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Economic risk analysis of agricultural tillage systems using the SMART stochastic efficiency software package

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Abstract: At the national level, one of the major challenges to United States agriculture during the coming decades will be to produce sufficient food and fiber 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. Farmers invest heavily in inputs (e.g., management and labor, equipment purchase and maintenance, fuel, seed, fertilizers, pesticides, etc.) every single farming season, but face uncertain natural and market conditions at harvest. One of the major decision-making processes farmers face is tillage system selection, either across the whole farm or for a specific crop. This decision 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 incontrovertible benefits, farmers in the United States 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., increased herbicide use under no-till) impacts. More specifically, farmers lack knowledge about risks related to tradeoffs between the upfront (or short-term) costs of implementing conservation management practices compared to long-term economic benefits that might be expected in the future.

Recently, a variant of stochastic dominance called stochastic efficiency with respect to a function (SERF) has been developed and applied. 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. The Screening and Multivariate Analysis for Risk and Tradeoffs (SMART) software package (both web-based and MS Excel spreadsheet applications) has been developed for integrated economic and environmental risk analysis through ranking of risky alternatives using the CE and SERF concepts. The SMART software also functions as a risk visualization tool for graphically displaying the CEs at various levels of decision maker attitude towards risk (e.g., risk neutral, moderately risk averse, or extremely risk averse). This paper provides a brief overview of the SMART risk analysis framework, and then describes use of the web-based tool to evaluate the efficacy of the SERF methodology for analyzing 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, Iowa, USA). Specifically, the SERF approach implemented in SMART is used to examine which of three different tillage systems (chisel plow, no-till, and ridge-till) on continuous corn and corn-soybean rotation cropping systems are the most risk-efficient in terms of maximizing economic profitability (net return) across a range of risk aversion preferences. In addition to the SERF analysis, an economic analysis of the tillage system alternatives is also performed using decision criteria and simple statistical measures. Finally, we demonstrate the use of a complementary method, the probability of target value or Stop Light approach, for analyzing and visually displaying the probabilistic information contained in the tillage system cumulative density functions (CDFs). Decision criteria analysis of the economic measures alone provided somewhat contradictive and non-conclusive rankings, e.g., examination of the decision criteria results for corn net return showed that different tillage system alternatives were the highest ranked depending on the decision criterion. SERF analysis results for corn net return showed that the no-till tillage system was preferred across the entire range of risk aversion (risk neutral to strongly risk averse). For the Stop Light analysis, the no-till tillage system was also preferred, regardless of whether the objective of the decision maker is minimizing risk or maximizing net return.

Keywords: risk assessment, stochastic efficiency, economic analysis, agriculture, stochastic dominance.

1. INTRODUCTION

In recent years, a method of stochastic dominance called stochastic efficiency with respect to a function (SERF) has been developed (Hardaker et al., 2004). SERF orders a set of risk-efficient alternatives instead of finding a subset of dominated alternatives, uses the concept of certainty equivalents (CEs) instead of CDFs for each alternative, and has stronger discriminating power than conventional stochastic dominance techniques (Hardaker et al., 2004). SERF has not been applied previously for the evaluation of tillage systems; however, Lien et al. (2007) used SERF within a whole-farm stochastic modeling framework to analyze organic and conventional cropping systems in eastern Norway. In addition, Pendell et al. (2007) used SERF to examine the economic potential of using no-till and conventional tillage with both commercial nitrogen and cattle manure to sequester soil in continuous corn production in northeastern Kansas.

This study uses the SMART (Screening and Multivariate Analysis for Risk and Tradeoffs) web-based software tool to evaluate the efficacy of the SERF methodology for analyzing 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, Iowa, USA. The primary objective of this research is to utilize the SERF approach within SMART to stochastically evaluate which of three different tillage system alternatives (chisel plow, no-till, and ridge-till) on continuous corn and corn-soybean rotation cropping systems maximize economic profitability (net return) for corn across a range of risk aversion preferences. In addition to the SERF analysis, an economic analysis of the tillage system alternatives is also performed using decision criteria and simple statistical measures. Finally, we demonstrate the use of a complementary method within SMART, the probability of target value or Stop Light approach, for analyzing and visually displaying the probabilistic information contained in the tillage system CDFs.

2. MATERIALS AND METHODS

2.1 Experimental Design and Economic Budget Data

Data for our study were obtained from 36, 0.4-ha plots located at the Iowa State University Northeast Research Station near Nashua, Iowa (43.0°N, 92.5°W), USA. Various experimental phases using different tillage treatments and cropping systems (continuous corn and both phases of a corn-soybean rotation) were conducted from 1978-2003. Experimental data collected included tile drain flow, nitrate concentration in tile drain flow, residual nitrogen (N) in soil, and crop yield, biomass, and plant N uptake. Economic budgets for 1990 to 2003 were developed as part of the web-based USDA Natural Resources Conservation Service (NRCS) – EconDoc exchange tool (http://ssiapps.sc.egov.usda.gov/EconDocs). 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 per unit (hectare) revenue and net return (revenue – total costs), resulting in 504 plot-years (36 plots x 14 years) of enterprise budget data. The net return data were discounted to reflect the net present values.

2.2 Stochastic Efficiency with Respect to a Function (SERF)

The SERF method orders a set of risky alternatives in terms of certainty equivalents (CE) calculated for specified ranges of risk attitudes (Hardaker et al. 2004). A CE is equal to the amount of certain payoff an individual would require to be indifferent between that payoff and a risky investment. The SERF method allows for simultaneous (rather than pairwise) comparison of risky alternatives, and graphical presentation of SERF results facilitates the presentation of alternative rankings for decision makers with different risk preferences. SERF calculates CE values over a range of absolute risk aversion coefficients (ARACs), representing a decision maker's degree of risk aversion. Decision makers are risk averse if ARAC > 0, risk neutral if ARAC = 0, and risk preferring if ARAC < 0. The ARAC values used in this analysis ranged from 0.0 (risk neutral) to 0.004 (strongly risk averse). The SERF model utilizing different functions (e.g., power, negative exponential) was programmed in the C# programming language and calculations verified against examples presented in the Simetar© 2006 User Manual (Richardson et al., 2006). Net return corn (both continuous and within a corn-soybean rotation) CE curves for the tillage system alternatives were produced by calculating 50 CE values for each curve over the entire range of risk aversion (i.e., ARAC between 0.0 and 0.004) with an initial wealth set to a predefined value.

3. SMART OVERVIEW

The SMART web-based tool is divided into six sections: Introduction, Input, Multivariate Monte Carlo Simulation, SERF, Stop Light, and Tradeoff. These sections are briefly discussed below.

3.1 Introduction Section

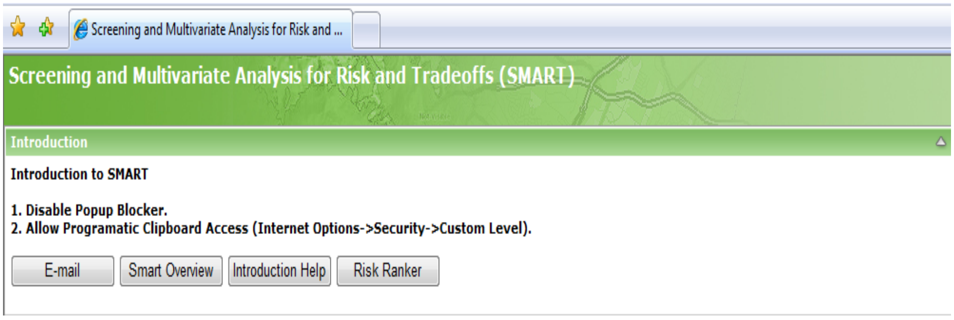

Figure 1. SMART Introduction screen.

The SMART Introduction screen is shown in Figure 1. The Introduction section provides information on how to set up Internet browsing tools to use SMART, an overview of SMART, and general help for the section including instructions on how to use Risk Ranker, a program for understanding how to rank risky alternatives.

3.2 Input Section

The input section facilitates data input into a flexible and customized spreadsheet tool. Data may be entered manually or loaded from an Excel 2003 spreadsheet. Both economic and environmental information (required for tradeoff purposes) can be input. SMART allows one economic measure (or variable) to be entered for up to three scenarios. Up to four environmental variables may be entered, also for a maximum of three scenarios. Once data have been entered or loaded, a statistical analysis can be performed and the resulting calculations [e.g., mean, standard deviation, coefficient of variation (CV), kurtosis, etc.] graphed.

3.3 Multivariate Monte Carlo Simulation Section

SMART has the ability to generate multivariate empirical distributions (MVEs) (up to 5,000 Monte Carlo iterations) for each input variable. An MVE distribution simulates random values from a frequency distribution made up of actual historical data and has been shown to appropriately correlate random variables based on their historical correlation (Richardson et al., 2006). Parameters for the MVE include means, deviations from the mean or trend expressed as a fraction of each variable, and correlation among variables. The MVE distribution is typically used in instances where data observations are too few to estimate parameters for another distribution (Pendell et al., 2006). In SMART, the user has the ability to select either historical data or generated MVE data in the SERF, Stop Light, and Tradeoff analyses.

3.4 SERF Analysis Section

The SERF simulation is performed in this section. Inputs to the SERF simulation for each variable include the minimum and maximum ARAC and the initial wealth. In addition, the user must select the type of utility function used for the SERF calculations and the number of CE values calculated (in order to define the CE curve across a range of risk preference). For ease in interpreting the SERF results, the CEs of the scenarios (in this case the tillage system alternatives) can be graphed on the vertical axis against risk aversion on the horizontal axis over the range of the absolute risk aversion coefficients (ARACs). When the lines intersect, this indicates the alternatives are equivalent to each other in terms of risk preferences.

3.5 Stop Light Analysis Section

Methods that rely on evaluating CDFs are difficult for many people to understand. A “probability of target value” or “Stop Light” graph relies on CDF information but is a more visually appealing depiction of probabilistic information. SMART contains a Stop Light procedure (Richardson et al., 2006) that calculates the probability of a measure (e.g., mean gross margin or net return) exceeding an upper cutoff value, being less than a lower cutoff value, or having a value between the upper and lower cutoff values. Like a stoplight, the three ranges are assigned colors of red (less than the lower cutoff value), yellow (between the upper and lower cutoff values), and green (exceeding the upper cutoff value). In SMART, the default values for the upper and lower cutoffs are one standard deviation above and below the mean, respectively (this can be overridden by the user).

3.6 Tradeoff Analysis Section

The tradeoff analysis in SMART can be performed between economic and environmental variables or between multiple environmental variables. At least two scenarios are required, and the tradeoff is defined to be the difference in outcome (CE) when a decision maker switches between one scenario and another. Displayed tradeoff graphs can be both discrete (i.e., specific risk aversion coefficients) and continuous (i.e., across all risk aversion coefficients). An increasing CE curve for the economic variable with a decreasing CE curve for the environmental variable(s) represents a win-win situation and no tradeoff is necessary. More often, however, changing scenarios may result in a situation where an increase in the economic variable comes at the expense of increased (negative) environmental impact. In this case, a tradeoff analysis should be performed. The tradeoff analysis feature of SMART is not considered in this paper.

4. RESULTS

4.1 Economic Analysis

The SMART input screen for the Nashua tillage system alternatives is shown in Figure 2 with the statistical analysis shown in Figure 3. Figure 3 shows that the no-till and chisel plow tillage systems had the highest mean net return for corn, while the ridge till and no-till plow tillage systems had the lowest standard deviation. There was no tillage system alternative that had the largest mean and smallest standard deviation. The no-till system had the largest mean net return, but also had a much higher standard deviation and CV than the ridge till tillage system. This indicates a larger degree of risk relative to the expected return, i.e., there could be a significant amount of net income given up to reduce risk with the no-till tillage system.

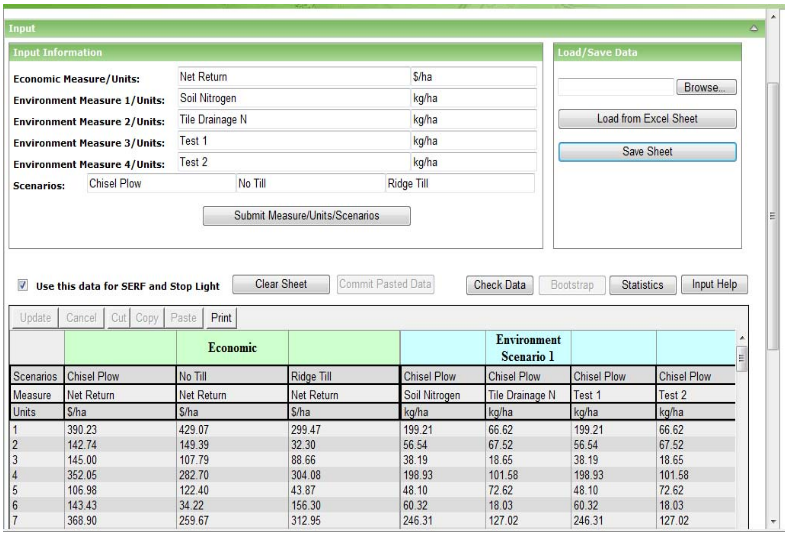

Figure 2. Inputs for the Nashua tillage system alternatives.

Overall, the system with the least amount of risk for net return, if measured by standard deviation, was the ridge till system. Based on a mean-standard deviation decision criteria, Figure 3 shows there would be little motivation for a farm manager to use the chisel plow system as it had both a much lower net return and higher standard deviation than the no-till system. Farm managers will give up income for reduced variability. If the manager accepts a dollar less of return for a dollar less of risk (standard deviation) at a one-to-one ratio, the CV can be used as a reasonable decision criterion. For net return, the chisel plow system had the highest CV with the ridge till system having the lowest CV. When the minimum net returns were compared and the maximin (i.e., the maximum of the minimum) decision criterion employed, the ridge till system was preferred (Figure 3). When the maximax decision criterion was employed (i.e., the maximum of the maximum), the no-till tillage system was preferred. This analysis illustrates that applying traditional decision criteria or simple statistical analysis to economic measures like net return may be inconclusive and inadequate for ranking risky alternatives, and may depend highly on the overall management goals and objectives of the decision maker. Application of decision criteria and statistical analysis alone to the economic measures can result in contradictive and nonconclusive 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 adequate. Furthermore, the high variability of criteria such as standard deviation for some of the tillage systems (particularly chisel plow and no-till) also indicates that further analysis should be performed. We next demonstrate the use of stochastic efficiency to overcome the shortcomings of the various decision criteria and statistical analysis approaches. The SERF method considers the net return distribution, not simply one point of measurement as does a mean-standard deviation analysis.

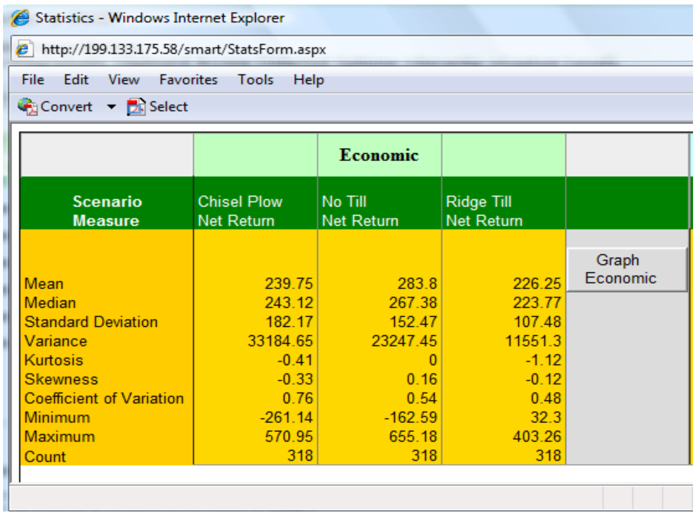

Figure 3. Nashua tillage system statistical analysis.

4.2 SERF Analysis

In order to further understand why the SERF methodology is preferable to traditional (i.e., mean-variance and stochastic dominance) methods, a brief explanation of first-degree (Hadar and Russell, 1969) and second-degree (Hanoch and Levy, 1969) stochastic dominance approaches is useful. These techniques have been commonly used to partially rank alternatives or strategies according to risk characteristics and preferences. 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 to the entirely to the right of another alternative (i.e., the curves must be non-intersecting). The corn gross margin CDFs for the tillage system alternatives are shown in Figure 4. Obviously, FSD is inconclusive since the gross margin CDFs intersect each other at several points. 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 all tillage system alternatives, especially where there are complex interactions in the tails of the CDFs. This is the case in Figure 4 where ridge till is the predominantly dominant tillage system alternative for corn gross margin at the lower tail (risk below the 0.25 CDF level); however, both the chisel plow and no-till CDFs cross the ridge till CDF at the upper tail (risk above the 0.75 CDF level). In addition, SSD does not consider various levels of risk aversion because it assumes a positive risk aversion only.

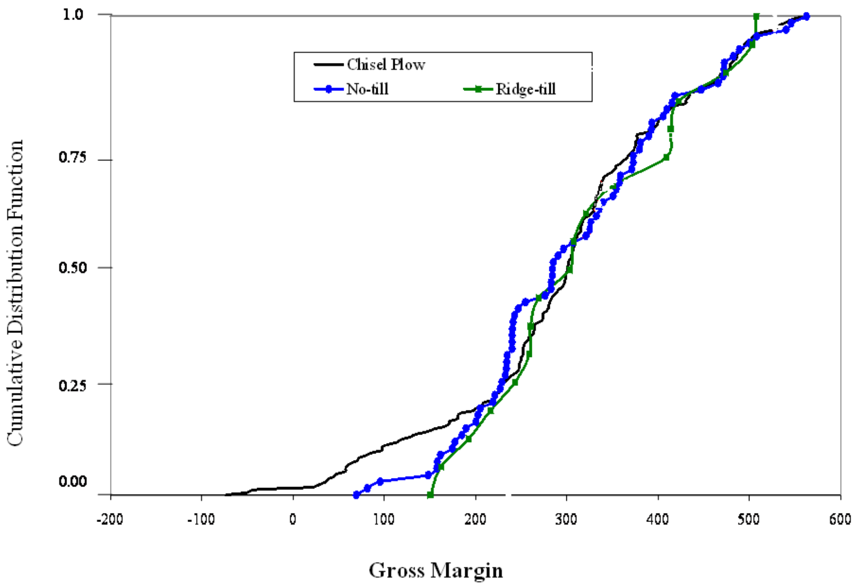

Figure 4. Corn gross margin CDFs for the tillage alternatives.

Figure 5 shows the net return CE results for all ARAC's for the tillage system alternatives under corn. The results show that the rankings do not change as risk aversion increases and that the no-till tillage system is preferred across the entire range of risk aversion. For a risk neutral decision maker, the overall difference in

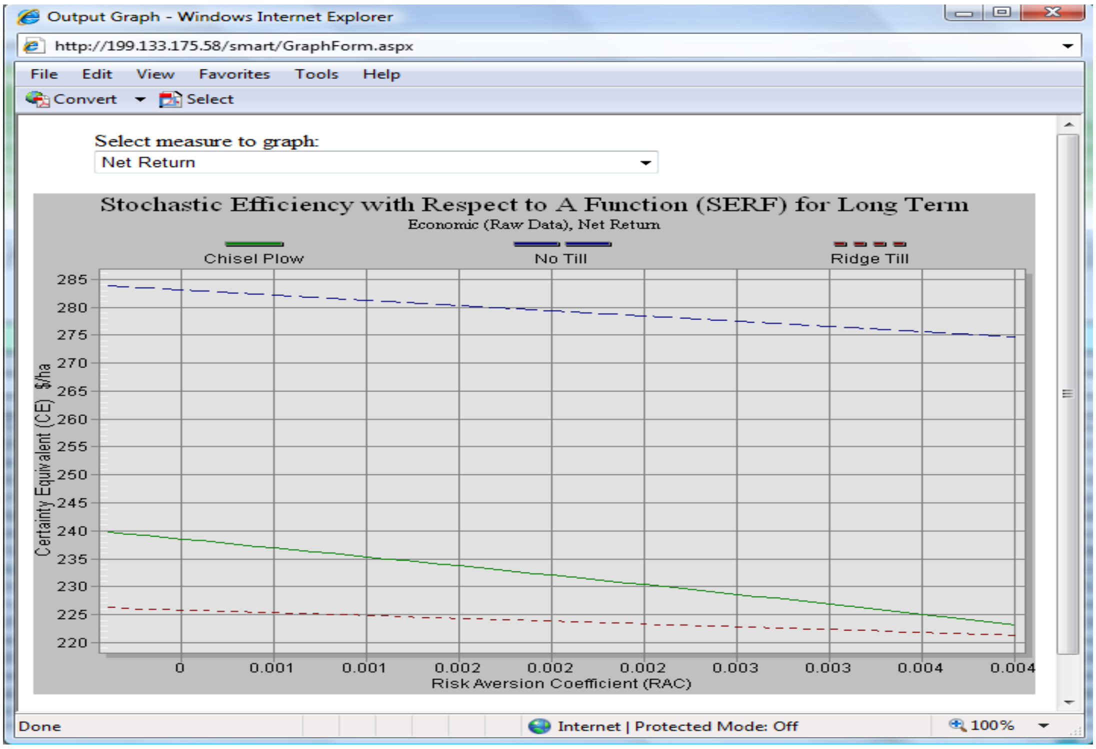

Figure 5.SERF corn net return certainty equivalents (CEs) for the tillage system alternatives.

the net return of the tillage system alternatives is ~ $60/ha. This indicates a risk neutral farmer will need to receive ~ $60/ha to be indifferent between the no-till tillage system (highest ranked) and the ridge till system (lowest ranked), and approximately $15/ha for the chisel plow and ridge-till systems (ranked second and third, respectively). The difference in net return between the tillage system alternatives decreases slightly as the risk aversion increases (Figure 5). Under extreme risk aversion (ARAC = 4.0), a farmer will need to receive ~ $50/ha to be indifferent between the no-till tillage system and the chisel plow system and less than $5/ha to be indifferent between the chisel plow and ridge-till systems (Figure 5).

4.2 Stop Light Analysis

The Stop Light visualization tool is effective when the objective of the decision maker is to determine the probability of an outcome between upper and lower cutoff values when analyzing alternatives. Figure 6 shows the probability (based on the cumulative probability function) of having a corn net return of plus (upper cutoff value) or minus (lower cutoff value) one standard deviation of the mean for each tillage system alternative. The upper and lower cutoff values ($/ha) for corn net return are $323.50/$176.36, respectively. Figure 6 illustrates that if the decision maker is interested in the downside risk associated with net return then the no-till tillage system is slightly preferred as the red probability range (less than the lower cutoff value which is one standard deviation below the mean) is the smallest of the three alternative tillage systems. The no-till tillage system is again preferred if the decision maker is interested in the probability of achieving a higher mean net return, as this tillage system has the largest green probability range (greater than the upper cutoff value which is one standard deviation above the mean). The Stop Light analysis results shown in Figure 6 are comparable to the SERF analysis where the no-till system was preferred across the entire range of risk aversion.

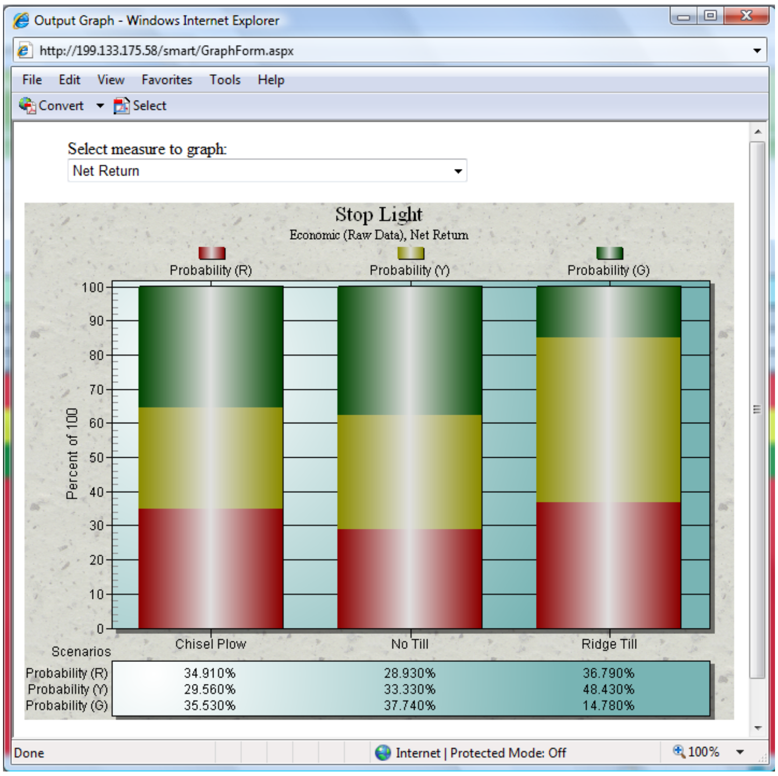

Figure 6. Stop Light analysis for the tillage system alternatives.

5. SUMMARY AND CONCLUSIONS

The primary goal of this study was to demonstrate the SMART web-based tool in evaluating the efficacy of SERF methodology 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, USA. Three tillage systems (chisel plow, no-till, and ridge till) were analyzed and certainty equivalent (CE) values for corn net return were calculated for each tillage system alternative. In addition to the SERF analysis, an economic analysis of the tillage system alternatives was also performed using decision criteria and simple statistical measures. Finally, the visually-based Stop Light method was employed for displaying net return probability distribution information at cutoff points one standard deviation above and below mean values. Decision criteria analysis of the economic measures alone provided somewhat contradictive and non-conclusive rankings, e.g., examination of the decision criteria results for corn net return showed that different tillage system alternatives were the highest ranked depending on the decision criterion. SERF analysis results showed that the no-till tillage system was preferred across the entire range of risk aversion for the corn net return. For the Stop Light analysis, the no-till tillage system was also preferred, regardless of whether the objective of the decision maker is to minimize risk or maximize net return.

Even with quantitative assessments, the typical absence in commonly advocated methods (e.g., mean-variance or stochastic dominance) of a systematic way to accommodate risk aversion seems unsatisfactory.

The SERF method of tillage system assessment by CEs demonstrated here helps to overcome these limitations. However, a SERF approach for ranking tillage system alternatives based solely upon economics may not tell the whole story. Furthermore, a focus on economic outcomes such as net return alone when ranking tillage systems may also be misleading, since environmental or other externalities may render certain systems unsustainable in the long run. It should be emphasized that this analysis has not taken into account differences in externalities for tillage system alternatives, and it would be possible to extend this study by valuing and including any externalities. The SMART web-based tool may be accessed at http://arsagsoftware.ars.usda.gov/smart/.

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