Present and Potential Future Nitrogen Gains from Legumes in Major Soil Zones of the Prairies

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ABSTRACT

Two developments have enabled us to realistically estimate N_2 fixation and N credits from legume crops across the Prairies: one is computerized processing of Statistics Canada's Census of Agriculture crop data by soil climatic zones (SCZ) rather than provincial borders; the other is availability of reliable field ^{15}N data on N fixation (% Ndfa) for various legumes and on partitioning of N (PTN) into harvested and residual parts. Total N fixation for each legume and SCZ was computed on the basis of crop area and SCZ average yields, adjusted for abnormal precipitation, and then multiplied with crop-specific Ndfa and PTN factors. Future legume cropping and N gains were 'guesstimated' according to the most likely crop sequences for various SCZs to be in use by the year 2005. Bctwcen 1991 and 1994 legume hcctaragc increased 69%, due mainly to more pulse cropping, to a total of 2.4 million and is expected to reach 5.5 million by 2005. Dcspitc the increased pulse cropping, 85% of total N fixation in 1994 occurred still in the northern parklands and was overwhelmingly due to forage legumes. The average fixation rate was 104 kg/ha and the total 250 million kg N fixed is equal to 24% of all fertilizer N used in 1994 on 25 million ha of Prairie cropland. In comparison with recent fertilizer N costs the present legume N fixation can bc valued at $220 million. Total N credit for 1994 was calculated to be 62 million kg N which is equal to 1/4 of total N fixation and suggests an average net gain of 26 kg N/ha of legume crop, although these amounts vary widely with legume type. Our N credit estimates ranged from a low of 0 kg N/ha for colored beans, to 9.4 for lentils, 18.1 for peas, 36.4 for forage hay legumes and a high of 65.4 kg N/ha for forage seed legumes. Through combination of the N credit effect with crop substitution and 'rotation' effects, the inclusion of forage, grain or green manure legumes in rotations can effect substantial energy savings for Prairie cropping systems. With continued expansion of legume crops and partial adoption of fallow replacement green manuring, N fixation is projected to total around 550 million kg N by 2005 with a residual N credit of about 190 million kg, indicating an average net gain of 35 kg N/ha. The N gains from legume cropping arc forecast to provide most of the N required for reasonable yields by a following cereal or oilseed crop.

INTRODUCTION

The beneficial effects of annual and perennial legumes in crop rotations on soil quality and microbial life have been well researched within the Canadian Prairies (Campbell et al., 1991; Biedcrbcck et al., 1995a; 1996b) and the soil improvement message is now being communicated to many Prairie producers (Green and Bicderbcck, 1995). Greatly increased yields of subsequent cereal crops have been reported, particularly from the northern Prairies (Wright, 1990) where soil moisture depletion by the legumes is less common. The increase in cereal yields has been largely, but not exclusively, attributed to enrichment of the soil's mineralizable N reserves through the symbiotic fixation of gaseous N_2 during the preceding legume growth (Janzcn and Schaalje, 1992).

Deep-rooted forage legumes boost the soil N-supplying power much more than pulses whose grain harvest frequently removes as much N as was previously fixed (Rice and Olsen, 1990).

The amounts of N fixed by pulses (Brcmcr et al., 1988; Bremer and van Kessel, 1990; Androsoff ct al., 1995) and by some forage lcgumcs (Rice, 1980; Rice and Olsen, 1983) have been measured at specific sites and the factors that control this symbiotic process have been studied in small plot experiments (Bremcr et al., 1989 and 1990; Cowcll ct al., 1989; Rice and Olsen. 1990; Stevenson ct al., 1995). Howcvcr, as far as WC know, no one has yet attempted (i) to estimate the amounts of N fixed by all seeded lcgumcs and (ii) to quantify the 'N credit' or net gain remaining after legume harvest - both on a Prairie-wide scale. With easier access to, and improved computerized processing of, Statistics Canada Census data according to the soil climatic zones of the Prairies and with solid research data, not only on measurements (by ^{15}N and other techniques) of N fixation, but also on the partitioning of N by grain (van Kesscl, 1994) and forage legumes WC considered that it should now bc feasible to develop reasonably realistic estimates of N fixation inputs and post-legume harvest N credits within each of the five SC zones of the Prairies and the only major cropland north of the boreal fringe, i.e., the Pcacc River region.

MATERIALS AND METHODS

To obtain agronomically meaningful estimates of N gains from seeded legumes to Prairie agriculture our computations were based on Census of Agriculture data from Statistics Canada for legume cropping being processed not by political or provincial borders but instead, through cross reference to the CANSIS inventory, according to the natural soil climatic zones of the Prairies. The most recent year for which Census of Agriculture data on crop production is available is 199 1. Thus we were unable to determine directly the distribution of legume hectarages by climatic zones for any subsequent year. However, we did determine the almost present (i.e., 1994) distribution of legume cropland by SCZ, shown in Table 1, indirectly by (i) apportionment of grain legume seedings from provincial statistics among soil zones according to crop districts and their predominant SCZ with subsequent prairie-wide summation and adjustments, and by (ii) allocating seeded forage legume hectarages from annual federal statistics (Plant Products Division, Agriculture Canada) among soil zones according to the distribution found in the most recent Census year. Since neither the Census cropping data nor the annual provincial or federal statistics provided any differentiation between the grass and the legume portion in 'mixed forages' (seeded for hay or pasture) we have consulted forage agronomists in all three Prairie provinces concerning reasonable apportioning. They emphasized that the abundance and persistence of legumes in mixed forages decreases significantly between soil zones as the moisture deficit increases. Their consensus was that the average proportion of ground occupied by legumes in mixed forages should be assumed to be 50%, 40% and 25% on Gray, Black and Brown soils, respectively. The total seeded cropland area within the five soil zones plus the Peace region in 1994 was determined by excluding summerfallow and by adding 3/1 0 of the prior 10 year increase to the 199 1 Census hectarage. This total was calculated to be about 25 million hectares in 1994 of which 5.6% was in the Peace region, 15.9% in the Gray, 4 1.5% in the Black, 2 1.8% in the Dark Brown, 13.6% in the Brown and 1.6% in the Dry Brown soil zone.

The approach we have used in our attempt to develop reasonably realistic estimates of the extent and type of future legume cropping and N gains is based on consultations of experienced agronomists and legume breeders in all three Prairie provinces with regard to major expected crop rotations for cereal, oilseed and legume production. We asked: 'Given recent technological and plant breeding advances, changes in agricultural policy, shifts in input costs and expanding

Table 1. Nearly present (i.e., 1994) distribution of legume cropand by soil climatic zone or region of the Prairies.

Crop	Peace region	Gray	Black	Dark Brown	Brown	Dry Brown	Crop total as: area	%
	hectares							
Legume portion of mixed forage[z]	98000	5 10420	388534	7790 1	63659	5537	1144051	47.7
Forage legumes for seed[y]	27040	39116	12861	5333	7201	864	92415	3.8
Peas	41193	222908	3494 13	77476	2093 1	449	712370	29.7
Lentils	466	24994	133035	161255	70550	12900	403200	16.8
Fababeans	304	690	5487	1178	213	33	7905	0.3
Beans	288	1822	20311	4773	12150	266	39610	1.7
Legume total for zone	167291	799950	90964 1	327916	174704	20049	239955 1[x]	100.0
Zone total as % of Prairie total legume cropland	7.0	33.3	37.9	13.7	7.3	0.8	100.0	

z The proportion of legumes in mixed forages was assessed to be 0.5, 0.4 and 0.25 on Gray, Black and Brown soils, respectively.

Y These include alfalfa, sweetclover, red clover, alsike clover and birdsfoot trefoil.

x The total area cropped to legumes amounts to 9.6% of the 25,000,000 ha of Prairie land that was in seeded crops in 1994.

international markets; what do you consider to be the most likclv crop sequences farmers will bc using in the various soil climatic zones or sub-zones by the year 2005?'. The collective wisdom gained from these consultations, tempered by our own assumptions and expectations for sequencing with more emphasis on maximizing the beneficial nitrogen and non-nutritional (also referred as 'rotational') effects of legumes on subsequent non-legumes, is listed in Table 3.

Symbiotic N fixation by each major legume in each SC zone was quantified by multiplying the crop area with a SC average yield that was adjusted according to precipitation conditions and was then multiplied by that legume's total N content and the crop-specific 'Ndfa', i.e., % N derived from N_2 fixation. Adjustments of SC average yields were deemed necessary whenever annual precipitation across a SC zone deviated abnormally from the 30-year 'Climatic Normal'. The minimum % deviation required to designate any one year as 'wet' or 'dry' obviously increases from the most humid to the more arid zones or regions. Upon consultation with several meteorologists WC have set these minimum deviations as 5% for the Black, 10% for the Gray, 15% for the Pcacc region and for the Dark Brown soils, 20% for the Brown and 25% for the Dry Brown zone. For years designated as wet or as dry the avcragc yield was 25% increased or dccrcascd, respectively. Whencvcr annual precipitation fluctuated by twofold or more of the required minimum deviation then that year was designated as 'very wet' or as 'very dry' and consequently a 50% adjustment of the avcragc yield was made. WC recognize that within any one year the rate of N_2 fixation by a legume crop can vary widely across SC zones according to precipitation and soil conditions. Fababcans are excluded from our N_2 fixation estimates in Table 2 because the area seeded to this high N_2-fixing legume was, unfortunately, always less than 0.5% of the total legume cropland (Table 1).

The 'net N credit' or N gain for each legume crop in each SC zone was computed by subtracting the N contained in the harvested portion (e.g., seed or hay) of the legume from that portion of legume N that was obtained by N_2 fixation.

RESULTS AND DISCUSSION

Past legume cropping according to Census of Agriculture data and estimates of the associated N gains were discused in detail in our earlier presentation (Biederbeck et al. 1995b). It seems appropriate to briefly review the main findings from these prior analyses. They showed that two decades earlier, i.e., before the energy crisis and the large-scale introduction of pulse crops, legumes occupied only 3.6% of all seeded Prairie cropland and forage legumes accounted for over 95% of all legume crops. The legume portion of seeded cropland had only increased to 4.0% by 198 I but it increased more during the eighties reaching 5.8% by 1991. Over this period the proportion of forage legumes decreased to 77% of legume cropland by 198 l and was further lowered to 69% by 199 l as more and more land was cropped to lentils and peas. Our estimates for total N_2 fixed by major legume crops, across all SC zones of the Prairies, increased from 79 million kg N in 1976 almost threefold to 207 million kg in 1991 while our estimated sum total of legume N credits increased from 2 l to 49 million kg N during the same 15-year period. In each Census year, total N credits accounted for about one quarter of total N_2 fixed symbiotically on the Prairies.

Present Legume Cropping and Nitrogen Gains

The legume hectarage jumped by an astounding 69% between 1991 and 1994 reaching a total of about 2.4 million ha (Table 1). Consequently, there have also been marked changes in the types of legumes commonly grown with the dominance of forage hay and seed legumes decreasing even further, i.e., from 69% in 1991 to 52%, while the proportion of legume cropland planted to peas and lentils jumped to 30% and 17%, respectively, by 1994 (Table 1) and did again increase in 1995, particularly in Saskatchewan. The distribution of legume cropland across the various soil climatic zones has changed relatively little since 1976 except for a moderate decrease on Black soils and a 48% increase, due largely to ever more lentils, in the Dark Brown soil zone. It must also be emphasized that, despite the recent expansion and changes in legume cropping, the area under legumes still accounts for less than 10% of total seeded cropland in the Prairies. Thus there remains considerable space and opportunity for fitting more and new legumes into crop rotations not only in the more humid northern Prairies but also, if combined with snow trapping, in the drought-prone southern Prairies to optimize the beneficial effects of legumes on soil quality, input cost reduction and increased sustainability of cropping systems (Bicderbeck, 1990).

Although total legume hcctaragc increased by 69% between 1991 and 1994 our estimated total N fixation increased only by 2 1% (Biederbeck ct al., 1995b). Two reasons for the lower response in N fixation are that weather conditions all across the Prairies were much less favorable to legume growth in 1994 and also that the hectarage of the high N_2-fixing forage legumes had actually decreased while pulse cropping continued to expand. However, even in 1994, forage hay and seed legumes together still contributed about two thirds of the total N fixed by all legumes (Table 2a). The overall average rate of N fixation declined from a high of 146 kg N/ha in 199 1 to a lower, but still respectable, 104 kg N/ha in 1994. As expected, rates of N fixation varied very widely between different legumes and according to weather and soil conditions. When averaged across all SC zones, rates of N fixation in 1994 decreased from 137 kg N/ha for forage legumes in hay mixtures to 90 kg for peas to 63 kg for forage legumes grown for seed to 56 kg for lentils and down to 30 kg for colored beans, as shown in Figure 1. The highest fixation rates were consistently associated with the perennial legumes in grass-legume mixtures because these mixed forage stands were assumed to be generally maintained without fertilization and located mainly on Gray and degraded Black soils such that the typically low fertility would always pressure the legume component to maximize its symbiotic activity. By contrast, the forage legumes grown exclusively for seed were assumed to be properly fertilized and would consequently be less dependent on symbiotic N fixation.

Although there has been a rapid expansion of pulse cropping on Dark Brown and Brown soils in recent years our N fixation estimates, when summed by SC zone, indicate that by 1994 about 85% of total N fixation by seeded legumes still occurred within the more humid northern Prairies and overwhelmingly due to forage legumes (Table 2a).

The grand total 250 million kg N fixed on only 2.4 million ha of legume crops during 1994 is equal to 24% of the total quantity of fertilizer N (i.e., 105 1 million kg) sold and used that year on 25 million ha of seeded cropland across the Prairies (Tables 1 and 2a; Biederbeck et al., 1995b). When compared with recent urea fertilizer N prices, averaging $0.88/kg N across Saskatchewan, the 1994 estimate of total N fixation could be valued at $220 million.

There is a distinct possibility that our calculated total for N fixed during 1994 underestimates the true sum of all symbiotic N fixation processes, not just by excluding several minor and new legumes that are grown in small localized areas or by failing to include in field measurements of N_2 fixation sizeable N losses from the root systems of field peas and other pulses in form of exudates during active plant growth (Sawatsky and Soper, 1991), but mainly because the Census data base compiles any fields that arc seeded to annual or biennial legumes for fallow replacement green manuring simply as 'summer-fallow'. Yet recent studies indicate that there arc several annual legumes that arc highly water USC efficient (Biederbeck and Bouman. 1994) and well adapted to short-term growth and effective N fixation during partial fallow in dryland cropping systems (Bailey et al., 1989; Biedcrbcck et al., 1993 and 1996a; Rice et al., 1993). Thus it seems reasonable to suggest that with more favorable weather conditions and the inclusion of all legume seedings, even those for fallow substitute green manures, the sum of all symbiotic N fixation during 1994 could well have reached the 300 million kg level.

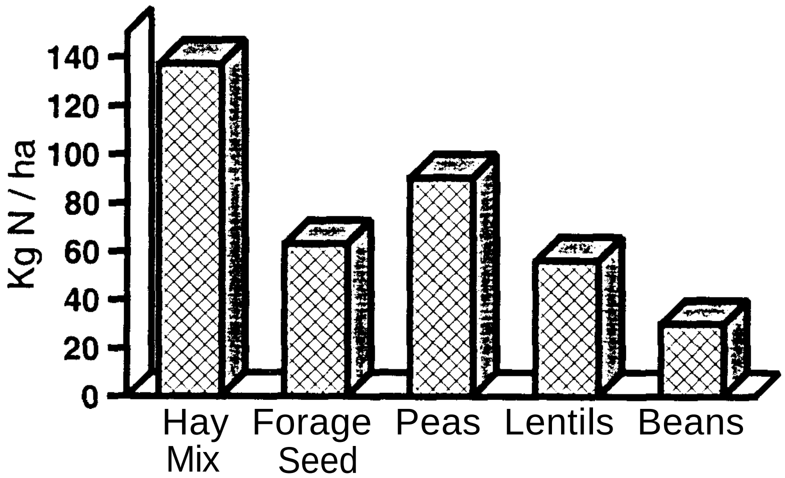

Figure 1. Estimated rates of N fixation for major legume crops in 1994 when averaged across six agroclimatic zones of the Prairies.

The sum of all legume N credits in 1994 amounted to 62 million kg N (Table 2b) and was, as in earlier years, again equal to one quarter of the total N that was fixed symbiotically during the same year. When averaged across all legumes, the credit was 26 kg N per hectare of legume crop and, due to the less favourable growing season weather, it was markedly lower than the 1991 average credit of 35 kg N/ha. The proportion of fixed N that remains after harvest as a net N credit varies widely with legume type and with the soil's N supplying power. Net gains are generally greatest with forage legumes grown for seed on the less fertile Gray soils (≈ 67%) and with legumes for hay (30 to 45%); they are considerably lower for peas (≈ 20%) and lentils (≈ 17%) and are nonexistent (0%) for colored and white beans. This explains why legumes in the Gray soil zone that represented 33% of legume cropland in 1994 (Table 1) contributed 50% of total N credits (Table 2b) while legumes on Black soils accounted for 40% of total N fixation (Table 2a), but contributed only 23% to the Prairie total net N credits.

When segregated by legume crop and soil zone, our estimates of N credits in 1994 ranged from a low (if beans are excluded) of 6.8 kg N/ha for lentils grown on Gray soils to a high of 65.4 kg N/ha for forage legume seeds produced, mainly under irrigation, on Brown soils. A comparison

Table 2. Estimates of nearly present (1994) amounts of (a) nitrogen fixed by legume crops, and (b) net gains or nitrogen credits remaining after legume harvest in soils of the climatic zones of the Prairies.

Crop	Peace region	Gray	Black	Dark Brown	Brown	Dry Brown	Crop total as:	
							kg	%
				(a) Nitrogen (kg N) fixed by legume crops				
Legume mix forage	20580000	68902600	53423500	8179600	4774500	311400	156171600	62.4
Forage legume seed	1236066	269 1944	553152	48855 1	706796	84816	5761325	2.3
Peas	3774100	15046300	37736600	6275500	1507000	30300	64369900	25.7
Lentils	38300	1025800	8189600	9191500	3 699600	617600	22762400	9.1
Beans	8640	54660	609330	143190	364500	7980	1188300	0.5
Zone total for all legumes	25637106	87721304	100512182	24278341	11052396	1052096	250253525	100.0
Zone total as % of Prairie total	10 .2	35.1	40.2	9.7	4.4	0.4	100.0	
				(b) Net nitrogen credits (kg N) from legumes				
Legume mix forage	6860000	25838500	4856700	2337000	1591500	103800	41587500	67.0
Forage legume seed	824044	1850712	276576	314069	471197	56827	3793425	6.1
Peas	754800	3009300	7547300	1255100	301400	6100	12874000	20.8
Lentils	6400	171000	1364900	1531900	616600	102900	3793700	6.1
Beans	0	0	0	0	0	0	0	0.0
Zone total for all legumes	8445244	30869512	14045476	5438069	2980697	269627	62048625	100.0
Zone total as % of Prairie total	13.6	49.8	22.6	8.8	4.8	0.4	100.0	

across all soil zones in 1994 indicated an average credit of 18.1 kg N/ha for peas but only 9.4 kg N/ha for lentils (Tables 1 and 2). This difference in N credit between the two main pulses is quite reasonable because crop sequence studies at Melfort, Scott and Saskatoon have shown that cereal yields are consistently higher on field pea than on lentil residues (Wright and Townicy-Smith, 1990).

The magnitude of our N credit estimates agrees well with the general observation that pulse residues usually contain from 5 to 25 kg N/ha more than cereal residues. Contrary to peas, most lentils are now being grown in the drier southern than in the more humid northern regions of the Prairies (Table 1). In this semiarid environment lentils can be grown in a 2-year rotation without danger of excessive crop damage from residual ascochyta inoculum. Consequently, the lower N credits from a single crop of lentil as compared to pea tend to be compensated by more frequent cropping to lentils. In a recent 12-year study of N fertility in a Brown Chemozem under wheat-lentil vs monoculture wheat rotations there was a progressive reduction in the fertilizer-N requirement for the wheat-lentil system, indicating a strong cumulative enhancement in the N-supplying power of the soil (Campbell et al., 1992).

Although by 1994 the proportion of legume cropland planted to forage hay and seed legumes had decreased to about half (Table 1) these perennial legumes were still providing three quarters of the total N credits (Table 2b). The contribution from peas to N credits did more than double since 1991 to reach 21% compared with an unchanged 6% contribution from lentils and still 0% net N gain from beans (Biederbcck et al., 1995b). Separation by soil climatic zone showed that legumes grown on Gray soils were still providing at least half of all legume N credits on the Prairies and were continuing their essential role in improving the fertility, humus content and structure of these qualitatively marginal soils. Contributions from legumes in the Black soil zone remained unchanged since 1991 at 23% while legumes in the Peace region increased their share of the N credits from 9% in 1991 to 145 due mainly to rapid expansion of the pea hectarage. Legumes grown in the drier zones of the Prairies are still providing rather little to total N credits. In 1994 the contributions from these zones accounted for < 10%, < 5% and < 1% on Dark Brown, Brown and dry Brown soils, respectively.

Inclusion of forage, grain or green manure legumes in Prairie cropping systems is being increasingly recognized as a very effective way to enhance agricultural sustainability, not only because of improvements in soil fertility and tilth but also because of great potential for energy conservation. In crop rotations, legumes effect energy savings in three ways: (i) by replacing non-legumes with high N fertilizer requirements (i.e., substitution effect), (ii) by leaving some symbiotically fixed N, after the legume harvest, in the soil for a following crop (i.e., N credit effect); and also (iii) by increasing yields of following crops through a non-nutritional or secondary legume effect (i.e., rotation effect). Across the more humid Black and Gray soil zones cereal yields are often greatly enhanced when alfalfa or alfalfa/grass mixtures are included in the rotation (Entz et al., 1995) and an earlier report suggested that fallow replacement with clover, as green manure, in a 4-year barley and canola rotation on Gray Luvisols would result in a net energy conservation of almost 3000 MJ (megajoules) per hectare (Rice and Biederbeck, 1983). In a very recent study of energy savings implications from the increased grain legume cropping in the generally drier, more southern regions of the Prairies Coxworth et al. (1996) calculated these savings to be 4.46 PJ (petajoules) per year, i.e., an amount equivalent to 7.5% of the total N fertilizer use in 1990.

Projected Future Legume Cropping and Nitrogen Gains

Total legume hectaragc has increased by 69% between 199 1 and 1994 and it is our vision for the Prairies that there will be further expansion of legume cropping during the next decade, in all soil climatic zones but most prominently in the more southerly, three Brown soil zones. With increased adoption of conservation tillage, improved cultivars with respect to disease resistance (particularly to Ascochyta), earlier maturity and greater productivity it will be technically feasible, by the year 2005, to grow pulses (pea, lentil, chickpea, bean) on 20 to 25% of the hectares sown to annual grain crops. However, WC realize that Prairie producers would not be able to profitably market such a huge volume of grain legumes. Thus, our projections for future pulse cropping in the major soil zones (Table 3) range from 5% of seeded cropland in the Gray to 16% in the Dark Brown soil zone. There is little doubt that the market for pulses will bc expanding as population size, industrialization, living standard and the resultant human demand for dietary plant protein ("dhal") in many Asian countries is growing fast and as pea protein becomes a more valued component in livestock rations in Europe and North America. The development of new Ascochyta resistant “niche market” pulse cultivars will facilitate access to additional international markets and thereby further increase the demand for western Canadian peas and lentils (Slinkard and Vandenberg, 1993).

As a result of recent soil conservation incentive programs, such as the PCP administered by PFRA, and very recent changes in agricultural policy, such as the elimination of grain transportation (“Crow Rate”) subsidies, forage legumes are likely to assume a greater economic importance than ever before as marginal land is converted back to forages. With a steady increase in the livestock herd and more cattle being fed out on the Prairies the demand for high quality legume hay and feed grain legumes will be strengthening. Consequently, we are forecasting a 20% increase in area and production of perennial legumes for mixed forage and in forage legumes for seed production by the year 2005. We expect most of these forage legume increases will occur on the Gray and degraded Black soils of the northern parklands. Another development that has made not only forage but also grain legumes more attractive all across the Prairies are the recent sharp increases in the cost of nitrogen fertilizers. Although N fertilizer prices are not expected to remain much longer at the current exorbitant peak they are forecast to stay fairly high for the remainder of this decade.

The predicted rotations listed in Table 3 suggest, in addition to expanded forage legume hay and seed production in the northern parklands and the Peace River region, a 2.4-fold overall increase in both pea and lentil cropping from the present scenario due, mainly, to the extending of rotations with further fallow replacement by pulses on the southern ‘brownish’ soils (cf. Tables 1 and 3). The desi chickpea is a new pulse crop that is predicted to fit well into future rotations in the Brown and Dry Brown soil zones (Slinkard and Vandenberg, 1996). With its good drought tolerance and high N_2-fixation capacity (Doughton et al., 1993) chickpea cropping can effect some reduction in fallow hectarage and will provide a more positive soil N balance or net N credits than either lentils or beans.

Estimates of symbiotic N fixation by each legume type in each SC zone for the year 2005 were computed based on the projected crop rotations and legume hectaragcs (Table 3), using the same legume-specific PTN and Ndfa factors as in previous estimations and assuming average legume yields and normal weather (precipitation) conditions in all SC zones. In addition to the N_2 fixed by legumes grown for seed or forage harvest we expect greatly increased contributions to total N fixation and N credits from the seeding of more and more fallow land in the three Brown soil zones to well adapted annual (e.g., black lentil, cv. Indianhead, and chickling vetch, cv. AC

Table 3. Major legume containing crop rotations projected to be in use on the Prairies by the year 2005.

Soil climatic zone	Rotation[z], including frequency (%) for 'or' and 'if options	% of seeded zone land used for rot'n	Area seeded to only legumes, ha
Peace region	CAN-WHT-LGH-LGH-LGH-BAR	40	140000
	CAN-WHT-PEA-BAR-BAR	30	84000
	CAN-WHT-FLS-FLS-BAR	10	56000
	CAN-WHT-LGH-LGH-LGH-BAR	65	646000
Gray	CAN-WHT-PEA-BAR-BAR	25	198000
	CAN-WHT-FLS-FLS-BAR-BAR	7	92000
Black			
- northern, humid	CAN-WHT-LGH-LGH-LGH-BAR-BAR	33	586000
- south & central	CAN-WHT-PEA(75) OR LEN(25)-BAR-FLX or CAN-WHT-BAR	67	995000
Dark Brown			
- northern moist D.B.	CAN-WHT-PEA(75) or LEN(25)-BAR-BAR	35	381500
- main Dk. Brown	FAL-CAN-WHT-WHT-FAL(33) if dry or PEA(45) or LEN(22)-BAR	65	572000
Brown	FAL-MUS or other oilseed-WHT-FAL(50) if dry or LEN(35) or CHI(5) or CDB(5) or PEA(S)-WHT	90	441000
Dry Brown	FAL-WHT-MUS or FLX(50) or LEN(33) or CHI(17)-WHT	90	70000

[z] Crop notations: BAR-barley, CAN-canola, CDB-colored & dry beans, CHI-chickpea, FAL-fallow, FLS-forage legumes for seed prod'n, FLX-flax, LEN-lentil, LGH-legume-grass hay (mix), MUS-oilseed mustard or sunola, PEA-field pea, WHT-wheat.

Grcenfix) and biennial (e.g., yellow swectclovcr) legumes for the purpose of green manuring. Thus we predict that by 2005 at least IO'!! (ix., 38,000 ha) of the fallow hectaragc in the Dry Brown soil zone will be in annual legume green manures that will fix, on average. 60 kg N/ha up to full bloom when the topgrowth will be diseed in or desiccated. With slightly better moisture on the Brown soils at least 15% (i.e., 393,000 ha) of that zone's fallow is predicted to be planted to annual (2/3) and biennial (1/3) legume green manures that should fix an average of 75 kg N/ha and, on the more humid Dark Brown soils, at least 20% (i.e., 488,000 ha) of fallow is projected to be in biennial (2/3) and annual (1/3) legumes that will fix, on average, 90 kg N/ha during vegetative growth.

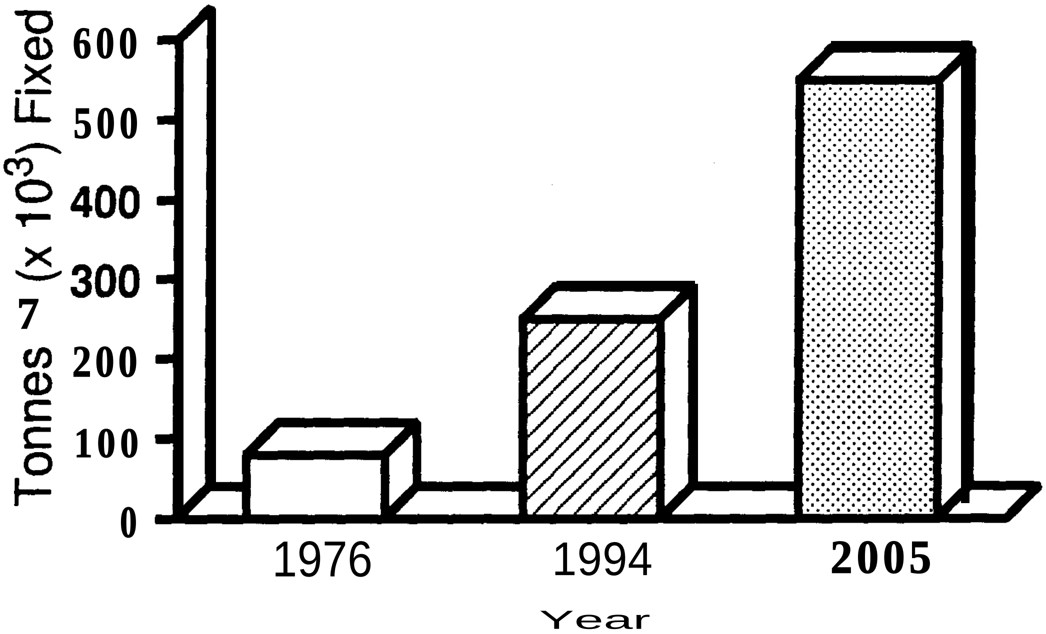

Figure 2. Estimates of past, nearly present and future total amounts of N fixed by legume crops on the Prairies.

Our computations suggest the total quantity of N fixed on the Prairies by the forage, grain and green manure legume crops, projected for the year 2005, could be around 550 million kg N (or 550,000 tonnes N). This would imply a 2.2-fold increase from our estimate for total N fixation by legume crops in 1994 (Figure 2) and would be equal to 52% of the total fertilizer N being presently used across the Prairies. Even in 2005, the largest portion, i.e., 45% of total N fixation is still expected to come from forage hay and seed legumes. Other legumes predicted to provide major inputs into total fixation are field peas (30%), green manures (14%) and lentils (10%). With further rapid expansion of pulse cropping (peas, lentils and desi chickpea) the portion of total N fixation originating in each of the three Brown soil zones is projected to more than double during the next IO years.

The sum of all legume N credits in 2005 was estimated to be around 190 million kg N, an amount equal to one-third of the total N fixed or an average credit of 35 kg N/ha on the total of 5.5 million hectares, projected to be seeded to legumes. Although green manure legumes were estimated to account for only 14% of total N fixation, they are projected to contribute 40% of all legume N credits by 2005 as all of their symbiotically fixed N_2 is returned to and retained by the soil for maximum net N gain and soil improvement. The other main contributors to legume N credits are forecast to be forage hay and seed legumes (37%), peas (17%) and lentils (5%).

CONCLUSIONS

The portion of Prairie cropland planted to grain legumes has greatly increased in recent years and is projected to expand, but primarily in the drier, southern soil zones. Yet, despite the increased pulse cropping and resultant addition to total N fixation on the Prairies, net N gains, when based on the sum of all portions of fixed N remaining after harvest, are still predominated by deep-rooted forage legumes that are grown for hay or seed mainly on Gray and degraded Black soils of the northern parklands. Due to the high proportion of zone cropland in forage legumes, the naturally less productive Gray soils arc benefiting more than other soils from the fertility- and structure-improving legume effects. Furthermore, the dominance of forage legumes infers the potential for large increases in legume N credits with relatively small improvements of forage practices (e.g., P fertilization, liming, more effective rhizobial inoculation, etc.) in the northern parklands. The agronomic and economic importance of all legume crops to Prairie agriculture is underlined by pointing out that the average net gain of 35 kg N/ha that is projected for 2005, when added to normal soil N mineralization, should be adequate to meet the N requirements of subsequent cereals and oilseeds on Brown soils and should provide at least half the N required for reasonable grain yields on moist Dark Brown, Black or Gray soils.

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