ECONOMIC AND RISK CONSIDERATIONS OF NITROGEN FERTILIZER USE IN THE BROWN SOIL ZONE

K.R. Handford*, R.P. Zentner, F. Selles, C.A. Campbell and B.G. McConkey
Agriculture Canada Research Station
Swift Current, Saskatchewan

ABSTRACT

Optimum use of nitrogen fertilizer requires consideration of factors that influence plant response and those that govern the decisions of producers. The response of spring wheat to soil moisture and N fertilizer was assessed in a 9-yr zero tillage study conducted on a medium texture soil at Swift Current, Saskatchewan. These data were used to assess the economic merit and risk considerations of alternate N fertilizer management systems when combined with snowtrapping to enhance soil moisture reserves. The N fertilizer system included rates from 0 to 100 kg ha^{-1}, spring versus fall applications and deep-banding versus surface broadcasting. The results showed that the optimum rates of fertilizer N (FN) varied directly with spring soil moisture reserves (SM) and the probability distribution for 1 May to 31 July precipitation, and inversely with soil N (SN), the ratio of FN cost to wheat price, and the level of risk aversion held by producers. The optimum FN rates were highest for spring- and fall-banding; they were 3 to 14 kg ha^{-1} lower for spring broadcasting and 7 to 22 kg ha^{-1} lower with fall broadcasting. The optimum rates increased 3.7 to 5.7 kg N ha^{-1} for each 10 mm increase in SM, with the higher rates associated with high SN. The FN rates declined 5 kg ha^{-1} for each additional year that the land was cropped continuously. For producers seeking to maximize expected profit or those with low risk aversion, the optimum FN rates were considerably higher than those recommended by the Saskatchewan Soil Testing Laboratory (SSTL). In contrast, the FN rates for producers with high risk aversion were generally lower than those of the SSTL. The SSTL recommended rates were most appropriate for producers with medium risk aversion. The study found no single combination of timing and method of N fertilizer placement to be superior in all cases. Spring- and fall-banding provided higher net margins than broadcasting N fertilizer when SM or wheat prices were high, or if banding fertilizer can be combined with a tillage operation for weed control. The economic benefit from snowtrapping averaged \$9 to \$32 ha^{-1} depending on FN rate and wheat price; however, little benefit or a small loss was incurred in some years when infiltration of melt water was low or winter snowfall was minimal.

INTRODUCTION

Producers in the dry Brown soil zone of western Canada have historically been reluctant to reduce summerfallow frequency and extend crop rotations. This occurs because production costs are higher for crops grown on stubble as compared to fallow, and because risks of low grain yields and economic losses are higher with stubble cropping as a consequence of lower soil moisture reserves and highly variable growing season precipitation (Zentner and Campbell 1988).

Newer production technologies such as snowtrapping, through use of tall cereal stubble trap strips (Campbell et al. 1992), and zero tillage management (Tessier et al. 1990) can increase spring soil moisture reserves, reduce in-crop evaporation losses, and thereby reduce the dependency of stubble crops on growing season precipitation. These practices, when combined with improved methods of N fertilizer management can further increase moisture use efficiency and grain yields (Campbell et al. 1992), and thus possibly contribute to improved profitability and reduced riskiness of stubble cropping in this region.

The objectives of this paper were to determine: i) economic optimum fertilizer N rates and riskiness of several newer fertilizer management options, and ii) the economic benefits of snowtrapping using tall stubble trap strips compared to stubble cut at a standard uniform height, for spring wheat grown continuously under zero tillage management in southwestern Saskatchewan.

MATERIALS AND METHODS

Experimental Data

Hard red spring wheat was grown annually for 9 years (1982 to 1990) using recommended zero tillage management practices on a Swinton loam at Swift Current, Saskatchewan. The treatments assessed were a factorial combination of stubble height, fertilizer N rate, time of N application, and method of N placement. Stubble height treatments compared tall stubble trap strips versus short stubble. Tall stubble consisted of trap strips, 40 to 60 cm tall by 90 to 120 cm wide, spaced every 6 m and running perpendicular to prevailing winds. These strips of tall stubble were created with a deflector or clipper device mounted on a self-propelled swather or straight cut header on a combine. The short stubble was cut at a uniform standard height of 15 to 20 cm. Fertilizer N rates were 25, 50, 75, and 100 kg ha^{-1} in most years, plus a zero N rate in the last four years. Time of N application was spring versus fall, except in 1985 when it was early April versus mid May. N placement was deep-band (10 to 12.5 cm depth on 30 cm spacing) versus surface broadcast N. The first 25 kg N ha^{-1} was seed placed. All plots received blanket applications of P fertilizer each year, and in the first five years blanket applications of K and S were also applied to remove any deficiencies in these nutrients. The N source was urea (46-0-0).

A split-split-split plot design with four replicates was used. Main plots were stubble heights, first split was N rates, the second was time of N application, and the third split was method of N placement. Each replicate was divided into three year-blocks, with only one block used each year as the test area. This allowed the treatments to be moved from year to year so as to minimize residual fertilizer effects. Year-blocks that were not under test received 25 kg ha^{-1} of N and P fertilizers applied with the seed.

Soil cores were taken from the test area to the 120 cm depth each fall and spring for determination of soil moisture and NO_3-N by depth segment as described by Campbell et al. (1992). Available soil water was determined by subtracting the water held at -4 MPa potential (154 mm for the 120 cm soil depth) from the volumetric moisture content. Growing season precipitation was recorded at a meteorological station located 1 km to the east of the test site.

Economic and Statistical Analysis

Decisions on optimal resource use strategies begin with specification of a production function that relates inputs to output:

$$Y = f(X_1, \ldots, X_i | X_{i+1}, \ldots, X_k | X_{k+1}, \ldots, X_n), \qquad (1)$$

where, Y is the level of product output; $X_1, \ldots, X_i$ are decision variables or inputs under the control of producers; $X_{i+1}, \ldots, X_k$ are uncontrollable variables that have predetermined or known values at the time of the decision; and $X_{k+1}, \ldots, X_n$ are uncontrollable random variables which interact with the other variables. Because the physical outcome from the production process depends upon uncontrollable stochastic factors, then economic returns, and hence the optimum levels of the decision variables are themselves random variables and thus can only be determined in a probabilistic sense. In the decision problem of this study, the controllable variables are fertilizer N rate (FN), time of N application, and method of N placement; uncontrollable nonstochastic variables are levels of soil NO_3-N (SN) and available soil moisture (SM); and, the uncontrollable stochastic variable is growing season precipitation (GSP).

Modern decision theory assumes that a producer's preferences for risky outcomes are encoded in a utility function for profit, $U=U(\pi)$, such that the derivatives take on signs $U'(\pi) > 0$, $U''(\pi) < 0$, and usually $U'''(\pi) > 0$, (Anderson et al. 1977). The utility function allows producers to rank, or assign a single-valued utility index to each risky outcome (profit). Profit is defined as the difference between total revenue and total costs and, under conditions of known or nonstochastic product prices and input costs, the profit equation for the fertilizer decision problem of this study is given by:

$$\pi = P*Y - (C*FN + A)*(1 + r/t), \qquad (2)$$

where, π is level of profit per unit area (\$ ha^{-1}); P is product price (\$ kg^{-1}); Y is wheat yield (kg ha^{-1}); C is cost of N fertilizer (\$ kg^{-1}); FN is rate of applied N fertilizer (kg ha^{-1}); A is cost of applying N fertilizer (\$ ha^{-1}); r is annual interest rate or opportunity cost of funds used for N fertilization (%); and t is the time period (years or portions thereof) for which the funds are committed or invested. In this risky environment, the goal of producers is to maximize expected utility (of profit) from application of N fertilizer:

$$\text{Max}_{FN}\ E[U(\pi)] = {}_{-\infty}^{+\infty} U(P*Y - (C*FN + A)*(1 + r/t))*g(\pi|FN)*\partial\pi \qquad (3)$$

$$\text{subject to: } Y = f(FN|SN, SM|GSP), \qquad (4)$$

where, E is the expectation operator and $g(\pi|FN)$ is the probability density function (PDF) for profit, conditional upon the level of FN.

If the utility function of a producer and the PDF for profit are known or can be estimated, it can be shown from the first-order condition for maximization of equation (3) ($E[\partial U(\pi)/\partial FN] = 0$) that the optimal N fertilizer rate, for each timing and method of N application, occurs where the expected marginal value product of N equals the marginal cost of N fertilizer plus a risk adjustment term. The latter is dependent on the nature of the PDF and the risk attitudes of producers as defined by the

Pratt-Arrow coefficient of absolute risk aversion (λ) (Anderson et al. 1977). The λ coefficient is a measure of the rate of change in curvature of the utility function; it is defined as the negative ratio of the second and first derivatives of the utility function for profit, [$\lambda = -U''(\pi)/U'(\pi)$], and represents the percent change in marginal utility per outcome unit. Risk aversion, risk neutrality, and risk taking imply that $\lambda > 0$, $\lambda = 0$, and $\lambda < 0$, respectively.

Risk averters are cautious individuals who are willing to give up some amount of expected profit in order to reduce the probability of an outcome occurring which has low or negative profit. Risk neutral individuals seek to maximize expected profit and are not concerned about variability of profit or the nature of the PDF of possible outcomes. Risk preferrers (data now shown) are characterized as adventuresome and are willing to make choices that have some probability of high profit while risking the possibility of lower profit.

When the risk preferences held by producers are unknown, the partial ordering of risky actions often proceeds using the principles of stochastic dominance (Anderson et al. 1977). This method involves performing pair-wise comparisons of the cumulative probability distributions (CDF) of profit for the action choices so as to determine if one dominates another under more general assumptions or characteristics about the underlying utility function. In our study, stochastic dominance with respect to a function (SDRF) was used to narrow the risk efficient set of optimal N rates when all that is known about the utility function is that the absolute risk aversion coefficient lies within some specified interval. The procedure allows one to divide the continuum of risk attitudes of producers into several groups and to rank the distributions for each group. Since estimates of λ were unavailable for western Canadian producers, values were selected from the literature (Raskin and Cochran 1986) and scaled using a farm size of 750 ha. Thus, the values used in this study for λ were 0 for risk neutral, 0 to 0.0075 for low risk aversion, 0.0075 to 0.0225 for medium risk aversion, and 0.0225 to 0.05 for high risk aversion.

To implement this decision framework, we had to empirically estimate the production function, define the probability distribution for growing season precipitation, and select appropriate values for the economic parameters.

In an earlier paper, Campbell et al. (1992) pooled all treatment data on grain yields and used ordinary least squares regression to establish a polynomial equation relating wheat yields to FN, SN in 0 to 60 cm depth measured in fall, moisture used by the crop (SM in 0 to 120 cm depth measured in spring plus 1 May to 31 July precipitation) (MU), years of continuous cropping (YR), and various interactions of these variables. In a separate analysis, they used analysis of variance to assess the effects of time of N application and method of N placement on grain yields; these latter effects were found to vary with moisture use and fertility conditions. For this study, the effects of time and method of N application were integrated into the yield equation developed by Campbell et al. (1992) through use of dummy variables. For this analysis, three dummy variables (D1, D2, D3) were established, in addition to the independent variables used by Campbell et al. (1992), to permit the regression coefficient for the SN x FN x MU interaction term to vary depending on the time and method of fertilizer N application.

Stepwise regression, with backward elimination and the criteria set to discard all terms whose estimated coefficients were not significantly different from zero ($P<0.05$), was used to estimate the general yield relationship employed in the economic analysis.

The PDF for growing season precipitation was estimated using historical data collected at the nearby meteorological station for the 50-yr period 1941 to 1990. An incomplete Gamma probability density function was constructed using the method of maximum likelihood estimation:

$$h(GSP) = \frac{1}{\Gamma(\delta)\beta^{\delta}} GSP^{(\delta-1)} e^{-GSP/\beta} \quad \text{for } GSP \geq 0, \tag{5}$$

where, δ and β are estimated parameters and $\Gamma(\delta)$ is the Gamma function. The continuous PDF for growing season precipitation was converted to discrete form using 10 mm increments prior to its application.

Base values were selected for the economic parameters so as to reflect 1990 cost conditions (Table 1) (Saskatchewan Agriculture and Food 1990). The cost for deep-banding fertilizer reflects only 50% of the total cost of the field operation because banding fertilizer is usually combined with a tillage operation for weed control. We used higher costs for spring compared to fall fertilization to reflect the higher opportunity cost for labor in the more busy spring period. For the economic analysis, values for predetermined variables and MU were constrained to be within limits of the experimental data for the 9-yr period.

Table 1. Summary of economic parameters

Item	Price/Cost	Units
Spring wheat	0.138[w]	$ kg^{-1}
Fertilizer N	0.442[x]	$ kg^{-1}
Spring - banding	8.84	$ ha^{-1}
Fall - banding	8.46	$ ha^{-1}
Spring - broadcast	4.32	$ ha^{-1}
Fall - broadcast	3.86	$ ha^{-1}
Stubble clipper[y]	0.87	$ ha^{-1}
Labor - spring	9.00	$ hr^{-1}
Labor - fall	4.50	$ hr^{-1}
Interest rate	10.00	%
Investment period - spring[z]	0.33	yr
Investment period - fall	1.00	yr

[w] Wheat prices were chosen to range from 0.103 to 0.207 $ kg^{-1} for some analyses.

[x] N fertilizer costs were chosen to range from 0.442 to 0.663 $ kg^{-1} for some analyses.

[y] Refers to the additional operating and investment costs for constructing tall stubble barriers using a clipper device.

[z] Length of time that funds for N fertilization were borrowed or committed.

RESULTS AND DISCUSSION

Production Function For Yield

The final regression model relating wheat yields to the controllable and uncontrollable input variables (Table 2) was similar to that reported by Campbell et al. (1992), with the exception of the SN x FN x MU term. Estimated coefficients for the dummy variables representing spring- and fall-broadcasting were significantly different from zero ($P<0.05$) and negative in sign indicating that the yield response to fertilizer N was lower with these methods of fertilizer placement compared to spring-banding. Further, the response was lowest for fall-broadcasting, *ceteris paribus*, as reported by Campbell et al. (1992). The regression coefficient for the dummy variable representing fall-banding was not significantly different from zero ($P>0.05$), indicating that the yield response to fall-banding was similar to spring-banding, as also reported by Campbell et al. (1992). The agronomic relevance of the other independent variables have been discussed previously (Campbell et al. 1992).

Table 2. Equation[w] relating grain yields to moisture use (MU), rates of fertilizer N (FN), soil N (SN), and method of fertilizer placement, based on 9 years (YR) of results

Independent variable	Estimated coefficient	Standard error of coefficient
Intercept	-7.81×10^{2}	7.91×10
MU	3.11	5.14×10^{-1}
FN	6.88	2.41
FN^2	-5.29×10^{-2}	7.61×10^{-3}
SN^2	-3.28×10^{-1}	6.05×10^{-2}
SN x MU	2.29×10^{-1}	1.81×10^{-2}
SN x FN	-2.51×10^{-1}	9.43×10^{-2}
FN x MU	3.47×10^{-2}	9.54×10^{-3}
SN x FN x MU	9.05×10^{-4}	4.08×10^{-4}
D2 x SN x FN x MU[x]	-1.33×10^{-4}	4.19×10^{-5}
D3 x SN x FN x MU[x]	-1.80×10^{-4}	4.19×10^{-5}
YR x SN	1.60	2.31×10^{-1}
YR x FN	-5.30×10^{-1}	8.92×10^{-2}
Coefficient of determination		$R^2 = 0.91^{***}$
Number of observations		N = 1248

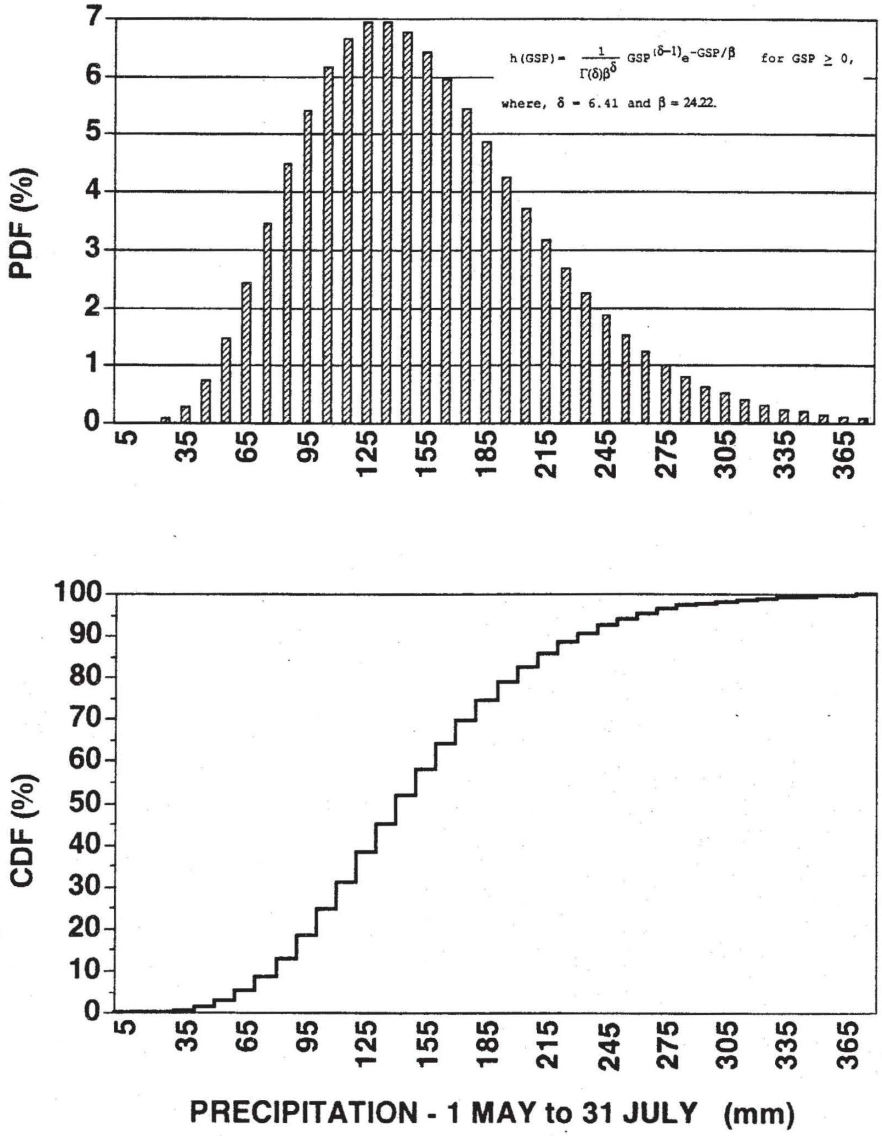
[w] The regression equation was obtained by backward elimination with independent variables not significant ($P < 0.05$) being deleted (i.e., MU^2, SN, and D1 x SN x FN x MU).

[x] Data were normalized on spring-banding, thus D2 = 1 for spring-broadcasting, otherwise D2 = 0; D3 = 1 for fall-broadcasting, otherwise D3 = 0.

Probability Distribution For Growing Season Precipitation (GSP)

When the probability distribution for growing season precipitation (and thus profit) is known or can be determined, producers can use this information to weigh the possible consequences from each unit of fertilizer input so as to maximize expected utility of profit subject to their risk attitudes.

At Swift Current the PDF for GSP (Figure 1, top) reflects the highly variable nature of precipitation that typifies this region. The PDF is characterized as nonsymmetric and concave, as is often reported for arid climates. The distribution of GSP had a mean (or expected value) of 155 mm; its standard deviation was 61.3 mm, its coefficient of variation was 39.5%, and its skewness was 0.79 mm. The positive skewness indicates that the frequency of years with high GSP was lower than the frequency of years with low amounts of precipitation. The CDF for GSP (Figure 1, bottom), which was obtained by numerically integrating the PDF, reinforces the latter point.



Optimum Rates of N Fertilizer Under Stochastic Growing Season Precipitation

The optimum FN rates varied directly with SM, and inversely with SN, the ratio of fertilizer N cost to wheat price (Tables 3 and 4), and YR (data not shown). The optimum FN rates for spring- and fall-banding were generally similar (data not shown), with those for fall-banding ranging from 0 to 3 kg ha^{-1} lower than for spring-banding reflecting the longer investment period for fertilizer funds committed in the fall. Although differences among fertilizer placement methods were small in some instances, the optimum N rates were generally highest for spring- and fall-banding, intermediate for spring-broadcasting (3 to 14 kg ha^{-1} less than for banding), and lowest for fall-broadcasting (7 to 22 kg ha^{-1} less). These latter results probably reflect differences in rates of immobilization and losses of FN by leaching, denitrification, and volatilization among the various methods of fertilizer placement (Penny 1985). The optimum FN rates increased by an average of 3.7, 4.6, and 5.7 kg ha^{-1} with each 10 mm increase in SM when SN levels were low (15 kg ha^{-1}), medium (30 kg ha^{-1}), and high (45 kg ha^{-1}), respectively. They also decreased by 5 kg ha^{-1} with each additional year of continuous cropping up to 9-yr (data not shown), reflecting an improvement in N supplying power of the soil with time under zero tillage management (Campbell et al. 1989).

For risk neutral producers (Table 3, top), the optimum N rates were generally higher than those recommended by the Saskatchewan Soil Testing Laboratory (SSTL) (1990), particularly for spring-banding and when spring soil moisture was low. For example, when the ratio of fertilizer N cost to wheat price was 4.8 (i.e., same as SSTL which uses a ratio of 3.2 times a 1.5 factor) and when SN was about 15 kg ha^{-1}, the SSTL recommended FN rates were 34, 50, and 78 kg ha^{-1} for all methods of fertilizer placement as moisture conditions increase from dry to normal to wet, respectively. By comparison, our recommended FN rates varied from 57 to 91 kg N ha^{-1} for spring- and fall-banding, and 50 to 82 kg N ha^{-1} for fall-broadcasting, as spring available soil moisture reserves increased from 15 to 105 mm (range of experimental data). At a SN level of about 30 kg ha^{-1}, the SSTL recommended FN rates were 19, 35, and 63 kg ha^{-1} for the three respective moisture classes, while our results showed 44 to 88 kg ha^{-1} for spring- and fall-banding and 32 to 72 kg ha^{-1} for fall-broadcasting over the 15 to 105 SM range. At a higher level of SN of about 45 kg ha^{-1}, the SSTL recommends 6, 20, and 48 kg N ha for the three moisture classes, respectively, while we would recommend 31 to 84 kg N ha^{-1} for spring- and fall-banding and 15 to 62 kg N ha^{-1} for fall-broadcasting. The higher optimum N rates obtained in our study reflects the lower effectiveness, or marginal rate of substitution, of FN for SN compared to that used by the SSTL and the improved soil moisture and microclimatic conditions observed with zero tillage management (Tessier et al. 1990)

For risk averse producers (Table 3, bottom and Table 4), the optimum FN rates appear as intervals which decrease with the level of risk aversion. For example, groups of producers with low risk aversion facing a situation of SN = 15 kg ha^{-1}, SM = 30 mm, and a ratio of N cost to wheat price of 4.8 would apply a FN rate of between 54 and 62 kg ha^{-1} when spring- or fall-banding the fertilizer. Alternately, a producer with medium risk aversion facing the same situation would apply between 44 and 53 kg N ha^{-1}, and a producer with high risk aversion between 39 and 43 kg N ha^{-1} for the same fertilizer placement method.

Table 3. Optimum rates of N fertilizer for risk neutral and low risk aversion producers[w]

Soil N (kg ha^{-1}) and Spring Soil Moisture (mm)[x]	Spring- & Fall-Band			Spring-Broadcast			Fall-Broadcast		
	N Cost/Wheat Price Ratio			N Cost/Wheat Price Ratio			N Cost/Wheat Price Ratio		
	3.2	4.8	6.4	3.2	4.8	6.4	3.2	4.8	6.4
	(kg ha^{-1})								
				Risk Neutral[y]					
Soil N = 15									
30	78	63	47	75	59	43	71	55	38
60	90	74	59	86	70	55	82	66	49
90	101	86	70	97	81	66	93	77	60
Soil N = 30									
30	67	51	35	60	44	28	55	38	22
60	81	66	50	73	58	42	69	52	35
90	96	81	65	87	72	56	82	66	49
Soil N = 45									
30	55	39	24	44	29	13	39	22	5
60	73	57	42	61	45	30	55	38	21
90	91	76	60	78	62	47	71	54	38
				Low Risk Aversion[y]					
Soil N = 15									
30	77-68	62-54	46-39	74-66	58-51	42-35	70-62	54-47	37-31
60	89-80	73-65	58-51	85-77	69-62	54-47	81-73	65-58	48-42
90	100-91	85-77	69-62	96-88	80-73	65-58	92-84	76-69	59-53
Soil N = 30									
30	66-51	50-37	34-21	59-46	43-31	27-15	54-42	37-25	21-10
60	80-65	65-42	49-36	72-59	57-45	41-29	68-56	51-39	34-23
90	95-80	80-67	64-51	86-73	71-59	55-43	81-69	65-53	48-37
Soil N = 45									
30	54-33	38-20	23-4	43-25	28-11	12-0	38-22	21-4	4-0
60	72-51	56-38	41-22	60-42	44-27	29-12	54-38	37-20	20-4
90	90-69	75-57	59-40	77-59	61-44	46-29	70-54	53-36	37-21

[w] Shown for years of continuous cropping = 1

[x] Soil N refers to NO_3-N in 0 to 60 cm depth measured in previous fall; soil moisture refers to available moisture in 0 to 120 cm depth measured in spring.

[y] Neutral and low risk aversion correspond to values for the Pratt-Arrow coefficient of absolute risk aversion of 0, and 0 to 0.0075, respectively.

The optimum FN rates for the three groups of risk averse producers were always less than those of risk neutral producers. The extent of these differences varied with level of SN and the degree of risk aversion, but were only slightly affected by changes in SM and the ratio of N cost to wheat price. For example, the optimum FN rates for low risk averse producers averaged as much as 8 kg ha^{-1} lower than those for risk neutral producers when SN was low (15 kg ha^{-1}). This difference increased to as much as 14 kg ha^{-1} when SN was intermediate (30 kg ha^{-1}), and up to 19 kg ha^{-1} when SN was high (45 kg ha^{-1}). By comparison, the optimum FN rates for high risk averse producers averaged from 18 to 23 kg ha^{-1} lower than those for risk neutral producers when SN was low, 26 to 31 kg ha^{-1} lower when SN was intermediate, and 33 to 38 kg ha^{-1} lower when SN was high.

Table 4. Optimum rates of N fertilizer for medium and high risk aversion producers[w]

Soil N (kg ha^{-1}) and Spring Soil Moisture (mm)[x]	Spring- & Fall-Band N Cost/Wheat Price Ratio			Spring-Broadcast N Cost/Wheat Price Ratio			Fall-Broadcast N Cost/Wheat Price Ratio		
	3.2	4.8	6.4	3.2	4.8	6.4	3.2	4.8	6.4
	(kg ha^{-1})								
	Medium Risk Aversion[y]								
Soil N = 15									
30	67-58	53-44	38-30	65-57	50-42	34-26	61-53	46-38	30-22
60	79-70	64-55	50-42	76-68	61-53	46-38	72-64	57-49	41-33
90	90-81	76-67	61-53	87-79	72-64	57-49	83-75	68-60	53-44
Soil N = 30									
30	50-39	36-24	20-9	45-34	30-19	14-0	41-31	24-13	9-0
60	64-53	41-39	35-24	58-47	44-33	28-17	55-45	38-27	22-11
90	79-68	66-54	50-39	72-61	58-47	42-31	68-58	52-41	36-25
Soil N = 45									
30	32-22	19-7	3-0	24-14	10-0	0	21-10	3-0	0
60	50-40	37-25	21-9	41-31	26-15	11-0	37-26	19-8	3-0
90	68-58	56-44	39-28	59-48	43-32	28-18	53-42	35-24	20-9
	High Risk Aversion[y]								
Soil N = 15									
30	57-53	43-39	29-24	56-52	41-36	25-21	52-48	37-33	21-17
60	69-65	54-50	41-36	67-63	52-47	37-33	63-59	48-44	32-27
90	80-76	66-62	52-47	78-74	63-58	48-44	74-70	59-55	43-38
Soil N = 30									
30	38-34	23-19	8-2	33-30	18-14	0	30-26	12-8	0
60	52-48	38-34	23-17	46-43	32-28	16-13	44-40	26-22	10-6
90	67-63	53-49	38-32	60-57	46-42	30-27	57-53	40-36	24-20
Soil N = 45									
30	21-14	6-0	0	13-7	0	0	9-4	0	0
60	39-32	24-17	8-0	30-24	14-8	0	25-20	7-0	0
90	57-50	43-36	27-17	47-41	31-25	17-11	41-36	23-16	8-1

[w] Shown for years of continuous cropping = 1.

[x] Soil N refers to NO_3-N in 0 to 60 cm depth measured in previous fall; soil moisture refers to available moisture in 0 to 120 cm depth measured in spring.

[y] Medium and high risk aversion correspond to values for the Pratt-Arrow coefficient of absolute risk aversion of 0.0075 to 0.0225, and 0.0225 to 0.05, respectively.

The optimum FN rates of the SSTL (1990) for a ratio of N cost to wheat price of 4.8 compared most closely with our values for medium risk aversion producers. Thus these results indicate that the SSTL recommended FN rates are generally too low for producers that are risk neutral or have low risk aversion, and too high for producers with high risk aversion.

Economics of Timing and Method of N Fertilizer Placement

The ratio of fertilizer N cost to wheat price determines the optimum rates of FN for each method of fertilizer placement; however, it is the absolute values assigned to these and other economic parameters that determines the level or extent of profit earned. Thus they determine whether banding is more profitable than broadcasting N fertilizer, whether fall applications are more profitable than spring applications, or whether sufficient net margin remains after paying for N fertilization costs (Table 5) to cover other input costs associated with stubble cropping.

Table 5. Returns above fertilization costs (margins) and expected wheat yields for selected economic scenarios[w]

Soil N (kg ha^{-1}) and Spring Soil Moisture (mm)	Spring-Band[x]		Spring-Broadcast		Fall-Broadcast	
	Margin	Yield	Margin	Yield	Margin	Yield
			Wheat Price = $0.207 kg^{-1}[y]			
Soil N = 15						
30	147	971	141	933	136	909
60	203	1279	195	1228	189	1202
90	262	1601	252	1541	245	1511
Soil N = 30						
30	220	1288	211	1218	205	1186
60	297	1702	283	1611	276	1576
90	379	2149	361	2032	351	1987
Soil N = 45						
30	266	1469	255	1377	249	1344
60	361	1989	344	1865	336	1819
90	465	2552	440	2389	429	2327
			Wheat Price = $0.138 kg^{-1}[y]			
Soil N = 15						
30	82	909	79	867	76	839
60	117	1213	112	1162	108	1132
90	153	1539	148	1475	143	1411
Soil N = 30						
30	134	1222	129	1152	125	1111
60	181	1640	174	1549	169	1502
90	232	2087	222	1970	216	1916
Soil N = 45						
30	167	1403	161	1315	159	1269
60	226	1923	217	1799	213	1744
90	291	2490	278	2323	271	2252
			Wheat Price = $0.103 kg^{-1}[y]			
Soil N = 15						
30	52	817	51	774	48	734
60	76	1126	74	1076	71	1027
90	102	1446	98	1388	94	1336
Soil N = 30						
30	93	1130	90	1060	89	1012
60	126	1548	122	1456	119	1397
90	162	1994	156	1878	152	1812
Soil N = 45						
30	120	1316	117	1223	117	1164
60	161	1836	156	1712	154	1639
90	207	2398	199	2236	195	2154

---

[w] Units for margin are \$ ha^{-1} and for yield it is kg ha^{-1}.

[x] Margins for fall-banding averaged about \$ 2 ha^{-1} lower than for spring-banding, while expected grain yields were generally similar for spring- and fall-banding (data not shown).

[y] Fertilizer N cost fixed at \$0.663 so that N cost to wheat price ratios equal 3.2, 4.8, and 6.4, respectively.

No one method of fertilizer N placement was economically superior under all conditions in this study. Spring-banding (Table 5) and fall-banding (data not shown) provided higher net margins than broadcasting N fertilizer when wheat prices and/or soil moisture levels were high, reflecting amplification of the yield advantage of banding over broadcasting by product price. But, at low wheat prices and low soil moisture, there was often little difference in net margins among methods of fertilizer placement; in fact, if full costs for the fertilizer banding operation had been used in the analysis (compared to only 50%), banding would have been less profitable than broadcast methods in some situations. Further, in this analysis we assumed that N costs were similar whether the fertilizer was purchased in fall or spring. Often, fertilizer costs are lower in fall as manufacturers attempt to reduce winter inventories. However, producers who take advantage of lower fertilizer costs in the fall do not necessarily have to apply it to the land in fall. Instead they may choose to store the fertilizer and apply it in spring. These additional considerations further obscure the choice of a best method of fertilizer placement.

The overall profitability of stubble cropping must also be assessed by examining total costs and returns, and comparing them to other opportunities such as fallow cropping (Zentner and Campbell 1988). This analysis was not performed in this study. However, a recent study comparing tillage management systems at Swift Current (Zentner et al. 1991) has determined that for zero-till continuous spring wheat total variable costs, and total variable plus fixed costs, averaged \$130 and \$192 ha^{-1} (less costs of N fertilization), respectively. Thus, there are many combinations of low wheat prices, low SN, and low SM in this study that would result in unacceptably low expected yields and net margins, indicating that producers would likely not recover all input costs with zero-till continuous cropping. Under these situations, the best option for producers may involve switching to a fallow-type rotation or to other cropping options.

Economic Benefits of Snowtrapping

Snowtrapping using tall stubble barriers was shown in an earlier paper (Campbell et al. 1992) to increase soil moisture reserves over that of conventional uniform stubble by an average of 13 mm; however, this varied greatly from year to year. The actual measured values for SM, SN, and GP were used to compare the relative profitability (change in yield due to snowtrapping multiplied by wheat price, less the additional cost of constructing trap strips) of using this technique for enhancing soil moisture reserves (Table 6). The results revealed an average net benefit of \$9 to \$32 ha^{-1}, with values being directly related to FN rate and wheat price. The greatest benefit occurred in years with lower growing season precipitation (data not shown). However, in some years when infiltration of snow melt water was low because of rapid thawing of the snowpack, or when winter snowfall was scarce, the net benefit from snowtrapping was zero or slightly negative (data not shown).

Table 6. Net benefit of tall stubble trap strips for snowtrapping, 1982 to 1990.

Applied N Fertilizer	Wheat Price ($ kg^{-1})			
	0.103	0.138	0.173	0.207
(kg ha^{-1})	- - - - -	($ ha^{-1})[w]	- - - - -	
0	9 (6)[x]	12 (8)	16 (10)	19 (12)
25	11 (7)	15 (9)	18 (12)	22 (14)
50	12 (8)	17 (10)	21 (13)	25 (16)
75	14 (9)	10 (12)	24 (15)	28 (18)
100	15 (10)	21 (13)	26 (17)	32 (20)

[w] Change in yield due to snowtrapping x wheat price, less the additional cost of constructing trap strips.

[x] Standard deviation shown in brackets.

CONCLUSIONS

This study examined the economic performance and riskiness of using tall strips of cereal stubble for snowtrapping, and examined how these were affected by the use of various rates, timing, and methods of N fertilizer placement, for spring wheat grown continuously under zero tillage management over a 9-yr period on a medium texture soil in southwestern Saskatchewan. Grain yields were strongly influenced by rate of N fertilizer applied (FN), level of soil N measured in fall (SN), moisture use [available soil moisture in spring (SM) plus growing season precipitation (GP)], years of continuous cropping (YR), and their interactions.

The economic optimum rates of FN varied directly with SM and the probability distribution for growing season precipitation, and inversely with SN, YR, the ratio of N cost to wheat price, and the level of risk aversion held by producers. They were highest for spring- and fall-banded N; they averaged 3 to 14 kg ha^{-1} lower for spring-broadcast N, and 7 to 22 kg ha^{-1} lower for fall-broadcast N. The optimum FN rates increased by 3.7 to 5.7 kg ha^{-1} for each 10 mm increase in SM, these changes being greater at high SN. Optimum FN rates also declined by 5 kg ha^{-1} for each year that the land was cropped continuously under zero tillage management, reflecting an improvement in soil fertility.

Producers seeking to maximize expected profit from fertilization, or those producers who have low aversion to risk, can apply considerably higher rates of N fertilizer than those recommended by the Saskatchewan Soil Testing Laboratory in 1990 (SSTL). In contrast, the recommended FN rates for producers with high risk aversion were generally lower than those of the SSTL. The SSTL recommended rates were most similar to those for producers with medium risk aversion. These findings call into question procedures used to establish fertilizer N recommendations wherein no adjustments are made to the FN rates for level of SM, timing, or method of N placement, years of continuous cropping with fertilization, economic parameters, or the degree of risk aversion held by individual producers.

The study found no one combination of timing and method of N fertilizer placement that was superior in all cases. Spring- and fall-banding provided somewhat higher net margins than broadcasting N fertilizer when SM or wheat prices were high, or when fertilizer banding could be combined with a tillage operation for weed control.

The economic benefit from snowtrapping using tall cereal stubble trap strips was substantial in most years, averaging \$9 to \$32 ha^{-1} and being directly related to FN rate and wheat price. Little benefit or a small loss was incurred with the snowtrapping practice in some years when infiltration of melt water was low or winter snowfall was minimal. Nevertheless, producers in this dry region of the Canadian Prairies are encouraged to adopt this practice as routine when stubble cropping because of its low cost and good potential for a positive benefit in most years.

ACKNOWLEDGEMENTS

Funding for the economic analyses was provided by a research grant to RM #259 Eston Crop Club under the Environmental Sustainability Initiative.

REFERENCES

Anderson, J.R., Dillon, J.L. and Hardaker, B. 1977. Agricultural decision analysis. The Iowa State University Press, Ames, Iowa. 344 pp.

Campbell, C.A., Biederbeck, V.O., Schnitzer, M., Selles, F. and Zentner, R.P. 1989. Effect of six years of zero-tillage and N fertilizer management on changes in soil quality of an orthic Brown Chernozem in southwestern Saskatchewan. Soil Tillage Res. 14: 39-52.

Campbell, C.A., Zentner, R.P., Selles, F. and McConkey, B.G. 1992. Nitrogen management for spring wheat grown annually on zero-tillage--yields and N use of efficiency. Agron. J. (In Press).

Penney, D.C. 1985. Making the most of nitrogen. Recommended practices resulting from recent research in Alberta. pp. 143-154. In proc. 28th Ann. Manitoba Soc. Soil Sci. meeting, Winnipeg, Man.

Raskin, R. and Cochran, M.J. 1986. Interpretations and transformations of scale for the Pratt-Arrow absolute risk aversion coefficient: implications for generalized stochastic dominance. West J. Agr. Econ. 11: 204-10.

Saskatchewan Agriculture and Food. 1990. Farm machinery custom and rental rate guide. 1990. Saskatchewan Agriculture and Food, Publ. 6M, Regina, Sask. 35 pp.

Saskatchewan Soil Testing Laboratory. 1990. Nutrient requirement guidelines for field crops in Saskatchewan. 1990. Saskatchewan Soil Testing Laboratory, Univ. of Saskatchewan, Saskatoon, Sask. (mimeo) 33 pp.

Tessier, S., Peru, M., Dyck, F.B., Zentner, R.P. and Campbell, C.A. 1990. Conservation tillage for spring wheat production in southwestern Saskatchewan (Canada). Soil Tillage Res. 18: 73-89.

Zentner, R.P. and Campbell, C.A. 1988. First 18 years of a long-term crop rotation study in southwestern Saskatchewan--yields, grain protein, and economic performance. Can. J. Plant Sci. 68: 1-21.

Zentner, R.P., Tessier, S., Peru, M., Dyck, F.B. and Campbell, C.A. 1991. Economics of tillage systems for spring wheat production in southwestern Saskatchewan (Canada). Soil Tillage Res. 21:225-242.

$$h(GSP) = \frac{1}{\Gamma(\delta)\beta^{\delta}} GSP^{(\delta-1)} e^{-GSP/\beta} \quad \text{for } GSP \geq 0,$$

where, $\delta = 6.41$ and $\beta = 24.22$.