FERTILITY MANAGEMENT FOR THE PULSE-BASED CROPPING SYSTEMS IN THE SEMIARID NORTHERN GREAT PLAINS

Y. Gan[1], B.G. McConkey[1], G.W. Clayton[2], G. Lafond[3], and F. Walley[4]
[1]Agriculture and Agri-Food Canada, Swift Current, SK, [2]Lacombe, AB, and [3]Indian Head, SK;
and [4]The University of Saskatchewan, Saskatoon, SK
gan@agr.gc.ca (306)778 7246

INTRODUCTION

Annual crop production of the semiarid Northern Great Plains has historically been dominated by cereals, chiefly spring wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum* var *durum*). Low prices for cereal grains, coupled with increasing production problems in wheat-based monoculture systems, are encouraging producers to seek alternative to cereals. In the past two decades, the area devoted to production of annual pulse crops has increased significantly in the semiarid northern Great Plains. In Saskatchewan, for example, the areas seeded to pulses, primarily field pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), and chickpea (*Cicer arietinum* L.) has increased from less than 2% of the total seeded areas in 1991 to more than 27% in 2001 (Statistics Canada, 2002). As the pulse production increases, so does the need to understand the impact of pulse crops on residual soil nutrients and the fertility management for crops grown after pulses. In this paper, we summarize the existing knowledge from published and unpublished data and try to address two issues: 1) the nitrogen contributions by annual pulses to the soil under different environmental conditions of semiarid Northern Great Plains, and 2) the response of non-pulse crops grown after a pulse to fertilizer N applied under various agronomic managements.

BENEFITS OF PULSE CROPS TO THE SOIL

Rotation Benefits

Positive cropping sequence effects from pulse crops on subsequent crops have been broadly recognized. Compared to wheat following wheat, wheat following field pea increased grain yield from 15 to 34%, when fertilizer N was adjusted to attain an equal sum of fertilizer N and soil NO_3-N (Wright 1990; Soon and Clayton, 2002; Miller et al., 2003b). Wheat grain yield increased up to 60% when the same amount of N was applied to the wheat on wheat or wheat on pulses (Stevenson and van Kessel, 1996; Beckie and Brandt, 1997). Durum wheat following two-years of continued broadleaf crops (pulse or *Brassica* species) increased grain yield by 15% and crude protein concentration by 16% compared to durum following two-years of continued wheat (Gan et al., 2003a). The magnitude of the rotation effect varied with crop species (Gan et al., 2003a), soil type (Miller et al., 2003b), and landscapes (Stevenson and van Kessel, 1996). Tillage practices generally do not affect crop sequence effects (Lafond et al., 1992; Lindwall et al., 1995; Soon and Clayton, 2002). A large portion of the rotation benefits was attributed to soil N contributed from the previous pulses.

N Contribution

Amounts of N fixed from the atmosphere by annual pulses are generally less than their requirements for growth (Cowell et al., 1989; Androsoff et al., 1995). In most cases, crops have a high N removal from harvested seed, which is similar to, or higher than the N they can fix. Consequently, the amount of N conserved in the soil for the following crop is usually small, even when the pulse crop straw is retained (Senaratne and Hardarson, 1988; Evans et al., 1989; Jensen, 1989). Only about 9-30% of N in mature field pea residue is made available to succeeding crops the following year through decomposition and mineralization processes (Rees et al., 1993; Stevenson and van Kessel, 1996). N will not be mineralized from crop residues until a critical N concentration is achieved during decomposition. It is estimated that about 40% of the N from lentil and wheat residue remained in the microbial biomass by the end of the subsequent growing season and 55% of this was is in the passive fraction of the soil organic matter (Bremer and Van Kessel, 1992). Up to 20% of the N from crop residue can be lost through leaching and denitrification (Jensen, 1994). In general, the N contributed by a pulse crop to the succeeding cereal is relatively small as compared to the N contributed from fertilizer and soil organic matter (Stevenson and van Kessel, 1996). Therefore, the application of addition N may be warranted for non-pulse crops grown following a pulse.

Zentner et al. (2001) reported that soil NO_3-N (in a 120-cm depth) averaged 11 kg ha^{-1} greater in wheat plots following lentil compared to following wheat in a long-term rotation study in Swift Current, Saskatchewan. In a more sub humid region of the northern Great Plains, soil N contribution from field pea ranged from 6 to 27 kg ha^{-1} (Stevenson and van Kessel, 1996; Beckie and Brandt, 1997).

A large amount of N may be stored in root materials. Armstrong et al. (1994) estimated that 15% of the total amount of N in pulses was in roots, and about 25% of the residual N remaining after the seed has been harvested was in below-ground biomass. Using 15^N technique, Peoples et al. (1995) estimated that actual root N could be three-fold higher than N calculated from recoverable root material. Pulse residue N increases the pool of soil organic N and contributes, in the long term, to the supply of available N by mineralization. Postharvest soil N following a pulse is usually higher than following a cereal (Evans et al., 1991). This is partly due to pulse plants taking up less N from the soil because part of their N requirement is met by N_2 fixation. Greater uptake of soil N (higher N yield) by crops grown after pulses is due to increased soil N mineralization. The combination of conserved soil N and greater mineralization potential in soil containing pulse above- and below-ground residues may explain why the indirect N benefit of annual legumes to subsequent non-legume crops can be considerable, even when there apparently are only modest apparent returns of fixed N in aboveground vegetative residues.

Relative N fixation among Pulses

Extensive research on N_2 fixation has been conducted for field pea and less extensive research on N_2 fixation for lentil. Relatively little information is available on N_2 fixation for chickpea and other pulses. Among major pulses grown in the semiarid Northern Great Plains, field pea appears to be the most effective N_2-fixer. In a six site-year study, Miller et al. (2003b) reported that post-harvest soil N was 36 kg ha^{-1} on field pea stubble, 28 kg ha^{-1} for lentil, and 25 kg ha^{-1} for chickpea, which were, respectively, 103, 60, and 43% higher than post-harvest soil N measured on wheat stubble. Highest N-fixation with field pea is evident from crop vegetation. Biederbeck et al. (1996) found that field pea held 22 kg ha^{-1} more N in its vegetation than lentil about two months after seeding. In an Australian semiarid environment, Armstrong et al. (1994) found that N_2 fixation and N benefits to subsequent wheat were greater for pea than chickpea. However, Rennie and Dubetz (1986) found similar N_2 fixation potential for pea and chickpea under irrigated conditions in southern Alberta.

Soil Type Effect

The amounts of NO_3-N that pulses contribute to the soil depend on soil type. Beckie and Brandt (1997) reported the residual soil NO_3-N from field pea averaged 27 kg N ha^{-1} on a moist Black soil at Melfort, and only 12 kg N ha^{-1} on a Dark Brown soil at Scott, Saskatchewan. Based on pea seed yield and the calculated N residual effect, the N credit (N fertilizer replacement value) of field pea to a succeeding non-pulse crop was 13 kg N ha^{-1} for every 1000 kg of pea seed on the moist Black soil at Melfort, but only 4 kg N ha^{-1} per 1000 kg of seed on the Dark Brown soil at Scott. Pulses grown on a clay texture soil appeared to contribute more N to the soil than those grown on a loam soil. In a semiarid environment of Saskatchewan, post-harvest soil NO_3-N under pea stubble was 43 kg ha^{-1} on a clay soil, or 53% higher than that measured on a loam soil (Gan et al., 2003a). Similarly, post-harvest NO_3-N on the clay soil under lentil (33 kg ha^{-1}) and chickpea (29 kg ha^{-1}) stubbles were 43 and 38% higher, respectively, than whose measured on the loam soil. Greater N contribution on the clay compared to the loam soil is possibly related to nodulation and root mass of the previous pulses. Gan et al. (2003b) found that well-inoculated chickpea produced 36% greater seed yield than non-inoculated plants on the clay soil, while on the loam soil the difference in yield response was only 3%. Chickpea grown on the clay soil produced 37% more root nodules and 75% greater nodule mass measured at flowering than when the pulse was grown on the loam soil (Hanson and Gan, 2002). Greater water holding capacity of the clay soil may permit better root development and nodulation. Colonization of the rhizosphere of annual pulses can be significantly reduced when soil moisture is low (Hynes et al., 2001), and the survival of rhizobia in a fine-textured soil is better than that in a coarse-textured soil (Postma et al., 1989).

Over-winter NO_3-N Changes

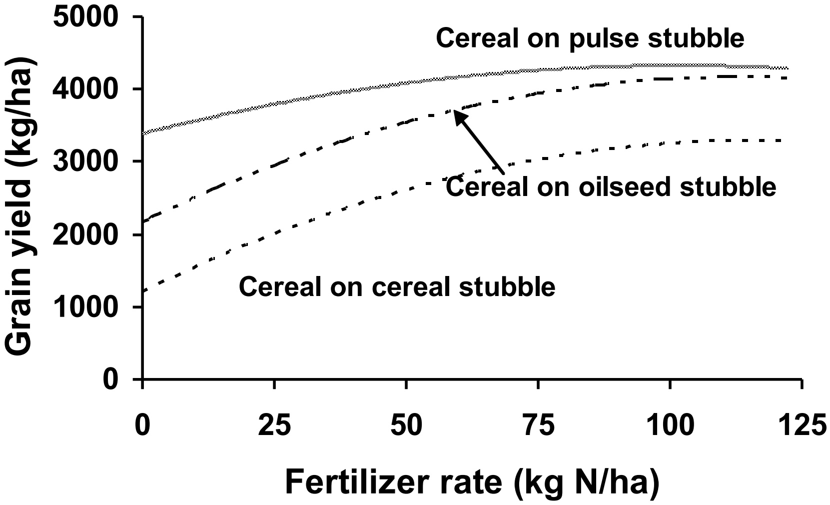
Compared with measurements post-harvest in the fall, NO_3-N measured in the following spring averaged 52% greater in semiarid southwest Saskatchewan (Miller et al., 2003a). Spring soil NO_3-N under pea, lentil, and chickpea averaged 16 kg N ha^{-1} greater than that measured in the previous fall. The magnitude of the N increase over the winter was about 30% greater in pulse stubble compared to wheat stubble. The significant increase in soil NO_3-N from fall to spring was mostly evident in the 0 to 60-cm soil depth and was attributed to mineralization of recent crop residues.

RESPONSE TO APPLIED N AFTER PULSE CROPS

In a study in northeast Saskatchewan, Wright (1990) found small differences in post-harvest residual soil NO_3-N among pea (53 kg N ha^{-1}), lentil (49 kg N ha^{-1}, and barley (46 kg N ha^{-1}) stubbles. In the following years barley grown on each of those stubbles had a similar, linear response to applied N ranging from 0 to 200 kg N ha^{-1}. The maximum grain yield of barley grown on field pea stubble was 3740 kg ha^{-1} with 200 kg N ha^{-1} applied, and was 3540 kg ha^{-1} with 170 kg N ha^{-1} applied when grown on lentil stubble. Regression analyses show that barley grain yield increased by an average of 8.9 kg ha^{-1} for every one kg ha^{-1} of N applied regardless of the previous crop type. However, at any given fertilizer N level barley produced greater yield on field pea stubble compared to other stubbles.

Beckie and Brandt (1997) found positive response of cereals grown on pulse, oilseed, and cereal stubble to applied N fertilizer ranging from 0 to 125 kg ha-1 (Fig. 1). At a given fertilizer-N level, cereal following a pulse produced the highest grain yield, while cereal following a cereal had the strongest response to N fertilization.

Fig.1. Grain yield response of cereals grown on pulse, oilseed, and cereal stubble to N fertilization at Melfort, Saskatchewan (Beckie and Brandt, 1997).



In a recent study in western Canada where N was applied to the medium (recommended rate based on fall soil NO_3-N level), low (15-30 kg ha^{-1} lower than medium), and high (15-30 kg ha^{-1} greater than medium) levels, McConkey et al. (2003) found a linear response of cereal grain yields to the applied N. Averaged across the 9 site-yr, barley grain yield increased by 6.6 kg ha^{-1}, and hard-red spring wheat increased by 8.9 kg ha^{-1} for every one kg ha^{-1} of N applied, regardless of the previous crop type. Grain protein concentration increased with the application of additional N to cereals the following year. On average, grain N concentration increased by 0.17 kg ha^{-1} in barley grain and 0.28 kg ha^{-1} in spring wheat grain for every one kg ha^{-1} of N applied. Lack of interactions between previous crop type and applied N for either grain yield or grain N imply that crops respond to applied N similarly for all stubbles. Similarly, Stevenson and van Kessel (1996) reported that wheat grain yield in a pea–wheat rotation responded linearly to rates of N fertilizer ranging from 0 to 200 kg N ha^{-1}. Grain yield increased by 2.3 kg ha^{-1} with every one kg N ha^{-1} increase in rate of N fertilizer. However, the effect of N fertilizer rates on wheat yields in a wheat–wheat rotation was curvilinear, with the maximum wheat yield being achieved at the 150 kg ha^{-1} N fertilizer rate. These studies clearly show that the greatest yield and protein potential of cereal crops is when they are grown on pulse stubble with a high rate of N applied, although the rate of the increase vary from trial to trial.

CONCLUSIONS

In conclusion, N_2 fixation allows annual pulses to contribute positively to soil N fertility. Pea and lentil residues contribute an extra 6 to 45 kg N ha^{-1} than wheat to the succeeding crops in the semiarid northern Great Plains. The N derived from pulse residues as compared with wheat residue contribute to less than half the extra N accumulated by wheat following pea. The non-N benefit of pulses to succeeding cereals accounts for a significant part of the overall rotation benefit. Management of crop rotation benefits provided by pulse crops should consider both the small N contribution and the importance of their non-N benefit. These non-N benefits for succeeding cereal crops grown after a pulse can be best captured with an optimized rate of N fertilizer.

REFERENCES

Androsoff, G.L., C. van Kessel, and D.J. Pennock. 1995. Landscape-scale estimates of dinitrogen fixation by *Pisum sativum* by nitrogen-15 natural abundance and enriched isotope dilution. Biol. Fertil. Soils 20: 33–40.

Armstrong, E.L., J.S. Pateand, M.J. Unkovich. 1994. Nitrogen balance of field pea crops in South Western Australia, studied using the ^{15}N natural abundance technique. Aust. J. Plant physiol. 21: 533-549.

Beckie, H.J., and S.A. Brandt. 1997. Nitrogen contribution of field pea in annual cropping systems. 1. Nitrogen residual effect. Can. J. Plant Sci. 77:311-322.

Bremer, E., and C. van Kessel. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Am. J. 56: 1155-1160.

Biederbeck, V.O., O.T. Bouman, C.A. Campbell, L.D. Bailey, and G.E. Winkleman. 1996. Nitrogen benefits from four green-manure legumes in dryland cropping systems. Can. J. Plant Sci. 76: 307-315.

Cowell, L. E., Bremer, E. and van Kessel, C. 1989. Yield and N_2 fixation of pea and lentil as affected by intercropping and N application. Can. J. Soil Sci. 69: 243–251.

Evans, J., O'Connor, G. E., Turner, G. L., Coventry, D. R., Fettell, N., Mahoney, J. and Armstrong, E. L. 1989. N_2 fixation and its value to soil N increase in lupin, field pea and other legumes in South-Eastern Australia. Aust. J. Agric. Res. 40: 791–805.

Evans, J., Fettell, N. A., Coventry, D. R., O'Connor, G. E., Walsgott, D. N., Mahoney, J. and Armstrong, E. L. 1991. Wheat response after temperate crop legumes in South Eastern Australia. Aust. J. Agric. Res. 42: 31–43.

Gan, Y., P.R. Miller, B.G. McConkey, R.P. Zentner, F.C. Stevenson, and C.L. McDonald 2003a. Influence of diverse cropping sequences on durum wheat yield and protein in the semiarid Northern Great Plains. Agron. J. 95: 245-252.

Gan, Y., F. Selles, K.G. Hanson, R.P. Zentner, B.G. McConkey, and C.L. McDonald. 2003b. Effect of formulation and placement of rhizobium inoculant on chickpea. *In* Proc. North American Pulse Improvement Meetings (CD-ROM), Sacramento, California, 26-27 October, 2003.

Hanson, K.G. and Gan, Y. 2002. Development of a rating scheme to evaluate root nodulation in chickpea (*Cicer arietinum* L.). *In* Proc. Soils and Crops Workshop 2002 (CD-ROM), University of Saskatchewan, Saskatoon, SK., Feb 21-22.

Hynes, R.K., Jan, D.C., Bremer, E., Lupwayi, N.Z., Rice, W.A., Clayton, G.W., Collins, M.M., 2001. Rhizobium population dynamics in pea rhizosphere of rhizobial inoculant strain applied in different formulations. Can. J. Microbiol. 47, 595-600.

Jensen, E. S. 1989. The role of pea cultivation in the nitrogen economy of soils and succeeding crops. Pages 3–15 *in* P. Planquaert and R. Haggar, eds. Legumes in farming systems. Kluwer, Dordrecht, The Netherlands.

Jensen, E. S. 1994. Availability of nitrogen in $_{15}$N-labelled mature pea residues to subsequent crops in the field. Soil Biol. Biochem. 26: 465–472.

Lafond, G.L., Loeppky, H. and Derkwen, D.A. 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.

Lindwall, C.W., Larney, F.J., and Carefoot, J.M. 1995. Rotation, tillage and seeder effects on winter wheat performance in various cropping systems in southern Alberta. Can. J. Plant Sci. 74: 79-86.

McConkey, B.G., D.Steinley, B.Nybo, P.R. Miller, J.McConnell, S.Anderson, K.Heil, and R.Oystryk. Response of cereals to fertilizer-N on pulse and other stubbles. *In* Proc. Soils and Crops Workshop 2002 (CD-ROM), University of Saskatchewan, Saskatoon, SK., Feb 21-22.

Miller, P.R., Y. Gan, B.G. McConkey, and C.L. McDonald 2003a. Pulse Crops for the Northern Great Plains: 1. Grain productivity and residual effects on soil water nitrogen. Agron. J. 95: 972-979.

Miller, P.R., Y. Gan, B.G. McConkey, and C.L. McDonald 2003b. Pulse Crops for the Northern Great Plains: 2. Cropping sequence effects on cereal, oilseed and pulse crop. Agron. J. 95: 980-986.

Peoples, M.B, Herridge, D.F. and Ladha, J.K. 1995. Biological N_2 fixation: an efficient source of nitrogen for sustainable agricultural production? Plant Soil 174: 3–28.

Postma, J., van Veen, J. A., Walter, S., 1989. Influence of different initial soil moisture contents on the distribution and population dynamics of introduced rhizobium leguminosarum biovar trifolii. Soil Biol. Biochem. 21, 437-442.

Rees, R. M., Yan, L. and Ferguson, M. 1993. The release and plant uptake of nitrogen from some plants and animal manures. Biol. Fert. Soils 15: 285–293.

Rennie, R.J., and S. Dubetz. 1986. Nitrogen-15-determined nitrogen fixation in field-grown chickpea, lentil, fababean, and field pea. Agron. J. 78: 654-660.

Soon, Y.K., and G.W. Clayton 2002. Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can. J. Soil Sci. 82: 165-172.

Stevenson, F.C., and C. Van Kessel. 1996. The nitrogen and non-nitrogen rotational benefits of pea to succeeding crops. Can. J. Plant Sci. 76: 735-745.

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

Zentner, R. P., C. A. Campbell, V. O. Biederbeck, P. R. Miller, F. Selles, and M. R. Fernadez. 2001. Search of a sustainable cropping system for the semiarid Canadian prairies. J. Sustainable Agric. 18: 117-136.