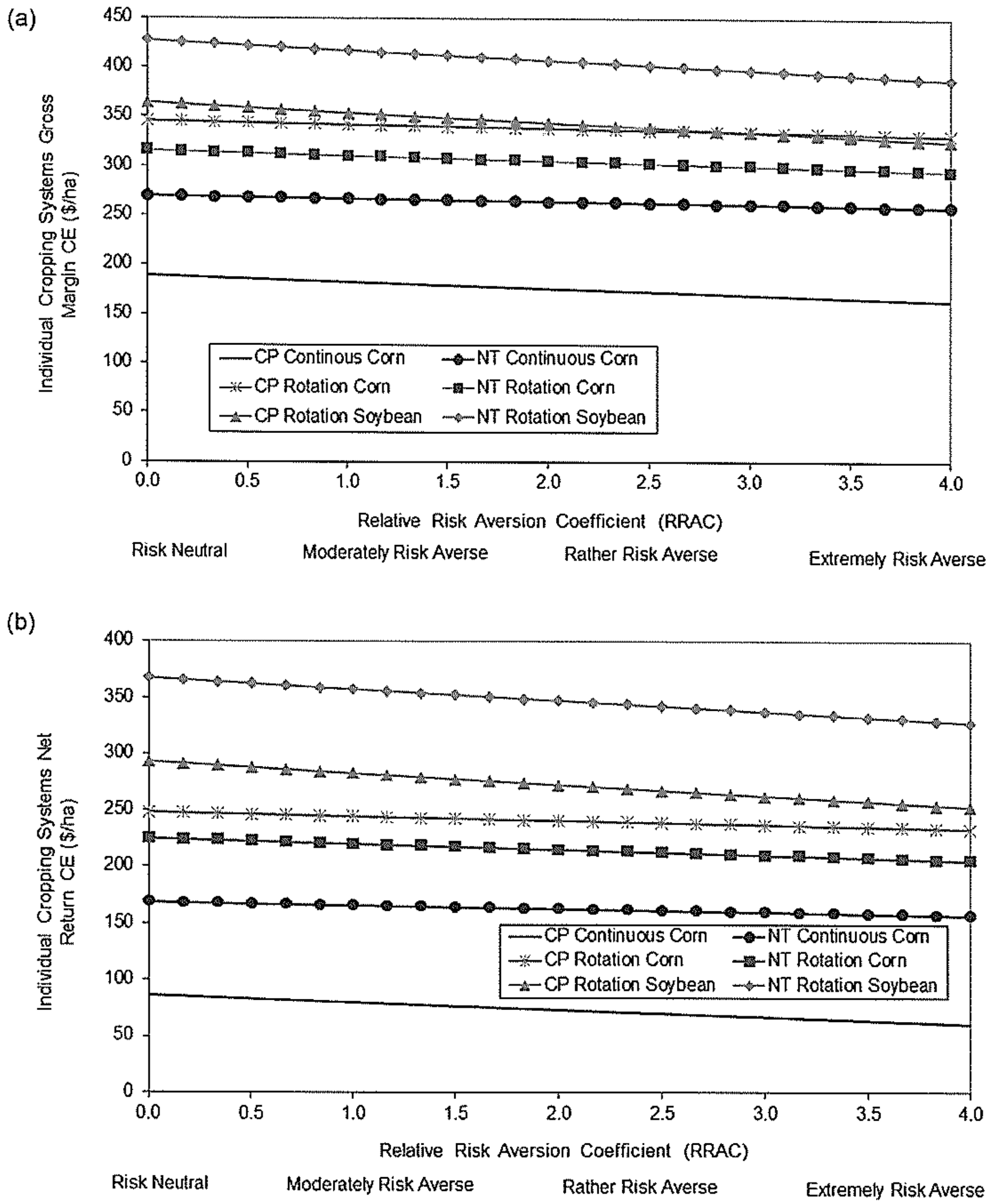

Figure 2. SERF gross margin (a) and net return (b) certainty equivalents (CEs) for the Nashua, IA individual cropping systems (continuous corn, rotation corn and rotation soyabean) and chisel plough (CP) and no-till (NT) tillage system alternatives.

between the tillage system alternatives remained nearly constant as risk aversion increased (Figure 2a). The net return results in Figure 2b were similar to the gross margin results with the exception that the chisel plough tillage rotation soyabean system was preferred over the chisel plough tillage continuous corn system across the entire range of risk aversion (i.e. the CE lines did not intersect as risk aversion increased).

SERF gross margin and net return CEs for the Nashua, IA continuous corn/corn-soyabean rotation cropping systems and chisel plough/no-till tillage system alternatives are shown in Figures 3a and 3b, respectively. For both gross margin and net return, the no-till tillage system was preferred to the chisel plough tillage system when ranking within the continuous corn and the corn-soyabean rotation cropping systems. For gross margin, the CE difference between the no-till and chisel plough tillage system alternatives was very small, particularly at the extremely risk averse level (RRAC > 3.5). In addition to illustrating the differences between the tillage system alternatives, Figure 3 also clearly demonstrates the superiority of the corn-soyabean rotation cropping system compared to the continuous corn cropping system. For gross margin, an extremely risk averse farm manager would need to receive ~ \$80 ha^{-1} to be indifferent between the no-till tillage continuous corn system and the no-till tillage corn-soyabean rotation system. Furthermore, this 'indifference' payment increases to ~\$100 ha^{-1} for the risk neutral decision maker.

When considering major changes in management such as the adoption of no-till, farm managers often analyse their production systems on a whole-farm basis. Figure 4 shows combined (both continuous corn and corn-soyabean rotation) SERF gross margin and net return CEs for the Nashua, IA chisel plough and no-till tillage system alternatives. For both gross margin and net return, the no-till tillage system was clearly preferred to the chisel plough tillage system. For gross margin CEs, the no-till tillage system consistently outperformed the chisel plough tillage system CE by ~ \$30 ha^{-1} across all levels of risk aversion. A comparable result was found for the net return CEs with the no-till tillage system outperforming the chisel plough tillage system by a slightly higher amount (~ \$40 ha^{-1}).

The RP results for corn (continuous and rotation) gross margin and continuous corn and corn-soyabean rotation gross margin relative to no-till continuous corn for the Nashua, IA chisel plough/no-till tillage system alternatives are shown in Figures 5a and 5b, respectively. The RP results were calculated using Eq. (3) and compare the absolute differences in the CEs for the no-till tillage and continuous corn system (the baseline system) to the corn (continuous and rotation, Figure 5a) and continuous corn and corn-soyabean rotation (Figure 5b) systems across the entire range of risk aversion. For corn (continuous and rotation) gross margin (Figure 5a), the RPs for the chisel plough tillage and no-till tillage rotation corn systems were positive, indicating a risk-neutral farm manager would pay up to ~ \$75 ha^{-1} to use the chisel plough tillage rotation corn system instead of the no-till tillage continuous corn system. The RP for the chisel plough tillage continuous corn system was negative, indicating a farm manager would not pay to use this system based on economic considerations alone. For continuous corn and corn-soyabean rotation cropping systems gross margin (Figure 5b), the RPs for the no-till tillage and chisel plough tillage corn-soyabean rotation systems again were positive, indicating a farm manager would pay up to \$100 ha^{-1} at the risk neutral level (or ~ \$80 ha^{-1} at the extremely risk averse level) to use the no-till tillage corn-soyabean rotation system instead of the no-till tillage

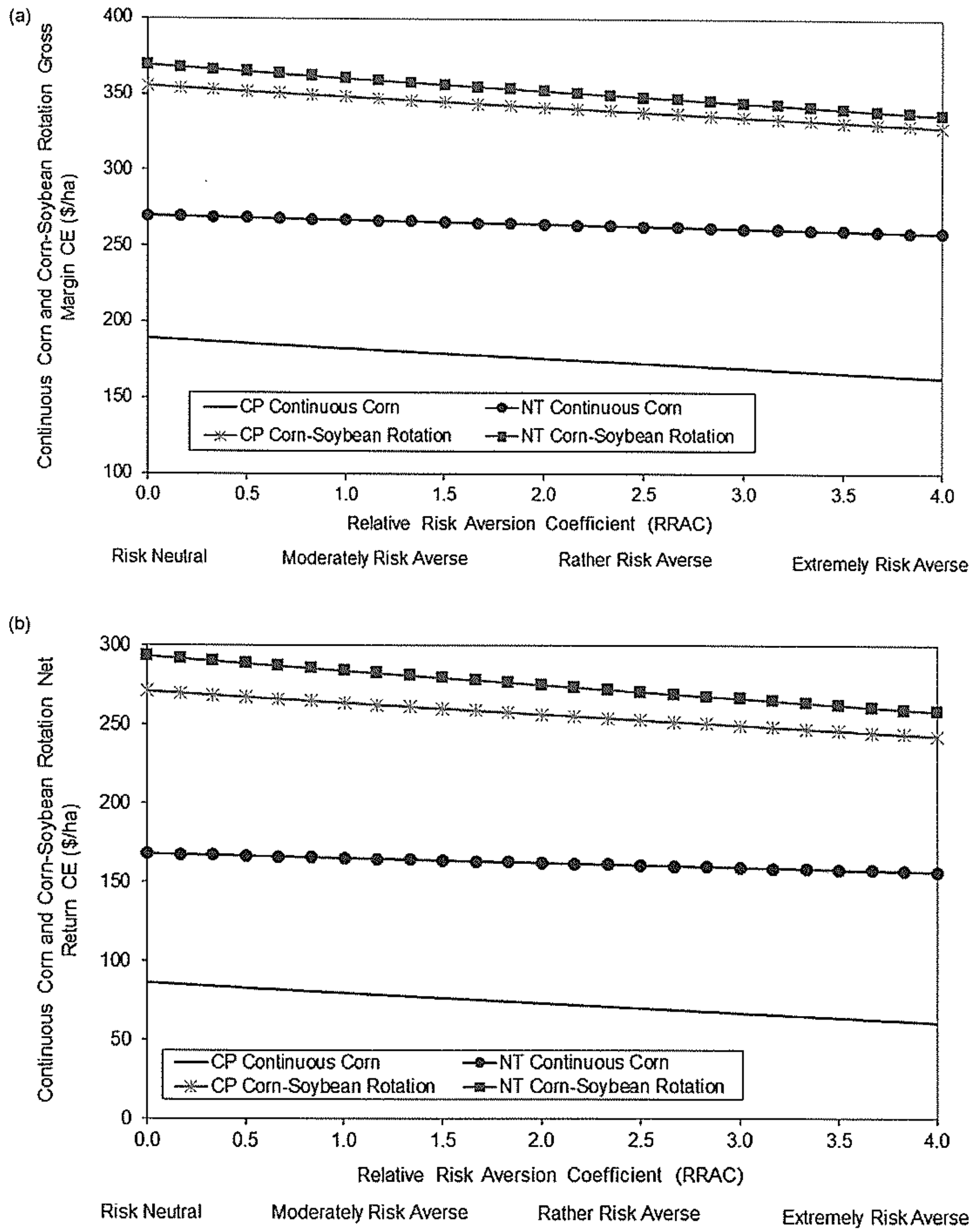

Figure 3. SERF gross margin (a) and net return (b) certainty equivalents (CEs) for the Nashua, IA continuous corn and corn-soyabean rotation cropping systems and chisel plough (CP) and no-till (NT) tillage system alternatives.

continuous corn system. Furthermore, the risk premium gross margin differences between the no-till tillage and chisel plough tillage corn-soyabean rotation systems were smaller (< \$15 ha^{-1}, Figure 5b) than for the chisel plough tillage and no-till tillage rotation corn systems (> \$25 ha^{-1}, Figure 5a).

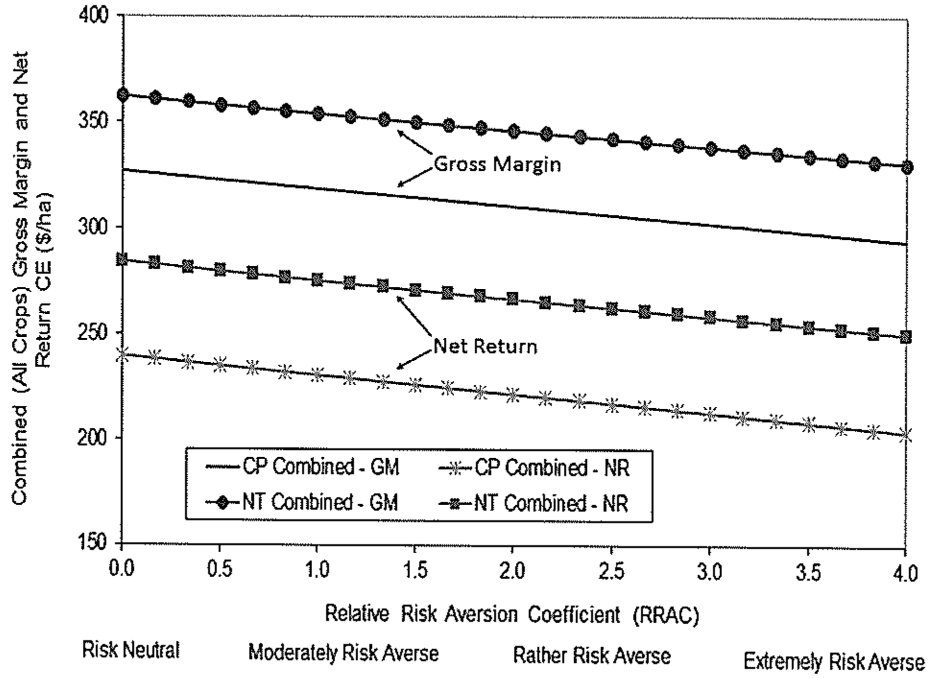

Figure 4. SERF gross margin (GM) and net return (NR) certainty equivalents (CEs) for the Nashua, IA combined (all crops) cropping systems and chisel plough (CP) and no-till (NT) tillage system alternatives.

DISCUSSION

Interest in conservation tillage has increased steadily over the past few decades because of the potential of these systems to conserve soil moisture, improve soil structure, reduce soil erosion and increase net returns to producers. However, lower production costs found in conservation tillage systems including labour, fuel, repairs and a reduction in frequency of field equipment operations (Burgess *et al.*, 1996) may be essentially offset by increased chemical costs and/or a decrease in yield for most crops when these systems are used (Klemme, 1985; Williams, 1988). Consequently, a large number of studies comparing net return or gross margin between conventional and conservation tillage systems are contradictory. The above risk analysis results indicate that, in general, the no-till tillage system was more risk efficient compared to the chisel plough tillage system irrespective of the level of risk aversion and agree with those of Archer and Reicosky (2009), Watkins *et al.* (2008) and Williams *et al.* (2010). In a SERF net return analysis of popular tenant and landlord rental arrangements used in eastern Arkansas rice production, Watkins *et al.* (2008) found that all tenant arrangements using no-till management ranked higher than their conventional tillage counterparts across the entire range of risk aversion, and that landlord arrangements using no-till management tended to dominate their conventional tillage counterparts as risk aversion increased. For a 7-year corn-soyabean rotation, Archer and Reicosky (2009) showed that net return CE values for a no-till tillage system far exceeded those for a chisel plough tillage system across a range of risk preferences from risk neutral to extremely risk averse. Furthermore, Archer and Reicosky (2009) found average yields

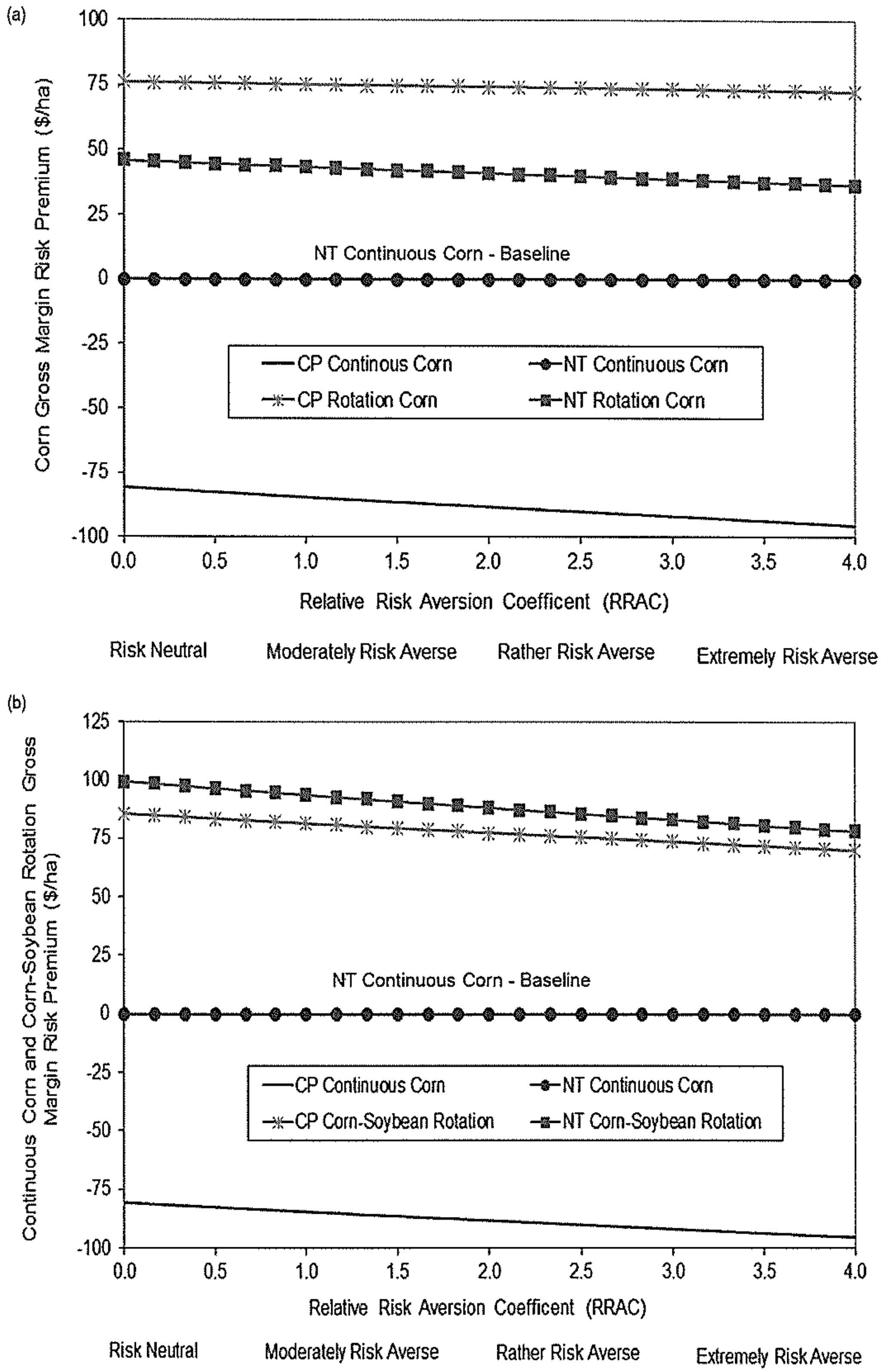

Figure 5. Corn (continuous and rotation) gross margin (a) and continuous corn and corn-soyabean rotation gross margin (b) risk premiums relative to no-till (NT) continuous corn for the Nashua, IA chisel plough (CP) and NT tillage system alternatives.

over the 7-year study were not significantly different among eight tillage systems, but average net returns for the no-till tillage system were \$85 ha^{-1} higher than for the mouldboard plough tillage system. Williams *et al.* (2010) found that a no-till tillage system had higher SERF net return RPs (across the entire range of risk aversion) compared to a conventional tillage system for a 3-year wheat-sorghum-fallow rotation (however, the no-till tillage system did not outperform a CRP strategy or a reduced-till tillage system). Our results are in contrast to those presented by Klemme (1985) showing that no-till tillage systems were dominated (using first and second-degree stochastic dominance techniques) by chisel plough tillage systems for a corn-soyabean rotation in north-central Indiana. In addition, Chase and Duffy (1991) demonstrated that the mouldboard plough system produced statistically significant higher returns to land, labour and management than the other Nashua, IA tillage systems for the years 1978–1987. For the Nashua, IA data set used in our study (1990–2003), both environmental (e.g. hail in 1994 and 1995) and management changes (e.g. a reduction in chemical fertilizer rates between 1990–93 and 1994–99 on most plots) occurred which could have affected yield and yield variability during the study period (Malone *et al.*, 2007). Indeed, Klemme (1985) stated that changes in yields or costs, such as reduced herbicide costs through improved weed control in no-till planting, could lead to quite different tillage system rankings for risk-averse farmers (and consequently improve the relative attractiveness of no-till). This observation was substantiated by Williams *et al.* (2010) who noted that in the current economic environment the volatility of input costs may play nearly as big a role in tillage and cropping decisions as commodity prices.

There is a growing scientific consensus that environmental and other sustainability benefits of no-till may outweigh potential disadvantages, especially on highly erodable land (Grandy *et al.*, 2006; Quincke *et al.*, 2007). Despite the superior performance of the mouldboard plough system in the early years of the Nashua, IA experiment, Chase and Duffy (1991) pointed out that 'the adoption of conservation tillage practices can be accomplished with lowering economic returns or significantly increasing chemical use'. Indeed, Figures 2–4 show that the no-till conservation tillage system performed very well compared to the chisel plough conventional tillage system. However, it is important to note that: (1) the SERF results focus strictly on economics without consideration of other externalities (e.g. environmental impacts such as soil erosion) which may render a conventional tillage system unsustainable in the long term and (2) most studies comparing economic and/or environmental data between conventional and conservation tillage systems omit an important aspect that affects profit and sustainability – the impact on farm business risk. If decisions are made without considering risk, the decision maker can easily determine which strategy is best, the one with the greatest average net income (Richardson, 2006). When decisions are made considering risk, such as in agriculture, the decision maker cannot use such a simple rule because the economic return for each alternative is a distribution of returns rather than a single value (Ribera *et al.*, 2004). In this study, we have used the SERF methodology to expand upon this concept, i.e. the application of SERF for quantifying the effects of tillage system alternatives on various economic outcomes (e.g. net return and gross margin) when comparing alternative production systems over time.

SUMMARY AND CONCLUSIONS

The primary goal of this study was to evaluate the efficacy of SERF methodology as a tool for analysis of long-term experimental data (in addition to traditional statistical approaches) when consideration of risk is involved. In this study, SERF was used for ranking conventional and conservation tillage systems using 14 years (1990–2003) of economic budget data collected from 36 plots at the Iowa State University Northeast Research Station near Nashua, IA. The SERF stochastic dominance CE approach was utilized in order to stochastically evaluate which of two different tillage system alternatives (chisel plough and no-till) maximize economic profitability (gross margin and net return) across individual (continuous corn, rotation corn and rotation soyabean), corn-soyabean rotation, and combined (all crops) cropping systems over a range of risk aversion preferences. In addition to the SERF analysis, an economic analysis of the tillage system alternatives was performed using decision criteria and simple statistical measures. Decision criteria analysis of the economic measures alone provided somewhat contradictory and non-conclusive rankings, e.g. examination of the decision criteria results for gross margin and net return showed that different tillage system alternatives were the highest ranked depending on the criterion and the cropping system (e.g. individual or rotation). SERF analysis results for the tillage systems were also dependent on the cropping system (individual, rotation or whole-farm combined) and economic outcome of interest (gross margin or net return) but only marginally on the level of risk aversion. For the individual cropping systems (continuous corn, rotation corn and rotation soyabean), the no-till tillage and rotation soyabean system was the most preferred and the chisel plough tillage and continuous corn system the least preferred across the entire range of risk aversion for both gross margin and net return. The no-till tillage system was preferred to the chisel plough tillage system when ranking within the continuous corn and the corn-soyabean rotation cropping systems for both gross margin and net return. Finally, when analysing the tillage system alternatives on a whole-farm basis (i.e. combined continuous corn and corn-soyabean rotation), the no-till tillage system was clearly preferred to the chisel plough tillage system for both gross margin and net return.

Our study illustrates that using the SERF methodology to examine gross margin and net return risk can be useful in analysing tillage systems. However, the difference in tillage systems, considering risk, may be difficult to discern because environmental/management changes and production cost instability can cause one tillage system to be selected over another. A critical factor that is difficult to enumerate but could affect yield levels (and thus gross margin and net return) is the farmer learning curve for mastering the management of a new tillage system. Lockwood (1987) noted that farmers are typically not able to adapt newer technologies to farm-specific conditions until a sizeable part of the 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 average net returns or gross margins (Yiridoe *et al.*, 2000). Generally, adoption of new tillage systems requires managerial and potentially significant economic adjustments, especially if purchase of new equipment is necessary. This study helps demonstrate that increased variability associated with expected yields and related gross margins/net returns make risk preference a vital consideration in the adoption of a different tillage system. This study also indicates that the SERF method appears to be a useful and easily understood tool to assist farm managers, experimental researchers, and potentially policy makers and advisers on similar problems of agricultural risk as demonstrated herein.

Several limitations of the study should be mentioned to assist in quantification of the results. First, similar to Lien *et al.* (2007b), we have used a single utility function that approximates an inter-temporal utility function. Future research should consider alternative utility functions for SERF such as the negative exponential, expo-power and log utility functions. Second, as previously stated, a shift from conventional to conservation tillage is often accompanied by farm reorganization and managerial changes. Farm reorganization can include farm expansion, machinery resizing and a shift of crop mix, the analyses of which are beyond the scope of this study. Finally, in this study, we have illustrated the use of the SERF framework for the problem of selecting an alternative tillage system based on long-term experimental data. The only behavioural attribute considered was risk attitude with regard to income. However, farmers have multiple farm management objectives including managing financial risk, institutional risk (e.g. maintaining government programme eligibility), and soil conservation or environmental benefits, which also deserve evaluation. The extension of the SERF methodology to these aspects of farm management with risk aversion included is left for future research.

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