INFORMATION NEEDS IN CHOOSING FERTILIZER RATES

by
Darrell M. Zbeetnoff and Rea Josephson

EXTENSION BULLETIN NO. 88-2

Department of Agricultural Economics
and Farm Management

Faculty of Agriculture
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

December 1988

As of September 1970, the Department of Agricultural Economics and Farm Management, The University of Manitoba, initiated a formal review procedure for departmental publications. Manuscripts submitted for puiblication are referred to qualified reviewers within and outside of the department.

The categories of departmental publications are:

1. RESEARCH BULLETINS: publications which communicate methodological and/or research information, and report on analytical techniques. Such publications are viewed as making new or substantial contributions to knowledge on problems or analytical techniques, and would have relevance primarily to professional audiences and teaching activities.
2. EXTENSION BULLETINS: publications which communicate information and research results of a general or specific nature to the general public.
3. OCCASIONAL SERIES: publications which are not primarily concerned with methodological, research, or extension information, but which do make a contribution to knowledge on problems relevant to the field of Agricultural Economics.

Copies of this publication may be obtained by writing to the Department of Agricultural Economics, 403 Agriculture Building, The University of Manitoba.

INFORMATION NEEDS IN CHOOSING FERTILIZER RATES

Darrell M. Zbeetnoff
Rea Josephson

Extension Bulletin No. 88-02

Department of Agricultural Economics and Farm Management
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

December 1988

ACKNOWLEDGEMENTS

This bulletin is the first of several reports on findings in a literature review of "Management Options for Low Price Grain Production". The project is jointly sponsored by the Manitoba Department of Agriculture (MDA) and the Faculty of Agriculture, University of Manitoba. The authors would like to thank the steering committee, comprised of representatives of MDA, the faculty, private industry and the grain farming community for guiding this research effort.

EXECUTIVE SUMMARY

The objective of adding fertilizer to crops is to increase revenue through higher levels of production. Determining a nitrogen (N) fertilizer rate requires an economic evaluation of several efficiency components by farmers. Assessments of the choice in terms of profit potential and risk are necessary to improve farm-level decision-making.

This assessment is complex because N recovery varies with selection of N source, application method (i.e. placement) and timing. Each of these decision points is composed of options with varying costs and expectations of N recovery.

Current approaches have established the aggregate or average recovery efficiencies of fertilizer options. More information is needed to assist the farmer in predicting recovery efficiencies for specific field conditions. Individual producer experience probably is the current basis for selecting particular options.

Selection of fertilizer options by considering the variability of recovery efficiency is one way of managing the risk associated with N use. In this respect, significant gaps exist in the data base. Since the distribution and range of potential variation in N recovery efficiency have not been determined, farmers cannot quantify N recovery risk as an element of yield uncertainty in their production response. This creates a serious limitation to the use of economic analysis in determining optimal fertilizer practices.

A second focus in the fertilizer rate decision relates to the physiological efficiencies of the crop species and/or varieties being considered. Information suggests that particular varieties produce more harvestable yield for given levels of N. Calibration of these differential yield responses for important field crops in the province is required. With this information farmers could choose crops which maximize profit potential for given price scenarios.

Third, there is evidence that certain species and varieties respond differently to fertilization under different physical soil conditions and management practices. Later seeding dates appear to result in some lower-yielding varieties being able to out-yield otherwise more productive varieties due to improved fertilizer efficiency. At present, fertilizer efficiency relationships are largely qualitative and the information has not been generated or evaluated in a framework which can be applied by producers.

Finally, N recovery efficiencies and variable yield responses have implications for economic decisions related to fertilizer use.

The first economic issue discussed is that of selecting production levels when yield varies due to unpredictable N recovery efficiencies in any particular year. The findings indicate that fertilization in Manitoba at rates exceeding target levels generate higher net returns over a period of years and suggest that the application rate should be based over several years yield expectations rather than one year. In essence, the cost of surplus fertilizer is more than compensated for by smaller yield reductions under adverse recovery conditions and by larger yield responses in years when N recovery is more efficient.

The second topic addressed is the implication of provincial target yield fertilizer recommendations for management of profit risk by individual producers. Investigation of the target yield concept suggests that current recommendations may inadvertently increase the risk of negative returns due to yield variation. The critical factor is the level of yield variation associated with higher fertilization rates relative to lower rates.

Limited Manitoba data suggests that yield variability may, in fact, decrease or stabilize at higher rates of fertilization. In these instances marginal revenue-marginal cost ratio of 1.5:1 identifies yield and fertilizer combinations which not only lie below the economically optimum production point (i.e. the maximum gross margin), but are also subject to greater profit risk. The implication is that if farmers wish to reduce the chance of yield fluctuations which result in operating costs exceeding revenues per acre, they should fertilize at levels higher than soil laboratory recommendations.

In summary, a number of directions for future research have been identified. If economic techniques capable of improving farm level fertilizer decisions are to be developed, information is required in the following areas:

1. quantification of fertilizer efficiency and variance under specific field conditions;
2. calibration of specie and variety yield response by region, soil factors and management practice;

3. probabilities of crop yield response to N in relation to seeding date and weather;
4. development of better economic techniques for identifying profit seeking and risk management production strategies related to fertilizer use; and
5. development of interdisciplinary approaches to generate the information required at the farm level.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (CONTINUATION)

LIST OF TABLES (CONTINUATION)

LIST OF FIGURES

INFORMATION NEEDS IN CHOOSING FERTILIZER RATES

1.0. Introduction

Dramatic drops in commodity prices, expected revenues and profit margins have forced grain producers to make adjustments to their farming operations. In the case of fertilizer application, optimum rates would have been expected to change because of changed relationships between the prices of commodities and the cost of fertilizer. Several recent agricultural publications in Manitoba, Saskatchewan and Alberta have illustrated how farmers can find these new points of potential profit maximization using marginal analysis.

The degree to which the economics of fertilizer application is useful in identifying more efficient fertilization strategies depends on the quality of the information base and the applicability of the analytical methods to the problems at hand. The current economic climate has lent new importance, in particular, to the consideration of uncertainty and risk when making fertilizer investment decisions. This is because variation in net returns, due to variation in yield response to fertilizer, now represents a much greater proportion of the potential profit margin. From a practical aspect, this publication tests economic approaches, given the current information base available to Manitoba farmers. In addition to a review of the methodology, the strengths and weaknesses of the data are identified. These are discussed in view of the economic situation facing many grain producers today.

2.0. Fertilizer Efficiency

The objective of adding fertilizers to crops is to increase production efficiency. To be economically efficient, however, means obtaining the greatest total profit from the use of fertilizer inputs. There are really two components of fertilizer efficiency and each presents the farmer with a problem to be solved within the current information base and his management capability.

2.1. Efficiency of Fertilizer Recovery

Efficiency of fertilizer recovery at any particular application rate is much lower than 100 percent. Fertilizer nitrogen recovery, for example, can range from 20-60 percent, depending on the weather, the timing and placement and the chemical form of the fertilizer, but usually is no greater than 65 percent of applied N under favorable conditions (Racz, G., Personal Communication, 1987).

The management decision to be made by the farmer in maximizing the net economic return from fertilizer use requires an assessment of his management options in relation to these factors. As presented in Table 1, nitrogen recovery of the various fertilizer forms is considered comparable when recommended practices are followed. Variation in the range of recovery efficiency however, is less established among the different forms depending on their timing and placement. For example, the recovery efficiency of broadcast N fertilizer fluctuates more widely than banded fertilization when time of application is held constant (Harapiak et al., 1986). The fluctuation, due to variable soil and weather conditions which can lead to extreme losses of broadcast N suggests greater risk of

Table 1

Indexes of Average Recovery Efficiencies of Selected Nitrogen Fertilizers by Time and Method of Placement, Manitoba

Method of Placement	Broadcast		Banded	
Timing	Fall	Spring	Fall	Spring
Fertilizer	Recovery Efficiency Index			
Liquid N	82[a] (41)[b]	100 (50)	93 (47)	120 (60)
Ammonium Nitrate	82[a] (41)[b]	100 (50)	93 (47)	120 (60)
Urea	70[a] (35)[b]	85 (43)	93 (47)	120 (60)
Anhydrous	- -	- -	93[a] (47)[b]	120 (60)

[a] Relative availability of N for plant growth where spring broadcast nitrogen has an index of 100.

[b] Overall recovery efficiency - 50 percent of available N is expected to be recovered.

Sources: Field Crop Fertilizer Recommendations for Manitoba, 1986, Harapiak, et al., 1986.
Racz, Personal Communication, 1987; McGill, Personal Communication, 1987.

efficiency losses, although the actual probability of these events has not been established (Racz, G., Personal Communication, 1987; McGill, K., Personal Communication, 1987).

Relative recovery efficiency and the degree to which recovery deviates from expected are not the only determinants of optimal fertilization practices. The other major factor is the cost of placing the fertilizer which depends on the type of fertilizer and method of application. The suitability of certain methods and timing of application also depend on specific soil conditions and producer choices in the allocation of time and labour.

The management challenge is to select the best fertilizer option from among a set of feasible alternatives. Ideally, highest economic returns from fertilization would be accompanied by lowest fluctuation in recovery efficiency across variable conditions, thereby allowing a farmer to predict his fertilization outcome with greater accuracy. In reality, fertilizer management decisions may require a tradeoff between economic returns and risks associated with recovery efficiency.

Even prior to consideration of a specific fertilizer option, the timing of fertilizer purchase may present opportunities for cost saving. Table 2 indicates that the price discount available to farmers who purchased fertilizer in the fall (1987) amounted to about \$0.03/lb actual N compared to estimated spring prices, with the exception of ammonium nitrate.[1] This price differential represents a

---

[1] Ammonium nitrate is being dropped from fertilizer company inventories in favour of other forms which are of higher analysis, more effective and/or require handling of smaller volumes. Nevertheless, it is included primarily since fertilizer efficiencies are still rated relative to broadcast incorporation of granular N products.

Table 2

Cost of Fertilizer and Applicator

Fertilizer	Analysis	$/tonne[a]		lbs N Per 100 lbs	$/lb N		Equipment[b] Cost	
		Fall	Spring		Fall	Spring	Broadcast Per Acre	Banded Per Acre
Liquid N	28-0-0	125	145	28	0.20	0.24	3.00	6.00
Ammonium Nitrate	34-0-0	185	178	34	0.25	0.24	3.00	6.00
Urea	46-0-0	205	230	46	0.20	0.23	3.00	6.00
Anhydrous	82-0-0	235	280	82	0.13	0.16	-	6.00

[a] Manitoba Agriculture Price Survey, fall, 1987 and anticipated prices in spring, 1988.

[b] Excluding labour.

15-23 percent discount (Liquid N or Urea and anhydrous, respectively) on fall-purchased N requirements. Where fall N application is the most effective alternative, the discount may increase the quantities purchased. In regions where spring banding is equally effective, however, the \$0.03/lb actual N price discount may pay farmers to undertake fall application, in addition to easing bottlenecks in their spring operations.

An annual interest rate of 11 percent on an operating line of credit would create interest costs of \$0.01 and \$0.015/lb actual N (for liquid N or urea and anhydrous, respectively) over the 7 months between October 1, 1987 and April 30, 1988. Clearly, if estimated spring 1988 prices are accurate, the economic choice is to purchase fertilizer in the fall. Even if held until spring, the total fertilizer bill financed at 11 percent[2] will produce a saving. On the other hand, a price discount of approximately 7 percent would have made a farmer indifferent between spring and fall fertilizer purchase.

The actual selection of fertilization alternative based on recovery efficiencies, requires two pieces of information. First the expected cost to deliver 35 lbs-N recoverable[3] depends on the interrelationship among unit cost of N, form, timing and placement of the fertilizer application. As illustrated in Table 3, N sources are characterized by different overall recovery efficiencies. Spring

---

[2] Assuming that new storage facilities were not required.

[3] Fertilization of seeded stubble acreage in Manitoba averaged 60 lbs actual N from 1981-1985. At 50 percent average recovery efficiency, this would have represented 30 lbs-N recoverable over the period. Indications are that recovery efficiency may exceed 50 percent, on average, in 1988 (Harapiak, personal communication, 1988).

applications tend to result in higher recovery of N than fall applications and banded applications are more effective than broadcasting. Ultimately, a less efficient source of N may be economically preferable if its price reflects this lower recovery efficiency.

The expected costs per acre of spring and fall, broadcast and banded N applications are presented in Table 4. A ranking of the fertilizer options (Table 5) indicates that the most cost-efficient choices from the standpoint of lowest costs per acre under expected conditions are spring and fall banding options. If spring banding is not feasible, spring broadcasting is more recovery efficient and less costly than fall broadcasting. Note that spring broadcasting to deliver the N requirement under current price assumptions is less costly than fall banding, on average (except for anhydrous application) and comparable to spring banding of lower analysis N sources (Table 5).

The second consideration is the potential variation in cost attributable to fluctuations in recovery efficiency under different field conditions. No one fertilization option is superior under all field conditions. A conventional assumption is that, when timing and application method are held constant, each fertilizer N source is equally effective if recommended incorporation practices are followed. This is evident from the recovery efficiencies presented in Table 3. It is important to note, however, that even if this is true, it reflects the average result. Efficiencies under specific field conditions are known to vary considerably among fertilizer forms, due

Table 3

Fertilizer Application Rate, and Actual N Requirements To Supply[a] lb-N Recoverable Based on Expected Recovery Efficiencies

Fertilizer		Broadcast		Banded	
		Fall	Spring	Fall	Spring
Liquid N (28-0-0)	Rate[a]	304	250	269	208
	lbs-N/ac[b]	85	70	74	58
Ammonium Nitrate (34-0-0)	Rate[a]	250	206	218	171
	lbs-N/ac[b]	85	70	74	58
Urea (46-0-0)	Rate[a]	217	179	161	126
	lbs-N/ac[b]	100	82	74	58
Anhydrous (82-0-0)	Rate[a]	-	-	90	70
	lbs-N/ac[b]	-	-	74	58

[a] 35 lbs-N recoverable represents an actual N rate of 20 lbs-N, with 50 percent recovery efficiency.

[b] Total lbs of fertilizer required per acre.

[c] Actual N equivalency levels needed to supply 35 lbs-N recoverable, given relative and overall recovery efficiencies (Table 1).

Table 4

Quantity (lbs/acre) and Costs ($/ac) to Deliver 35 lbs-N Recoverable[a] N Per Acre With Different Fertilizer Forms, Timing and Placement

Fertilizer		Broadcast Fall	Broadcast Spring	Banded Fall	Banded Spring
28-0-0	lbs-N/ac[a]	85	70	74	58
	Cost/ac[b]	$20.00	$19.80	$20.80	$19.92
34-0-0	lbs-N/ac[a]	85	70	74	58
	Cost/ac[b]	$24.25	$19.80	$24.50	$19.92
46-0-0	lbs-N/ac[a]	100	82	74	58
	Cost/ac[b]	$23.00	$21.86	$20.80	$19.34
82-0-0	lbs-N/ac[a]	-	-	74	58
	Cost/ac[b]	-	-	$15.62	$15.28

[a] 35 lbs-N recoverable represents an actual N rate of 70 lb-N, with 50 percent recovery efficiency.

b Actual N-equivalency levels needed to supply 35 lb-N recoverable, given relative and overall recovery efficiencies (Table 1).

[c] Cost of selected fertilizers at calculated price per lb-N. This includes the cost of broadcasting = $3/acre and banding = $6/acre (excluding labour).

Table 5

Expected Costs and Variation in Costs of
Selected Fertilizers, Timing and Method of Application
to Delivery 35 lbs-N Recoverable

Option	Fertilizer Analysis	Practice	Fertilizer Rate/Ac	Actual lbs-N/Ac	Estimated Cost/Ac ($)	Relative[a] Variation In Recovery Efficiency
1.	82-0-0	Spring Band	70	58	$15.28	1
2.	82-0-0	Fall Band	90	74	15.62	2
3.	46-0-0	Spring Band	126	58	19.34	1
4.	28-0-0	Spring Broadcast	250	70	19.80	3
5.	34-0-0	Spring Broadcast	206	70	19.80	1
6.	28-0-0	Spring Band	208	58	19.92	1
7.	34-0-0	Spring Band	171	58	19.92	1
8.	28-0-0	Fall Broadcast	304	85	20.00	3
9.	28-0-0	Fall Band	269	74	20.80	2
10.	46-0-0	Fall Band	161	74	20.80	2
11.	46-0-0	Spring Broadcast	179	82	21.86	2
12.	46-0-0	Fall Broadcast	217	100	23.00	3
13.	34-0-0	Fall Broadcast	250	85	24.25	3
14.	34-0-0	Fall Banded	218	74	24.50	2

[a] Ranked where 1 = lower variation under field conditions;
3 = higher variation under field conditions.

to the chemical properties of the N carrier and differential responses to temperature, moisture, and soil factors.

The problem emerging here is that different ranges of recovery efficiency for different forms, timing and application methods are possible or even likely, but unquantified at the present time. In Table 5, the last column is an estimated rating of recovery variation reported in the literature. Of the top ten, some low cost options may perform less consistently than others. Although there is little information presently available to discern differences in variation in recovery efficiency, the implications for farm management are significant.

Recovery efficiencies are not calibrated to specific field conditions in a manner which allows economic evaluation of the relative risks of using particular N sources, or methods for actual or anticipated field conditions. Farmers, therefore, could benefit from schedules of the recovery probabilities and potential cost variations of these practices. Clearly, an ineffective choice of fertilization option may invalidate the level of fertilization decision based on yield response.

2.2. Physiological Efficiency

The second measure of fertilizer efficiency, physiological efficiency, refers to the level of realized yield per unit of fertilizer recovered. This component is generally not distinguished in fertility trials, but has a direct bearing on varietal improvement because some cultivars are more efficient in converting fertilizer into harvestable yield.

At the present time, physiological efficiency pertains mostly to the use of nitrogen because it is the only nutrient for which yield response is calibrated to the level of fertilization in Manitoba. The ability to choose varieties on the basis of production values, given quantities of fertilizer recovered, has the potential to increase net economic returns.

The information base available to Manitoba farmers on physiological efficiency is characterized by gaps and deficiencies. The majority of research has focussed on altering N recovery efficiency rather than physiological efficiency to improve yields for field crops grown in the province. Nevertheless, limited research indicates potential areas for increasing yield relative to quantity of N recovered (yield refers to both grain quantity and grain quality).

Where grain protein content is an important factor in marketing, plot testing (Gehl, et al., 1986; 1987) suggests that the ratio of N recovered in harvested versus non-harvested components (i.e. the harvest index) of semi-dwarf cereal crops may be higher than conventional hard red spring (HRS) varieties. Morever these studies indicate a positive correlation between levels of grain protein yield and grain yield. If greater N translocation has the potential to increase grain protein concentration at higher grain yields and fertilizer rates than previously considered possible it could have a significant impact on grain breeding programs.[4] In the past, plant

---

[4] There is research to suggest that varietal selection for grain protein content has not been adequately focussed on protein content response to varying rates of N fertilization, particularly at high N rates (see Racz, 1983).

breeders have sacrificed yield potential to ensure quality standards of HRS wheats because the rate of increase of grain yield typically exceeded that of protein yield, resulting in lower overall protein concentration levels (Baker and Townley-Smith, 1986; Fowler, 1986).

Where the crop is not used primarily as a protein source, the content of the harvested product is less important. Soft, utility, winter and semi-dwarf wheats all produce more grain per lb-N fertilizer than conventional HRS wheat varieties when N is the limiting factor in plant growth. Similarly, Bedford and Heartland six-row feed barleys out yield Bonanza, a six-row malting variety in Manitoba (Gehl et al., 1986), which is often sold for feed. Clearly, the producer requires information on the physiological efficiencies of particular varieties, related to the marketing opportunities he wishes to pursue and the levels of fertilizer he chooses to apply.

Improved physiological efficiency may be managed if the effect of timing fertilizer application, method of placement and field conditions can be related to N translocation in the plant harvestable parts. In Manitoba, split N application may increase the potential for achieving high protein wheat yields, but research results have not been consistent under Manitoba conditions (Alkier et al., 1972).

No mention has been made in the literature of the variability of physiological efficiency over a range of field conditions. Risk-reducing production strategies would entail the choice of crops and varieties with high yield responses to given levels of N fertilization with relatively low variability under adverse climatic conditions.

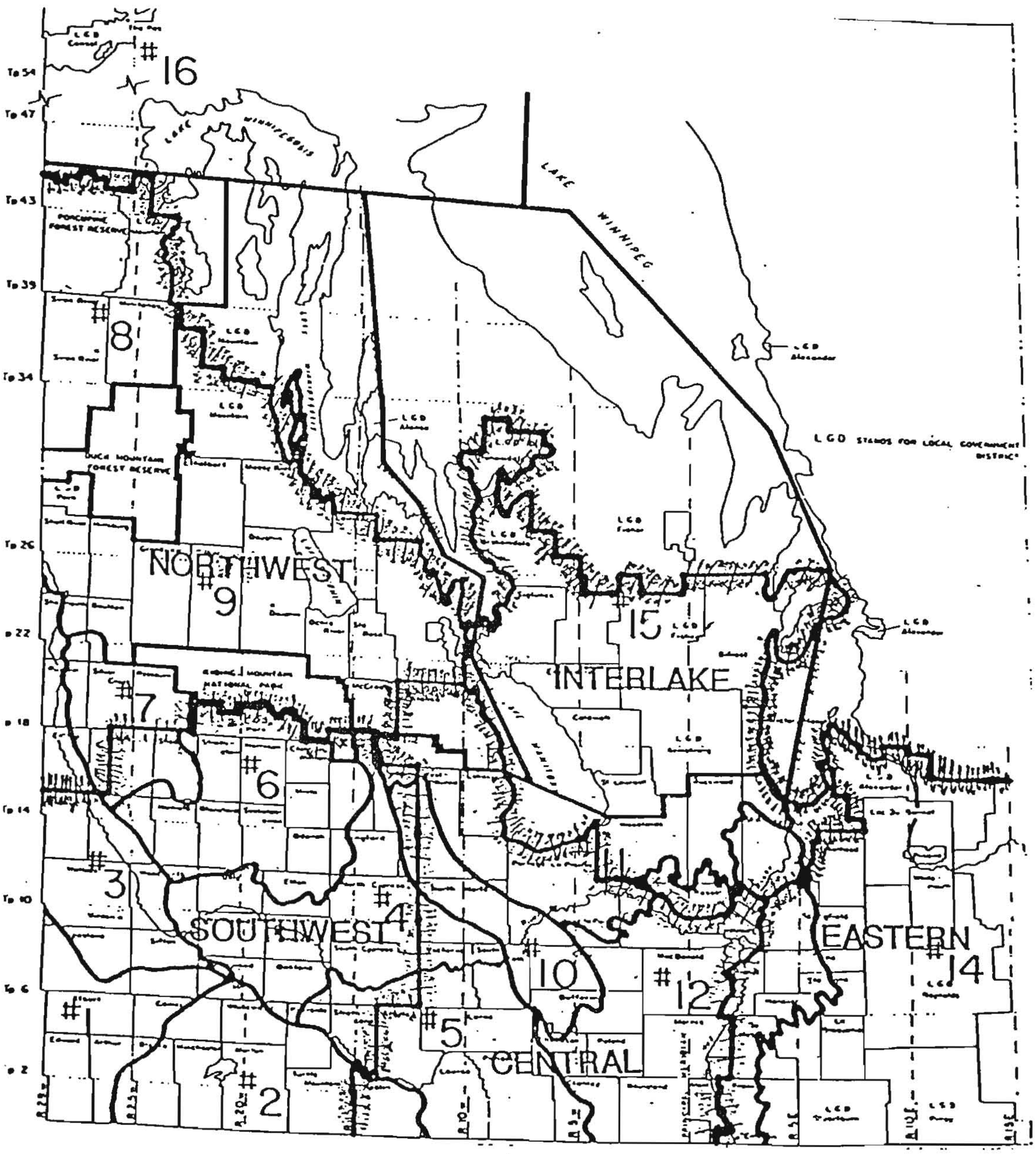
Finally, seeding date plays a role in the yield response of cultivars to N fertilization (Nelson, 1986). Average yields on stubble vary not only by week of seeding but also by region (see Figure 1) and crop, as Appendix A, Tables A.1 to A.5. illustrate. It is assumed that fertilization levels were comparable between earlier-seeded and later-seeded crops. Yield indexes for wheat grown on stubble in the five regions of Manitoba over the period 1981 to 1985 are presented graphically in Figure 2.

Certain varieties of wheat also appear able to achieve yields closer to the regional average, given later seeding dates (Andrews, 1986). For example, Benito yield indexes after second week seeding dates in May tend to be closer to the regional average than Neepawa in the Central (Table 6 and Figure 3) and Southwest regions (Table 7). On the other hand, Glenlea yield indexes on later seeded acreages match or exceed yield indexes of Benito in the Southwest (Figure 4). Caution in the interpretation of these tables and figures should be emphasized in view of the limited number of years of data available.

In general, varieties that respond well to later seeding dates improve the fertilizer efficiencies for given levels of fertilization. A producer would wish to know if a variety with a higher physiological efficiency overall is likely to be out yielded by a variety with a lower physiological efficiency for given seeding dates in his locale. This applies not only to wheat varieties; in recent years the realized yields of Polish canola are reported to be higher than realized yields of Argentina canola, although physiological efficiencies generally favour the latter.

Figure 1

Canada-Manitoba Crop Insurance Risk Areas and Crop Insurance Regions of Manitoba



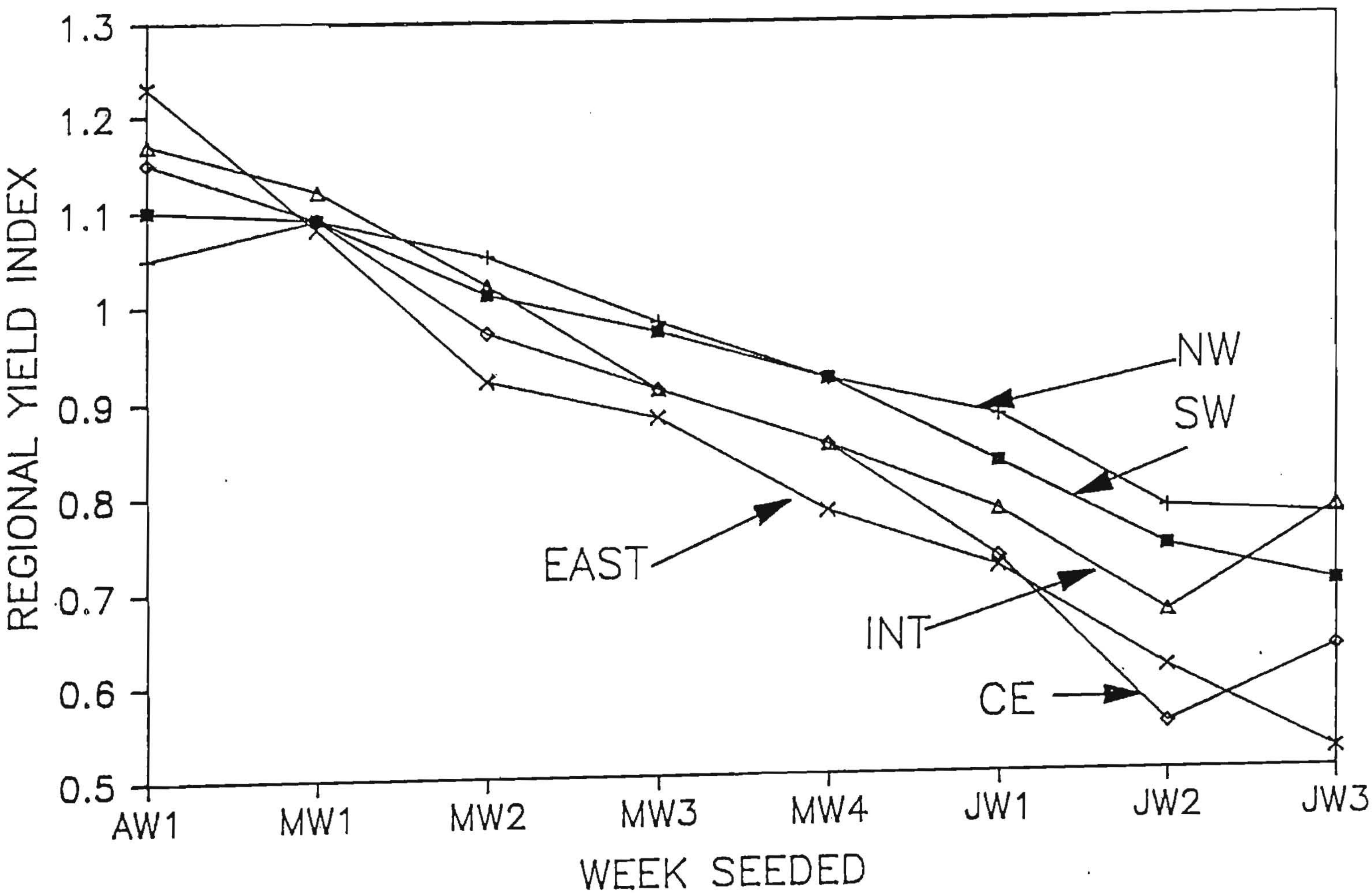


Figure 2
Yield Indexes for Wheat Grown on Stubble By Seeding Date (1981 to 1985), Manitoba

Table 6

Yield Indexes of Wheat Varieties (1981 to 1985), Manitoba
By Seeding Date, Central Region

Variety	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	Average Yields (bu/ac)
Neepawa (81-85)	1.08	1.03	0.99	0.94	0.83	0.71	37.5
Benito (81-85)	1.06	1.03	1.00	0.98	0.88	0.84	37.8
Glenlea (81-85)	1.06	1.04	0.99	0.94	0.87	0.75	41.6
Columbus (83-85)	1.03	1.05	0.98	0.93	0.83	0.74	37.5
Katepwa (84-85)	1.06	1.03	1.01	0.91	0.89	0.71	42.4

Source: Andrews, Personal Communication, 1987.

Figure 3

Yield Indexes of Wheat Varieties (1981 to 1985)
Manitoba by Seeding Date, Central Region

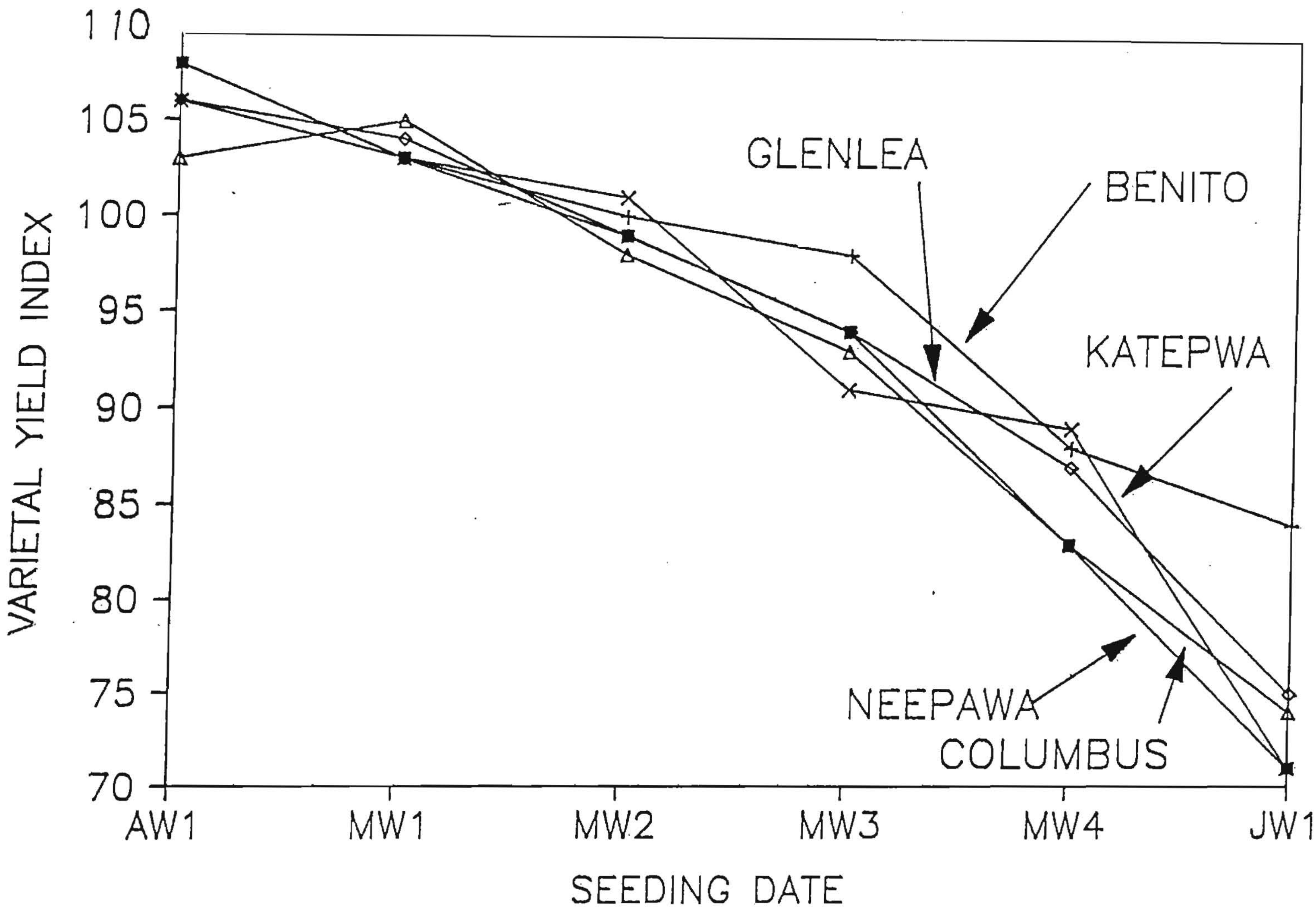


Table 7

Yield Indexes of Wheat Varieties (1981 to 1985), Manitoba
By Seeding Date, Southwest Region

Variety	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	Average Yields (bu/ac)
Neepawa (81-85)	1.08	1.03	1.01	1.00	0.91	0.81	31.6
Benito (81-85)	1.04	1.01	1.02	0.99	0.95	0.87	31.6
Glenlea (81-85)	0.98	1.06	1.05	0.99	0.94	0.90	33.5
Columbus (83-85)	1.05	1.02	1.01	0.97	0.92	0.89	31.6
Katepwa (84-85)	1.03	1.01	1.01	0.97	0.91	0.82	36.3

Source: Andrews, Personal Communication, 1987.

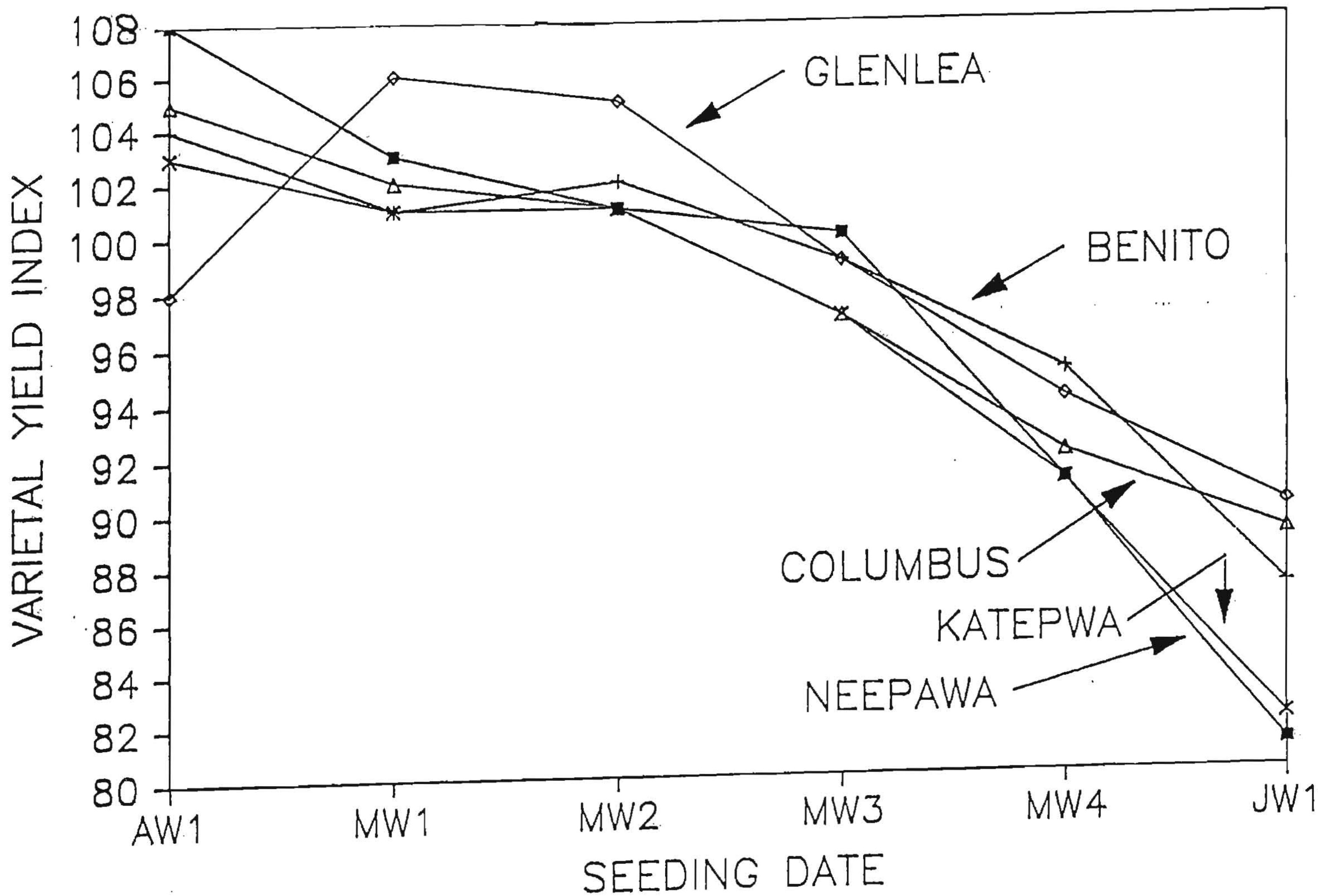


Figure 4

Yield Indexes of Wheat Varieties (1981 to 1985)
Manitoba by Seeding Date, Southwest Region

2.3. Yield Efficiency

The common focus of fertilizer recommendations is yield efficiency defined as yield increase per unit of applied fertilizer. Yield efficiency, in fact, is the product of fertilizer recovery efficiency and physiological efficiency. As the previous two sections have indicated, the variability of these efficiencies is sensitive to field conditions and varietal selection.

In addition to seed variety and level of N recovery, further variability in yield efficiency is created by growing conditions in any particular year, of which the most influential is moisture availability. Yield efficiency analysis consists of the calibration of yield responses to fertilization rate and moisture conditions. Determination of optimal economic levels is based upon an index of the return from additional production in relation to the incremental cost of added fertilizer. This decision-assisting approach will be discussed in detail later.

From a management perspective, the producer should select his fertilization-yield objective based upon an estimate of N recovery, adjustment for physiological factors and their management and expectation about the impact of the weather. These three areas contribute to yield variability independently and the conditions which optimize N recovery, for example, may not be ideal for plant growth or physiological response. This suggests that fertilizer decisions on the economic impacts of combinations of these factors should be jointly determined.

There are significant components of yield uncertainty associated with fertilizer use. Yield efficiency analysis in the prairie provinces lumps these components into an aggregate estimate of fertilizer-yield relationships. The fundamental question is how the current information base of yield responses to fertilizer assists farmers in making good economic decisions about fertilizer use. In particular, the characteristics of yield uncertainty are a primary economic concern since there is a desire to manage the tradeoff between profit potential and risk.

2.3.1. Calibration of Yield Response to Fertilizer

In Manitoba, yield responses are estimated for most field crops only with respect to the level of nitrogen (N). Actual calibration of yields to level of N fertilization is provided by the provincial soil testing laboratory for wheat, barley, oats, corn, sunflowers, flax and canola. The recommended N rates for the other crops are based on nutrient requirements to attain their growth potential and are presented as standard target rates. Adjustments in yield potential are made by regional moisture index and soil type across the province for wheat, barley and oats (Table 8). Attempts to calibrate yield response of other crops to moisture have not been reliable to date (Racz, Personal Communication, 1987).

Note that the "moisture modified" yield index varies with level of N fertilization and moisture conditions. With no N fertilization, soil N reserves are expected to provide comparable yields over "irrigated, moist and dry" moisture conditions and approximately 88 percent under arid conditions. The spread in yield potential between

Table 8

Index of Yield Response[a] in Relation to Moisture Conditions[b]

	Irrigation	Moist	Dry	Arid
At 1987 Provincial Soil N Levels With lbs-N/ac Applied to Produce Maximum Yield Response		Index		
Wheat	100	85	72	57
Barley	100	92	76	59
Oats	100	92	76	60
At 1987 Provincial Soil N Levels and Zero lbs-N/ac Applied				
Wheat	100	100	99	91
Barley	100	100	99	86
Oats	100	100	99	87
At 1987 Provincial Soil N Levels and 67 lb-N/ac Applied				
Wheat	100	97	89	75
Barley	100	100	92	75
Oats	100	100	92	76

[a] In this table, the base used is the target yield under "irrigated" moisture conditions for each crop at each level of available N.

[b] Indexes may be calculated using any moisture condition as a base. Convert wheat yields to a "moist" base for 1987 Provincial soil N levels and 67 lbs lbs-N/ac applied as follows:

$$\frac{\text{index}}{97} \times 100.$$

Source: Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982.

moisture classes widens substantially at higher N fertilization rates, indicating that variation in yield response due to moisture is likely to increase at higher fertility levels.

The degree to which the fertilizer management strategy indicated above may be implemented is limited by the quality of the yield response information available. At present, yield effects of changes in fertilizer rates have been estimated empirically only for nitrogen on the seven crops indicated. Implicitly, the fertilizer recommendation assumes knowledge of soil nutrient status. Management decisions made without soil test information, in of themselves, impose greater risk on the farm operation in targeting yields and net returns to fertilizer use.

For a given region, yield calibrations reflect soil N reserves, moisture index and rate of applied N. Yield responses to N exhibit diminishing marginal productivity at higher rates and at higher soil N reserve levels. Moisture classification adjusts yield targets upward substantially from arid to ideal conditions.

2.3.2. Predicting Yields

Target yield fertilizer recommendations of the Manitoba provincial soil testing laboratory (MPL) for field crops are not intended to be yield predictions. The levels of fertilizer specified fulfill the nutritional requirements of the crop, whereas the yield target is an attainable goal under favorable conditions. Although wheat, barley and oats recommendations are further modified to reflect "average" moisture levels; even then, a variety of factors which influence growth response on specific acreages are not accounted for. In this context, farmers should recognize that:

1. the accuracy of yield targets and fertilizer recommendations on lands which are soil tested is directly related to the presence of "average" conditions for which MPL adjusts for;

2. other factors which cause variation in yield potential and nutritional requirements are either not known or unadjusted for on specific soil tested acreages; and

3. application of soil test recommendations to lands which have not been soil-tested can multiply the errors inherent in (1) and (2), above.

It is often not possible to attribute yield effects to specific factors in (1) and (2). Many soil physical factors indirectly affect yield performance; primarily, by causing deviations in moisture availability from "average" conditions. In other instances, soil characteristics may influence the level of plant available N, causing it to differ from measured soil N reserve level. And superimposed on these fertility constraints to attaining yield potential are the varying management capabilities of different producers.

As illustrated in Tables 9 to 13, it is remarkable how closely target yields based on regional soil N reserves reflect regional yield experience, given the complexity of yield response factors and their interrelationships. Nevertheless, from an individual farmer's perspective, there is further need to know how accurately target yields predict yield potentials on specific acreages and what pattern of yield responses are characteristic of lands of differing production

Table 9

Comparison of Actual Yields with Target Yields Based on N-Rates
Manitoba Provincial Soil Testing Laboratory, Stubble Wheat, 1985
Southwest Region - "Dry" Moisture Index

Soil Class	(1) Yield Expect[a] (N Res) 1985	(2) MCIC 1985 Yield	(3) Lbs N App. 1985	(4) Target $\bar{Y}$ (Dry)	(5) Y (2)-(1)	(6) Y/ N (5)/(3)	(7) 1985 $\bar{Y}$ Minus Target (2)-(4)
A	-	-	-	-	-	-	-
B	39.8[b]	41.8	58	40.0[c]	2.0	0.03	1.8
C	38.9	40.3	57	40.0	1.4	0.02	0.3
D	38.0	39.0	57	40.0	1.0	0.02	-1.0
E	38.2	41.8	54	39.8	3.6	0.07	2.0
F	33.2	34.9	43	39.4	1.7	0.04	-4.5
G	32.6	34.1	46	39.5	1.5	0.03	-5.4
H	30.9	31.1	46	39.5	0.2	0.01	-8.4
I	28.6	28.6	49	39.6	0	0	-11.0
J	26.1	-	-	-	-	-	-
Weighted Averages	36.8	38.9	53	39.8			

[a] Based on (i) Regional soil N research = 61.4 lbs N/ac in spring, 1985; and
(ii) Distribution of yields across soil classes, crop insurance data, 1981 to 1985.

[b] Acres > 5000.

[c] Derived from Target Yield Tables, 1982.

Source: Manitoba Crop Insurance Corporation (MCIC) and Manitoba Provincial Soil Testing Laboratory.

Table 10

Comparison of Actual Yields with Target Yields Based on N-Rates
Manitoba Provincial Soil Testing Laboratory, Stubble Wheat, 1985
Northwest Region - "Moist" Moisture Index

Soil Class	(1) Yield Expect[a] (N Res) 1985 (bu/ac)	(2) MCIC 1985 Yield (bu/ac)	(3) lbs N App. 1985 (lbs/ac)	(4) Target $\overline{Y}$ (Moist) (bu/ac)	(5) Y (2)-(1)	(6) Y/ N (5)/(3)	(7) 1985 $\overline{Y}$ Minus Target (2)-(4)
A	38.9[b]	-	-	-	-	-	-
B	33.0	41.5	56	43.5[c]	8.5	0.15	-2.0
C	34.8	42.3	60	44.0	7.5	0.13	-1.7
D	34.0	41.7	60	44.0	7.7	0.13	-2.3
E	32.3	37.7	57	43.6	5.4	0.09	-5.9
F	31.0	35.9	58	43.8	4.9	0.08	-7.9
G	29.4	35.0	57	43.6	5.6	0.10	-8.6
H	29.9	-	-	-	-	-	-
I	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-
Weighted Averages	33.2	40.0	58	42.5			

[a] Based on: (i) regional soil N reserve = 49.0 lbs N/ac in spring, 1985; (ii) distribution of yields across soil classes, crop insurance data, 1981 to 1985.

[b] Acres > 5000.

[c] Derived from Target Yield Tables, 1982.

Sources: Manitoba Crop Insurance Corporation (MCIC) and Manitoba Provincial Soil Testing Laboratory.

Table 11

Comparison of Actual Yields with Target Yields Based on N-Rates
Manitoba Provincial Soil Testing Laboratory, Stubble Wheat, 1985
Central Region - "Moist" Moisture Index

Soil Class	(1) Yield Expect (N Res)[a] 1985	(2) MCIC 1985 Yield	(3) lbs N App. 1985	(4) Target $\bar{Y}$ (Moist)	(5) Y (2)-(1)	(6) Y/ N (5)/(3)	(7) 1985 $\bar{Y}$ Minus Target (2)-(4)
A	36.7[b]	48.2	66	45.2[c]	11.5	0.17	3.0
B	36.5	49.5	68	45.3	13.0	0.19	4.2
C	35.9	50.4	70	45.4	14.5	0.21	5.0
D	34.2	49.0	70	45.4	14.8	0.21	3.6
E	32.7	47.1	68	45.3	14.4	0.21	1.8
F	31.5	44.8	63	45.1	13.3	0.21	-0.3
G	29.4	42.2	61	45.0	12.8	0.21	-2.8
H	25.6	37.4	56	44.9	11.8	0.21	-7.5
I	24.8	-	-	-	-	-	-
J	-	-	-	-	-	-	-
Weighted Averages	33.4	47.6	68	45.4			

[a] Based on: (i) regional soil N reserve = 54.3 lbs N/ac in spring, 1985; (ii) distribution of yields across soil classes, crop insurance data, 1981 to 1985.

[b] Acres > 5000.

[c] Derived from Target Yield Tables, 1982.

Sources: Manitoba Crop Insurance Corporation (MCIC) and Manitoba Provincial Soil Testing Laboratory.

Table 12

Comparison of Actual Yields with Target Yields Based on N-Rates
Manitoba Provincial Soil Testing Laboratory, Stubble Wheat, 1985
Interlake Region - "Moist" Moisture Index

Soil Class	(1) Yield Expect[a] (N Res) 1985	(2) MCIC 1985 Yield	(3) lbs N App. 1985	(4) Target $\bar{Y}$ (Moist)	(5) Y (2)-(1)	(6) Y/ N (5)/(3)	(7) 1985 $\bar{Y}$ Minus Target (2)-(4)
A	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-
C	31.7[b]	36.8	62	44.2[c]	5.1	0.08	-7.4
D	33.2	39.9	61	44.1	6.8	0.11	-4.2
E	31.5	38.4	59	43.9	6.9	0.12	-5.5
F	29.4	35.5	56	43.5	6.1	0.11	-8.0
G	28.7	36.2	56	43.5	7.5	0.13	-7.3
H	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-
Weighted Averages	31.3	37.3	59	43.9			

[a] Based on: (i) regional soil N reserve = 50.7 lbs N/ac in spring, 1985; (ii) distribution of yields across soil classes, crop insurance data, 1981 to 1985.

[b] Acres > 5000.

[c] Derived from Target Yield Tables, 1982.

Sources: Manitoba Crop Insurance Corporation (MCIC) and Manitoba Provincial Soil Testing Laboratory.

Table 13

Comparison of Actual Yields with Target Yields Based on N-Rates
Manitoba Provincial Soil Testing Laboratory, Stubble Wheat, 1985
Eastern Region - "Moist" Moisture Index

Soil Class	(1) Yield Expect[a] (N Res) 1985	(2) MCIC 1985 Yield	(3) lbs N App. 1985	(4) Target $\bar{Y}$ (Moist)	(5) Y (2)-(1)	(6) Y/ N (5)/(3)	(7) 1985 $\bar{Y}$ Minus Target (2)-(4)
A	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-
C	31.4[b]	43.2	69	44.6[c]	11.8	0.17	-1.4
D	32.9	43.6	71	44.7	10.7	0.15	-1.1
E	31.6	44.6	75	44.9	13.0	0.17	-0.3
F	25.2	37.0	46	41.7	11.8	0.25	-4.7
G	-	-	-	-	-	-	-
H	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-
Weighted Averages	31.8	43.5	71	44.8			

[a] Based on: (i) regional soil N reserve = 46.3 lbs N/ac in spring, 1985; (ii) distribution of yields across soil classes, crop insurance data, 1981 to 1985.

[b] Acres > 5000.

[c] Derived from Target Yield Tables, 1982.

Sources: Manitoba Crop Insurance Corporation (MCIC) and Manitoba Provincial Soil Testing Laboratory.

capabilities. In the current economic climate, summaries of soil test information may be instrumental in assisting other farmers to make better fertilizer decisions, even if they have not soil tested to date.

Using stubble-seeded wheat crop data, Manitoba Crop Insurance Corporation (MCIC) records of yield have been compared with a regional target yield that would have been recommended by the Manitoba provincial soil testing laboratory based on regional soil N reserves. The distribution of actual yields has been further segregated in terms of the 10 MCIC soil classes in 5 regions (Figure 1) and matched with reconstructed target yields based on known regional soil N levels, average fertilization by soil class and moisture conditions.

The year 1985 was selected as one in which growing conditions were generally favorable province-wide and one in which actual yields had a good chance of approaching target yield levels. The yield expectations in column (1) in Tables 9 to 13 were determined by calculating yield indexes across the soil classes relative to the regional weighted average over the period 1981 to 1985. In Table 11, for example, the weighted average yield in column (1) is derived from the provincial target yield tables, assuming a constant soil N reserve level of 54.3 lbs-N/ac and "moist" moisture conditions. This regional average and historical yields, 1981 to 1985, are used to estimate yield expectations by soil class.[5]

5

$$\text{Yield Expectation for Soil Class, 1985} = \frac{\text{Average Yield for Soil Class, 1981 to 1985}}{\text{Weighted Average Yield (All Soil Classes, 1981 to 1985)}} \times \text{Weighted Regional Yield Expectation (1985 N) Reserve Level}$$

Column (4) of the tables represents the target yield that would have been recommended by the provincial soil test laboratory, based on the regional soil N level and the rate of N fertilizer applied in 1985 (Column (3)). As Tables 9 to 13 indicate, regional yield expectations based on N application rates correspond reasonably well with average regional yield averages for the dry moisture index in the Southwest region and for moist conditions elsewhere. The data would indicate that moisture conditions approached ideal in the Central and Eastern regions in 1985.

A comparison of actual versus target yields by MCIC soil class shows interesting relationships:

(a) Yields decline substantially and consistently from class A to J in each region, and are at least as great as the yield responses within classes to N fertilization. These differences would appear to be only partially attributable to nutrition, since the N rates across MCIC soil classes within regions are reasonably consistent (Column 3, Tables 9 to 13).

(b) The yield increases attributable to N fertilization are very consistent across soil classes within regions. This characteristic is well known to MCIC and is incorporated in its coverage adjustment mechanism.[6]

(c) Target yields are exceeded by actual yields in the upper MCIC soil classes and exceed actual yields in lower MCIC soil classes.

---

[6] Nelson, H. Research Director, Manitoba Crop Insurance Corporation, Personal Communication, 1987.

The patterns exhibited are consistent across regions and may reflect problems in fertility and/or moisture availability assessment. Noise factors, such as pockets of exceedingly high soil N reserves in the Southwest and excessive moisture in the Interlake in 1985, have probably made the magnitude of incremental yield responses to N fertilization meaningless. Nevertheless, the differing yields in the various soil classes are real although the reasons are not readily identifiable based on the data presented.

At least two possible explanations are immediately apparent. First, fertility in each soil class may be masked by the averaging of soil N reserves to the regional level. That is, individual soil tests may have indicated higher soil N reserves in soil classes A to E (Table 9) and lower soil N reserves in soil classes F and lower. In this case, the statistical calculations would obscure initially different soil N reserves in all soil classes in all regions. Reference to an individual producer's soil test results and soil class would support or reject this explanation. It would appear however, that at least some farmers who employ soil testing use the soil N reserve assessment rather than the target yield recommendation as their guide to fertilizer requirements (Farmer Survey, Pre-Test, 1987). In this event, not all of the differential yield response would seem to be attributable to differing soil N levels, indicating a need for further refinement of the target yield calibration process.

Second, it is also likely that at least some of the observed variation in yields across soil classes at the regional level is attributable to differing fertility not related to N levels. In this instance, a producer using soil test data presented here would observe the differing yield capabilities of the various soil classes and set more realistic yield expectations for his own production.

In summary, it may be concluded that the information base for the target yield recommendation is still too generalized to provide good predictions for specific field conditions. The effect of nutrient factors on yields of field crops grown in the prairie provinces is not predictable, in terms of the factors which determine the response, due to the lack of adequate data and/or an understanding of the relationships involved (also see Watt and Arthur, 1987).

2.3.3. Variability of Yields About Targets

Regional yield variation across MCIC soil classes has obvious implications for farm-level decisions about fertilizer rates since field soil testing does not appear to adjust target yields for many factors causing yield potential to vary between class A to J lands. A producer applying 53 lbs-N/ac (regional average) in the SW region in 1985 could have had actual yield expectations for barley on stubble ranging from 44.1 to 66.8 bu/ac, depending on soil class under "moist" moisture conditions (Table 14). Similarly, stubble wheat yields in the central region would have had potential variation from 33.4 to 49.7 bu/ac across MCIC soil classes under moist conditions (Table 15) at 68 lbs-N/ac (regional average). This is to be contrasted with regional target yields of 63.0 and 45.2 bu/ac for barley and wheat, respectively, for the N application rates in the regions indicated. Clearly, the yield index-adjusted target values using MCIC data corresponds better to the actual yields observed

Table 14

Target Yields for Barley Based on Adjustments for Yield Variation Across MCIC Soil Class 1985 Soil N Reserves and 1985 Fertilization Rates Compared with Actual Yields in 1985 Southwest Region, Manitoba

MCIC Soil Class	1981-85 Yield Index[b]	Soil Class Adjusted Yields for Moisture Conditions (bu/ac)[a]				Actual N Applied 1985 (lbs/ac)	Actual Yields 1985 (bu/ac)
		Irrigation	Moist	Dry	Arid		
A	-	-	-	-	-	-	-
B	106	66.8	66.8	61.5	50.1	58	63.5
C	105	66.2	66.2	60.9	49.7	57	62.5
D	104	65.5	65.5	60.3	49.1	57	61.9
E	101	63.6	63.6	58.5	47.7	54	64.7
F	91	57.3	57.3	52.7	43.0	53	55.8
G	89	56.1	56.1	51.6	42.1	43	54.8
H	86	54.2	54.2	49.9	40.7	46	48.9
I	83	52.3	52.3	48.1	39.2	46	48.8
J	70	44.1	44.1	40.6	33.1	49	42.6
Weighted Averages (bu/ac)	51.1	63.0	63.0[c]	58.0	47.3	53	60.7

[a] 1985 regional soil N reserves = 61.4 lbs-N/ac (69 Kg/ha), 1985 average applied N = 53 lbs/ac (59.6 Kg/ha).

[b] Regional weighted average yield = 100.

[c] Regional target yield is calculated to be 63.0 bu/ac under average "moist" moisture conditions. Reconstruction of target yields due to moisture variation use the following indexes: irrigation = 100, moist = 100, dry = 92, arid = 75, at 60 lbs applied N (see Table 8).

Source: Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982.

Table 15

Target Yields for Wheat Based on Adjustments for Yield Variation Across MCIC Soil Class 1985 Soil N Reserves and 1985 Fertilization Rates Compared with Actual Yields in 1985 Central Region, Manitoba

MCIC Soil Class	1981-85 Yield Index[b]	Soil Class Adjusted Yields for Moisture Conditions (bu/ac)[a]				Actual N Applied 1985 (lbs/ac)	Actual Yields 1985 (bu/ac)
		Irrigation	Moist	Dry	Arid		
A	110	51.3	49.7	49.3	38.3	66	48.2
B	109	50.8	49.3	45.4	38.0	68	49.5
C	107	49.9	48.4	44.5	37.3	70	50.4
D	102	47.5	46.1	42.4	35.5	70	49.0
E	98	45.7	44.3	40.8	34.1	68	47.1
F	94	43.8	42.5	39.1	32.7	63	44.8
G	88	41.0	39.8	36.6	30.6	61	42.2
H	77	35.9	34.8	32.0	26.8	56	37.4
I	74	34.4	33.4	30.7	25.7	56	33.6
J	-	-	-	-	-	-	-
Weighted Averages (bu/ac)	37.9	46.6	45.2[c]	41.6	34.8	68	47.6

[a] 1985 regional soil N reserves = 54.3 lbs-N/ac (61 Kg/ha), 1985 average applied N = 68 lbs/ac (76.4 Kg/ha).

[b] Regional weighted average yield = 100.

[c] Regional target yield is calculated to be 45.2.0 bu/ac under average "moist" moisture conditions. Reconstruction of target yields due to moisture variation use the following indexes: irrigation = 103, moist = 100, dry = 92, arid = 77, at 60 lbs applied N (see Table 8).

Source: Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982.

within soil classes in 1985. Within any particular soil class, the yield variability for given levels of N fertilization is not determined. Yet, it is precisely this variation about target yields which is critical to the N rate decision when the possibility of not recovering operating costs with below average yields is likely.

What is known about the effect of N fertilization on yield variability in Manitoba? If the coefficient of variation[7] about the expected value (i.e. target value) increases with N rate, then fertilization would be regarded as a risk-increasing input. This is the conventional assumption of prairie provincial soil testing laboratories (see Fertilizer Economics, Saskatchewan Agriculture, 1986; Fertilizer Economic, Alberta Agriculture, 1985). These laboratories attempt to adjust for the risk in the method by which they determine their target yield fertilizer recommendation. Ratios of marginal returns to marginal fertilizer costs in the range of 1.5 to 2.0 have been used to set recommendations and are considered to reduce risk of not obtaining a yield response to the last unit of applied N to manageable levels (Fehr, 1970; Fertilizer Economics, Alberta Agriculture, 1985; Fertilizer Economics, Saskatchewan Agriculture, 1986).

There are two different variability concepts that should be distinguished here. First, yields vary in response to N as a function of moisture conditions. The spread between yields under "irrigated"

7

$$\text{Coefficient of variation (cv)} = \frac{\text{standard deviation}}{\text{yield mean}} \times 100.$$

and "arid" moisture conditions widens as levels of fertilizer N increase.

If provincial target yield fertilizer recommendations are already "climate modified" for wheat, barley and oats already, what does the use of a marginal revenue to marginal cost ratio greater than unity signify? It would appear that the moisture adjustment does not accurately estimate moisture availability across soil types within the province. A need exists for more knowledge about yield responses to soil factors which determine moisture availability. The use of a compensating marginal analysis technique to adjust for these information deficiencies is totally inappropriate.

On the one hand, reducing N inputs by using a 1.5:1 ratio for making the fertilization decision reduces the upside yield potential when moisture is available. On the other hand, yield responses will be obtained under all but extreme moisture conditions, however small they may be. Thus, the vital information for the producer is the incremental yield response to N under these conditions, not an arbitrary ratio which attempts to approximate the economic effect.

The second factor at work is the variability of yield response to N, given any specific moisture condition. An inflated marginal revenue-marginal cost ratio makes an implicit assumption that higher N rates are accompanied by greater economic risk. This may not be the case.

Research undertaken in Manitoba to calibrate crop responses to fertilizer N use has suggested that as wheat and barley yields increase with added N (Table 16), yield variability as measured by the

Table 16

Yield Variability - Barley 1962 to 1968

X	80% Y~	95% Y~	Standard Deviation	Coef. of[a] Variation (CV)
20	12.5 ~ 8.4	12.5 ~ 13.0	6.63	53.0
60	49.4 ~ 7.8	49.4 ~ 12.1	6.17	12.5
100	66.6 ~ 8.0	66.6 ~ 12.3	6.28	9.4
140	77.9 ~ 8.2	77.9 ~ 12.7	6.50	8.3
180	86.4 ~ 8.5	86.4 ~ 13.1	6.68	7.7

[a] CV = (standard deviation/y) x 100.

Source: Fehr, 1970, p. 123.

coefficient of variation tends to decline (Fehr, 1970; Racz, 1973). The graphical effect of Table 16 is shown in Figure 5, indicating that the band of variation about expected barley yields remains relatively constant at all N rates. Researchers elsewhere have indicated that the variance-increasing effect of fertilizer on yield is much smaller than conventionally thought and reflects a problem in traditional specifications of production functions, i.e. if any input has a positive effect on output, then a positive effect on variability of output is also imposed (Just and Pope, 1979).

At the farm level many producers are reported to perceive nitrogen fertilizer use as risk-reducing (Sriramaratnam et al., 1987). This would imply lower variability in yield response at target yield N rates and could be attributable, if real, to a host of management factors, more consistent responses of fertilized crops to adverse conditions and better resistance to diseases, insects, etc.

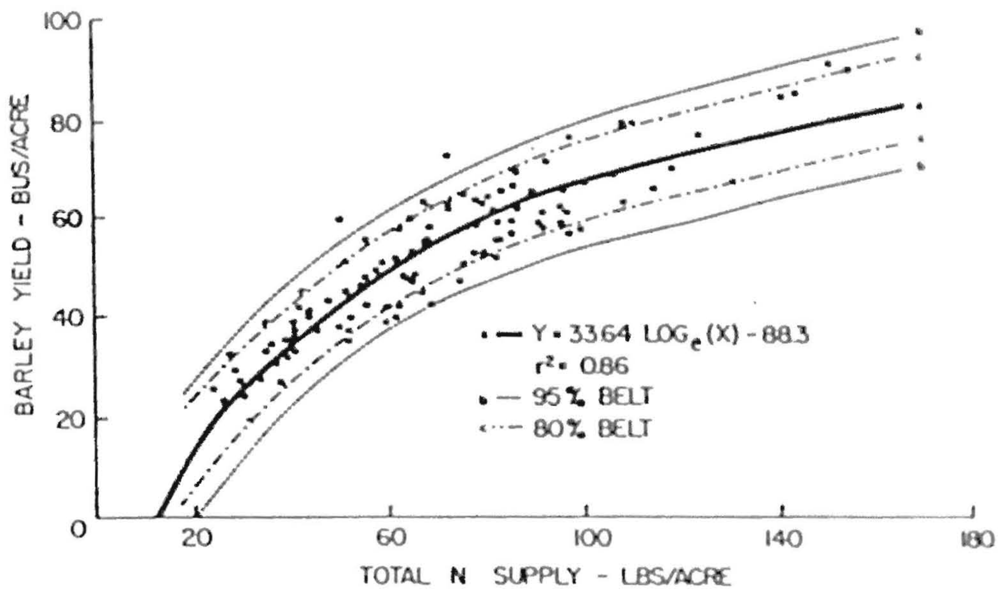
A perception of fertilizer N use as risk-reducing vis-a-vis return variability has also been encountered in Manitoba (Pretest, Manitoba Farm Survey, 1987).

Clearly, the data base is not adequate at this point in time to resolve the variability issue for wheat, let alone other crops. The ramifications of the variability characteristic for making the fertilizer rate decision, however, are central to the economic arguments for determining optimal fertilizer inputs and managing risk.

Whether the net effect of unquantified yield response factors and higher production levels with N use is risk-increasing is not immediately obvious. The nature of the variability in yield response

Figure 5

Variance of Barley Yields About Expected Yield



Source: Fehr, 1970, p. 127.

to N under Manitoba field conditions is masked by gaps in the information base. Nevertheless, it would appear that fertilization decisions are made more risky if accompanied by uncertain assumptions about their economic characteristics. The following section relates these concepts to economic approaches to fertilizer use.

3.0. Economic Considerations

Maximization of net income[8] from fertilizer N use requires an assessment of the effect of N rate and yield increase from applied N on revenues and costs. It must be emphasized here that a decision to minimize per bushel production costs does not maximize total profits. This rationale only works if there is no possibility of increasing net returns at any fertilization rate. The technique of marginal analysis is used to derive the profit-maximizing rate of N fertilization where the added costs of N equal the returns from crop yield increases.

To review, when the yield response is certain and the level of fertilizer inputs unconstrained, the optimal production point on the production function occurs where the cost from the last increment of N equals the value of the last yield increment. This clearly depends on the price of N and the price of crop.

The current economic climate for grain producers has resulted in frequent situations where the resources available to purchase fertilizer are limited. In these cases, equal marginal returns analysis is employed to derive the profit maximizing N rates, taking into account the added returns from each crop from incremental units

---

[8] Net may represent net of operating or net of operating and fixed costs.

of fertilizer. Limited N would be allocated in a manner that maximizes of the total return from N across all crops and is clearly dependent on the relative prices of these crops, yield responses to N and cost of N.

The current fertilizer decision climate, however, is more accurately portrayed as one in which yield responses are subject to significant uncertainty. Fluctuations of crop and N prices, while also unpredictable, are less influential than yield response variation on net income. What are the economic guidelines for making input investment decisions under these circumstances?

In light of previous sections, there are at least two approaches for minimizing the adverse impact of uncertainty on yield efficiency and return from fertilizer use.

3.1. Maximizing Profit Potential Under Uncertainty of N Recovery Efficiency

Ideally, a producer wishes to apply just that amount of N needed by his crop to produce his expected yield. In determining the fertilization rate and yield target, the costs of N and price of crop are critical to the determination of economic optimum levels. Manitoba provincial target yield fertilization recommendations use a marginal revenue (value of added yield) to marginal cost (cost of added fertilizer) ratio of 1.5:1 to select this production point (see example calculations in Table 17).

Currently available information to identify optimal N rate includes average relative N recovery efficiencies of different N carriers by timing and method of fertilizer placement (Manitoba

Table 17

Scenario 1: Example Showing Effect of Different Yield Efficiencies On Yields and Fertilizer Recommendations for Wheat, Manitoba

N rate (lbs/ac)	Target Wheat Yields With N Efficiencies of			Marginal Yields (bu/ac) per 10 lb-N/ac			Marginal Costs (MC) Per 10 lbs-N/ac	Marginal Revenues (MR) With N Efficiencies of		
	0.35	0.50[a]	0.65	0.35	0.50	0.65		0.35	0.50	0.65
0	27.8[b]	27.8	27.8	-	-	-	-			
10	30.1	31.1	32.1	2.3	3.3	4.3	8.50	5.64	8.09	10.54
20	32.2	34.1	36.0	2.1	3.0	3.9	2.50	5.15	7.35	9.56
30	34.1	36.8	39.5	1.9	2.7	3.5	2.50	4.66	6.62	8.58
40	35.7[c]	39.1	42.5	1.8	2.3	3.0	2.50	4.41	5.64	7.35
50	37.1	41.1	45.1	1.4	2.0	2.6	2.50	3.43	4.90	6.37
60[d]	38.3	42.8[c]	47.3	1.2	1.7	2.2	2.50	2.94	4.17[d]	5.39
70	39.2	44.1	49.0[c]	0.9	1.3	1.7	2.50	2.21	3.19[e]	4.17
75	39.6	44.6	49.7	-	-	-	-			
80	39.9	45.0	50.3	0.7	0.9	1.3	2.50	1.72	2.21	3.19
90	40.3	45.6	50.9	0.4	0.6	0.6	2.50	0.98	1.47	1.47
100	40.6	46.1	51.5	0.3	0.5	0.6	2.50	0.74	1.23	1.47
110	40.8	46.4	52.0	0.2	0.3	0.5	2.50	0.49	0.74	1.23

[a] Manitoba provincial soil testing laboratory uses an average nitrogen recovery index of 0.5 for spring broadcast granular fertilizer.

[b] Assumes a soil N reserve of 38.7 lbs-N/ac (43.5 Kg/ha).

[c] Reconstructed target yield recommendations based on a 1.5:1 marginal revenue-marginal cost ratio with fertilizer @ $0.25 per lb. actual and #2 HRS wheat @ $2.45 per bu. The optimising ratio would be $3.75:$2.50 per 10 lbs-N increments.

[d] Profit maximizing level given a 1.5 revenue cost ratio with average N recovery efficiency = 0.5.

[e] Profit maximizing level given a 1:1 revenue cost ratio with average N recovery efficiency = 0.5.

Department of Agriculture, Nitrogen Fertilization in Crop Production, 1986) as discussed in Section 2, above. These figures should be used to adjust yield responses and fertilizer costs and are likely to affect the target N rate.

Variation in N recovery efficiency for specific applications however, may also be substantial but is essentially unpredictable in any particular year (see Harapiak et al., 1986). The amount of N actually recovered by the plant varies independently from growth or environmental factors which limit yield potential. This begs the question of what fertilizer strategy to employ, given recovery uncertainty, to maximize profit potential.

One particular avenue for investigation is the effect of applying N at higher than economic optimum rates. Economic optimum here is defined as the production level at which marginal revenue equals marginal cost or where gross margin (total yield revenues minus total fertilizer costs) is maximized. Conceptually, the "extra" N would minimize yield reductions in years with below-normal recovery efficiency and increase yield responses in years of above-normal recovery efficiency. This fertilization strategy has been termed the "insurance approach" in the economic literature (Bock, 1984).

"Extra" indicates application of N in excess of that calculated using average N recovery efficiencies for Manitoba (e.g. 0.5) and a 1:1 marginal revenue-marginal cost ratio. The relative benefits of this approach would be assessable in a period of years in which the true distribution and frequency of N recovery efficiency outcomes were observed.

In reality, the probability distribution of N recovery efficiency for Manitoba field/management conditions is unknown. As a result, two situations were created to evaluate the concept using soil N level, Central region in the spring, 1987. Several provisos are in order. Producers could not be subject to capital constraints since the extra N would represent added variable costs of production. As well, yields or quality characteristics of selected crops at excess N levels would not be expected to create adverse economic effects. Finally, yield effects due to variations in recovery efficiency of soil N and left over (residual) fertilizer N are not considered here but are research areas requiring further investigation (see Broadbent, 1984).

Based on an average expected recovery efficiency of 0.5 for Manitoba field conditions (Racz, G., personal communication, 1987) scenario 1 assumes that over three years, each of the N recovery efficiency values, i.e. 0.35, 0.50 and 0.65 occurs once, or with 33 percent frequency. This gives a range of variability about the average which is critical to the economic assessment of the insurance approach.

As illustrated in Table 17, higher recovery efficiencies result in higher marginal revenues at higher N rates. Using the provincial target yield fertilizer recommendation strategy (1.5 MR = MC) N rate of 60 lbs-N/ac would have been selected. At the economic optimum level (MR = MC), 75 lbs-N/ac would have been applied.

Table 18 indicates that net returns over three years would have been maximized by fertilizing at the economic optimum level. The

Table 18

Yield Increases Attributable to N Fertilization
at 60, 75 and 80 lbs-N/ac and a
Comparison of Net Yield Returns at the Different Rates
(Based on Table 17)

Rate	Year	Cumulative Increase (bu/ac) With N Recovery Efficiencies of: 0.35	0.50	0.65	Yield Returns @ $2.45/bu	Per Acre Total N Costs @ $0.25/lb	Per Acre[a] Yield Returns Minus N Costs
60	Yr 1	10.5			25.73	21.00	4.73
60	Yr 2		15.0		36.75	21.00	15.75
60	Yr 3			19.5	47.78	21.00	26.78
					111.26	63.00	47.26
75	Yr 1	11.8			28.91	24.75	4.16
75	Yr 2		16.8		41.16	24.75	16.41
75	Yr 3			21.9	53.66	24.75	29.91
					123.73	74.25	49.48
80	Yr 1	12.1			29.65	26.00	3.65
80	Yr 2		17.2		42.14	26.00	16.14
80	Yr 3			22.5	55.13	26.00	29.13
					126.92	78.00	48.92

[a] Includes $6.00/ac application cost for banding.

result is characterized by N rates which exceeded the economic optimum in the below-normal recovery efficiency year. Offsetting this however, was a larger yield response in the above-normal recovery efficiency year which fully compensated for the extra fertilizer costs in year 1. Note that fertilizing at N levels of 80 lbs/ac, i.e. beyond the economic optimum of 75 lbs-ac, would not have produced greater total net revenues in this scenario ($49.48 versus $48.92 per acre).

Scenario 2 considers a wider range of variability in N recovery efficiency over the three years, i.e. 0.20, 0.50, 0.80 (Table 19). Each outcome was assumed to have a 33 percent chance of occurring and thus, the average recovery efficiency remained at 0.50. The effect however, was to identify a profit maximizing fertilization rate which exceeded the economic optimum level ($48.43 versus $48.01 per acre).

Tables 19 and 20 also illustrate the mechanism of the effect. At 80 lbs-N/ac, the per acre net revenues for 0.20 and 0.50 and 0.80 recovery efficiency levels are $-9.09, $16.14 and $41.38, respectively. These values are lower than their corresponding values at the average economic optimum fertilization level (i.e. 75 lbs/ac) for 0.20 and 0.50. recovery efficiency. However, at the 0.80 level higher N rates lead to higher total profits and this effect outweighs losses at the two lower efficiency levels. Reference to Table 19, columns (4), (5) and (6) illustrates that larger marginal yield response with 0.80 recovery efficiency at 80 lbs-N/ac causes the result.

Table 19

Scenario 2: Effect of Different Yield Efficiencies on Yields and Fertilizer Recommendations for Wheat, Manitoba

N Rate (lbs/ac)	Target Wheat Yields With N Recovery Efficiencies of 0.20	0.50[a]	0.80	Marginal Yields (bu/ac) per 10 lbs-N/ac 0.20	0.50	0.80	Marginal Costs (MC) Per 10 lbs-N/ac	Marginal Revenues (MR) With N Recovery Efficiencies 0.20	0.50	0.80
0	27.8[bc]	27.8	27.8	-	-	-	-	-	-	-
10	29.1	31.1	33.1	1.3	3.3	5.3	8.50	3.19	8.09	12.99
20	30.3	34.1	37.9	1.2	3.0	4.8	2.50	2.94	7.35	11.76
30	31.4	36.8	42.2	1.1	2.7	4.3	2.50	2.70	6.62	10.54
40	32.3	39.1	45.9	0.9	2.3	3.7	2.50	2.21	5.64	9.07
50	33.1	41.1	49.1	0.8	2.0	3.2	2.50	1.96	4.90	7.84
60[d]	33.8	42.8[c]	51.8	0.7	1.7	2.7	2.50	1.72	4.17[d]	6.62
70	34.3	44.1	53.9	0.5	1.3	2.1	2.50	1.23	3.19	5.15
75	34.5	44.6	54.6[c]	-	-	-				
80[e]	34.7	45.0	55.3	0.4	0.9	1.4	2.50	0.98	2.21[e]	3.43
90	34.9	45.6	56.3	0.2	0.6	1.0	2.50	0.49	1.47	2.45
100	35.1	46.1	57.1	0.2	0.5	0.8	2.50	0.49	1.23	1.96
110	35.2	46.4	57.6	0.1	0.3	0.5	2.50	0.25	0.74	1.23

[a] Manitoba provincial soil testing laboratory uses an average nitrogen recovery index of 0.5 for spring broadcast granular fertilizer.

[b] Assumes a soil N reserve of 38.7 lbs-N/ac (43.5 Kg/ha).

[c] Reconstructed target yield recommendations based on a 1.5:1 marginal revenue-marginal cost ratio with fertilizer @ $0.25 per lb. actual and #2 HRS wheat @ $2.45 per bu. The optimising ratio would be $3.75:$2.50 per 10 lbs-N increments.

[d] Profit maximizing level given a 1.5 revenue cost ratio with average N recovery efficiency = 0.5.

[e] Profit maximizing level given a 1.1 revenue cost ratio with average N recovery efficiency = 0.5.

Table 20

Yield Increase Attributable to N Fertilizer at 60, 75, 80 lbs-N/ac and a Comparison of Net Yield Returns at the Different Rates (Based on Table 19)

Rate	Year	Cumulative Increase (bu/ac) With N Recovery Efficiencies of: 0.20	0.50	0.80	Yield Returns @ $2.45/bu	Per Acre[a] Total N Costs @ $0.25/lb	Per Acre Yield Returns Minus N Costs
60	Yr 1	6.0			14.70	21.00	-6.30
60	Yr 2		15.0		36.75	21.00	15.75
60	Yr 3			24.0	38.80	21.00	37.80
					110.25	63.00	47.25
75	Yr 1	6.7			16.42	24.75	-8.13
75	Yr 2		16.8		41.16	24.75	16.41
75	Yr 3			26.4	64.68	24.75	39.93
					122.26	74.25	48.01
80	Yr 1	6.9			16.91	26.00	-9.09
80	Yr 2		17.2		42.14	26.00	16.14
80	Yr 3			27.5	67.38	26.00	41.38
					126.43	78.00	48.43

[a] Includes $6.00/ac application cost for banding.

The effect illustrated above would have even greater significance if the frequency distribution of N recovery efficiencies is wider and/or more dispersed than that assumed in the examples. Can a normal distribution be assumed or do farmers with superior management skills know how to consistently attain average recovery efficiencies greater than 0.5? Do certain soils exhibit a narrow or wide range of recovery efficiency variation? In addition, low commodity prices and relatively high N/crop price ratios reduce the effect of the insurance approach. Increases in grain prices relative to N costs would make the potential gains more substantial.

From a management perspective, the most economic fertilization decision would appear to be best evaluated on the basis of repeated outcomes, since N recovery efficiencies cannot be predicted for any particular year. Annually, the producer faces the prospects of excessive N costs in below-normal efficiency years if he adds extra N and constrained yields in above-normal efficiency years if he lowers his N rate. Based on the numerical analysis above, the longer-term profit-maximizing point is critically dependent on the range of variation in N recovery efficiency as is illustrated by the different profits maximization points in Tables 19 and 20. In addition, the N to crop price ratio governs the level to which fertilization in excess of the economic optimum rate may be feasible.

Nothing has yet been said about the risks associated with striving for maximum economic yield. This is largely in uncharted waters since the probability distribution of N recovery efficiencies outcomes has been assumed, for the purposes of discussion, to be equal but is unknown. Clearly, farmers require information in this area in order to assess their risk management strategies and need research on management practices which will increase the probabilities of high recovery efficiency outcomes.

In summary, this section on N recovery efficiencies may be viewed within the context of whether N rates should have increased or decreased in response to depressed commodity prices in 1987. There were three considerations in the adjustments to be made by the producer:

1. a decrease in N rate to new levels reflecting the change in revenue-cost ratio between crop and fertilizer;

2. an increase in N rate above provincial target levels at least to the economic optimum (MR = MC) point; and

3. a possible further increase beyond the economic optimum if the producer's individual yield experience and management skills indicate higher than average N recovery efficiencies. There is no empirical data to delineate thresholds in this area.

3.2. Managing Risk Under Yield Uncertainty

This consideration applies to the risk averse producer who wants to select the fertilizer rate which maximizes the probability of earning a return from cropping. This is to be distinguished from the conventional option which maximizes net return potential from cropping.

As noted earlier, the equal marginal principle is an analytical tool by which farmer can determine highest profit potential when there is not enough capital available to fertilize all crops at optimum rates. The common assumption is that this is the appropriate economic procedure for minimizing risk and/or allocating a limited fertilizer budget. Less discussion, however has centered on how reduced fertilizer inputs affect risk and net returns in the farm operation. In particular, the relationship between revenues and costs of production requires consideration of "break-even" yields in the fertilizer decision.

Estimates of yield expectations for the five regions of Manitoba, based upon soil N reserves at spring seeding time in 1987, are presented in Tables 21 to 25. The adjustment for moisture conditions is based on moisture differentials incorporated in provincial yield targets at zero N application.[9] Soil N reserve levels are indicated in those tables to produce similar yields under a range of moisture conditions, except for "arid" moisture conditions (see Table 8).

Within any particular MCIC soil class then, yield responses to soil N reserves may be considered more predictable than yield responses to N fertilization. This is with the proviso that the yield index of that soil class to the regional yield target has been reasonably estimated.

Table 26 shows average provincial operating costs associated with putting in a crop in 1987 without nitrogen fertilizer. Note that at $65.50 per stubble acre, operating costs were expected to be recovered under most moisture conditions on all MCIC soil classes in the Central, Interlake and Eastern regions (Tables 23 to 25) with no

---

[9] Target Yield Tables, Provincial Soil Testing Laboratory, 1982.

Table 21

Estimated Wheat Yield Expectations on Stubble Under "Variable" Moisture Conditions with No N Fertilization[a] Across MCIC Soil Classes Southwest Region, Manitoba, 1987

Average Yields by MCIC Soil Class (1981-85)		Yield as a % of Weighted Average	Moisture Conditions: Irrigation	Moist	Dry	Arid
			Yield Expectation (bu/ac)			
A	-	-	-	-	-	-
B	34.3	108	28.7	28.7	28.4	26.1
C	33.5	106	28.2	28.2	27.9	25.7
D	32.7	103	27.4	27.4	27.1	25.0
E	32.9	104	27.7	27.7	27.4	25.2
F	28.6	90	23.9	23.9	23.6	21.8
G	28.1	89	23.7	23.7	23.4	21.6
H	26.6	84	22.3	22.3	22.1	20.3
I	24.6	78	20.7	20.7	20.5	18.9
J	22.5	71	18.9	18.9	18.7	17.2
Weighted Averages	31.7		27.0	27.0[b]	26.7	17.8

[a] Soil N reserves in spring, 1987 were estimated at 37.4 lbs/ac (42 Kg/ha) (McGill, 1987).

[b] Regional target yield is 27.0 bu/ac (Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982). Targets for other moisture levels were adjusted by yield indexes for moisture (irrigation = 100, moist = 100, dry = 99, arid = 91) and indexes of yields for MCIC soil class at zero N fertilization (see Table 8).

[c] Yields northwest of this line would produce revenues exceeding operating costs. Revenue = yield times $2.45/bu, operating = $65.50, breakeven yield = 26.7 bu/ac.

Table 22

Estimated Wheat Yield Expectations on Stubble Under "Variable" Moisture Conditions with No N Fertilization[a] Across MCIC Soil Classes Northwest Region, Manitoba, 1987

Average Yields by MCIC Soil Class (1981-85)		Yield as a % of Weighted Average	Moisture Conditions: Irrigation	Moist	Dry	Arid
			Yield Expectation (bu/ac)			
A	39.6	117	30.0	30.0	29.7	27.3
B	33.6	99	25.3	25.3	25.0	23.0
C	35.4	105	26.9	26.9	26.6	24.5
D	34.6	102	26.1	26.1	25.8	23.8
E	32.9	97	24.8	24.8	24.6	22.6
F	31.6	93	23.8	23.8	23.6	21.7
G	29.9	88	22.5	22.5	22.3	20.5
H	30.4	90	23.0	23.0	22.8	20.9
I	-	-	-	-	-	-
J	-	-	-	-	-	-
Weighted Averages	33.8		25.6	25.6[b]	25.3	23.3

[a] Soil N reserves in spring, 1987 were estimated at 34.7 lbs/ac (39 Kg/ha) (McGill, 1987).

[b] Regional target yield is 25.6 bu/ac (Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982). Targets for other moisture levels were adjusted by yield indexes for moisture (irrigation = 100, moist = 100, dry = 99, arid = 91) and indexes of yields for MCIC soil class at zero N fertilization (see Table 8).

[c] Yields northwest of this line would produce revenues exceeding operating costs. Revenue = yield times \$2.45/bu, operating = \$65.50, breakeven yield = 26.7 bu/ac.

Table 23

Estimated Wheat Yield Expectations on Stubble Under "Variable" Moisture Conditions with No N Fertilization[a] Across MCIC Soil Classes Central Region, Manitoba, 1987

MCIC Soil Class	Average Yields by MCIC Soil Class (1981-85)	Yield as a % of Weighted Average	Moisture Conditions: Irrigation	Moisture Conditions: Moist	Moisture Conditions: Dry	Moisture Conditions: Arid
			Yield Expectation (bu/ac)			
A	41.7	110	35.0	35.0	34.7	31.9
B	41.4	109	34.7	34.7	34.4	31.6
C	40.7	107	34.0	34.0	33.7	30.9
D	38.8	102	32.4	32.4	32.1	29.5
E	37.1	98	31.2	31.2	30.9	28.4
F	35.7	94	29.9	29.9	29.6	27.2
G	33.4	88	28.0	28.0	27.7	25.5
H	29.0	77	24.5	24.5	24.3	22.3
I	28.1	74	23.5	23.5	23.3	21.4
J	-	-	-	-	-	-
Weighted Averages	37.9		31.8	31.8[b]	31.5	28.9

[a] Soil N reserves in spring, 1987 were estimated at 46.3 lbs/ac (52 Kg/ha) (McGill, 1987).

[b] Regional target yield is 31.8 bu/ac (Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982). Targets for other moisture levels were adjusted by yield indexes for moisture (irrigation = 100, moist = 100, dry = 99, arid = 91) and indexes of yields for MCIC soil class at zero N fertilization (see Table 8).

[c] Yields northwest of this line would produce revenues exceeding operating costs. Revenue = yield times $2.45/bu, operating = $65.50, breakeven yield = 26.7 bu/ac.

Table 24

Estimated Wheat Yield Expectations on Stubble Under "Variable" Moisture Conditions with No N Fertilization[a] Across MCIC Soil Classes Interlake Region, Manitoba, 1987

MCIC Soil Class	Average Yields by MCIC Soil Class (1981-85)	Yield as a % of Weighted Average	Moisture Conditions: Irrigation	Moist	Dry	Arid
			Yield Expectation (bu/ac)			
A	-	-	-	-	-	-
B	-	-	-	-	-	-
C	32.6	101	34.0	34.0	33.7	30.9
D	34.2	106	35.7	35.7	35.3	32.5
E	32.4	101	34.0	34.0	33.7	30.9
F	30.2	94	37.2	31.7	31.4	28.8
G	29.5	92	31.0	31.0	30.7	28.2
H	-	-	-	-	-	-
I	-	-	-	-	-	-
J	-	-	-	-	-	-
Weighted Averages	32.2		33.7	33.7[b]	33.4	30.7

[a] Soil N reserves in spring, 1987 were estimated at 49.8 lbs/ac (56 Kg/ha) (McGill, 1987).

[b] Regional target yield is 33.7 bu/ac (Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982). Targets for other moisture levels were adjusted by yield indexes for moisture (irrigation = 100, moist = 100, dry = 99, arid = 91) and indexes of yields for MCIC soil class at zero N fertilization (see Table 8).

[c] Yields northwest of this line would produce revenues exceeding operating costs. Revenue = yield times $2.45/bu, operating = $65.50, breakeven yield = 26.7 bu/ac.

Table 25

Estimated Wheat Yield Expectations on Stubble Under "Variable" Moisture Conditions with No N Fertilization[a] Across MCIC Soil Classes Eastern Region, Manitoba, 1987

	Average Yields by MCIC Soil Class (1981-85)	Yield as a % of Weighted Average	Moisture Conditions: Irrigation	Moist	Dry	Arid
			Yield Expectation (bu/ac)			
A	-	-	-	-	-	-
B	-	-	-	-	-	-
C	34.4	99	30.6	30.6	30.3	27.8
D	36.0	103	31.8	31.8	31.5	28.9
E	34.6	99	30.6	30.6	30.3	27.8
F	27.6	79	24.4	24.4	24.2	22.2
G	-	-	-	-	-	-
H	-	-	-	-	-	-
I	-	-	-	-	-	-
J	-	-	-	-	-	-
Weighted Averages	34.8		30.9	30.9[b]	30.6	28.1

[a] Soil N reserves in spring, 1987 were estimated at 44.5 lbs/ac (50 Kg/ha) (McGill, 1987).

[b] Regional target yield is 30.9 bu/ac (Target Yield Tables, Manitoba Provincial Soil Testing Laboratory, 1982). Targets for other moisture levels were adjusted by yield indexes for moisture (irrigation = 100, moist = 100, dry = 99, arid = 91) and indexes of yields for MCIC soil class at zero N fertilization (see Table 8).

[c] Yields northwest of this line would produce revenues exceeding operating costs. Revenue = yield times \$2.45/bu, operating = \$65.50, breakeven yield = 26.7 bu/ac.

Table 26

Average Provincial Operating Costs for
Unfertilized N Wheat Production
Manitoba, 1987

Operating Costs	$/acre
1. Seed and Treatment	5.75
2. Fertilizer	8.25[a]
3. Chemicals	18.50
4. Fuel	10.00
5. Machinery Operating Costs	6.50
6. Crop Insurance	6.50
7. Other Costs	5.50
8. Drying Costs	0
9. Interest on Operating	4.50
Total	$65.50

[a] Represents P fertilization costs.

Source: Modified from Farm Planning Guide, Manitoba Agriculture, 1987.

applied N (assuming #2 HRS wheat quality at $2.45/bu). On the other hand, operating costs were expected to exceed stubble returns under all but the highest soil classes in the Northwest region (Table 22). The Southwest region was intermediate between the two extremes (Table 21).

As a result, the economic rationale for fertilization differed substantially among regions. N application in the Central, Interlake, and Eastern regions added to expectations of positive returns over cash costs. In the Southwest region, revenues from lower soil classes would fall short of operating costs without fertilization and in the Northwest Region, soil N yields in virtually all soil classes created negative returns over operating. This meant that N fertilizer was required in order for some soils in these last two areas to break even on operating costs with average expected yields. Clearly, lower MCIC soil classes were less likely to generate positive returns in all regions. Added yield responses and added revenue to incremental applications of N are presented in Table 27.

Expected 1987 yield responses of HRS wheat to N application rates are calculated for "dry" and "moist" moisture conditions in the Southwest, Northwest and Central regions in Tables 28 and 29, respectively. Note that in the Northwest region, the regional yield expectation with zero N application was below the yield level necessary to recover operating costs. Operating costs were just offset in the Southwest while the Central region was expected to produce a net return. The characteristics of responses at the two

Table 27

Determination of Fertilizer Rates Using Marginal Analysis
Dry and Moist Moisture Conditions, Manitoba, 1987

		Dry Conditions		Moist Conditions	
N Added	Increment Cost of N	Added[a] Yield	Added Revenue	Added Yield	Added Revenue
0	-			-	
10	5.50	2.5	6.13	3.3	8.09
20	2.50	2.2	5.39	3.0	7.35
30	2.50	1.8	4.41[b]	2.7	6.62
40	2.50	1.5	3.68	2.4	5.88
50	2.50	1.2	2.94	1.8	4.41
60	2.50	.8	1.96	1.6	3.92[b]
70	2.50	.5	1.23	1.3	3.19
80	2.50	0	0	1.0	2.45
90	2.50	0	0	0.5	1.23
100	2.50	0	0	0.5	1.23
110	2.50	0	0	0	0

[a] Provincial soil N reserve of 46 lbs/ac in spring, 1987.

[b] Profit maximizing points given a 1.5:1 revenue - cost ratio with fertilizer @ $0.25 per lb. actual and #2 HRS wheat @ $2.45/bu. The optimising ratio would be $3.75:$2.50 per 10 lbs-N increments.

Table 28

Expected Yield Responses of HRS Wheat in the Southwest Northwest and Central Regions Manitoba to N Fertilization Under "Dry" Moisture Conditions, 1987

N Rate (lbs/ac)	Incremental Yield Response to 10 lb Units of N (bu/ac)	Regional Target Yields (bu/ac) ("Dry" Moisture Conditions)		
		Southwest	Northwest	Central
0	(Soil N Reserve)	26.8	25.5	31.3
10	2.5	29.3	28.0	33.8
20	2.2	31.5	30.2	36.0
30	1.8	33.3[a]	32.0[a]	37.8[a]
40	1.5	34.8	33.5	38.3
50	1.2	36.0	34.7	40.5
60	.8	36.8	35.5	41.3
70	.5	37.3	36.0	41.8
80	0	0	0	0
90	0	0	0	0
100	0	0	0	0

[a] Target yields as calculated from Table 27.

Table 29

Expected Yield Responses of HRS Wheat in the Southwest Northwest and Central Regions, Manitoba To N Fertilization Under "Moist" Moisture Conditions, 1987

N Rate (lbs/ac)	Incremental Yield Response to 10 lb Units of N (bu/ac)	Regional Target Yields (bu/ac) ("Moist" Moisture Conditions)		
		Southwest	Northwest	Central
0	(Soil N Reserve)	27.0	25.6	31.8
10	3.3	30.3	28.9	35.1
20	3.0	33.3	31.9	38.1
30	2.7	36.0	34.6	40.8
40	2.4	38.4	37.0	43.2
50	1.8	40.2	38.8	45.0
60	1.6	41.8[a]	40.4[a]	46.6a
70	1.3	43.1	41.7	47.9
80	1.0	44.1	42.7	48.9
90	0.5	44.6	43.2	49.4
100	0.5	45.1	43.5	49.9
110	0	0	0	0

[a] Target yields as calculated from Table 27.

moisture levels are similar since the yields based on soil N levels as a function of moisture are not considered to vary appreciably.

Application of the target yield fertilizer recommendation reveals that, at a 1.5:1 ratio of added revenue to incremental cost of applied N, approximately 35 lbs and 60 lbs-N/ac would have been recommended under "dry" and "moist" moisture conditions, respectively (Table 27), producing yield expectations as indicated in Tables 28 and 29. In terms of the producers' own operating cost schedule and consideration of yield risk, would these be the optimal (i.e. economic) production points to be striving for?

The answer would appear to be no. The N rates determined by marginal analysis, above, produce positive expectations of net returns over operating costs but represent production points where gross margins (GM) are not maximized. The gross margin maximum under "dry" moisture conditions is attained at fertilizer rates of approximately 15 lbs-N/ac more than that recommended via marginal analysis (Table 30). Under "moist" moisture conditions, gross margins are maximized in the vicinity of 75 lbs-N/ac, or about 15 lbs above the recommended rate (Table 31).

In terms of dollar value, the differences between the GM at the target yield and at GM maximization points amounts to $0.90 per acre in both "dry" and "moist" moisture scenarios (i.e. compare GMs at 35 and 50 lbs-N/ac in Table 30 and at 60 and 75 lbs-N/ac in Table 31). Note, however, that under more favorable commodity prices, a higher bushel price to N cost ratio would result in larger discrepancies between net returns at the two points.

Table 30

Expected Gross Margins at Different N Rates in the Southwest Northwest and Central Regions, Manitoba, to N Fertilization Under "Dry" Moisture Conditions, HRS Wheat Production, 1987

		Southwest		Northwest		Central	
N Rate (lbs/ac)	Average Provincial Operating Costs ($/ac)	Yield[a] Revenue ($/ac)	Gross Margin ($/ac)	Yield Revenue ($/ac)	Gross Margin ($/ac)	Yield Revenue ($/ac)	Gross Revenue ($/ac)
0	65.50	65.66[b]	0.16	62.48	-3.02	76.69	11.19
10	71.00	71.79	1.79	68.60	-2.40	82.81	11.81
20	73.50	77.18	3.68	73.99	0.49	88.20	14.70
30	76.00	81.59	5.59	78.40	2.40	92.61	16.61
35	77.25	83.55	6.30	80.36	3.11	94.57	17.32
40	78.50	85.26	6.76	82.08	3.58	96.29	17.79
50	81.00	88.20	7.20[c]	85.02	4.02[c]	99.23	18.23[c]
60	83.50	90.16	6.66	86.98	3.48	101.19	17.69
70	86.00	91.39	5.39	88.02	2.02	102.41	16.41
80	88.50	91.39	2.89	88.02	-0.48	102.41	13.91
90	91.00	91.39	0.39	88.02	-2.98	102.41	11.41
100	93.50	91.39	-2.11	88.02	-5.48	102.41	8.91

[a] Based on regional target yields, Table 28.

[b] #2 HRS wheat at $2.45/bu.

[c] Points at which gross margin is maximized.

Table 31

Estimated Gross Margins at Different N Rates in the Southwest Northwest and Central Regions, Manitoba, HRS Wheat Production 1987 Under "Moist" Conditions

		Southwest		Northwest		Central	
N Rate (lbs/ac)	Average Provincial Operating Costs ($/ac)	Yield[a] Revenue ($/ac)	Gross[b] Margin ($/ac)	Yield Revenue ($/ac)	Gross Margin ($/ac)	Yield Revenue ($/ac)	Gross Revenue ($/ac)
0	65.50	66.15	0.65	62.72	-2.78	77.91	12.41
10	71.00	74.24	3.24	70.81	-0.19	86.00	15.00
20	73.50	81.59	8.09	78.16	4.66	93.35	19.85
30	76.00	88.20	12.20	84.78	8.79	99.96	23.96
40	78.50	94.08	15.58	90.65	12.15	105.84	27.34
50	81.00	98.49	12.49	95.06	14.06	110.25	29.25
60	83.50	102.41	18.91	98.98	15.48	114.17	30.67
70	86.00	105.60	19.60	102.17	16.17	117.36	31.36
75	87.25	107.07	19.82[c]	103.64	16.39[c]	118.83	31.58[c]
80	88.50	108.05	19.55	104.67	16.12	119.81	31.31
90	91.00	109.27	18.27	105.84	14.84	121.03	30.03
100	93.50	110.50	17.00	106.58	13.08	122.26	28.76

[a] Based on regional target yields, Table 29.

[b] No. 2 HRS wheat at $2.45/bu.

[c] Points at which gross margin is maximized.

The economic implications of the target yield, and maximum gross margin fertilizer rates are critical to this discussion. If a 1:1 marginal revenue to marginal cost ratio were used to set target yields, the recommended N rates would be identical to those required to maximize GM. To maximize GM is to select the production point where total profits from N fertilization are highest and the cost of N to achieve that last increment of yield exactly equals its value.

Use of a marginal revenue - marginal cost ratio of other than 1:1 to select target fertilizer rates runs the risk of over-adjusting for risk factors related to variable yield response. Note that using higher marginal revenue - marginal cost ratios, (2:1, for example) as a fertilizer decision response to lower commodity prices would have increased this effect even more.

The maximum gross margin represents the point on the production function which also maximizes the chance of producing positive net returns should actual yields vary from expectations. When the target yield recommendation falls to the left of the GM, below-expected yields have greater probability of creating a loss. Prior to recent low commodity prices, a return over operating costs has been implicitly assumed, except in the event of crop failure.

The revenue and cost schedules for the three regions are graphically portrayed in Figures 2 and 3. Closer examination of Table 30 also indicates that fertilizer rates of over 20 lbs-N/ac were required in the Northwest region to provide an expectation of return over operating costs under "dry" conditions. In other words, there was no economic justification for seeding acreages if less than approximately 20 lbs-N/ac were applied. Note that over the spectrum of MCIC yield capabilities, even higher N rates would be required on class E lands and lower (Table 22).

In view of the uncertainty associated with target yields, points B, B_1 and B_2 appear to indicate yield objectives which minimize risks of not recovering operating costs in comparison with points A, A_1 and A_2 (Figures 6 and 7). Potential changes in variability of yield response with higher N use are assumed not to negate the overall economic effect. If so, farmers should be applying N at rates exceeding the recommended level both to increase "profit" margins and to maximize likelihood of positive returns from fertilizer to offset the effect of variable yields due to unpredictable moisture conditions.

The implication is that current fertilizer recommendations are not sensitive to the risk implications of production strategies at levels below the highest gross margin. Application of the 1.5 ratio of added returns to marginal costs in provincial soil test recommendations overcompensates for the recognized risk factors associated with level of production and increases the risk associated with yield variability. The 1.5 ratio is arbitrary and, if altered to any value other than 1:1, does not specify optimal fertilization rates.

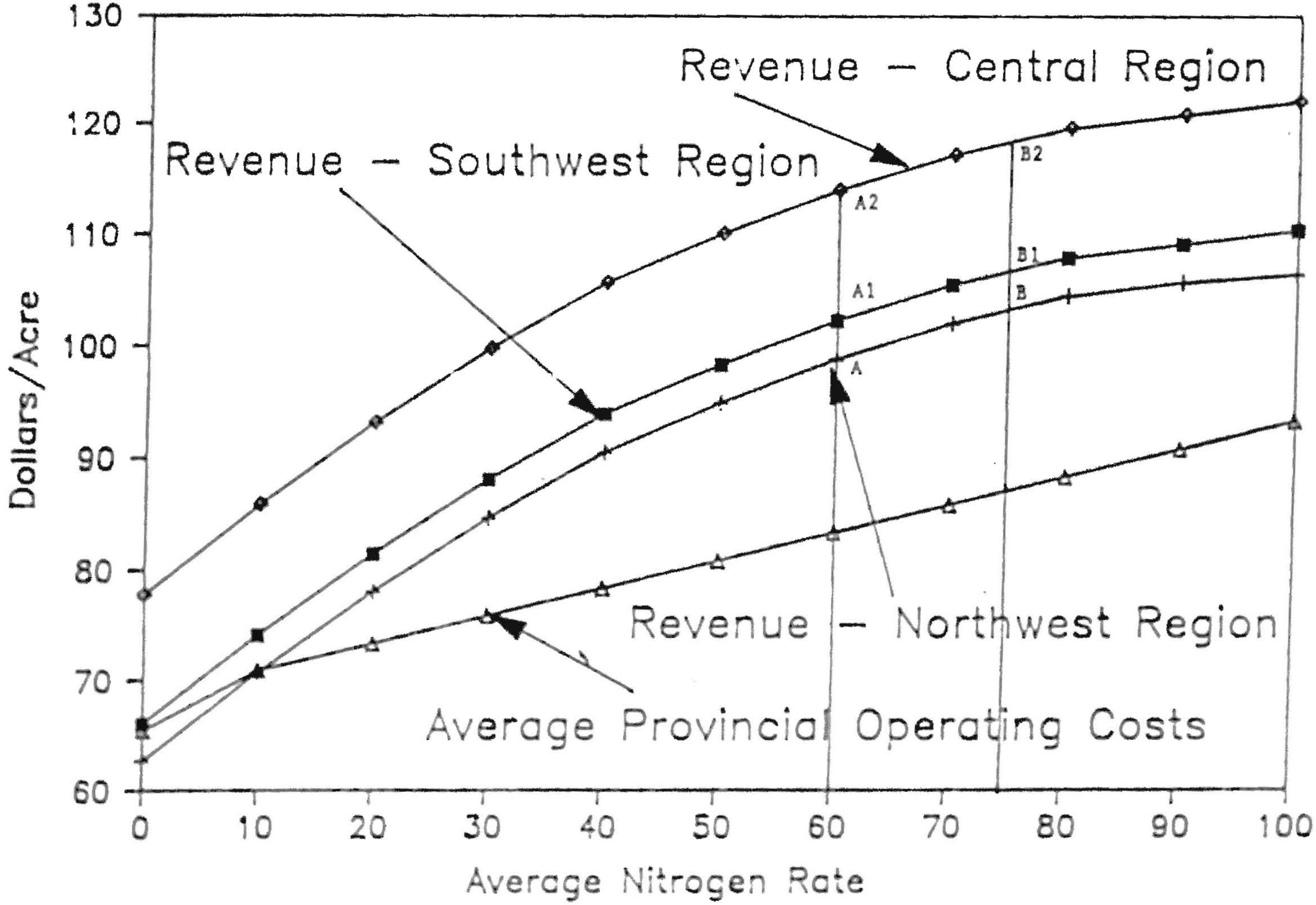
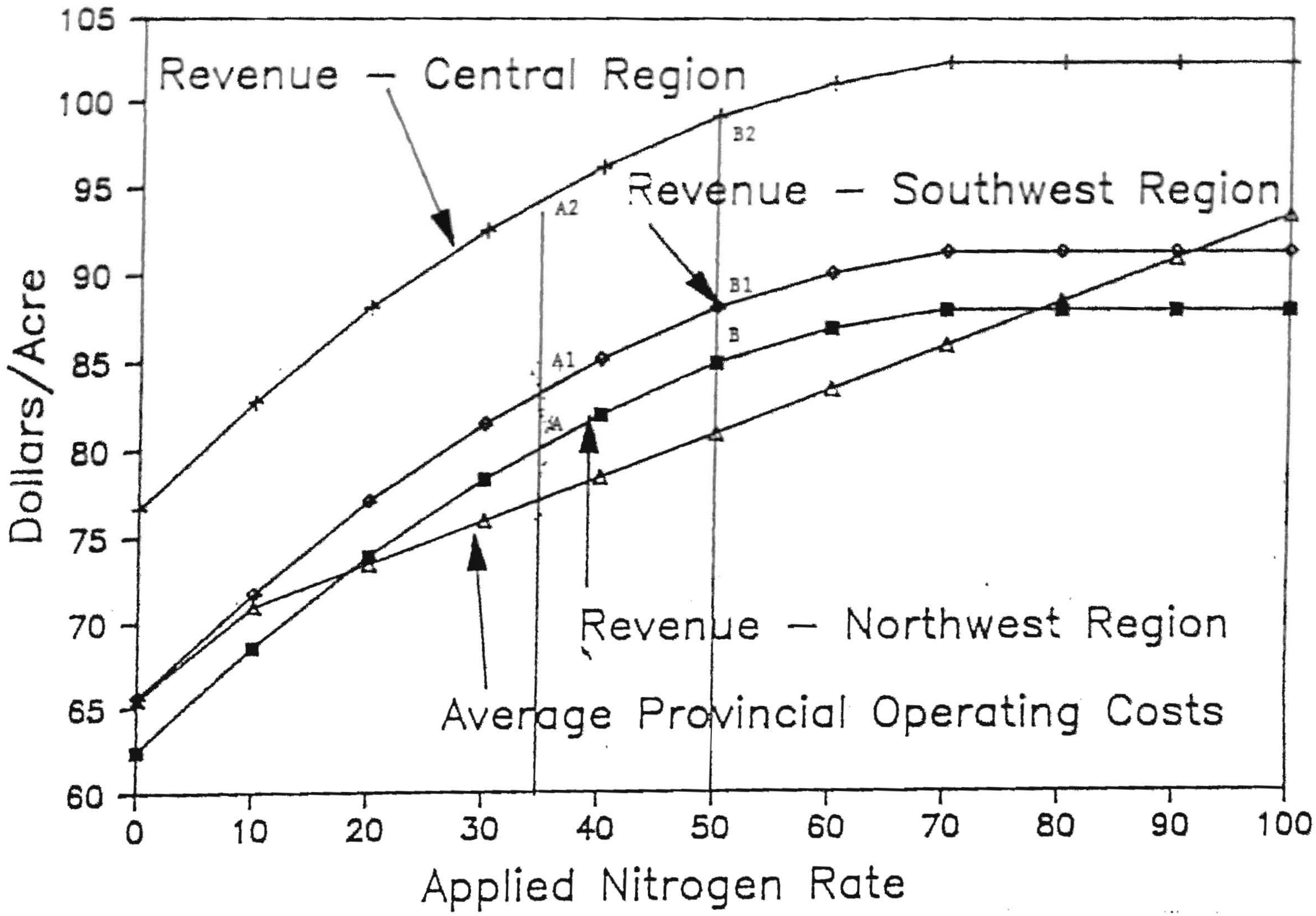


Figure 6

Revenue and Cost Expectations With Varying Levels of Applied N Under "Dry" Moisture Conditions

Figure 7

Revenue and Cost Expectations With Varying Levels of Applied N Under "Moist" Moisture Conditions



4.0. Summary

This paper has discussed the components of yield efficiency that play major roles in determining the level of fertilization application. The general conclusion is that variability about the average efficiency values is as important as the average values themselves. In fact, given a specific production function, the target yield fertilizer recommendation probably misrepresents the risk factors facing producers by being insensitive to the budgetary conditions which influence risk management strategies. Clearly, the application of provincial soil test recommendations to specific field conditions is made uncertain by varying soil capability, moisture availability, fertilizer management practices and individual economic circumstances. Given the present uncertainty in the prediction of yield responses to N fertilization, the fertilizer decision involves evaluation of the probability of attaining yield outcomes. Economic fertilizer decisions require more information relating to the assessment of components of yield efficiency and interpretation in terms of the economics facing individual producers.

In order to make more informed fertilizer decisions, producers require the following:

1. quantification of the efficiency and variation in efficiency of N fertilizer sources and of the conditions under which their efficiencies are altered;

2. calibration of the yield response of different varieties of crops to N fertilization under varying moisture conditions;

3. identification and quantification of those factors which are recognized elsewhere to affect yield potentials/capabilities, e.g. crop variety, seeding date, soil physical factors;

4. better interpretation of yield efficiencies due to N fertilization in terms of the effect of fertilizer decisions on producer objectives of profit-maximization and risk management. In particular, this requires identification of the yield risk associated with fertilizer N use; and

5. better understanding of yield responses to nutrients other than N and in combination with N fertilization.

APPENDIX A

Table A.1

Yield Indexes for Wheat Grown on Stubble
By Seeding Date (1981 to 1985), Manitoba
(% of Average)

Region	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	June Week 2	June Week 3	Average Regional Yields (bu/ac) 1981-1985
	Week Seeded								
SW	1.10[a]	1.09	1.01	0.97	0.92	0.83	0.74	0.70	31.2
NW	1.05	1.09	1.05	0.98	0.92	0.88	0.78	0.77	33.4
CE	1.15	1.09	0.97	0.91	0.85	0.73	0.55	0.63	37.3
INT	1.17	1.12	1.02	0.91	0.85	0.78	0.67	0.78	32.1
EAST	1.23	1.08	0.92	0.88	0.78	0.72	0.61	0.52	34.6

[a] Indexes are calculated within regions as follows:

$$\text{Index} = \frac{\text{Yield in week x, 1981-1985}}{\text{Regional yield, 1981-1985}}.$$

Source: Manitoba Crop Insurance Corporation.

Table A.2

Yield Indexes for Barley Grown on Stubble
By Seeding Date (1981 to 1985), Manitoba
(% of Average)

Region	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	June Week 2	June Week 3	Average Regional Yields (bu/ac) 1981-1985
	Week Seeded								
SW	1.09[a]	1.06	1.01	0.99	0.99	0.92	0.78	0.61	50.2
NW	1.14	1.09	1.07	1.01	1.03	0.92	0.84	0.73	49.6
CE	1.19	1.08	1.01	0.95	0.91	0.76	0.65	0.58	59.2
INT	1.25	1.16	1.10	0.92	0.83	0.79	0.62	0.47	48.8
EAST	1.23	1.09	0.94	0.86	0.80	0.85	0.42	0.26	57.6

[a] Indexes are calculated within regions as follows:

$$\text{Index} = \frac{\text{Yield in week x, 1981-1985}}{\text{Regional yield, 1981-1985}}.$$

Source: Manitoba Crop Insurance Corporation.

Table A.3

Yield Indexes for Flax Grown on Stubble
By Seeding Date (1981 to 1985), Manitoba
(% of Average)

Region	Week Seeded								
	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	June Week 2	June Week 3	Average Regional Yields (bu/ac) 1981-1985
SW	1.11[a]	1.05	1.05	1.03	1.00	0.89	0.89	0.62	15.7
NW	0.90	1.15	1.12	1.01	0.95	0.89	0.81	0.60	18.9
CE	0.97	1.12	1.06	1.01	0.97	0.84	0.80	0.72	20.0
INT	0.92	1.11	1.13	1.02	0.88	0.89	0.59	0.79	17.7
EAST	1.01	1.14	1.05	0.96	0.85	0.72	0.60	0.63	21.5

[a] Indexes are calculated within regions as follows:

$$\text{Index} = \frac{\text{Yield in week x, 1981-1985}}{\text{Regional yield, 1981-1985}}.$$

Source: Manitoba Crop Insurance Corporation.

Table A.4

Yield Indexes for Argentine Canola Grown on Stubble
By Seeding Date (1981 to 1985), Manitoba
(% of Average)

	Week Seeded								
Region	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	June Week 2	June Week 3	Average Regional Yields (bu/ac) 1981-1985
SW	1.10[a]	1.12	1.09	1.04	0.97	0.86	0.88	0.95	20.5
NW	1.10	1.01	1.11	1.10	0.96	0.84	0.87	0.88	21.3
CE	1.24	1.13	1.08	1.02	0.94	0.89	0.83	0.62	22.7
INT	0.95	1.07	1.12	0.98	0.87	1.09	0.77	-	19.9
EAST	0.88	1.21	1.00	1.08	0.95	0.62	0.74	-	22.1

[a] Indexes are calculated within regions as follows:

$$\text{Index} = \frac{\text{Yield in week x, 1981-1985}}{\text{Regional yield, 1981-1985}}.$$

Source: Manitoba Crop Insurance Corporation.

Table A.5

Yield Indexes for Polish Canola Grown on Stubble
By Seeding Date (1981 to 1985), Manitoba
(% of Average)

Region	Week Seeded								
	April Week 4	May Week 1	May Week 2	May Week 3	May Week 4	June Week 1	June Week 2	June Week 3	Average Regional Yields (bu/ac) 1981-1985
SW	1.19[a]	1.09	1.04	1.04	0.96	0.82	0.94	0.75	21.7
NW	0.96	1.22	1.12	1.12	0.98	0.81	0.65	0.57	23.1
CE	0.95	1.02	1.04	1.06	0.91	0.76	0.88	0.54	27.5
INT	0.96	1.10	1.15	1.10	1.01	0.66	0.70	0.40	22.3
EAST	0.69	1.12	1.09	0.98	1.01	0.71	0.70	0.39	25.7

[a] Indexes are calculated within regions as follows:

$$\text{Index} = \frac{\text{Yield in week x, 1981-1985}}{\text{Regional yield, 1981-1985}}.$$

Source: Manitoba Crop Insurance Corporation.

REFERENCES

1. Alberta Department of Agriculture. Fertilizer Economics. Farm Planning Section, Farm Business Management Branch, Agdex 822-11, (July, 1985).

2. Alkier, A.C., G.J. Racz and R.J. Soper. "Effects of Foliar - and Soil-Applied Nitrogen and Soil Nitrate - Nitrogen Level on the Protein Content of Neepawa Wheat. Canadian Journal of Soil Science, 52(1972):301-9.

3. Andrews, B. "Response of Wheat to Seeding Date." In Proceedings of Manitoba Agronomists Conference, Winnipeg (1986):104-112.

4. Baker, R.J. and T.F. Townley-Smith. "Breeding Wheat For Yield." In Slinkard, A.E. and D.B. Fowler (Editors). Wheat Production in Canada: A Review. Proceedings of Canadian Wheat Production Symposium. Saskatoon: University of Saskatchewan, Division of Extension and Community Relations, (1986):443-452.

5. Bock, J.R. "Efficient Use of Nitrogen in Cropping Systems." In Nitrogen in Crop Production, Hauck, R.D. (Editor) . American Society of Agronomists, Madison, Wisconsin (1984):273-294.

6. Broadbent, F.E. "Plant Use of Soil Nitrogen." In Nitrogen in Crop Production, Hauck, R.D. (Editor). American Society of Agronomists, Madison, Wisconsin (1984): 171-182.

7. de Jong, E. and D.A. Rennie. "Physical Soil Factors Influencing the Growth of Wheat." In Proceedings of Canadian Centennial Wheat Symposium, Nielsen, K.E. (Editor). Saskatoon: Modern Press, (1967):69-132.

8. Farmer Survey, Pre-Test. Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg, 1987.

8. Fehr, P. "Interpretation of Target Yield Fertilizer Recommendations." In Proceedings of the 14th Annual Manitoba Soil Science Meeting, Winnipeg (1970):79-90.

9. Fowler, D.B. "Breeding Wheat for Quality." In Slinkard, A.E. and D.B. Fowler (Editors) Wheat Production in Canada: A Review. Proceedings of Canadian Wheat Production Symposium Saskatoon: University of Saskatchewan, Division of Extension and Community Relations, (1986):453-474.

10. Gehl, D.T., J.M. Sadler and R.B. Irvine. "Nitrogen Fertility Responses of Standard Height and Semidwarf Barley Cultivars Under Manitoba Conditions.". In Proceedings of 30th Annual Manitoba Soil Science Meeting, Winnipeg, (1987):209-213.

11. ______________________. "Nitrogen Requirements of Semi-Dwarf Versus Conventional Varieties of Wheat Under Manitoba Conditions." In Proceedings of 29th Annual Manitoba Soil Science Meeting, Winnipeg, (1986):73-90.

12. Harapiak, J.T., R.M.N. Kucey and D. Flaten. "Nitrogen Sources and Placement in Wheat Production." In Wheat Production in Canada; A Review. Proceedings of Canadian Wheat Production Symposium. Slinkard, A.E. and D.B. Fowler (Editors). Saskatoon: University of Saskatchewan, Division of Extension and Community Relations, (1986):87-135.

13. Just, R.E. and R.D. Pope. "Production Function Estimation and Related Risk Considerations." American Journal of Agricultural Economics 61(1979):276-84.

14. Manitoba Department of Agriculture. Soil Facts: Nitrogen Fertilization in Crop Production. Agdex No. 540, 1986.

15. Manitoba Department of Agriculture. Information Update. Farm Planning Guide. 1987 Crop Estimate.

16. Manitoba Provincial Soil Testing Laboratory. Target Yield Tables. Department of Soil Science, University of Manitoba, Winnipeg, (September, 1982).

17. McGill, K.S. "Climate Modified Fertilizer Recommendations for Wheat, Barley and Oats." In Proceedings of Manitoba Agronomists Conference, Winnipeg, (1982):137-9.

18. __________. "Nutrient Trends in Manitoba Soils: A Summary of Results from the Provincial Soil Testing Laboratory." In Proceedings 30th Annual Manitoba Soil Science Meeting, Winnipeg, Manitoba, (January, 1987):172-85.

19. Nelson, H. "The Effects of Planting Dates on Crop Yields." Unpublished Paper, Manitoba Crop Insurance Corporation, 1986.

20. Racz, G.J. "Effects of Agronomic Practices on Protein Content of Wheat." Paper presented at the Wheat Protein Management Workshop, Canadian International Grains Institute, Winnipeg, Manitoba, (February 17-18,1983).

21. Racz, G.J. "Effect of Nitrogen Supply, Water Supply and Temperature on the Yield and Protein Content of Cereal Grains." In Proceedings of 18th Annual Manitoba Soil Science Meeting, Winnipeg, (1974):219-28.

22. Saskatchewan Department of Agriculture. Fertilizer Economics. Economics Branch, Farm Management Section, (March, 1986).

23. Sriramaratnam, S., D.A. Bessler, M.E. Rister, J.E. Matocha and J. Novak. "Fertilization Under Uncertainty: An Analysis Based on Producer Yield Expectations." American Journal of Agricultural Economics 69(1987):349-57.

24. Watt, J. and L. Arthur. "Opportunities and Prospects for Reduced Input Agricultural Systems: Wheat and Canola in the Prairie Provinces." Department of Agricultural Economics and Farm Management Report to Agriculture Canada. University of Manitoba, Winnipeg, March, (1987).