CHAPTER 2

The changing fertility of prairie soils

L.E. Cowell and P.J. Doyle[1]

ABSTRACT

Widespread studies on soil quality suggest that significant changes in crop response to one or more of the macronutrients could be expected. In this review responses to fertilizer nutrients prior to 1969 were compiled and compared to field test data carried out between 1970 and 1990 in Saskatchewan. Regretfully data from extensive and widely distributed field fertilizer test trials that have been conducted in Alberta and Manitoba was not available.

Phosphorus

In field trials carried out prior to 1970, the probability of obtaining a yield response to phosphate fertilizer across a broad range of Saskatchewan soils was remarkably high and approximated 92 and 95% on stubble and fallow, respectively. The probability of obtaining a yield response of 250 kg ha^{-1} was 48% on stubble and 71% on fallow. The mean yield response was approximately 350 kg ha^{-1} (5.3 bu ac^{-1}).

Field trials conducted since 1970 suggest a very significant change in the P fertility level of all soils, and the response to added P was much less consistent. A 250 kg ha^{-1} yield increase occurred for only 32% and 48% of the trials conducted on stubble and fallow, respectively. Suggested reasons for the reduced response to P fertilizer are presented.

Nitrogen

With the exclusion of the Grey Wooded soils, the diverse soils across the prairies initially contained abundant quantities of N, the majority of which was present in soil organic matter. Crops grown during the early part of the century and even beyond mid-century were rarely in need of additional N. Fallow rotations lead to rapid mineralization of organic N providing a flush of nitrates in excess of crop needs. By the mid-1950s field test trials demonstrated a growing need for supplemental N. The growing popularity of recropping and improved agronomic practices, coupled with reduced organic N mineralization has increased the frequency of economic crop response to N fertilizer. In contrast to the period prior to 1970, when P was considered the major nutrient required for agronomic crop production, N has now become the dominant nutrient required. Today, a large majority of crops seeded on fallow fields respond profitably to fertilizer N inputs.

No reference is made to changing trends in yield responses to K and S, principally because the area of deficient soils remains relatively small even today.

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[1] Dept. of Soil Science, Univ. of Saskatchewan, Saskatoon, SK, S7N 0W0, and Ciba-Geigy Canada Ltd., Plant Protection Division, 484 Henderson Dr., Regina, SK, S4N 6E3.

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INTRODUCTION

The cultivated acreage of western Canada increased rapidly in the late 1800s and early 1900s. The virgin soil was fertile and produced bountifully with adequate rainfall, without fertilizer additions. However, it was soon apparent that sod breaking compounded with frequent summerfallow led to rapid erosion and decomposition of organic matter. F.T. Shutt, the Soil Chemist for the Dominion Department of Agriculture, first demonstrated a loss of over 20% of organic matter and 30% of organic N within 20 years of sod breaking (Shutt, 1925). This rapid loss of organic matter was confirmed by later studies (Doughty, 1947; Doughty et al., 1954).

While it was recognized that it would be impossible to maintain organic matter levels in the diverse grassland soils at their virgin level, it was felt that "with good farm management, optimum levels could be maintained providing soil erosion could be controlled" (Mitchell et al., 1944). However, concern for declining soil fertility led to investigations to ascertain the fertilizer requirements of specific prairie soils. Three nutrient elements were demonstrated to deserve special attention: P, N and S. Early field experiments established that P was at that time the most likely nutrient to become deficient for plant growth. Soil surveys also confirmed that P was present in the soil in relatively small amounts and a large portion was unavailable for plant uptake. In contrast, N was initially in adequate supply, except on some stubble land in the more humid areas of the prairies. Sulphur, which was present in sufficient quantities in almost all soil, was shown to limit growth of legumes on some Grey Wooded soil. The remaining nutrients, including K, were generally present in satisfactory amounts. These early plant nutrient experiments not only established these nutrient deficiencies, but also determined the best fertilizer forms, placement, rates, and soil extraction methods on which to base fertilizer recommendations.

This chapter will attempt to answer the question, *has the fertility status of prairie soils changed significantly?* Certainly, based on widespread studies on soil quality, very significant changes in the fertility status of the soils would be expected (Rennie and Ellis, 1978; Rennie, 1982; PFRA, 1982). Model predictions developed at the Swift Current Agriculture Canada Research Station suggest the continued decline of mineralizable soil N may severely limit crop production in the near future with unfertilized wheat-fallow rotations (Fig. 1). In the discussion that follows, yield response data from the various fertilizer trials conducted between 1930 and 1969 were compiled to represent old or "historic" yield responses. The "current" yield responses include studies from 1970 to 1990. Yield responses from each province were compiled and are discussed separately.

ALBERTA

Very extensive and widely distributed field fertilizer test trials have been conducted across Alberta during the past four to five decades. Results of the historical fertilizer tests conducted between 1951 and 1970 inclusive were recorded in one volume each year by the Alberta Soils Advisory Committee. The results included those from the University of Alberta, Agriculture Canada Research Stations at Lacombe and Lethbridge and, on a less frequent basis, results from industry trials such as those conducted by Sherritt Gordon Mines Ltd. More recently, in addition to the ongoing nutrient studies carried out by a number of agencies, two large multi-agency projects were carried out. The first titled 'Risk Adjusted Yield Potential' resulted in the largest pool of data ever collected from a single project in the province. This study was coordinated by the Alberta Soil and Feed Testing Laboratory in the years 1971 to 1974 and focussed on barley and rapeseed in particular. A more recent study, with treatments designed to determine the fertilizer requirements (N, P, K and S) for irrigated crops in the province, was carried out during the period 1983-1987 (McKenzie et al., 1989). This study included such crops as soft wheat, hard wheat, durum wheat, Canada prairie spring wheat, feed and malting barley, canola, flax, silage and grain corn and sunflowers.

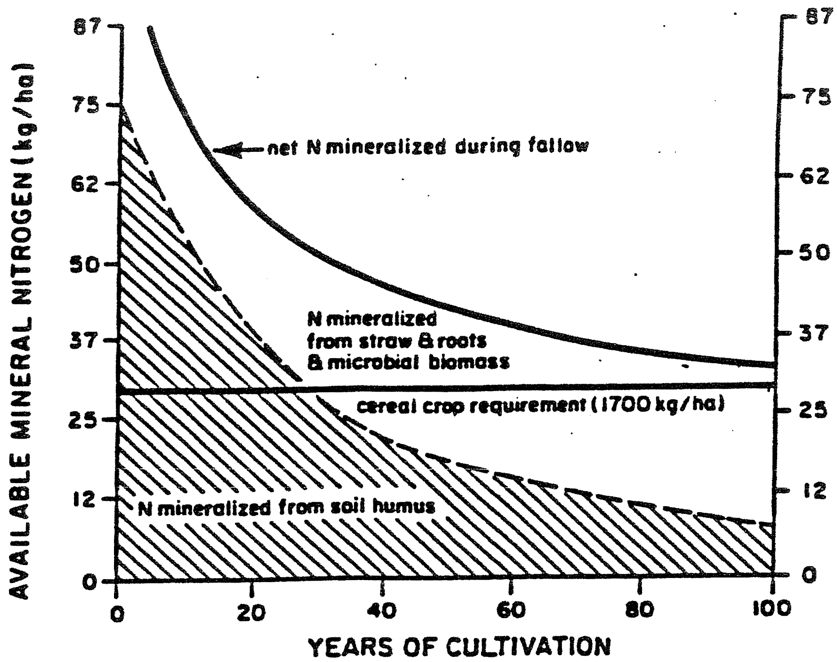

Figure 1. Net N mineralized during fallow (from soil humus plus crop residue and microbial biomass), as affected by years of cultivation as presented by a model based on data from Swift Current.

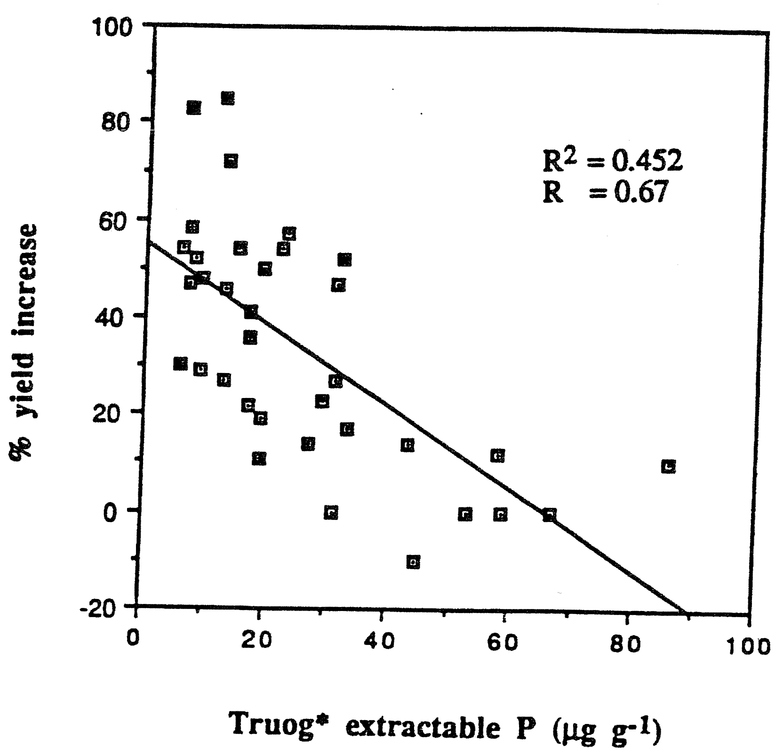

Figure 2. Relation between yield increase of wheat from phosphate fertilizer addition and the level of available P (by K_2SO_4 / H_2SO_4 extraction; Truog, 1930) in untreated soil for 35 sites across Saskatchewan. Data from 1928 to 1930 experiments (redrawn from Mitchell, 1932).

It is unfortunate that circumstances did not permit Alberta collaborators to review and evaluate results from the early and more recent test trials and to determine if any significant trends have occurred in the response of these crops to fertilizer N, P, K and S as has been shown, particularly for P in Saskatchewan (*see next section*). McKenzie et al. (1989) report that under irrigation significant responses to fertilizer P occurred in less than 50% of the test sites when the P was seed applied and less than 25% for deep banded P. This low frequency of response to fertilizer P is very close to the "recent data" for Saskatchewan, and sharply contrasts with the almost guaranteed response to fertilizer P which was characteristic of the phosphate fertilizer production curves obtained in Alberta during the 1940s and 1950s.

SASKATCHEWAN

P and N Responses Prior to 1970

Phosphorus: In the late 1920s, field experimentation involving P had begun at the University of Saskatchewan to address problems of relatively infertile soils in northern areas and declining organic matter in prairie and parkland soils.

The first high analysis phosphate fertilizers and appropriate equipment for seed placement of fertilizer were introduced in 1927 (Mitchell, 1932). Demonstration field trials in 1928, 1929, and 1933 with 0-53-0 fertilizer applied to wheat seeded on summerfallow measured an average yield increase of 32%. Mitchell also reported a fairly close relationship between available soil P as measured by a modified Truog test (Truog, 1930) and percent yield increase (Fig. 2).

Ammonium phosphate fertilizer was introduced in Western Canada by the Consolidated Mining and Smelting Company of Canada in 1931 (Edwards, 1954). Extensive use of these fertilizers was not common in the dry 1930s, but gained popularity with the increased demand for wheat and increased prices in the 1940s. Application of P fertilizer almost assured a yield response during this period.

Field experiments conducted across Saskatchewan from 1939 to 1953 revealed consistent yield increases of spring wheat sown on fallow (Mitchell, 1946; Edwards, 1954). These early tests demonstrated a number of P fertilizer facts which are generally still true. Small applications of P such as 10 to 20 kg P_2O_5 ha^{-1} produced relatively large increases compared to larger P additions, even on very P deficient soils (Fig. 3). Ammonium phosphate fertilizers were shown to be superior to calcium phosphates for most prairie soils. The benefits of earlier crop maturity and depressed root diseases when P fertilizers were applied were recognized. It was assumed, but never proven, that very large responses to P additions could be expected in cool, wet springs from even small amounts of seed placed P (the "pop up" effect). On the other hand, yield increases due to phosphate fertilizers were frequently nonexistent for late-seeded crops. Yield responses were largest in the moister soil zones and on clay-textured soils (Warder and Ferguson, 1968). These experiments established a general recommendation rate of 22-45 kg P_2O_5 ha^{-1} for most soil conditions. In the latter years of these trials, soil extractions with carbonated water were found to be correlated to grain yield (Fig. 4).

Province-wide trials were continued during the 1950s and 1960s by the Department of Soil Science at the University of Saskatchewan, with wheat seeded on fallow land (Dept. Soil Science, University of Saskatchewan, Soil and Plant Nutrient Research Report, 1965). The $NaHCO_3$ soil extraction was established as the basis for P fertilizer recommendations. Of 1,471 field strips tested, the mean extractable P was 17.0 ± 8.6 ppm in the 0-15 cm depth. Yield response to P increased and measured soil P decreased as soil pH increased. Gleysolic soils were often responsive to P fertilizer despite high extractable P levels. Again, early-seeded crops were the most likely to respond to P fertilizer.

During the 1960s, the Veterans Land Act and School of Agriculture cooperative farmer trials with the University of Saskatchewan provided comparisons of P fertilizer applied to wheat seeded on both stubble and fallow fields (University of Saskatchewan Dept. Soil Science Soil and Plant Nutrient Research Reports, 1965-69; Halstead, 1971).

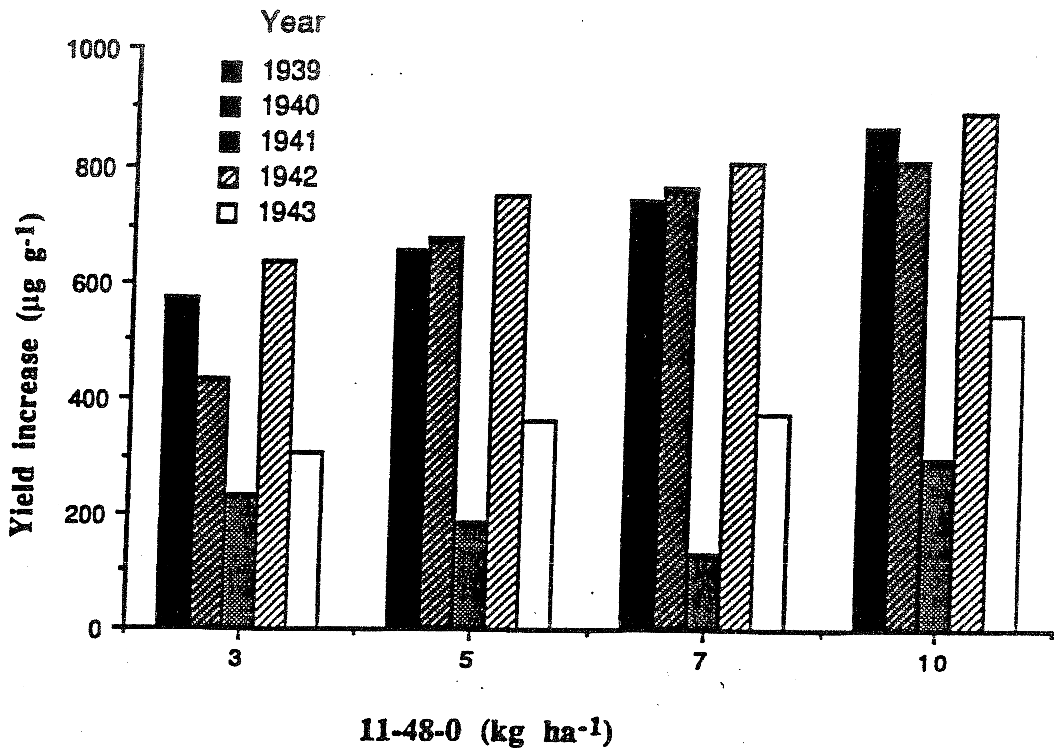

Figure 3. Average yield response of wheat grown on fallow to seed-placed P fertilizer (11-48-0). The number of sites for 1939, 1940, 1941, 1942, and 1943 were 20, 14, 14, 15, and 10 respectively. The sites were generally well distributed across the Saskatchewan (adapted from Mitchell, 1932).

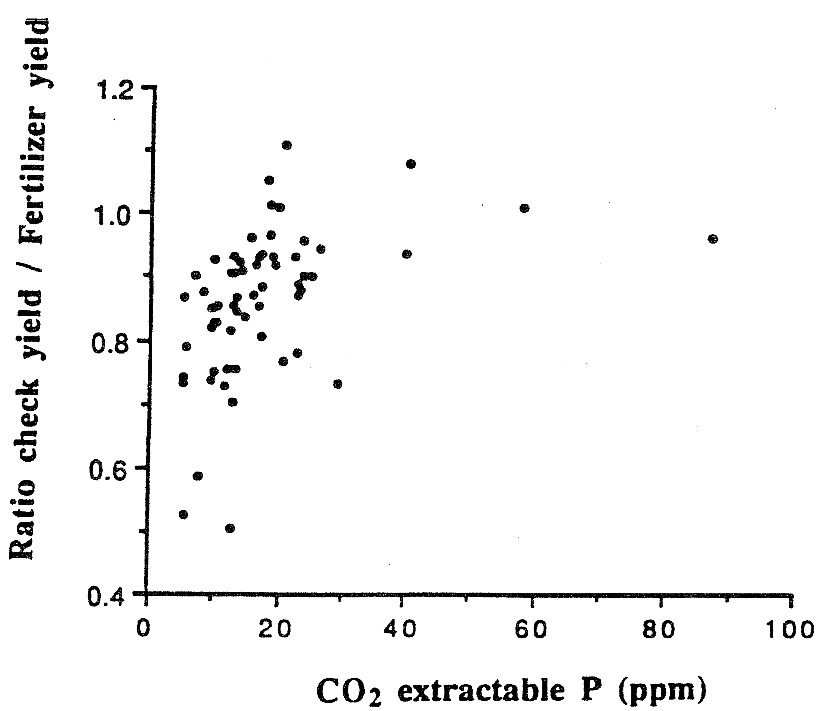

Figure 4. Yield response of spring wheat compared to available soil P (redrawn from Edwards, 1954).

Again, these projects covered a broad range of soil types, and soil test correlations were further refined.

Similar field fertilizer experiments were conducted from 1950-1968 in the Brown soil zone in cooperation with farmers situated on various soil textures throughout the southwest of Saskatchewan (Warder and Ferguson, 1968). These authors noted that yield increases on the Brown heavy clay Sceptre soils were 5.6 bu ac^{-1} (370 kg ha^{-1}) compared to 3 bu ac^{-1} (200 kg ha^{-1}) on loam soils, supporting the previous observations by Edwards and Mitchell. Over 75% of the soils contained 10 to 30 kg ha^{-1} $NaHCO_3$ extractable P in the top 15 cm of soil.

We combined the results of these early P fertilizer trials into a single data set. The mean wheat yield increase due to P fertilizer application across this broad range of Saskatchewan soils was 350 kg ha^{-1} (5.3 bu ac^{-1}) (Table 1). These data clearly underscore the widespread deficiency of P, the much stronger response to P fertilizer on fallow as compared to stubble, and the increasing response with decreasing moisture deficit (i.e. from Brown to Grey soils). It should be noted that in almost all cases care was taken to ensure that N was not limiting crop growth. The probability of obtaining a yield response to P fertilizer was remarkably high, approximately 92% and 96% on stubble and fallow, respectively (Fig. 5). However, the probability of a yield response of 250 kg ha^{-1} was only 48% for stubble and 71% for fallow.

Field tests with barley were much fewer than with wheat (Table 2). While the magnitude of the yield response of barley on fallow was significantly greater than that on stubble, on a percentage basis, response on fallow and stubble were similar. These data do not support the common belief that barley responds better than wheat to P fertilizer.

The large and consistent yield increases reflected in the experimental data noted above did a great deal to popularize annual applications of seed-placed P with cereal grains. Consumption of fertilizer P in Saskatchewan doubled between 1960 and 1963 to

Table 1. Wheat yield response to P fertilizer for trials in Saskatchewan prior to 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
All data	1550	1900	350	26	874
Stubble	1400	1610	210	17	238
Fallow	1600	2000	400	29	636
Brown soils	1530	1820	290	21	328
Dark Brown soils	1580	1860	280	21	178
Thin Black soils	1530	1960	430	32	152
Thick Black soils	1830	2340	510	32	104
Grey soils	1530	1910	380	38	64

(Data from ; Dept. Soil Science, University of Saskatchewan, annual Soil and Plant Nutrient Research Reports 1965-1969; Warder and Ferguson, 1950-67 (unpublished data); Edwards, 1954; Hutchinson, 1941)

Table 2. Barley yield response to P and N fertilizer for trials in Saskatchewan prior to 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
Phosphorus					
All data	2050	2470	420	24	122
Stubble	1800	2170	370	23	47
Fallow	2220	2670	450	24	75
Nitrogen	1760	2160	400	26	55

(Data from Dept. Soil Science, University of Saskatchewan, annual Soil and Plant Nutrient Research Reports 1965-1969; Warder and Ferguson, 1950-67 (unpublished data); Edwards, 1954;)

approximately 29 000 tonnes of P_2O_5 and tripled again to 97 000 tonnes by 1968 (*see Chapter 1*).

Nitrogen: Rapid mineralization of fresh organic N after the native sod was broken provided a flush of nitrates in excess of that required by crops (Fig. 1). Nitrogen was rarely deficient for crop growth in the early part of the century. Fallow rotations and use of manures further prevented the need for N fertilizer amendments. For these reasons, experiments and farm trials with N fertilizer were not seriously pursued until the 1950s. Unlike P fertilization, for which seed placement of ammonium phosphate has been practiced from the very early field trials, N fertilization techniques have evolved constantly up to today. Ammonium nitrate was first introduced, and was usually seed placed at low rates. Application equipment and techniques were slowly improved towards the goal of maximum N fertilizer use efficiency (*see Chapter 7*).

By the early 1960s the nitrate test was well established (*see Chapter 8*). Farmers, assisted by what were considered highly precise N fertilizer recommendations based on soil test data, a very strong extension program focussing on extended cropping systems and a clearly established, highly economic response to N fertilizer increased purchase of N fertilizer by seven-fold from 1960 to 1967 (Rennie, 1982). The response of spring wheat to N fertilizer (Table 3) shows the reason for this rapid increase in fertilizer N use on stubble seeded crops by Saskatchewan farmers. The primary data from which the averages were calculated were obtained from the Swift Current Research Station files and the University of Saskatchewan Department of Soil Science annual Soil Plant Nutrient Research reports for the period 1956-1969. Nitrogen fertilizer application rates averaged 40 kg ha^{-1} for these trials. While the percent response to N on stubble land was approximately four times that on fallow, it is significant that yield increases were recorded for some fallow-seeded crops. As found for phosphate, percent response in the more arid soils was much less than that for the more humid regions.

Table 3. Wheat yield response to N for trials in Saskatchewan prior to 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
All data	1550	1860	310	24	348
Stubble	1490	1870	380	31	241
Fallow	1700	1830	130	8	107
Brown soils	1490	1660	170	12	117
Dark Brown soils	1630	1960	330	23	145
Thin Black soils	1560	1870	310	24	19
Thick Black soils	1890	2190	300	23	34
Grey soils	1050	1730	680	76	30

(Data from Warder and Ferguson,1954-1968 (unpublished data); University of Saskatchewan Dept. Soil Science Soil and Plant Nutrient Research Reports, 1956-1969)

Table 4. Wheat yield response to P fertilizer for trials in Saskatchewan since 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
All data	2100	2270	170	11	252
Stubble	2050	2130	80	7	130
Fallow	2150	2400	250	14	122
Brown soils	1710	1850	140	13	56
Dark Brown soils	2330	2520	190	11	92
Thin Black soils	2150	2330	180	10	67
Thick Black soils	2000	2030	30	3	11
Grey soils	2170	2370	200	11	17

(Data from Androsoff et al, 1991; Doyle et al, 1991; Henry and Harder, 1991 (unpublished data); Lafond, 1991 (unpublished data); Ukrainetz,1991(unpublished data); Bullock et al, 1990; Elliott et al, 1990; Philom Bios, 1990 (unpublished data) Campbell et al, 1988; Innovative Acres, 1981-1988; University of Saskatchewan Dept. Soil Science Soil and Plant Nutrient Research Reports, 1976-1979)

Post 1970 Responses to P and N

Phosphorus: Recent trials with P fertilizer in Saskatchewan have focussed on specific topics such as P uptake kinetics, residual P, and phosphorus/mycorrhiza interactions. However, the Innovative Acres program utilized field scale strips extensively to measure P responses on a broad range of soil types from 1981 to 1988 (Innovative Acres reports, 1981-1987).

The results of a number of field experiments were summarized in a similar manner to the pre-1970 data (Table 4 and Fig. 6). Although P fertilizer additions produced a wheat yield increase on 70% of stubble trials and 90% of fallow trials, the response was much less consistent and smaller than for the pre-1970 data set. A 250 kg ha^{-1} yield increase occurred for only 32% of stubble and 48% of fallow fields compared to 48% stubble and 71% of fallow fields in the pre-1970 period. This apparent reduction in response to P fertilizer was consistent through all soil zones. Barley, and especially canola, also showed inconsistent response to P fertilizer (Table 5). It is significant that many of the recent trials utilized soil tests to help identify P deficient soils for research plots, yet significant yield increases were often elusive. This reduced response to P fertilizer in recent years may be attributed to a number of factors:

- residual P fertilizer
- mineralization of organic soil P
- reduced soil pH, thereby increasing soil P availability
- increased infection of roots by mycorrhiza capable of P uptake
- incidental selection of crop varieties with increased ability for P uptake

Of these factors, mineralization of organic P and residual P from increased P fertilizer use in recent years (as outlined in Chapter 1) seems to be the most plausible contributors to the dampened response to fertilizer in recent years. However, agronomists and farmers should not necessarily view smaller yield increases as a reason to stop P fertilizer addition. Rather, the improvement of the fertility of our chronically P deficient

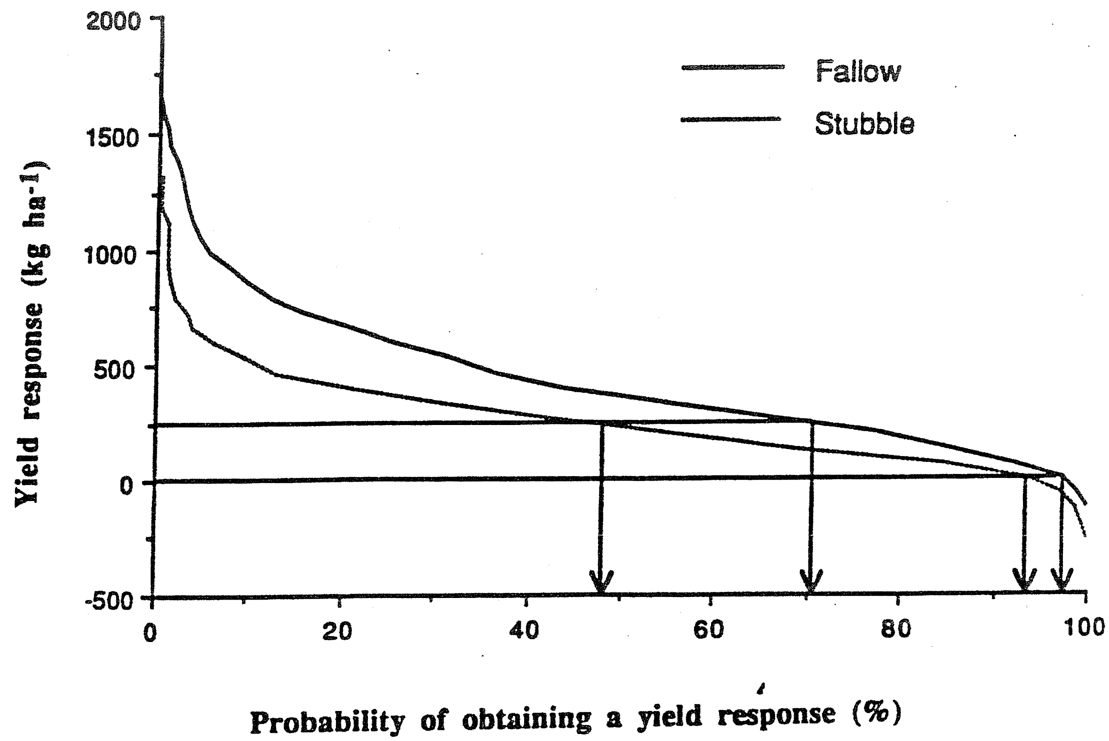

Figure 5. Probability of obtaining a wheat yield response to P fertilizer in trials prior to 1970.

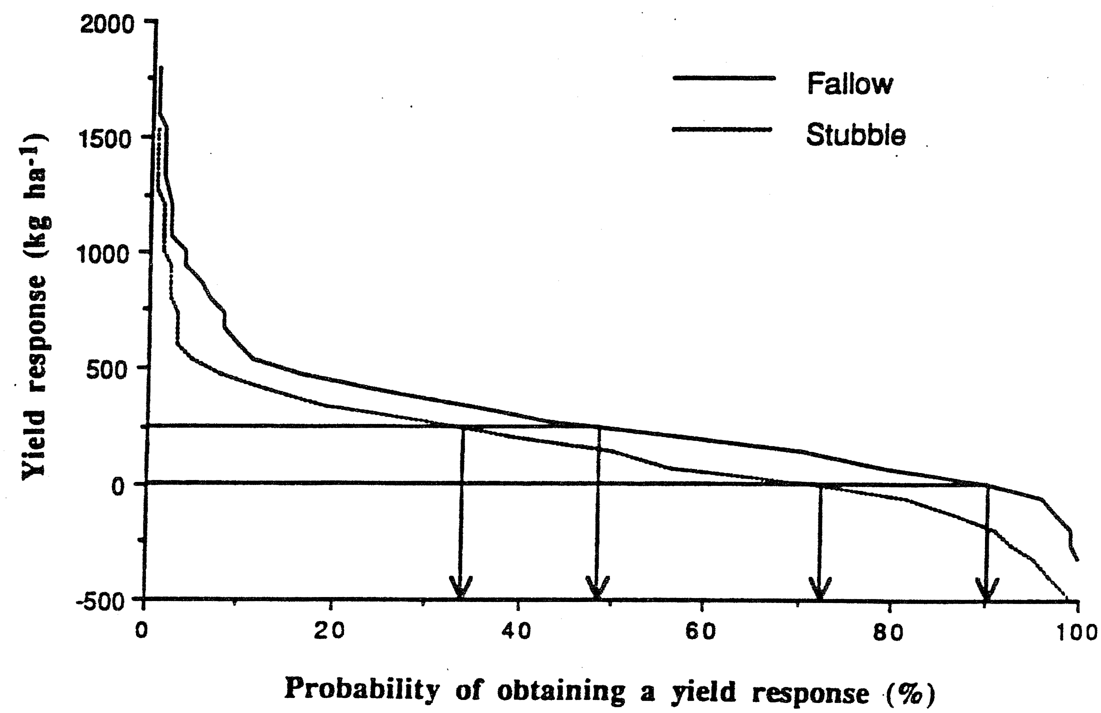

Figure 6. Probability of obtaining a wheat yield response to P fertilizer in trials after 1970.

soils by past fertilizer applications should be viewed as a success. We must now strive to sustain this new P balance for the future with accurate fertilizer application according to soil tests.

It is significant that the results of a 24-year crop rotational (fallow-wheat-wheat) experiment at Swift Current, Saskatchewan, clearly confirms most of the above observations, namely: (1) the response from P fertilizers on stubble land was significantly less than on fallow; responses of 70 kg ha^{-1} or more to a starter application of P (approximately 15 kg of P_2O_5 ha^{-1}) were recorded in 42% of stubble and 71% of fallow years; (2) the mean yield increases to the applied P were approximately 10% on both fallow and stubble; and (3) the trend in available soil P ($NaHCO_3$ extractable) was positive on the plots receiving P fertilizer based on soil tests, increasing by approximately 1 kg ha^{-1} yr^{-1}, and constant on the zero-P plots (Zentner et al., 1993). Phosphorus removed in the grain was approximately equal to the P released from soil organic matter.

Nitrogen: The consumption of N fertilizer increased rapidly during the 1970s and 1980s (*see Chapter 1*). This strong increase which occurred despite serious economic stress affecting agriculture during the 1980s, reflects a realization by farmers that "maximum economic yields" on either fallow or stubble land can only be achieved if the N requirements of the crop are met. In contrast to the period prior to 1970 when P was considered the major nutrient required for economic crop production, N has now become the dominant fertilizer nutrient.

The combination of more extensive N deficiencies, improved fertilizer use efficiency, and higher rates of N fertilizer, led to larger and more consistent yield responses than in the earlier period (Table 6). It should be noted that N application rates were 80 kg ha^{-1} on average, twice that of the early trials. Even summerfallow fields have begun to show requirements for N additions. Very large increases due to N fertilization have been measured in barley and canola trials on stubble, indicating the importance of N nutrition to these particular crops (Table 5).

Table 5. Barley and canola yield response to P and N fertilizer for trials in Saskatchewan since 1970. All N trials were on stubble; P trials were divided between stubble and fallow.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	($kg\ ha^{-1}$)		$kg\ ha^{-1}$	%	
Barley					
Phosphorus	1660	1950	290	22	99
Nitrogen	2240	2940	700	44	219
Canola					
Phosphorus	970	1050	80	8	78
Nitrogen	1050	1290	240	42	425

(Data from Androsoff et al, 1991; Ukrainetz, 1991 (unpublished data); Bullock et al, 1990; Philom Bios, 1990 (unpublished data); Innovative Acres, 1981-1988; University of Saskatchewan Dept. Soil Science Soil and Plant Nutrient Research Reports, 1974-1978)

Table 6. Wheat yield response to N for trials in Saskatchewan since 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	($kg\ ha^{-1}$)		$kg\ ha^{-1}$	%	
All data	1990	2530	540	35	618
Stubble	1900	2450	550	37	554
Fallow	2700	3140	440	21	64
Brown soils	1340	1930	590	53	82
Dark Brown soils	2300	2780	480	27	295
Thin Black soils	1720	2440	720	45	80
Thick Black soils	1360	1830	470	35	8
Grey soils	1890	2420	530	38	159

(Data from Ukrainetz,1991 (unpublished data); Innovative Acres, 1981-1988; University of Saskatchewan Dept. Soil Science Soil and Plant Nutrient Research Reports, 1974-1978)

MANITOBA

Fertilizer plot trials for a wide range of crops in Manitoba in the last three decades have been reported annually in the Manitoba Soil Science Proceedings. Results of trials of N and P fertilization of wheat, barley, canola and flax have been summarized (Tables 7, 8, and 9). Although there are not as many test data as for Saskatchewan, a number of interesting trends are apparent and are discussed below. However, the values presented are averages only; a wide range of yield responses was found in each of the data sets.

Phosphorus: The average wheat yield and yield increase due to P fertilization for trials prior to 1970 were very similar to results from Saskatchewan (Tables 3 and 7). In contrast to the Saskatchewan data, there was little difference in yield increase between trials on stubble and fallow fields in Manitoba (Table 7). The trend towards a smaller response to P fertilizer since 1970 is apparent in the Manitoba data. Barley response to P was very similar to that of wheat (Table 7). Although yield response to P has apparently decreased in recent years, significant yield increases still occur.

There were insufficient comparisons of fertilized and unfertilized canola and flax to realistically separate the old and new trials (Table 8). Furthermore, these small-seeded oilseeds are very sensitive to seed-placed fertilizers, and this effect often overrides any nutrient requirements. On average, canola did respond moderately to seed-placed P. In contrast, average flax yields were slightly lower for fertilized crops. These values underscore the need for continued research of fertilizer-P application technology for these crops.

Nitrogen: Nitrogen fertilizer response has been large and consistent for crops in Manitoba. This reflects the moist growing conditions prevalent in this province. As most N fertilizer experiments were conducted on stubble fields, no separation of rotation was attempted. Wheat and barley yields have averaged over 40% higher with N fertilizer application (Table 9). Barley may be slightly more responsive than wheat to N. Canola has been very responsive to nitrogen, with yields increased by 115% on average (Table 8).

Table 7. Wheat and barley yield response to P fertilizer for trials in Manitoba prior to and after 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
		Trials prior to 1970			
Wheat					
All data	1654	2000	346	28	115
Stubble	1470	1784	314	26	56
Fallow	1835	2214	379	29	57
Barley					
All data	2137	2676	539	33	70
Stubble	1834	2296	462	28	28
Fallow	2333	2923	590	36	42
		Trials after 1970			
Wheat	2387	2875	170	23	74
Barley	2370	2814	444	20	9

(Data from Racz and Soper, 1963; Ridley and Fehr, 1963; Soper and Racz, 1963; Bradley, 1964, 1967, 1970; Webber, 1965; Bell, 1966; Webber and Soper, 1966; Bailey, 1967; Ridley, 1967, 1968, 1969; Soper, 1968; Bonnefoy, 1968; Bourrier, 1968; McGregor, 1970; Toews, 1982;)

Table 8. Canola and flax yield response to N fertilizer for trials in Manitoba prior to and after 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	(kg ha^{-1})		kg ha^{-1}	%	
Canola					
Phosphorus	902	1078	176	25	39
Nitrogen	652	1130	477	115	51
Flax					
Phosphorus	963	930	-43	-2	62
Nitrogen	709	917	208	31	31

(Data from Racz and Soper, 1963; Soper and Racz, 1963; Racz, 1964, 1965, 1967a, 1967b, 1970; Soper,1964, 1965; Bonnefoy, 1965; Toews, 1966; Bailey, 1967; Duek, 1967; Stiver and Racz, 1967; Bell, 1970; Bradley, 1971a, 197ab; Penner, 1972; Ridley, 1972, 1973b; Spratt, 1980)

Table 9. Wheat and barley yield response to N fertilizer for trials in Manitoba prior to and after 1970.

	Yield Control	Yield Fertilized	Yield increase		No. of trials
	($kg\ ha^{-1}$)		$kg\ ha^{-1}$	%	
		Trials prior to 1970			
Wheat	1544	2080	536	46	49
Barley	1876	2693	817	57	59
		Trials after 1970			
Wheat	2119	2812	693	43	57
Barley	1806	2512	706	48	60

(Data from Racz and Soper, 1963; Ridley and Fehr, 1963; Soper and Racz, 1963; Bradley, 1964, 1967, 1970, 1971a, 1971b, 1978; Hedlin and Soper, 1965; Soper, 1965; Webber, 1965; Bell, 1966, 1970; Ridley, 1967; Bonnefoy, 1968; Bourrier, 1968; Harapiak, 1968; Ridley, 1968a, 1968b; Webber and Soper, 1966; Gramiak, 1969; Ridley, 1969; McGregor, 1970; Penner, 1972; Racz, 1973, 1974; Toews, 1982; Green and Ridley, 1986; Gehl et al., 1987)

In comparison, flax does not respond as strongly, but yield increases were often significant. Obviously, careful N fertilizer management will continue to be an essential element in Manitoba agriculture.

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