Management of Soil Fertility in Crop Rotations on the Canadian Prairies

Jeff J. Schoenau

Dept. of Soil Science, University of Saskatchewan

Introduction

There is a tremendous diversity of cropping systems and crop rotations utilized on the prairies today as compared to only a few decades ago. From the turn of the century until the 1960's, cereal-fallow rotations dominated in Western Canadian fields regardless of location. In the early 1970's, rising grain prices coupled with better agronomic information and availability of fertilizers and more effective herbicides led to adoption of extended cereal cropping including cereal -cereal - fallow and continuous cereal (usually wheat) rotations by many producers. The extended cropping rotations were most rapidly and successfully adopted by producers in the more moist Black and Gray soil - climatic regions of the prairies, where inclusion of a fallow period to accumulate additional soil moisture was not as critical as in the drier Dark Brown and Brown soil zones. Producers in the more moist regions were able to overcome limitations on nutrient availability, particularly nitrogen deficiency, in extended cereal rotations through use of high analysis N sources such as anhydrous ammonia, and effectively control weeds through the use of selective herbicides which became available at that time. As well, the introduction of low eurucic acid rapeseed (canola) in the mid 1970’s allowed producers, particularly those in the northwestern regions of Saskatchewan and northeastern regions of Alberta, to add diversity to their cropping system by substituting one of the cereal phases with canola.

It was the period of depressed cereal grain prices in the late 1980's that probably contributed most to development and adoption of the diverse range of rotations in use across the Canadian prairies today, along with the realization that previously employed tillage dependent cereal - fallow rotations were contributing to soil degradation. Many crop rotations, particularly those in the Black and Gray soil zones, now routinely employ forage and pulse legumes, oilseeds and cereals with little or no fallow, and often with reduced or no-tillage. The recent series of wetter than normal years in many areas of the Brown and Dark Brown soil zones, along with poor returns for traditional cereals such as wheat, has led many producers in these areas to extend the rotation and diversify into oilseeds and grain legumes as well.

The diversity in rotation that now presently exists is challenging to those individuals involved in developing specific fertility management recommendations. Recommendations must now be tailored for the specific cropping system and rotation utilized by the producer, which can vary greatly from farm to farm as well as region to region. For example, rather than covering only cereal - mechanical tillage fallow rotations, today’s more complex and variable rotations may require adjusting for a preceding pea crop versus a cereal crop and predicting its effect on the availability of soil and fertilizer nutrient to this year’s planned wheat crop. This ability to adjust fertilizer recommendations upwards or downwards to account for the influence of last years crop on nutrient availability is largely dependent on an understanding of how different crop residues and tillage managements affect nutrient release and availability to the following crop. Longer term fertility effects are also an important consideration, as extended cropping and inclusion of legumes in the rotation are known to contribute extensively to "soil building" of degraded soils (Campbell et al., 1992), with long term adoption increasing the amount of organic nutrient and its release rate to the available form. This also must be taken into account in soil fertility management recommendations.

The objective of this paper is to examine how previous cropping practice is liable to influence the nutrient availability and fertilizer requirements for following crops. This includes consideration of short-term impacts: the effect of the immediately preceding crop on nutrient availability to the following crop; and longer-term effects: the effect of long-term adoption of crop rotation systems on nutrient supplying power of the soil.

Short Term Effects: How does last year's cropping practice affect the fertility needs of the current crop?

The yield response to added fertilizer in Western Canada is often limited by the amount of water available to the crop. The extent that the preceding crop depletes soil moisture reserves will affect the amount of water available in the soil profile at the start of the next year. This in turn will influence the degree of response expected from addition of fertilizer. Water use in cropping rotations is therefore an important consideration affecting fertility management in rotations and is covered in the previous section. This section emphasizes the role of the previous year's cropping practice on nutrient availability to the following crop.

Fallow Management

Traditionally, summerfallow in Western Canada has been accomplished through the use of mechanical tillage, most recently heavy duty cultivators with sweeps, often followed by a rod and/or harrows. Typically, at least three tillage operations are necessary to control weed growth during the fallow season and depending on the year, as many as five to eight operations may be conducted. The tillage operations, depending on equipment used, can result in significant residue burial and overall reduction of surface cover, leaving the soil prone to wind and water erosion. Mixing and incorporation of the residue into the mineral soil also increases the decomposition rate of the residue. As well, in soils with a high proportion of macro-aggregates such as recently broken pasture soils, tillage results in break - down of the aggregates and increased aeration which can accelerate the decomposition of the native soil organic matter (Doran and Smith, 1987). Because of the control of plant growth and the release of plant available nitrate by mineralization over the fallow season, summerfallow fields usually experience an increase in available water and nitrate stored in the soil profile from the start to the end of the fallow period.

Since crop residue burial and accelerated residue decomposition is a feature of intensive mechanical tillage fallow, the overall effect is to greatly reduce the amount of residue by the end of the season. As a result, the impact of crop residue on nutrient availability to the fallow seeded crop is of relatively little consequence as much of the mineralization/immobilization turnover related to the residue has taken place during the fallow period. This situation may change, however, when tillage is substituted by herbicide application to control weeds during the fallow season. The application of herbicide to control weeds during a fallow season is commonly referred to as herbicide fallow or chemfallow and can be considered a type of reduced or zero-tillage management.

In a complete herbicide fallow system, tillage during the fallow season is eliminated and consequently the surface residue and standing straw persists throughout the entire fallow period and, if not tilled in the fall, overwinters to the following spring. The impact of allowing the residue to persist on the soil surface is to increase surface soil moisture slightly and slightly lower surface soil temperature (Carefoot et al. 1990; Lafond et al. 1992; Jowkin and Schoenau, 1995). While the decomposition rate of the residue is slowed by lack of incorporation with mineral soil, decomposition on the soil surface does take place. Nutrients are therefore released from the standing straw and surface residue by microbial decomposition and also by physical leaching of soluble nutrients forms contained in the straw into the mineral soil below. While microbial decomposition is an essential feature for release of organically bound nitrogen from residue, the return of nutrient to the underlying mineral soil by leaching from the residue appears to be most important for phosphorus and potassium (Gares and Schoenau, 1995) with upwards of 50% of the total cereal straw phosphorus and almost all of the straw potassium contained in soluble, leachable forms. It is therefore apparent that recycling of nutrients from surface residues does take place in a chemfallow (no-till) season.

Some concerns have been raised about the impact of elimination of tillage and soil disturbance in a no-till chemfallow system, particularly as to its effect on nitrogen cycling and availability. An intensive two year comparison of soil nitrogen release and availability in mechanical tillage versus no-till fallow in a loamy textured Brown Chemozem (Ardill association) in southwestern Saskatchewan revealed that the initial elimination of tillage did not reduce the amount or supply rate of available nitrogen either during the fallow season itself or to a wheat crop grown the following year (Table 1). In fact, slightly higher nitrogen availability was observed in the no-till fallow, possibly reflecting the higher surface soil moisture contents. Similar results were obtained in a comparison of nitrogen availability and crop uptake in long-term (10 yr) no-till and mechanical tillage plots on a Sutherland clay loam near Saskatoon (Table 1), with no significant differences in N availability to the crop observed between mechanical tillage and no - till. These results suggest that elimination of mechanical tillage on Brown and Dark Brown soils which have been cultivated for long time periods does not necessarily result in reduced mineralization of soil organic matter, and the need to always apply additional nitrogen fertilizer as an initial prerequisite when shifting to no-till management should be reconsidered.

It is important to note that under conditions where no-till fallow has been in place for a number of years and soil disturbance during seeding is minimal, reduced N availability and yield has sometimes been reported in no-till fallow rotation experiments (B. McConkey, unpublished data). Johnston et al. (1994) noted that while average spring wheat and barley yields were similar on no-till and mechanical - tillage long - term fallow management plots at Lethbridge, profile nitrate was lowest in the no-till fallow. This could reflect greater denitrification losses during the no-till fallow period as Elliott (1990) has reported generally greater denitrification losses under no-till fallow (7-l 12 kg N/ha) compared to mechanical tillage fallow (30 - 70 kg N/ha). The potential for denitrification losses is likely to vary from year to year depending on weather conditions. As well, soil type will influence potential for denitrification losses with the greatest denitrification likely on poorly structured soils of high clay content.

In many cereal-fallow based cropping systems, particularly those where the use of nitrogen fertilizers has been minimal, the soil organic nitrogen content and overall nitrogen mineralization potential of the soil organic matter has declined considerably since the onset of cultivation. (Campbell et al., 1990; Greer and Schoenau, 1992). The decrease in nitrogen supply power has proceeded in the last few years to a level now where in the absence of nitrogen fertilizer use, nitrogen availability is limiting yield on fallow seeded crops in wet years. For this reason, nitrogen fertilizer recommendations and use on fallow-seeded crops is becoming more widespread. A recent field study (Jowkin and Schoenau, 1996) in which N- 15 labelled ammonium sulfate was surface - applied to a wheat crop seeded on no-till fallow and mechanical tillage fallow revealed no difference in nitrogen derived from fertilizer by the crop in the two tillage systems. In contrast to these results, some other research work has reported lower use efficiency from nitrogen fertilizer applied in no-till versus conventional tillage treatments (Mengel et al., 1982; Hrapiak, 1986). Lower use efficiency would be expected when the fertilizer nitrogen source is urea, which is susceptible to volatilization losses when surface applied to high residue soils.

Table 1. In - field nitrogen availability and yield of spring wheat grown under different short and long-term fallow managements (Jowkin and Schoenau, 1996).

Brown Chernozem (Ardill) Short -Term Fallow Comparison

Fallow Treatment	Fallow Season (0- 15cm) NO_3 amount mg/kg	NO3 supply rate *μg / 10cm²/ 2 wks*	Crop N uptake ***kg N/ha***	Grain Yield ***kg/ha***
Mechanical (Tillage)	7.2 a	102 a	43 a	1970a
Herbicide (No-till)	8.5 b	130 b	52 a	2145 a

Dark Brown Chernozem (Sutherland) Long-term (1 Oyr) Fallow Comparison

Fallow Treatment	Fallow Season (0-15cm) NO_3 amount mg/kg	NO_3 supply rate *μg / 10cm²/ 2 wks*	Crop N uptake ***kg N/ha***	Grain Yield ***kg/ha***
Mechanical (Tillage)	5.9 a	122a	57a	3351a
Herbicide (No-till)	5.0 a	181 b	75a	3285 a

Note: Values in a column followed by the same letter are not significantly different.
Values presented for nitrate amount and supply rate in the Ardill soil are median values of several successive in-field measurements over the fallow season while values for the Sutherland soil are means for one measurement period in spring prior to seeding. Nitrate supply rate is determined by anion exchange membrane burial.

Nutrient Release and Tie-up From Residues

Probably the most significant short-term effect of the previous crop in a rotation on nutrient availability to the following crop is related to the impact of the crop residues, both straw and root residue. Perhaps best documented is the effect of cereal straw residues on nitrogen availability to a following crop. Because cereal straw residues are usually characterized by a low nitrogen content (wide C:N ratio), initial decomposition of the residue typically results in a temporary reduction in plant available inorganic N, followed by a period of nitrogen release back into the available pool. The extent and duration of the tie-up depends on the amount and nitrogen content of the residue and the environmental conditions as they affect microbial activity. Thorough incorporation of a large amount of nitrogen - poor, finely divided or chopped cereal straw residue into a warm, moist well - aerated soil will result in the greatest nitrate depletion associated with decomposition. Lack of incorporation of the residue and cool, dry soil conditions will tend to slow the decomposition rate and reduce the magnitude of the nitrate depression but extend it over a longer time period. Such tends to be the case in no-till systems and also in the drier regions of the prairies where the surface of the soil is usually quite dry when the residue is incorporated. Because of the preponderance of cereal seeded on cereal stubble cropping in the past, generally the effects of cereal straw residues on nitrogen availability to the following crop are quite well documented and accounted for in Western Canadian fertilizer recommendations. The role of other nutrients in cereal straw residue to the following crop is less well understood. However, there is increasing evidence which points towards soluble phosphorus, sulfur and potassium forms in crop residues making an important contribution to the nutrient available to a following crop (Gares and Schoenau, 1995). This is currently being evaluated for both cereal and pulse crop residues under greenhouse and field conditions.

The ability of forage legumes such as alfalfa and clover to fix nitrogen which is subsequently released by root and residue decomposition to crops in following years is well documented (Campbell et al., 1990). Upwards of 250 lb N / ac of nitrogen has been reported fixed by several forage legume species in the Peace River region, with up to 60 - 100 lb N / ac returned to the soil the following year after a green manure plow down of sweet clover and alfalfa at Melfort (Bowren et al., 1969). Harvesting the above-ground portion of the forage will reduce the amount of nitrogen released the following year, and can reduce the contribution by as much as 50 - 80 % as only the roots are available for decomposition and release of available N by mineralization. However, legume roots have similar C:N or slightly lower ratios as the above ground plant parts (Jensen, 1994) and so forage legume roots are likely to release available nitrogen upon decomposition at rates similar to the surface residue. The nitrogen benefits can persist, to a lesser degree each successive year, as long as five to seven years into the future (Hoyt and Leitch, 1983).

The expansion of grain legume (pulse) crop acreage in recent years has led to more interest in pulse crop effects on nutrient availability to subsequent crops. Generally the total amount of nitrogen fixed by pulse crops is lower than for forage legumes, and most of the nitrogen (~ 75%) is contained in the seed which is removed, so the amounts of nitrogen contributed to the soil N pool are not nearly as large as for forage legumes. As well, it is important to keep in mind that nitrogen derived from fixation is highest (-75%) when available nitrogen levels are low, and legumes seeded on fallow that is high in available N will preferentially use soil available N, reducing the amount derived from fixation.

Generally, nitrogen benefits in a cereal crop following a pulse crop like pea or lentil are reported in the range of 15 to 100 lb of added fertilizer N per acre (Wright, 1990; Stevenson and van Kessel, 1995). However, recent studies (Stevenson and van Kessel, 1995) have also indicated that only a small portion of the yield benefit observed from pea in the rotation is attributable to nitrogen directly released from the pea residue, which appears to range from about 5 to 15 lb N / acre. Janzen and Kucey (1988) have shown little difference in direct availability of nitrogen from lentil and wheat residue. Additional nitrogen uptake that is observed has been attributed to the reduction of disease severity, better rooting environment and reduced weed infestation enhancing nitrogen uptake by the wheat crop following the pulse.

The non-nitrogen benefit of pulse crops in the rotation appears rather large and has been reported by a number of researchers (Wright and Coxworth, 1987; Bullock, 1992). Non-nitrogen benefits appear to be related to reduced severity of disease in following cereal crops, a better rooting environment, and may also be related to return of other nutrient elements from the pulse crop residue. Legumes, especially forage legumes, have high requirements for phosphorus, sulfur and potassium. Consequently, a well PKS fertilized legume crop residue can contribute substantial amounts of other nutrients to following crops as well. Legumes are also capable of rooting deep and may be able to tap into subsoil nutrient reserves. These nutrients assimilated are subsequently made available for use by following crops when the legume residues undergo degradation and decomposition.

Soil Amendments in the Rotation

The addition of inorganic fertilizers is probably the most common soil "amendment" in rotations. Some of the added fertilizer nutrient will be recycled through crop residue and made available to a crop the following year. The other contribution fertilizer addition can make to a following crop is through the fertilizer nutrient applied (residual) that was not taken up by the previous crop. The potential contribution from this source can usually be accounted for in fall or spring soil testing for available nutrient levels. However, residual fertilizer nutrient does pose some concerns if a fallow year is planned immediately following the crop. The potential for loss of carryover fertilizer nitrogen during the fallow year can be quite large from denitrification and leaching, and if the carryover is high, recropping rather than fallow may be the most economic as well as environmentally sound choice.

Animal manures are another form of soil amendment that may be used in a rotation and can influence the availability of nutrient to a following crop. Usually only a portion of the nitrogen contained in a manure is present in the immediately available ammonium or nitrate form. For example, in swine manure slurry, roughly 50% of the N is present as ammonium and the remaining 50% in organic forms (Choudhary et al., 1996). The organic N forms must be mineralized to inorganic ammonium and nitrate in order to be rendered plant available. It has been estimated that about 20% of organic N in manure (Beauchamp, 1983) will be mineralized during a growing season and so the effect of manure addition on N availability to succeeding crops in the rotation will persist for a number of years into the future. Successive applications of manure to the same land area can result in buildup of high levels of nitrate. In such cases, the utilization in the rotation of a crop like a forage grass to act as a nitrogen "sponge" may be advisable to prevent the buildup of excessive levels of nitrate in the soil.

Long - Term Effects: What are the fertility building attributes of rotations?

The impact of long - term adoption of extended rotations on the nutrient supplying power of the soil has been widely studied in western Canada This work has included many comparisons of long-term cereal - fallow versus extended, usually cereal- based rotations in long term plot studies at the Agriculture Canada Research Stations. The major soil parameters measured that are used as an indicator of nutrient release potential include organic carbon and nitrogen concentrations, and mineralizable nitrogen.

At Swift Current, a comparison of fifteen years of continuous wheat versus wheat - fallow revealed about 17 % higher C and N concentrations in the continuous wheat system with mineralizable nitrogen about 40% higher (Biederbeck et al., 1984). Similar results were observed when flax was substituted every third year in the continuous crop rotation. In Dk Brown and Black soils a similar positive effect on nutrient release potential has been observed in comparisons of long term cereal-fallow versus continuous crop rotation (Campbell et al., 1990). The soil building attributes of extended rotations have more recently been documented using a variety of different indices of nitrogen supplying power (Table 2).

Table 2. Effect of long - term crop rotation on soil nitrogen supplying power as revealed by several indices used on samples from long-term rotation plots (Data from Jalil et al., 1996; Greer, 1992; and Schoenau and Campbell, 1996 unpublished data).

Swift Current Agriculture Canada Long - Term Rotation (N+P Fertilizer)

Treatment	*Indice of Soil Nitrogen Supply Power*			
	NO_3 Supply Rate *μg/10cm²/2wk*	Hot KC1 ***mgN / kg***	24 week Incubation ***mg NO_3-N/kg***	Canola Uptake ***mg N /pot***
Cont. W	***757***	15.9	125	15.5
F-W	622	12.1	65	12.3
Wheat-Lentil	n.d.	21.0	104	n.d.

Indian Head Agriculture Canada Long-Term Rotation

Treatment	*Indice of Soil Nitrogen Supply Power*		
	NO_3 Supply Rate *μg/10cm²/2wk*	24 week Incubation ***mg NO_3-N/kg***	Canola Uptake ***mg N/pot***
Cont. W	1816	226	19.6
FWWHHH	1364	212	17.6
FWW+straw	959	149	10.9
FWW-straw	987	135	12.8
FW	871	80	10.5

Cont. W = fertilized continuous wheat
FWWHHH = unfertilized fallow-wheat-wheat-hay-hay-hay
FWW+straw = fertilized (N+P) fallow-wheat-wheat
FWW-straw = fertilized (N+P) fallow-wheat-wheat with straw baled
FW = fertilized fallow-wheat (Swift Current); unfertilized fallow-wheat (Indian Head)

It is important to note that the largest benefits in the build-up of soil nutrient supplying power as a result of shifting to extended rotation is when the switch to more intensive cropping is coupled with an increase in fertilizer use, particularly nitrogen inputs as are required by elimination of the fallow period. For example, comparison of unfertilized continuous wheat and fallow-wheat-wheat rotations at Melfort revealed only a 6% increase in organic nitrogen concentration. In fact, the long term utilization of fertilizers, particularly nitrogen fertilizers at soil test recommended rates in any given rotation has been shown to significantly increase the nitrogen supplying power of the soil as assessed in a variety of ways (Janzen 1987). Addition of phosphorus fertilizers also contribute to the build-up of available P (0 Halloran, 1986). The utilization of nitrogen fertilizer, which is necessitated in a continuous cropping system in order to achieve economic yield, rather than relying on mineralization of native humus during a fallow period, helps to reduce nitrogen output from the system. As well, fertilizer nitrogen that is immobilized in the soil microbial biomass and crop residues will ultimately lead to build-up of a larger pool of mineralizable nitrogen.

The long-term soil building attributes of a forage legume or grass in rotation are also well documented. For example, a rotation study at the Indian Head Experimental farm showed that potentially mineralizable nitrogen and nitrogen supply rates in the extended rotation including an alfalfa/brome (hay) phase were higher than all other rotations except the fertilized continuous wheat (Table 2). The addition of nitrogen to the soil through nitrogen fixation by the legume contributes to the gradual build-up of a potentially mineralizable pool in the soil similar to the way that addition of inorganic N fertilizer contributes to build-up (Campbell et al., 1992).

Many cropping systems today employ the reduction or elimination of tillage as both an economic feature and to conserve and build soil. The widespread adoption of direct seeding into standing residue has led to questions about the long term effects of this system on nutrient release potential. Comparisons of long-term no-till versus conventionally tilled fields have revealed higher nitrogen mineralization potential under no-till when this management system is included as part of a long term shift to more intensive extended cropping (Greer and Schoenau, 1992). This may be attributed to the buildup of a larger active fraction of organic nitrogen as well as increased retention of organic matter as a result of reduced erosion.

Conclusions

Good fertility management in rotational cropping systems involves accounting for the impact of the previous rotational phase on nutrient availability. This is related to the effect of the preceding crop on the available nutrient level itself which is evident at the start of the growing season, as well as the rate of release of residue nutrient over the growing season. Therefore, good recommendations for applied fertilizer nutrient require assessment of what amount of nutrient is in the soil already in an available form as well as some prediction of what will be slowly released or tied up over the growing season as related to the previous crop. Methodologies for assessing the release potential are currently being developed and evaluated.

Elimination of tillage in the initial stages does not appear to have a large impact on soil organic nitrogen turnover. However attention should be given to potentially greater immobilization when large amounts of nitrogen - poor residue are incorporated at the time of seeding and potential for volatilization losses when urea nitrogen fertilizer is placed directly into surface residue. Pulse legumes such as peas appear to make less of a direct nitrogen contribution to following crops than forage legumes but have a large non-nitrogen benefit. The use of recommended levels of applied fertilizer nutrients in rotations will contribute to greater net release of nutrient from residues and soil organic matter mineralization the next year and beyond. Soil amendments such as manures which add both organic and inorganic nutrients contribute to the supply of nutrient available to crops in the year of application as well as following years. Long term utilization of extended rotations which include reduced or no-tillage, inclusion of a legume or grass, and use of recommended rates of fertilizer nutrient all will contribute to enhanced soil nutrient supplying power and greater soil quality in future years.

References

Biederbeck,V.O.; Campbell, C.A.; Zentner, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. Can. J. Soil Sci. 64: 355-367.

Beauchamp,E.G. 1983. Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure. Can. J. Soil Sci. 63: 377-386.

Bowren, K.E.; Cooke,D.A.; Downey, R.K. 1969. Yield of dry matter and nitrogen from top and roots of sweetclover, alfalfa and red clover at five stages of growth. Can. J. Plant Sci. 49: 61-69.

Bullock, D.G. 1992. Crop rotation. Crit. Rev. Plant Sci. 11: 309-326.

Campbell, C.A.; Zentner,R.P.; Janzen, H.H.; Bowren, K.E. 1990. Crop rotation studies on the Canadian Prairies. Agriculture Canada Research Branch Publication 1841/E. 133pp.

Campbell, C.A. ; Zentner, R.P.; Selles,F.; Biederbeck, V.O.; Leyshon,A.J. 1992. Comparative effects of grain lentil-wheat and monoculture wheat on crop production, N economy and N fertility in a Brown Chemozem. Can. J. Plant Sci. 72: 1091-l 107.

Carefoot, J.M.; Nyborg, M.; Lindwall,C.W. 1990. Differential fertilizer N immobilization in two tillage systems influences grain N concentrations. Can. J. Soil Sci. 70: 215-225.

Choudhary, M.; Bailey,L.D.; Grant C.A. 1996. Review of the use of swine manure in crop production: effects on yield and composition and on soil and water quality. Waste Management and Research. (in press).

Doran, J.W. and Smith, M.S. 1987. Organic matter management and utilization of soil and fertilizer nutrients. In: Soil Fertility and Organic Matter as Critical Components of Production Systems. Soil Science Society of America Special Publication 19. Madison, Wisc. pp. 53-72.

Elliott, J.A. 1990. Denitrification as influenced by landscape position and management practice. Ph.D. thesis, Dept. of Soil Science, Univ. of Saskatchewan. 195 pp.

Gares, R. and Schoenau,J.J.. 1995. Chemical changes in cereal straw under two fallow systems and its relationship to nutrient availability. Proceedings of "Soils and Crops 95', University of Saskatchewan, Saskatoon. pp. 320-328.

Greer, K.J. 1989. Evaluating the soil quality of long-term crop rotations at Indian Head. M.Sc. thesis, University of Saskatchewan, Saskatoon.

Greer, K.J. and Schoenau,J.J. 1992. Soil organic matter content and nutrient turnover in thin Black Oxbow soils after intensive conservation management. Proceedings of the Soils and Crops Workshop '92, University of Saskatchewan, Saskatoon. pp. 167-173.

Hoyt, P.B. and Leitch,R.H. 1983. Effects of forage legume species on soil moisture, nitrogen and yield of succeeding barley crops. Can. J. Soil Sci. 63: 125-136.

Harapiak, J.T.; Kucey,R.M.N.; Flaten, D. 1986. Nitrogen sources and placement in wheat production. p. 65-69. IN: A.E. Slinkard and D.B. Fowler (ed.) Wheat production in Canada: A review. Univ. of Saskatchewan, Saskatoon.

Jalil,A.; Campbell, C.A.; Schoenau, J.; Henry, J.L.; Jame, Y.W.; Lafond, G.P. 1996. Assessment of two chemical extraction methods as indices of available nitrogen. Soil Science Society of America Journal (accepted).

Janzen, H.H. and Kucey, R.M.N. 1988. C.N, and S mineralization of crop residues as influenced by crop species and nutrient regime. Plant Soil 106: 35-41.

Janzen, H.H. 1987. Effect of fertilizer on soil productivity in long term spring wheat rotations. Can.J.Soil Sci. 67: 165-174.

Jensen,E.S. 1994. Dynamics of mature pea residue nitrogen turnover in unplanted soil under field conditions. Soil Biol. Biochem 26: 455464.

Johnston, A.M.; Lamey, F.J.; Lindwall, C.W. 1994. Impact of long-term summerfallow practices in southern Alberta. Proceedings of “Soils and Crops '94", University of Saskatchewan, Saskatoon. pp. 15-20.

Jowkin,V. and J. Schoenau. 1995. Changes in available nitrogen over a fallow season in an undulating landscape in southwestern Saskatchewan. Proceedings of ‘Soils and Crops 95', University of Saskatchewan, Saskatoon. pp. 299-310.

Lafond, G.P; Loeppky,H.; Derksen, D. 1992. The effects of tillage system and crop rotations on soil water conservation, seedling establishment and crop yield. Can. J. Plant Sci. 72: 103-115.

Mengel, D.G.; Nelson,D.W.; and Huber,D.M. 1982. Placement of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 74: 515-518.

O'Halloran, I.P. 1986. Phosphorus transformations in soils as affected by management. PhD. thesis, University of Saskatchewan, Saskatoon.

Stevenson, C. and van Kessel,C. 1995, Landscape-scale controls on the availability of pea residue nitrogen for the subsequent wheat crop. Proceedings of “Soils and Crops'95", University of Saskatchewan, Saskatoon, Saskatchewan. pp. 283-291.

Wright,A.T. and Coxworth,E. 1987. Benefits from pulses in the cropping systems of northern Canada. IN Power,J.F. ed. The Role of Legumes in Conservation Tillage. Proceedings of Soil Conservation Society of America Conference, Athens Ga. 1987.

Wright, A.T. 1990. Yield effect of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70: 1023-1032.