Maximum Economic Yield as Related to Fertilizer Use*

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Introduction

Maximum economic yield (MEY) is an excellent objective for soil and crop management in Western Canada. The term, MEY, reinforces the need to recognize that the physical and financial aspects of crop production management are equally important and complex, that high net returns are more important than just low costs or high yields. With optimum net returns as its objective, MEY is an excellent vehicle for promoting investment in crop inputs and more attentive or integrated management of those inputs.

MEY may be a new phrase but it is not a new concept. In 1956 Earl Johnson, the Provincial Soils Specialist, addressed a crowd at the University of Saskatchewan Farm and Home Week with the following words:

> "At a time when lower prices for farm products, surpluses and diminishing net returns loom large on the farm front improved soil management assumes special importance. Lower costs of production through better soil treatment and higher acre yields offers the most certain method of beating the cost-price squeeze ... Maximum input of fertilizer, tillage, weed control, quality seed and other factors can be expected to give maximum yields. Maximum yields, however, may not be the most profitable. The ideal combination is that which will provide for optimum continued production, keeping the soil productive and giving satisfactory economic returns" (Johnson 1956).

Managing towards MEY is like building a chain where the overall strength is determined by the weakest link, whether that link is a crop input or a management skill. In many cases, it can be shown that investment of more time, effort or money in strengthening the weak link can reduce the costs of growing a crop -- on a per unit of production basis -- by spreading the overhead or fixed costs over more bushels or tonnes. Because fertilizer is a crop input that increases yield dramatically it therefore receives a great deal of attention in MEY discussions.

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MEY and Fertilization -- the General Relationship

The difference between MEY and the absolute maximum yield is typically illustrated in Figure 1. Unfortunately agronomists often present an overly simplistic and therefore erroneous picture of how easy it is to achieve MEY. For example, marginal returns analysis is often used to describe the optimum rate of applying a single input such as nitrogen fertilizer (Figure 2). The economic optimum occurs at a point on the response curve where marginal returns equal marginal costs. Unfortunately, this sort of marginal returns analysis does not describe MEY except when the number of inputs to be managed are few in number. MEY can only be described and analysed as a complete package.

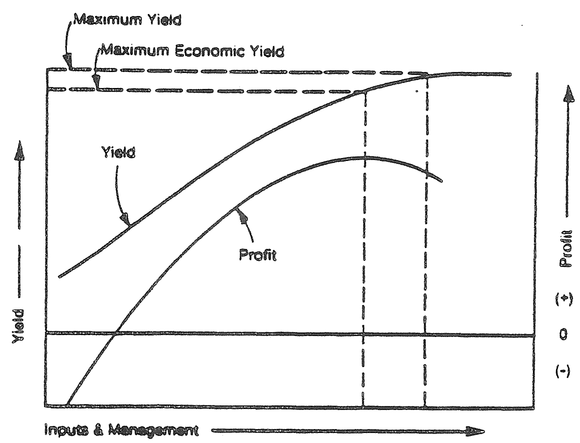

Figure 1. The relationship between maximum yield, maximum economic yield and inputs.

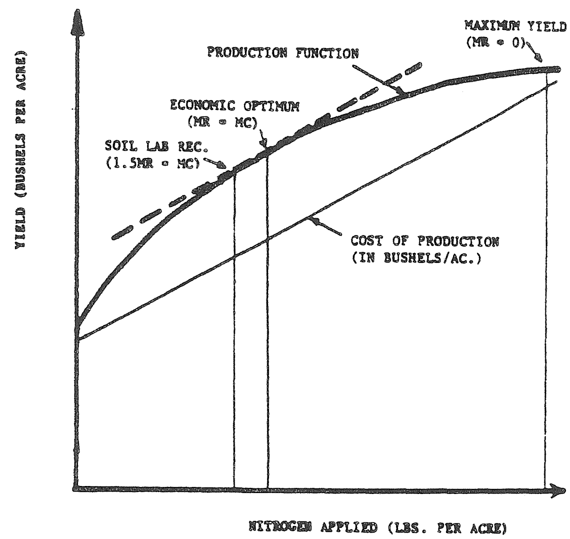

Figure 2. Marginal revenue compared to marginal costs for yield response to nitrogen fertilizer (MR=Marginal Revenue, MC=Marginal cost).

The misuse of yield responses to single inputs is illustrated by a hypothetical example in Table 1. Although the example is an extreme one it does illustrate that if the decision of how to use each input were based on the typical sorts of yield responses that are often reported, totally unrealistic yield and profit goals would be assumed. This is because research information is typically gathered under conditions where only one factor is varied while the other yield-limiting factors are eliminated to the greatest extent possible.

Table 1. Theoretical yield increases and economic returns for canola managed with a large number of inputs (canola price = $4.50/bu)

INPUT	YIELD INCREASE* bu/ac	VARIABLE COST $/ac	INCREASED GROSS REVENUE* $/ac	GROSS MARGIN* $/ac
N (60)	20	13.00	90.00	77.00
P (25)	5	6.00	22.50	16.50
K (30)	3	4.00	13.50	9.50
S (25)	5	4.00	22.50	18.50
Insecticide	5	3.00	22.50	19.50
Herbicide	10	16.00	45.00	29.00
Fungicide	10	20.00	45.00	25.00
Subsoiling @10%	5	5.00	22.50	17.50
Packing	3	4.00	13.50	9.50
Snow Trap	2	0.25	9.00	8.75
New Variety	2	2.00	9.00	7.00
	70	77.25	315.00	237.75
+CHECK YIELD	13	3.50	58.50	55.00
TOTAL THEORETICAL YD*	83	80.75	373.50	292.75
REALISTIC YD	30	80.75	135.00	54.25

*based on hypothetical yield data gathered from research where the factor in question was varied and other factors were not limiting yield.

Instead of conducting traditional marginal economic analyses on an input by input basis, the farmer must identify all the factors that limit yield, examine the physical and economic feasability of overcoming those limitations and select an integrated crop management package developed for a suitable intensity of production. Even so, the farmer then must extrapolate from the field level to the whole farm considering a host of other factors such as financing, marketing, the family's personal goals and the effect of government programs such as crop insurance, stabilization and deficiency payments. A software package for a personal computer could possibly assist this process if the right sort of information were used. Perhaps a program that combined the Cropfile program of Montana (Kresge 1986) and Roy Button's spreadsheet (Button 1987) would be useful.

For many farms in Western Canada the major factors limiting yield are fewer than in the hypothetical example. Therefore the best soil and crop management package is easier to identify than Table 1 would suggest. Still it is worthwhile to keep in mind that as Earl wrote in

1956, "Commercial fertilizer does not give maximum returns unless it is accompanied by good tillage, good tilth and good farming in general" (Johnson 1956).

MEY and Fertilizer Rates, Forms and Placement

Nitrogen and phosphorus continue to be the principle fertilizer nutrients needed for crop production in Western Canada. Sulphur is becoming more and more deficient, especially for the production of oilseeds and legume crops. Yield responses to potassium fertilizer are significant but only on a minority of Prairie soils.

1. Nitrogen

At the time that Earl gave his talk to the 1956 Farm and Home Week phosphate was "the major need" while nitrogen was forecast to "assume greater importance in our fertilizer program as our soils are cropped for longer periods" (Johnson 1956). An example of how great the soil's nitrogen supply was at that time can be found in a mimeographed report by Rennie and Nyborg from the same year where they reported on fertilization trials conducted with stubble wheat grown on Regina heavy clay. The unfertilized check yielded 42.5 bu/ac; applying 30 lb/ac of phosphate increased the yield to 49.1 bu/ac; adding 100 lb/ac of nitrogen in addition to the phosphate increased the yield only 4.3 bu/ac more to 53.4 bu/ac. Incidentally, Rennie and Nyborg also conducted experiments with foliar applied ammonium nitrate solution applied at the eight leaf stage -- it didn't work in those days, either. Earl's forecast came true, of course, as can be seen in the fertilizer consumption figures of the last 35 years (Table 2).

Table 2. Fertilizer Sales in Saskatchewan

YEAR	N	P
	tonnes/year	
1952	2 800	9 600
1962	5 600	18 000
1972	20 200	39 100
1982	192 000	143 200
1986	319 000	184 300
1987	280 000	163 300

Source: Canadian Fertilizer Institute

Another change that has occurred since 1956 is the degree to which we understand how much nitrogen fertilizer is needed for a given field. For example, a huge research effort was invested to generate a series of nitrogen response curves for a variety of soil zones in Saskatchewan (Figure 3). Presumably most of the differences between those response curves is due to the strong interaction between nitrogen response and the different moisture supplies typical of each soil zone.

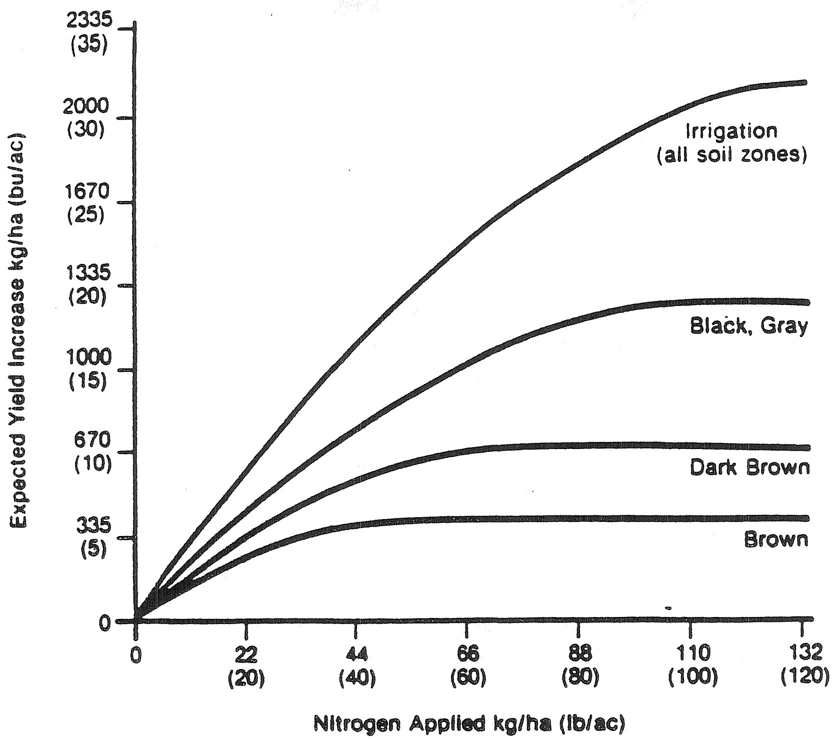

Figure 3. Effect of nitrogen fertilizer on the yield of wheat seeded on stubble under moisture conditions typical of the various soil zones in Saskatchewan. Source: SSTL Expected Yield Increase Tables.

Excellent reviews of the interaction between nitrogen and moisture have been presented recently (Henry et al. 1986; Marantz 1987). These reviews plus other recent work (Campbell et al. 1987; Campbell and Zentner 1987; de Jong and Halstead 1987) indicate that for every cm of water available during the growing season, one could expect a yield increase of approximately 100 kg/ha of spring wheat. Campbell and Zentner also reported that over an 18 year period stubble fields contained an average of 5 cm less stored water than fallow fields at planting, giving stubble crops a significantly lower yield potential. None of these findings are particularly startling except when one considers that there is no difference between the fertilizer response curves used for stubble and summerfallow fields in Saskatchewan. In spite of the expensive and sophisticated research into the relationship between nitrogen and moisture, the very basic differences in yield potential between stubble and fallow have not been recognized in a way that helps farmers manage towards MEY. Once that gap is overcome, then the soil testing labs can start to work towards developing more sophisticated models that utilize weather probabilities to predict the most profitable application rates for nitrogen fertilizer (Josephson and Zbeetnoff 1988).

The large variability in the nitrogen supplying power of various soils is another challenge to face when trying to predict the optimum rate of N to apply for MEY. The variation is due not only to soil type and native organic N reserves. Crop residues from legume crops may have a large effect on the amount of nitrogen available to subsequent crops. Soper has summarized the results of studies with Manitoba soils and reported that the wheat fertilized with 25 kg/ha of N and seeded into lentil stubble yielded the same as that seeded into cereal stubble and fertilized with 75 kg/ha of N (Soper and Grenier 1987). Part of this yield benefit can be attributed to residual N; part to other factors. Tillage system and crop rotation also have a significant effect on the nitrogen supplying power of a soil. Bauer and Black (1983) found that after 25 years, a soil treated with minimum tillage contained 10% or 700 lb/ac more total nitrogen than soil had been tilled conventionally. Janzen (1987) analysed soils at Lethbridge which had been in specific crop rotations for 33 years and found that soil which had been continuously cropped contained slightly more total nitrogen than soil which was summerfallowed frequently. However, soil which had been in the fallow wheat rotation was capable of mineralizing only half as much nitrogen as that which had been cropped continuously.

Besides the problems of measuring mineralizeable organic nitrogen, there are also problems with measuring the nitrate nitrogen content within a field due to variability. In a recent Saskatchewan Agriculture demonstration project near Fort QuAppelle, Dwayne Simmons examined the variability in available N and P among individual soil sample cores in two soil types. One soil was an Oxbow loam, a typical parkland soil found in rolling topography. The other soil was an Indian Head clay, a lacustrine soil found on what appears to be level, uniform topography. A summary of these data is presented in Table 3. Nitrogen variability was highest in the Oxbow soil, ranging from 6 to 161 lb/ac; phosphorus variability was greatest in the Indian Head soil, ranging from 6 to 52 lb/ac. Given this sort of variability it is questionable whether or not to invest a great deal of effort to fine tune a fertilizer program to the last couple of pounds per acre if the fertilizer is to be applied uniformly over the entire field. Variable rate fertilizer application technology is being developed, but it is not yet a proven technology. One of the major problems with variable rate fertilization is taking into consideration the variability in moisture supply that is also likely to occur in fields with a large variability in nutrient supply (Kachanoski et al. 1985), especially on land which is stubble cropped (Bens and Hamm 1987).

Table 3. Nutrient variability between individual soil sample cores taken near Fort QuAppelle.

SOIL TYPE	AVAILABLE N			AVAILABLE P		
	LOWEST	HIGHEST	AVERAGE	LOWEST	HIGHEST	AVERAGE
	LB/AC					
Oxbow L	6	161	44	6	28	11
Indian Head C	5	26	11	6	52	8

In an integrated, MEY type of crop production system it is very important to consider more than just the direct effect of nitrogen fertilizer on grain yield. For example, crop quality, especially protein content, is an important factor. If adequate premiums were available, it could be worthwhile to fertilize wheat for increasing the protein content. It may sound unrealistic, but as of June 11, 1987, the protein premiums in Minneapolis were US $.28 for 13-14% protein and US $1.07 for 14-15%, and if you were close to 14% the extra N could pay off handsomely. For crops like malting barley where high protein content is undesirable, high yields due to high N rates may be offset by poorer acceptability in terms of protein. However, it is quite possible for other factors such as late seeding to have considerably more effect than N rate (Dahnke et al. 1981). And, under otherwise careful management, barley fertilized with N at rates as high as 168 kg/ha may not exceed acceptable standards for malting barley (Varvel and Severson 1987). Other effects of N such as lodging, disease incidence, delayed ripening and induced deficiencies of other nutrients such as sulfur must also be considered.

In the early 1950's anhydrous ammonia was introduced to Saskatchewan and there was some concern over whether or not to recommend applying nitrogen fertilizer in an operation separate from seeding (Johnson 1956). Nitrogen fertilizer source and placement continues to be controversial issue, just as it was 32 years ago. There have been a considerable number of papers presented at the Soils and Crops Workshops that have dealt with this subject. Comprehensive reviews of nitrogen fertilizer placement under Western Canadian conditions are available in the Alberta Soils Workshops Proceedings of 1976, 1979 and 1984, plus the review of Harapiak et al. in 1986. However, it may be worthwhile to consider a few ways in which fertilizer placement interacts with other aspects of the MEY system.

The so-called "best" way of applying nitrogen fertilizer varies greatly from farm to farm, even within a particular region of the province. The efficiency of nutrient uptake is only one of a number of criteria to be considered. Some of the other criteria include the effect of fertilizer source and placement on the quality of the seed bed, timeliness of other operations, the cost and availability of the fertilizer and associated application equipment and the ability to integrate fertilizer application with other necessary field operations. An important trend to note, however, is that the improved fertilization capabilities of seeding implements and the lower fertilization rates farmers are working with today are conducive to a resurgence of interest in seed placed nitrogen fertilizer application. Considering the high cost of applying fertilizer in a separate operation it may be at least as profitable to apply the equivalent rate or perhaps less N with the seed even if the farmer has to use the higher priced ammonium nitrate form of N.

2. Phosphorus

Defining a profitable rate of applying P fertilizer is even more difficult than for N. Phosphate is very reactive in the soil environment and its availability is difficult to predict. The availability of soil P to crops varies substantially with temperature and moisture conditions, for example. In general, it appears that wet, cold soils are more likely to respond to P fertilizer than dry, warm soils. And although no one has found a better P test than the sodium bicarbonate test for Saskatchewan soils, its predictive capabilities are very limited. Poorly drained soils, for example, may have extremely high extractable P concentrations and yet may be at least as likely to respond to P fertilizer as a neighbouring soil with better drainage. And, as mentioned previously, there is considerable variation in P status within a field (Table 3). In the demonstration project from which Table 3 was generated extracting 1 of 20 cores from an abandoned barnyard, now under cultivation, raised the average apparent P concentration for the field by 30 lb/ac. So, asking a stranger to sample a field without supervision could be a costly error.

The lack of predictability of a profitable P response is illustrated in the data from the Innovative Acres project (de Jong and Halstead 1987). These data also indicate that there is a higher probability of obtaining a yield response to P on fallow than on stubble fields. Part of the reason for the greater response on fallow may be related to a lower incidence of mycorrhizal fungi on the roots of fallow crops.

As a result of the combination of low grain prices and the unpredictable nature of P response, only modest rates of P are justifiable except where soil test P is very low or where experience has proven otherwise. It is important not to quickly dismiss the application of P fertilizer altogether, though. Although P fertilization for the yield response, itself, may be questionable, there are other significant benefits from applying modest rates of P, especially in the seed row. These include increased resistance to diseases such as root and foot rot, earlier maturity, improved frost tolerance and greater competition against weeds. In many cases these benefits may pay greater dividends than the yield increase.

The issue of whether seed row placement or preplant banding is the best method of placing P fertilizer has been discussed many times at the Soils and Crops Workshops. In summary, it appears that the importance of placing fertilizer P in the seed row depends on the availability of soil P. Under conditions where the soil has very low soil test P concentrations and/or where the soil is cold and wet, at least a portion of the P fertilizer should be placed in the seed row. And, considering the low commodity prices, there is little incentive to apply rates of P which are higher than that which can be applied safely with the seed, especially for cereals.

3. Other Nutrients

Potassium fertilization is discussed very well in the Saskatchewan Agriculture bulletin, "Potassium Fertilization in Crop Production" and in the "Western Canada Potash Handbook" recently published by the Western Canada Fertilizer Association. In most cases, soils that test low in K are coarse in texture and from the Gray and Gray Black soil zones.

For the minority of farms in Saskatchewan that require additional K for MEY, proper fertilization recommendations for K are very important. For annual crops, placing K fertilizer with or near the seed is much more effective than broadcasting. For perennial forages such as alfalfa, K fertilizer should be broadcast and incorporated prior to seeding.

Potassium is not, however, the only nutrient in potash fertilizer. The chloride in potash may also increase yields to a modest degree, especially through its effect of suppressing root and leaf diseases (Fixen et al. 1987a; Fixen et al. 1986b; Fixen 1987; Goos 1987). The challenge associated with chloride fertilization is to predict the likelihood of a profitable yield response under typical Western Canadian conditions. So far, the relationship between soil test chloride concentration and yield response to chloride is not described adequately for Saskatchewan conditions.

Sulfur fertilization practices are summarized in the Saskatchewan Agriculture bulletin entitled "Sulfur Fertilization in Crop Production." More and more soils in Western Canada are testing low in sulfur, especially for legume and oilseed crop production. The principle reason for this increase is likely the decline in mineralizeable sulfur that comes from soil organic matter. As with potassium, deficiencies are most likely on coarse-textured Northern soils. However, in contrast with potassium, the overall frequency of low soil test values is much higher.

Sulfate-sulfur fertilizer is a relatively low cost input and, with new granular forms that have been introduced recently, it can be blended readily with common granular fertilizers such as urea and monoammonium phosphate. The question of whether elemental S should be used instead of the sulfate form continues to be a contentious issue (Karamanos et al. 1987; Nuttall 1987). However, considering the cost of elemental S, there is little incentive to use it on an annual basis and there is considerable risk of elemental sulfur remaining unavailable during the first year after application.

Following soil test recommendations for sulfur is reasonably reliable in most cases. There are, however, two cases where deviation from the recommendations should be seriously considered. The first is when low sulphur concentrations are detected on Brown or Dark Brown soils which are medium or fine textured. So far, there is no evidence for expecting a yield increase to sulfur fertilizer in these circumstances (Tomasiewicz and Marantz 1987). The second case is where there is little available sulfur in the surface soil but adequate supplies of sulfur in the subsoil. Under these conditions a moderate application of sulfur fertilizer may benefit the crop especially in its early stages and if high rates of other nutrients are applied.

Micronutrient deficiencies in Western Canada are infrequent and highly localized. And, with low prices for grains and oilseeds combined with very high prices for micronutrient fertilizers, profitable responses to micronutrients are rare. In a few cases, however, such as coarse-textured Gray soils or organic soils, there may be a profitable response to micronutrient applications. For more information on this subject, refer to the Saskatchewan Agriculture publication, "Micronutrients in Crop Production" plus the proceedings of the Saskatchewan Soils and Crops Workshop of 1983.

Summary

1. Even though scientists and agronomists usually deal with individual components of the crop production chain, farmers must manage and pay for those components as part of an integrated system. The challenge is to apply the knowledge of a single component in a way that will be compatible with the objectives of the overall system. Fertilizer selection, application rates and placement methods have a profound effect on yield, but each must be considered within the context of the overall system. That is why there is not necessarily any problem with a wide variety of fertilization practices within a region.

2. From the farmer's perspective fertilizing for MEY relies on a very careful soil testing program followed by judicious interpretation of the recommendations. Most soils contain adequate supplies of potassium and sulfur and many soils do not give a large yield response to phosphate fertilizer, especially on stubble. Therefore, nitrogen fertilizer offers the greatest economic returns on investment for the majority of farmers in Saskatchewan, provided there are adequate supplies of moisture. In the case where an integrated cost analysis shows negative returns from a management package—a new package must be developed. If a suitable package cannot be developed for one crop, another crop should be considered. For marginal land, there may be little choice but to plant perennial forage, for it may be an opportune time to "retire unproductive areas to soil-improving crops, to take care of special weed problem areas and make a careful study of the whole farm program" (Johnson 1956).

3. From the agronomist's perspective there is a need to improve our information base and the way that information is delivered to farmers, so that they can make better decisions about investing in inputs. Updating and improving our soil test program is crucial, especially with respect to nitrogen supplying power and moisture/nitrogen interactions. In addition, more information is needed regarding the nutrient requirements of new crops, plus the residual effects of these crops on the nutrient supply for subsequent crops.

4. Last and not least, long term productivity and, therefore, the soil conservation component of soil management cannot be forgotten:

> "Good soil management is the basis for all agricultural production...Soil management can be considered the integration of all practices affecting fertility supply, maintenance of tilth and erosion control...Much of Saskatchewan has been farmed for a mere fifty years. To the pioneers who developed this large agricultural area without much knowledge of the best methods, trial and error was the best approach. The farmer of today has available machinery, supplies and knowledge unknown fifty years ago. The next fifty years presents a challenge to maintain and improve that great heritage that the pioneers opened up and developed. Scientific knowledge, intelligence, careful planning and a real appreciation of this great heritage can assure that the task is well done" (Johnson 1956).

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