# Economic Feasibility of Conservation Tillage in the Palouse with Stochastic Erosion Rates and Yields

**Tony Prato**
**Professor**

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Several soil and water conservation studies have demonstrated that farmers are risk averse. Farm surveys conducted by Ervin and Ervin and Nowak and Korsching found that as risk aversion increased, farmers reduced their use of conservation practices. Miranowski's preliminary results indicated that farmers believed that no-till farming was more risky than conventional tillage, that risk-averse farmers were more likely to use conventional tillage, and that farmers, as a group, tended to be slightly risk averse. Nowak and Wagener concluded that farmers' attitudes toward risk can affect their willingness to adopt soil conservation practices. They suggest that further research on how risk affects adoption of soil conservation practices would be helpful in designing or implementing practices.

Kramer et al. found that risk aversion in combination with variation in gross revenues per acre and monthly availability of field hours significantly affected optimal choices of crops and best management practices. Setia used expected utility maximization and safety-first decision criteria to rank soil conservation systems for corn and soybeans in Illinois. Stochastic dominance has been used by Williams and Mikesell to rank cropping systems in Kansas, and by Klemme to compare conventional and reduced tillage systems for corn and soybeans in Indiana.

This paper examines the extent to which variability in erosion rates and crop yields affect the economic feasibility of, and farmers' willingness to adopt minimum and no tillage for a winter wheat-spring pea rotation in the Palouse region of northern Idaho. Unlike previous studies, stochastic variation in yield is determined by sampling empirically-determined frequency distributions for the difference in yield between conventional and conservation tillage and for errors in predicting soil losses. This method of handling stochasticity provides a much larger sample for analyzing risk than the time series approach used in other studies.

## Model

A model was developed to estimate changes in annualized net returns per acre between conventional tillage and each of two conservation tillage practices. Crop yield is

$$Y_{jt} = (\mu + R_j) + \delta(X_{jt}, G_{jt}) + \psi(F_t) \tag{1}$$

where:

$Y_{jt}$ = stochastic yield for practice j in year t;

$\mu$ = average yield with conventional tillage for zero topsoil depth, zero use of fertilizer and pesticides, and initial technology;

$R_j$ = stochastic yield adjustment for practice j relative to conventional tillage;

$X_{jt}$ = stochastic topsoil depth for practice j in year t;

$G_{jt}$ = technological change variable for practice j in year t;

$F_t$ = fertilizer and pesticide use in year t;

$\delta(.)$ = yield enhancement due to topsoil depth and technological change;

$\psi(.)$ = yield enhancement due to fertilizer and pesticide use;

j = practice designation (s for conservation tillage and v for conventional tillage);

t = time designation.

The effect of topsoil depth and technological change on crop yield, $\delta(X_{jt},G_{jt})$, is determined from the following Mitscherlich-Spillman (M-S) yield-topsoil depth function

$$(2) \qquad Y_t = [\alpha + \beta(1-M^{Xt})]e^{rt} \qquad 0<M<1 \text{ and } X_t \geq 0,$$

where: Y is yield; $\alpha$ is yield for zero topsoil depth; $\beta$ and M are parameters specific to the crop and geographic location; X is topsoil depth; e is the exponential operator; r is the compound rate of growth in yield due to technological change; and t is an annual time index. This M-S yield function has been used in the Palouse region because it fits the data better than other functional forms (Harker et al.; Pawson et al.; Taylor; Walker; Walker, Young; Young; Young, Hoag, Taylor).

Combining (1) and (2), the difference in yield between conservation tillage (s) and conventional tillage (v) is

$$(3) \qquad \Delta Y_{svt} = Y_{st} - Y_{vt} = R_{st} + \beta e^{rt}(M^{Xvt} - M^{Xst}),$$

where $R_{st}$ is the yield adjustment for conservation tillage and the second term is the yield enhancement resulting from greater topsoil depth with conservation tillage.

Topsoil depth is determined by

$$(4) \qquad X_{jt} = X_{j(t-1)} - .007\ E^*_j \qquad X_j \geq 0.$$

where $X_{jt}$ is topsoil depth in inches for practice j in year t, $E^*_j$ is the unknown, true erosion rate in tons per acre per year (TAY) for practice j and .007 is the topsoil depth in inches equivalent to one ton of topsoil spread over one acre.[1]

Since USLE predictions are subject to measurement errors, predicted erosion rates were assumed to be a stochastic, proportional function of the true erosion rate

$$(5) \qquad E_j = d_j E^*_j \qquad d_j>0.$$

where $d_j$ has a mean of 1 and constant variance. Solving for $E^*_j$ in (5) and substituting into (4) gives

$$(6) \qquad X_j = X_{j(t-1)} - .007 d^{-1}_j E_j.$$

The yield adjustment for conservation tillage is

$$(7) \qquad R_{st} = (1 - g_s) Y_{vt} \qquad g_s>0,$$

where $g_s$ is the yield for conservation tillage as a proportion of the yield for conventional tillage and $Y_{vt}$ is the yield for conventional tillage at time t.

Per acre cost of production is

$$(8) \qquad C_{jt} = VC_{j0} e^{\phi t} + FC_{j0} e^{\rho t}.$$

where $VC_{j0}$ and $FC_{j0}$ are initial values and $\phi$ and $\rho$ are real annual compound growth rates for variable and fixed costs, respectively.

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1. This conversion factor is based on the average bulk density for the soils analyzed in this paper, namely, 80.29 $lbs/ft^3$.

The difference in net returns per acre between conservation and conventional tillage in year t is

$$(9) \qquad \Delta NR_{svt} = P_t \Delta Y_{svt} - \Delta C_{svt},$$

where $P_t$ equals the farm price of the commodity in year t and $\Delta C_{svt} = (\Delta VC_{sv})e^{\phi t} + (\Delta FC_{sv})e^{\rho t}$. The annualized difference in net return per acre (ADNR) between conservation and conventional tillage is

$$(10) \qquad ADNR_{sv} = [\Sigma_t \, (\Delta NR_{svt} \div (1 + r)^t)] \; f(r,T),$$

where $r$ is a real discount rate, T is the length of the evaluation period and $f(r,T)$ is the amortization factor which is function of $r$ and T.

## Risk Analysis

Equation (1) shows that yield is stochastic because the yield adjustment and topsoil depth are stochastic. Topsoil depth is stochastic because of random errors in predicting erosion rates. Both $g_s$ and $d_j$ are assumed to vary with tillage practices and soil type but to remain constant over the 100-year evaluation period used in each simulation. $ADNR_{sv}$ was simulated for 200 randomly selected values of $g_s$ and $d_j$.

For a risk-averse farmer, expected utility maximization implies that the utility function is everywhere concave with respect to net farm income, i.e., $U(\pi) = 1 - \exp(-\theta\pi)$, where $\pi$ is net farm income and $\theta$ is the Arrow-Platt absolute risk aversion coefficient. Risk-taking, risk-neutrality and risk-aversion imply $\theta<0$, $\theta=0$ and $\theta>0$, respectively. When the utility function is quadratic or the distribution of net farm income is normal, maximizing expected utility is equivalent to maximizing $E(\pi) - (\theta/2)\text{var}(\pi)$ (Paris, Musser and Stamoulis).

Almost risk neutral preferences have been represented by values of $\theta$ between - .0000001 and .005, and strong risk aversion by values of $\theta$ between .000015 and $\infty$ (Raskin and Cochran). Values selected for $\theta$ are -.00001 and 0 for risk neutrality and .00001, .00003, and .001 for risk aversion. Since the income units for net returns are in dollars per acre instead of dollars per farm, $\theta$ was rescaled to $\theta^{*}=c\theta$ where c=1,000 acres is the average farm size in the study area (Raskin and Cochran). The values of $\theta^{*}$ are: -.01, 0, .01, .03, and .10.

The following annualized risk-adjusted difference in net returns per acre was maximized

$$(12) \qquad \text{RADNR}_{\text{sv}} = \text{mean}(\text{ADNR}_{\text{sv}}) - (\theta^{*}/2)\ \text{var}(\text{ADNR}_{\text{sv}}).$$

The sample mean and variance of $\text{ADNR}_{\text{sv}}$ were calculated from the 200 simulated values of $\text{ADNR}_{\text{sv}}$. Switching from conventional to conservation tillage is considered economically feasible when $\text{RADNR}_{\text{sv}}$ is positive and economically infeasible when $\text{RADNR}_{\text{sv}}$ is negative.

## Data and Relationships

The following M-S yield-topsoil depth functions were used

$$(12) \qquad \text{Winter Wheat:}\quad Y = [38.923 + 40.503(1-.9^{X})]e^{0.0167t}$$

Dry Peas: $Y = [636.579 + 711.324(1-.7^{X})]e^{0.0098t}$.

Taylor and Young estimated these functions without the technological variable using cross-sectional and time series data for the 1970-78 period.

Initial topsoil depths for the three soil types, erosion rates for conventional, minimum and no tillage, and costs and prices for wheat and peas are given in Table 1. Thatuna-Naff soil has low erosion rates and a deep topsoil, Linville soil has medium erosion rates and moderately deep topsoil and Broadax soil has high erosion rates and shallow topsoil.[2] Erosion rates are the annual average values predicted by the USLE for a wheat-pea rotation and contour farming for each tillage system.

Annual real growth rates for variable and fixed costs are average values for all Idaho crops as estimated by Thomas et al. using annual data for the 1949-81 period. Wheat prices are the target prices established by the Food Security Act of 1985, adjusted for predicted inflation, namely: \$4.38 in 1987 (the first year of the simulation); \$4.14 in 1988; \$3.93 in 1989; and \$3.71 in 1990. Real target prices were assumed to remain constant at \$3.71 per bushel after 1990. Real pea prices were assumed to remain constant at their 1987 market level of 8 cents per pound. A 100-year evaluation period and 4% discount rate were used.

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2. Although other conservation treatments such as cross slope and divided slope farming were considered, erosion rates for these treatments are very similar to those for contour farming. Therefore, only the contour farming alternative was analyzed.

The stochastic error in predicting erosion rates, $d_j$, was assumed to have a symmetric distribution with the spread indicated in Wischmeier's data (Wischmeier 1972, Wischmeier 1976). Separate beta distributions were fit to the yield adjustments for minimum and no tillage.

The values of $d_j$ and $g_s$ used in the simulations were generated by randomly selecting 200 observations from these empirically-derived distributions. Separate samples were drawn for each practice and soil type.

## Results

Non-stochastic and stochastic annualized differences in net return per acre (ADNR) for minimum tillage and no tillage and each soil are given in Table 2. Non-stochastic values are calculated assuming zero errors in predicting erosion rates ($d_j = 0$) and sample means for yield adjustments. Stochastic values are the risk-adjusted annualized differences in net returns (RADNR).

ADNRs for the non-stochastic cases are very similar to the mean RADNRs. The variances of ADNRs are large because net returns per acre are very sensitive to the yield adjustment. When the yield adjustment exceeds one, ADNR is positive and when the yield adjustment is below one, ADNR is negative. Since the means of the yield adjustment distributions for minimum and no tillage are less than one and skewed to the left, the yield adjustment is less than one more often than it is greater than one. High variances of ADNRs cause RADNRs to become more negative as $\theta^*$ increases. When $\theta^*$ equals zero, RADNR equals the mean RADNR.

The non-stochastic values and all stochastic values except for the low risk-neutral level in Broadax soil show that minimum and no tillage are economically infeasible in all three soils. Except in Broadax soil at the highest risk-averse level, no till has consistently lower RADNRs than minimum tillage because no tillage has almost twice the average yield penalty as minimum tillage. The ADNR for both conservation practices increases from Thatuna-Naff to Linville to Broadax soil because initial topsoil depth decreases and erosion rates increase which cause the benefits of erosion control to be greater. Except at the low risk-neutral level ($\theta* = -.01$) in Broadax soil, conventional tillage is preferred to minimum and no tillage as evidenced by the negative ADNRs.

### Conclusions

Stochastic variation in yield penalties appear to increase the economic feasibility of minimum and no tillage when farmers are risk takers and decrease economic feasibility when farmers are risk averse relative to the non-stochastic case. Net returns per acre with minimum tillage and no tillage fall below the levels for conventional tillage when farmers are risk averse. The largest reductions in net returns occur when no tillage is substituted for conventional tillage in highly eroding, shallow topsoil.

Current levels of cost sharing are generally sufficient to stimulate the adoption of minimum and no tillage. Furthermore, the level of cost sharing required for adoption increases with the level of risk aversion. In the few cases where cost sharing is sufficient to stimulate adoption, use of the practice is often discontinued after one to three years. This suggests that higher levels of cost sharing may be needed to compensate farmers for stochastic variation in net returns.

**Table 1. Topsoil Depth, Erosion Rates, Costs and Prices**

| Variable | Soil | | |
|---|---|---|---|
| | Thatuna-Naff | Linville | Broadax |
| Initial topsoil depth(") | 37 | 25 | 16 |
| Erosion rates (TAY) | | | |
| Conventional | 7 | 18 | 24 |
| Minimum Tillage | 4 | 11 | 15 |
| No Tillage | 2 | 7 | 11 |

| | Crop | |
|---|---|---|
| | Wheat | Peas |
| Variable cost ($/ac) | | |
| Conventional tillage | 100.53 | 113.98 |
| Minimum tillage | 93.43 | ---- |
| No tillage | 136.33 | ---- |
| Annual growth rate (%) | 2.872 | 2.872 |
| Fixed cost ($/ac) | | |
| Conventional tillage | 56.33 | 45.13 |
| Minimum tillage | 62.29 | ---- |
| No tillage | 24.96 | ---- |
| Annual growth rate (%) | 2.215 | 2.215 |
| Prices | $3.71-$4.38/bu | $0.08/lb |

Table 2. Nonstochastic and Stochastic Annualized Differences in Net Returns Per Acre, by Soil Type

| Tillage Alternative | Soil | | |
|---|---|---|---|
| | Thatuna-Naff | Linville | Broadax |
| Minimum Tillage | | | |
| Non-stochastic | -29.28 | -24.65 | -7.87 |
| Stochastic | | | |
| Mean | -30.34 | -25.91 | -8.60 |
| Variance | 4830.06 | 4085.18 | 3562.10 |
| -.01 | -7.19 | -5.48 | 9.21 |
| 0.0 | -31.34 | -25.91 | -8.60 |
| .01 | -55.49 | -46.34 | -26.41 |
| .03 | -103.79 | -87.19 | -62.03 |
| .10 | -272.84 | -230.17 | -186.71 |
| No Tillage | | | |
| Non-Stochastic | -76.87 | -69.46 | -45.37 |
| Stochastic | | | |
| Mean | -73.24 | -71.36 | -45.37 |
| Variance | 4321.06 | 3825.79 | 2752.22 |
| -.01 | -51.63 | -52.23 | -31.61 |
| 0.0 | -73.24 | -71.36 | -45.37 |
| .01 | -94.85 | -90.49 | -59.13 |
| .03 | -138.06 | -128.75 | -86.65 |
| .10 | -289.30 | -262.65 | -182.98 |

a. Based on expected utility maximization, equation (11).

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