A 25 Year Review of Fertilizer Consumption and Plant Nutrient Removal in the Prairie Provinces.

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Abstract

Nutrient removal / replacement ratios were calculated in Manitoba, Saskatchewan, and Alberta from 1965 to 1989 by dividing total fertilizer (N, P, and K) sales by the total crop removal of plant nutrients. The nutrient removal / replacement ratios revealed that significant depletions of soil reserves of N, P, and K have taken place over the past 25 years. The average negative balance of N, P_2O_5, and K_2O on the prairies is estimated at 640, 125, and 490 thousand tonnes. Even with the substantial increase in the use of fertilizers in the past five years compared to the 25 year average, the nutrient deficit continues to be unacceptably high for nitrogen (485,000 tonnes), only modest for phosphorus (86,000 tonnes), and as could be expected for potassium, has increased significantly to 570,000 tonnes. Overall, the calculations suggest that Manitoba is very close to nitrogen and phosphorus balance. Alberta has a relatively close balance, while Saskatchewan has not only experienced an unacceptably high N and P deficit for the past 25 years, but continues to do so at the present time.

Introduction

A pillar of sustainable agriculture is the need to balance inputs and exports of the major plant nutrients. In the data reported in this paper for the period 1965 to 1990, certain key assumptions were made:

(1) All grains are removed from the field and all straw is reincorporated after harvest.
(2) Loss or exports of the major fertilizer nutrients due to leaching, soil erosion,denitrification or volatilization, while undoubtedly large in some instances can be regarded as relatively small as compared to that included in the grain, and therefore can, as a first approximation, be ignored.
(3) Fertilizer nutrient inputs are closely reflected in fertilizer sales.
(4) The recycling of nutrients by incorporating animal manure, while significant and important on specific farms, overall can be disregarded relative to fertilizer nutrient additions.
(5) Biological nitrogen fixation by legumes supplies 50% of the required nitrogen to these crops. Changes in this value will not have a large impact on the overall nitrogen balance, as legumes production is still relatively small.

Calculations:

To calculate the % summerfallow in each province, the total summerfallow acreage was divided by the arable land in each province. The arable land acreage was calculated by totalling the areas used for annual crop production plus that in fallow.

The amount of nutrients (N, P, K, or S) removed each year by each crop, and for each province, was calculated from the data given in Table 1 and the several statistical publications listed in the reference section. The ratio of each nutrient removal to

replacement was calculated by dividing the total nutrient removal by crop growth by the total nutrient addition by fertilizer sales. For example, in Alberta the total crop removal of N in 1989 was 577,500 tonnes, and the total amount of fertilizer nitrogen sold in Alberta in the same year was 346,500 tonnes. The ratio of N export to input in 1989 was therefore 1.67. Similar calculations are reported for P and K for Alberta, Manitoba, Saskatchewan, and for all three prairie provinces together.

Fertilizer export / import calculations were not calculated for sulfur because suitable reports of sulfur fertilizer sales in Western Canada are not available for years before 1987.

Table 1. Plant nutrients in the seed portion of various crops (kg nutrient / tonne crop), assuming average growing conditions (Converted from data compiled by the Western Canada Fertilizer Association, 1978).

Crop	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulfur (S)
Wheat	25	10.0	6.7	1.7
Barley	21	7.6	7.0	1.7
Oats	18	7.7	5.2	2.2
Rye†	21	8.4	6.3	1.9
Buckwheat	21	10.0	7.0	3.5
Corn	14	7.2	4.5	1.3
Canola	38	18.0	9.2	6.9
Flax	35	15.0	13.0	2.7
Mustard††	37	17.0	11.0	5.0
Mixed Grains¥¥	19	8.0	5.8	2.2
Sunflowers	25	8.8	6.9	1.5
Peas	37	9.6	12.0	2.4
Fababeans	45	11.0	39.0	2.0
Lentils¥	41	10.0	26.0	2.2
Sugarbeets	2	0.9	3.3	0.3
Tame Hay¥¥	21	5.7	26.0	2.1
Potatoes¥¥	3	1.5	5.0	0.3

† taken as the average of wheat, barley, and oats. †† taken as the average of canola and flax
¥ taken as the average of peas and fababeans
¥¥ Goettel (1987)

Summerfallow Acreage

Nutrient removal across the three prairie provinces is affected by all factors which directly influence total production. Included among these is the fallow acreage (Table 2). Percent fallow remained relatively constant until the late 1970's and then has declined rather dramatically, reaching a low of approximately 23% for the prairies in 1989. As long as the soil has a reasonable reserve of organic N, mineralization of N will be maximized under the more optimum microbial environment which occurs under intensive till fallow. This of course means that less fertilizer N would be required for optimum economic yields. However, with rather significant decreases in fallow over the past 15 years, not only has

the release of N from soil organic matter likely declined, but also the resulting increase in moisture use efficiency together with increased seeded acreage has lead to significantly greater yields and consequently greater total nutrient removal through the export of grain.

The fallow acreage in Alberta dropped from 30 to 18 % from 1965 to 1989 (Table 2). The drop in summerfallow acres was consistent from 1965 - 1981 except for 1970 (37 % fallow). This was the year that the LIFT (Lower Inventories For Tomorrow) was introduced. This program encouraged fallow acreage to decrease crop production. Alberta fallow acreages leveled off at about 19 % from 1982 - 1989 (suggesting relatively consistent land use).

In Manitoba, fallow acreage dropped from 25 to 10 % from 1965 -1989 (Table 2). The decrease in the acres of fallow was consistent from year to year except for 1970 when the LIFT program skewed the long term downward trend.

Table 2. Percentage summerfallow of total acreage in Alberta, Manitoba, Saskatchewan, and for all three prairie provinces (1965 - 1989)[1].

	% Summerfallow			
Year	Alberta	Manitoba	Saskatchewan	Prairies
1965	30.3	25.2	40.2	35.0
1966	28.0	23.9	37.5	32.6
1967	28.0	23.8	39.1	33.5
1968	28.9	24.1	38.6	33.6
1969	30.5	28.3	42.1	36.6
1970	36.7	34.8	55.4	46.7
1971	29.2	22.8	38.2	33.2
1972	31.4	24.8	47.2	36.6
1973	28.4	21.1	39.5	33.4
1974	30.5	23.5	41.2	35.4
1975	28.2	21.7	41.1	34.3
1976	26.5	19.8	40.8	33.3
1977	28.4	19.4	40.4	33.6
1978	25.1	16.7	38.3	31.0
1979	25.6	17.5	38.4	31.4
1980	24.1	18.5	40.5	32.1
1981	21.6	12.4	36.7	28.5
1982	20.5	12.0	36.1	27.8
1983	19.7	11.1	35.2	26.9
1984	19.2	8.1	32.6	24.8
1985	19.1	8.1	31.6	24.3
1986	19.4	10.2	30.1	23.9
1987	19.5	10.6	31.5	24.8
1988	19.6	9.4	33.0	25.4
1989	18.1	9.6	30.9	23.5

[1] Calculated from data obtained from: Canada Grains Council, Statistics Canada, 1974, 1981, & 1989.

The % summerfallow in Saskatchewan was relatively constant from 1965 - 1980 (excluding 1970) at approximately 40 % of total agricultural land (Table 2). In 1970, the

LIFT program resulted in 55 % of the agricultural land in fallow. The largest decrease in fallow acreage was between 1981 and 1989 (41 to 31 % fallow). The decrease in fallow acreage in the 1980's was likely due to increased awareness of the very low efficiency of water capture during fallow and the very high risk of soil erosion.

For the prairies as a whole, the average percent summerfallow from 1965 to 1977 (excluding 1970) was $\approx 34 \pm 1$ % (Table 2). From 1977 to 1989, fallow acreages dropped from 34 to 24 % for the three prairie provinces (Table 2).

Nutrient Addition / Removal:

The majority of N, P, K, and S removal in Manitoba, Alberta, and Saskatchewan is by grains (wheat, barley, oats, and rye). The 25 year (1965 -1989) averages of grain production (as a percentage of total production) for Alberta, Manitoba, Saskatchewan, and all three prairie provinces totaled are: 61, 58 , 81, and 67 % respectively (Statistics Canada, 1989). Each of these crops also has relatively high demand for N, P, K, and S (Table 1).

The average total N, P_2O_5, and K_2O removal by the grain calculated on the basis of each crop grown and addition by fertilizers for Alberta, Manitoba, and Saskatchewan is given in Tables 3, 4, and 5. The same tables show, on a comparison basis, averages calculated for the five-year period ending in 1989. Clearly a very significant draw-down in soil reserves of N, P, and K have taken place over the past 25 years. For the prairies, the negative balance expressed on a yearly average for N, P_2O_5, and K_2O has been 638 700, 123 400, and 488 200 tonnes (Table 6). Even with the substantial increase in use of fertilizers during the past five years compared to the average for the past 25 years, the nutrient deficit continues to be unacceptably high for nitrogen (485 400), modest for phosphorus (86 400), and as could be expected for nutrients such as potash, has increased significantly to 586 500 tonnes.

This nutrient balance did not account for several avenues of nitrogen losses (leaching, denitrification, volatilization and erosion) and gains (free nitrogen fixation and symbiotic N fixation). While there is no doubt that these additional losses and gains are important to the overall nutrient balance, their net effect wold be minute in comparison to fertilizer additions and grain harvest losses. Accordingly, from a plant nutrient prospective, contemporary agriculture even during the past five years is unsustainable from the standpoint of nitrogen balance. Soil N reserves continue to be drawn down at an unacceptable rate. In contrast, the negative P balance is relatively small and suggests that phosphorus is in relatively good balance. While potassium is in a very strong deficit situation, soil reserves of potassium are more than sufficient to meet crop requirements, except in isolate cases. Fortunately, these soils have been clearly identified.

The provincial nitrogen, phosphorus, and potassium nutrient removal / replacement ratios for Alberta, Manitoba, and Saskatchewan are given for the past 25 years in Tables 7 - 9. Average ratios for the three prairie provinces alone and as a whole are summarized in Table 10. It should be noted that these data suggest that Manitoba is very close to "full sustainability" in terms of nitrogen and phosphorus balance. Alberta is relatively close, while Saskatchewan has not only experienced an unacceptably high N and P deficit for the past 25 years, but continues to do so at the present time.

Table 3. Average N, P, and K removal and addition by crops and fertilizers in Alberta.
Note: assumes nutrient removal by grain only, i.e., straw is returned to soil.

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O
		1965 -1989	
Crop removal (tonnes)			
Average	424,300	152,300	239,600
Std. dev.	82,400	29,800	50,800
Fertilizer addition (tonnes)			
Average	198,100	113,300	12,900
Std. dev.	108,000	39,000	12,300
		1984 -1989	
Crop removal (tonnes)			
Average	536,500	192,700	311,400
Std. dev.	81,700	27,800	61,000
Fertilizer addition (tonnes)			
Average	322,800	151,000	28,800
Std. dev.	26,800	14,600	2,400

1965 - 1979 data from Statistics Canada Fertilizer Trade Catalogue (46-207 Annual) Pub. Minister of Industry, Trade, and Commerce. Information Canada, Ottawa. Western Canadian Fertilizer Association
Crop data = Spearin and O'Connor (1991)

Table 4. Average N, P, and K removal and addition by crops and fertilizers in Manitoba.
Note: assumes nutrient removal by grain only, i.e., straw is returned to soil.

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O
		1965 -1989	
Crop removal (tonnes)			
Average	189,800	70,800	98,600
Std. dev.	48,400	18,800	21,700
Fertilizer addition (tonnes)			
Average	124,000	70,800	9,900
Std. dev.	77,900	28,500	9,200
		1984 -1989	
Crop removal (tonnes)			
Average	243,000	91,700	121,900
Std. dev.	52,500	20,100	24,100
Fertilizer addition (tonnes)			
Average	232,800	103,700	21,600
Std. dev.	11,000	5,400	2,100

1965 - 1979 data from Statistics Canada Fertilizer Trade Catalogue (46-207 Annual) Pub. Minister of Industry, Trade, and Commerce. Information Canada, Ottawa. Western Canadian Fertilizer Association
Crop data = Spearin and O'Connor (1991)

Table 5. Average N, P, and K removal and addition by crops and fertilizers in Saskatchewan.
Note: assumes nutrient removal by grain only, i.e., straw is returned to soil.

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O
		1965 -1989	
Crop removal (tonnes)			
Average	476,314	185,407	179,496
Std. dev.	97,246	38,526	36,073
Fertilizer addition (tonnes)			
Average	124,642	106,810	4,030
Std. dev.	107,217	50,627	4,811
		1984 -1989	
Crop removal (tonnes)			
Average	542,788	214,397	200,897
Std. dev.	135,396	52,876	47,219
Fertilizer addition (tonnes)			
Average	261,424	148,459	11,863
Std. dev.	14,499	10,107	4,662

1965 - 1979 data from Statistics Canada Fertilizer Trade Catalogue (46-207 Annual) Pub. Minister of Industry, Trade, and Commerce. Information Canada, Ottawa. Western Canadian Fertilizer Association
Crop data = Spearin and O'Connor (1991)

Table 6. Average N, P, and K removal and addition by crops and fertilizers in the prairie provinces.
Note: assumes nutrient removal by grain only, i.e., straw is returned to soil.

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O
		1965 -1989	
Crop removal (tonnes)			
Average	1,085,700	415,200	515,900
Std. dev.	202,200	82,500	91,500
Fertilizer addition (tonnes)			
Average	447,000	291,800	27,700
Std. dev.	287,900	116,000	26,900
		1984 -1989	
Crop removal (tonnes)			
Average	1,320,900	507,000	632,300
Std. dev.	196,100	74,500	86,800
Fertilizer addition (tonnes)			
Average	835,500	420,600	63,800
Std. dev.	39,500	32,700	5,900

1965 - 1979 data from Statistics Canada Fertilizer Trade Catalogue (46-207 Annual) Pub. Minister of Industry, Trade, and Commerce. Information Canada, Ottawa. Western Canadian Fertilizer Association
Crop data = Spearin and O'Connor (1991)

Table 7. Ratio between nitrogen removed by crop harvest and fertilizer nitrogen input for Alberta, Manitoba, Saskatchewan, and the prairie provinces from 1965 to 1989.

Year	Alberta	Manitoba	Saskatchewan	Prairies
1965	7.82	9.73	20.60	11.30
1966	6.77	5.30	15.70	8.84
1967	4.26	3.99	7.08	4.99
1968	4.06	2.93	8.61	4.75
1969	5.34	4.56	23.80	8.03
1970	6.00	4.16	35.40	8.65
1971	4.07	4.03	31.59	7.13
1972	4.14	3.41	19.85	6.03
1973	2.88	2.43	12.71	4.26
1974	2.26	1.61	7.78	3.05
1975	2.26	1.80	8.21	3.19
1976	2.28	1.55	9.81	3.23
1977	2.07	1.98	8.75	3.05
1978	1.98	1.57	5.59	2.64
1979	1.62	1.11	2.98	1.58
1980	1.87	0.84	2.94	1.83
1981	1.64	1.48	3.15	2.01
1982	1.60	1.47	3.20	2.04
1983	1.60	1.23	2.50	1.80
1984	1.29	1.16	1.60	1.37
1985	1.11	1.26	1.80	1.38
1986	1.94	1.17	2.22	1.83
1987	1.91	1.14	2.24	1.81
1988	1.77	0.65	1.28	1.28
1989	1.67	1.03	2.12	1.62

*Wheat (spring, winter, durum), Oats, Barley, Rye, Flax, Canola, Mixed Grains, Mustard, Sunflowers, Lentils, Peas, Canary Seed, Grain Corn, Buckwheat, Tame Hay, Sugar Beets, and Potatoes.
Calculated from data obtained from: Canada Grains Council, Statistics Canada, 1974, 1981, & 1989. Agriculture Canada Policy Directorate, 1991. and Western Canada Fertilizer Association, 1991

Table 8. Ratio between phosphorus removed by crop harvest and fertilizer phosphorus input for Alberta, Manitoba, Saskatchewan, and the prairie provinces from 1965 to 1989.

Year	Alberta	Manitoba	Saskatchewan	Prairies
1965	2.13	2.77	3.22	2.65
1966	2.18	1.38	2.77	2.24
1967	1.53	1.26	1.54	1.48
1968	1.53	1.18	1.55	1.47
1969	2.07	1.89	3.85	2.64
1970	2.75	1.57	6.71	3.34
1971	1.91	1.63	5.62	2.78
1972	1.96	1.50	3.92	2.40
1973	1.42	1.11	2.63	1.73
1974	1.01	0.72	1.55	1.13
1975	1.13	0.81	1.64	1.24
1976	1.39	0.93	2.37	1.61
1977	1.17	1.24	2.69	1.59
1978	1.29	1.02	1.98	1.44
1979	1.26	0.77	1.27	1.03
1980	1.26	0.58	1.43	1.18
1981	1.16	0.93	1.47	1.31
1982	1.18	1.09	1.67	1.40
1983	1.08	0.93	1.35	1.20
1984	0.93	0.88	0.98	0.98
1985	0.83	1.08	1.14	1.03
1986	1.40	0.98	1.50	1.36
1987	1.41	0.98	1.55	1.39
1988	1.46	0.55	0.86	1.00
1989	1.37	0.85	1.42	1.27

*Wheat (spring, winter, durum), Oats, Barley, Rye, Flax, Canola, Mixed Grains, Mustard, Sunflowers, Lentils, Peas, Canary Seed, Grain Corn, Buckwheat, Tame Hay, Sugar Beets, and Potatoes.
Calculated from data obtained from: Canada Grains Council, Statistics Canada, 1974, 1981, & 1989. Spearin and O'Connor, 1991. and Western Canada Fertilizer Association, 1991

Table 9. Ratio between potassium removed by crop harvest and fertilizer potassium input for Alberta, Manitoba, Saskatchewan, and the prairie provinces from 1965 to 1989.

Year	Alberta	Manitoba	Saskatchewan	Prairies
1965	1140	276	818	674
1966	769	116	689	382
1967	253	62	267	161
1968	143	52	192	114
1969	236	64	996	196
1970	149	56	1190	159
1971	117	70	937	150
1972	80	62	35	53
1973	166	54	619	147
1974	97	65	259	112
1975	65	40	324	80
1976	32	35	281	50
1977	18	23	180	117
1978	19	13	351	26
1979	16	8.2	56	15
1980	10	3.7	19	9
1981	11	5.6	48	10
1982	11	5.6	45	11
1983	10	6.5	37	12
1984	10	6.4	21	9.8
1985	9	6.4	25	8.9
1986	7	7.4	28	12
1987	12	6.5	19	12
1988	12	3.3	7	7.6
1989	11	5.2	22	10

Calculated from data obtained from: Canada Grains Council, Statistics Canada, 1974, 1981, & 1989. Spearin and O'Connor, 1991. and Western Canada Fertilizer Association, 1991

Table 10. Average nutrient removal / replacement ratios for Alberta, Manitoba, Saskatchewan, and the prairie provinces for 1965 to 1989 (25 years) and 1984 to 1989 (5 years).

	Alberta	Manitoba	Saskatchewan	Prairies
Nitrogen				
1965 - 1989:	2.14	1.53	3.82	2.43
1984 - 1989:	1.66	1.04	2.08	1.58
Phosphorus				
1965 - 1989:	1.34	1.00	1.74	1.42
1984 - 1989:	1.28	0.88	1.44	1.21
Potassium				
1965 - 1989:	18.60	9.99	44.50	18.60
1984 - 1989:	10.80	5.65	16.90	9.90

Contribution of Fertilizer Nutrients into Crop Production

The amount of additional production produced per kilogram of fertilizer N and P depends on efficiency of nutrient uptake. A large number of factors affect fertilizer use efficiency (FUE) either positively or negatively, including the level of available soil nutrients, soil moisture, source of fertilizer, timing and placement of fertilizer, weed and pest population, biological immobilization, gaseous losses, and leaching.

Approximate estimates of the relationship between FUE and yield increases expressed in terms of wheat equivalents are given in Table 11a. The values given for the theoretical maximum or 100 % uptake assume a 40 bushel crop of wheat (2690 kg grain) contains 95 kg of N and 33 kg of P_2O_5 in the grain plus straw (WCFA, 1978). These estimates have been translated into tonnes of increased production for the 25 and 5 year periods ending in 1989, respectively (Table 11b). The dramatic impact of nutrient use efficiency is clearly demonstrated; the percent of total production due to fertilizer N and P for the past 5 years was minimally 15% or approximately 8 million tonnes, but with optimum fertilizer management practices could have been as high as 37% or 19 million tonnes of additional production .

Table 11(a). Fertilizer use efficiencies (FUE) of nitrogen and phosphorus fertilizers, based on wheat yields.

	kg grain per kg N or P_2O_5[1]		
	Theoretical maximum FUE (100%)	Research plot data FUE	Estimated "farm gate" FUE
Nitrogen (N)	28.3	14.2	5.7
Phosphorus (P_2O_5)	81.5	16.3	8.1

[1] Estimated from the WCFA (1978) nutrient requirement table and Beaton (1980), Campbell (1991), and Rennie (1990).

Table 11(b). Estimated annual production increase (wheat equivalents) for the prairies due to N and P fertilization, for specified fertilizer use efficiencies; 10^6 tonnes (% of total yield due to fertilizers).

	Nitrogen FUE		Phosphorus FUE	
Time period	50 %	20 %	20 %	10 %
1965 - 89	*6.3 (15)	2.5 (6)	4.8 (11)	2.4 (6)
1984 - 89	11.9 (23)	4.8(9)	6.9 (14)	3.4 (6)

* Calculated from the average production data given in Table 6.

Discussion:

From 1965 to 1989, the amount of cultivated land on the prairies increased from 20 to 27 million hectares. The increase in land base resulted in an increase in total crop production from 38 to 57 million tonnes of crop from 1965 to 1989 respectively (Statistics Canada, 1974, 1989). Concurrently, the amounts of N, P_2O_5, and K_2O fertilizer applied increased from 76 to 840 thousand tonnes of nutrients from 1965 to 1989 (Statistics Canada, 1979; Spearin and O'Connor, 1991). Such increases are due in part to the onset of continuous cropping through the late 1970's and early 1980's and a decline in the N supplying power of the soil. Improved fertilizer management (eg., new placement techniques), the introduction of fertilizer blends, and improved soil testing procedures also aided in the increased production as these factors lead to improved FUE. An earlier review by Beaton (1980) provides an excellent review of some improvements and advances made in the western Canadian fertilizer industry.

Balance of N and P removal and replacement is a key to sustainable crop production. Such balances may be achieved through sound agronomic management. Generally, fertilizer management practices that lead to high fertilizer use efficiency simultaneously result in maximum economic benefits, and minimum environmental contamination.

The percent of total yield due to fertilizer N and P has been shown to vary dramatically with changing FUE. Production increases (for the prairies) from fertilizer N and P expressed as tonnes of wheat equivalent per year is estimated to be at least 8.2 million tonnes and could range to as high as 18.8 million tonnes, depending on fertilizer management practices. Conversely, improved fertilizer management practices could have lead to dramatic reductions in fertilizer N and P requirements, with the same yields maintained.

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