GROWTH OF ANNUAL LEGUMES FOR SOIL CONSERVATION UNDER SEVERE DROUGHT CONDITIONS

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INTRODUCTION

It has long been recognized that legume green manures in cereal rotations increase available soil nitrogen, add soil organic matter, reduce soil and water losses, reduce leaching of nutrients, reduce salinization, and often increase the yield of succeeding crops. Yet, despite growing concerns about the alarming rate of loss of fertility due to soil erosion and degradation under the traditional wheat-fallow rotation (Biederbeck et al. 1981; Senate Comm. Rept. 1984) few prairie grain growers like the idea of including a forage or green manure legume in the rotation to control soil erosion. The aversion to green manuring is particularly strong on grain farms in the drought-prone Brown Soil Zone of Saskatchewan as was indicated by a recent farm survey from Statistics Canada (Table 1).

Table 1. Percentage of Prairie Grain and Oilseed Farms With Green Manure Plow Down in 1982

Province and Soil Zone	With green manuring	No green manuring	No response to questionnaire
	percent		
Manitoba			
Black	1.0	97.6	1.4
Grey Wooded	3.0	95.6	1.9
Saskatchewan			
Brown	0.0	97.0	3.0
Dark Brown	1.9	97.7	0.4
Black	1.3	98.3	0.3
Alberta			
Brown	5.0	89.7	5.3
Dark Brown	0.0	94.8	5.2
Grey Wooded	2.3	89.2	8.5
Black	1.7	96.5	1.8

Source: Farm Energy Survey 1982, Special Tabulation by Statistics Canada.

Major reasons for the failure to include legume green manures in cereal rotations on Brown and Dark Brown soils are: the high cost of seed and resultant reduced cash flow, the excessive depletion of soil moisture reserves, the difficulty of establishment and the poor competition with weeds. The implications of these disadvantages were recently discussed by Slinkard (1984). In earlier reviews of the effects of green manures on dryland cropping systems in the northern Great Plains Army and Hide (1959) and also Brown (1964) concluded that legumes such as alfalfa and biennial sweetclover should not be used for the production of wheat in short rotations on Brown or Dark Brown soils with present cultural techniques.

New approaches must, therefore, be developed and tested if legume green manuring is to become an economically viable soil conservation practice in cereal rotations on the Prairies. Two promising approaches, presently under investigation (Slinkard 1984, Wilkins 1985), are (i) the use of new types of annual legumes, and (ii) the use of perennial or biennial legumes when managed as annuals. The latter approach which includes the use of non-hardy, southern alfalfas may have summerfallow replacement potential but primarily on soils with adequate moisture as in the Black and Gray soil zones.

In the drier Brown and Dark Brown soil zones current research on green manuring is focussed on screening and testing various annual legumes for their potential as fallow replacements (Biederbeck and Looman 1983, Townley-Smith and Slinkard 1984). The use of annual rather than biennial or perennial legumes could result in considerable nitrogen fixation without excessive depletion of soil moisture reserves.

Our selection criteria are rigorous and well defined. We contend that an annual legume should meet the following seven requirements to be effective as fallow substitute-green manure for reducing N-fertilizer input and improving soil conservation on the Brown soils of southwestern Saskatchewan:

- provide an early ground cover for protection against erosion;
- high rate of N_2-fixation and biomass production;
- high water use efficiency (i.e., equal or better than wheat);
- ability to compete primarily with broadleaf weeds;
- provide an emergency source of nutritious feed in dry years;
- high seed production in 'leave' strips to reduce seed costs;
- adequate stand height in 'leave' strips for overwinter snow trapping.

The objectives of this paper are to report on the performance of several N_2-fixing and non-fixing annual legumes under the severe drought conditions that prevailed during the 1984 growing season in the Swift Current area.

MATERIALS AND METHODS

Tangier flatpea (Lathyrus tingitanus cv. 'Tinga'), Chicken vetch (Lathyrus sativus cv. 'NC8-3'), Austrian winter pea (Pisum sativum arvense cv. 'Melrose'), Black lentil (Lens culinaris cv. 'NEL 481') and a 1:1 mixture of Tangier flatpea and Austrian winter pea (cv. 'Tinga'/ cv. 'Melrose') were seeded in a split plot randomized complete block experiment with four replicates. The main plot treatments were rhizobial inoculation and non-inoculation of the green manure crops, with the legume species as sub-plot treatments. Each replicate also contained summerfallow plot as control. The legumes were seeded into wheat stubble with tall stubble snow trap strips on a Swinton loam (Orthic Brown Chernozem) that had been cropped continuously since 1982. Just prior to seeding all plots were fertilized with phosphorus by broadcasting 0-45-0 at a rate of 112 kg/ha (50 kg P_2O_5/ha). Four rows of spring wheat cv. 'Canuck' were seeded along the west side of each of the 6.75 m x 25 m plots to again provide tall stubble strips for uniform overwinter snow trapping. Commercial peat-base inoculants (products of Nitragin Co. and of Agricultural Laboratories Inc.) and an effective sticking agent (NutriGum from Nitragin Co.) were used for the rhizobial inoculation of the various legume seeds. Seeding was completed on May 17, 1984.

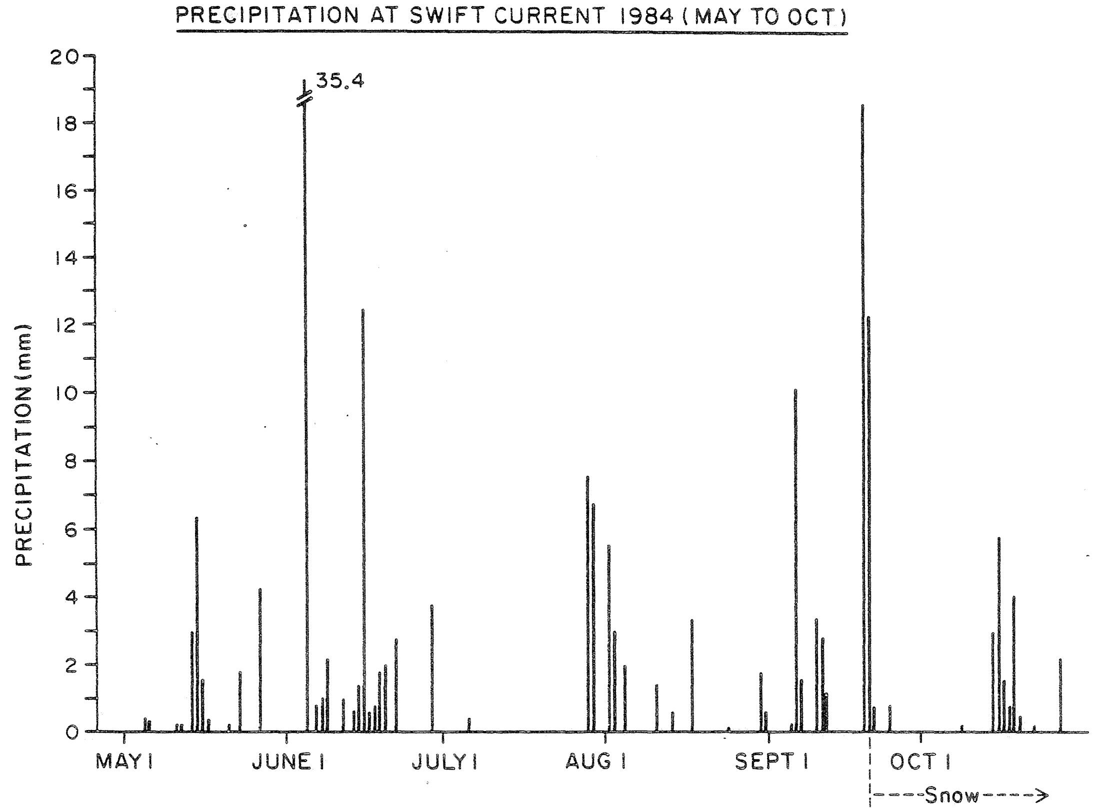
In each legume plot the top growth on an 18-m long portion was incorporated on July 27, 1984, i.e., after all legumes had reached full bloom, in one operation with a heavy tandem disc (BushHog, Model 146). On the other 7-m long portion, which was used for frequent soil and plant sampling and growth measurements, the legumes were left unincorporated to grow to maturity.

All plots were cored hydraulically to 120-cm depth before seeding, at green manure incorporation and in early and late fall for soil moisture and nutrient analyses. Soil cores to at least 60-cm depth were taken manually every 2 weeks after emergence. Measurements of plant height, stand density, dry matter production of tops and roots, and number and weight of nodules were made at regular intervals during the growing season.

Just before green manure incorporation all top growth of legumes and of weeds was separately collected, manually, from two different 1.0 m^2 areas in each plot for dry matter and nutrient content analyses. Counting the number of legume plants collected on July 25, 1984 from each 1.0 m^2 area facilitated the estimation of below-ground legume dry matter and nitrogen based on excavation to 30-cm depth, root washing and nodule separation from 10 representative plants/plot sampled on July 23, 1984 and conversion of root- and nodule-D.M. and N to m^2 according to the mean plant density in each plot.

The difference between the amount of N present in nodulated and in nonnodulated plants (i.e., the 'difference method') was used to estimate the amount of N fixed by the annual legumes. We chose this method because estimates from the difference and ^{15}N methods for the amount of total N fixed by annual legumes are reported to be highly correlated under field conditions (Talbott et al. 1982). Furthermore, this method provides a more direct measure of N_2 fixation than the acetylene reduction assay, since the latter method does not actually provide a measure of N_2 fixation itself. Another advantage is that the difference method does not require the special techniques and equipment necessary for isotopic-N tracer studies.

The difference in soil moisture between the beginning of the growing season and green manure incorporation, coupled with precipitation, provided an estimate of water consumption and water use efficiency of the various legumes as biomass producers and N_2 fixers. Precipitation was assumed to be similar to that recorded at the meteorological site located 0.2 km north of the plots (Figure 1).



RESULTS AND DISCUSSION

Severity of the Drought

The drought stress suffered by crops in southwestern Saskatchewan in 1984 was due not only to the shortage of rain during the growing season but also due to the shortfall of soil moisture recharge between the 1983 harvest and 1984 seeding. Precipitation during the fall of 1983 was down by 64% from the long-term average and winter snowfall in

1983-84 was only 59 cm (i.e., 50 mm H_2O), down 38% compared to the long-term average. An examination of the 1984 precipitation pattern (cf. Fig. 1) reveals that there were actually 18 days with some rainfall between the seeding of the legumes on May 17 and their incorporation on July 27. However, most of these rains were very small and if one assumes, as most farmers and agronomists in the Southwest do, that any rain of less than 5 mm (or 1/5 inch) is quickly evaporated and rather useless, then there were only two significant rainfall events during the entire growth period of the green manure legumes viz. a 35.4 mm rain on June 5 and a 12.5 mm rain on June 16. Furthermore, the very high temperatures and strong winds, that were so prevalent during late June and most of July, boosted evaporation to the point where the 'evaporation/precipitation ratio' -- a crude type of drought index -- rose to 10.4:1 while the long-term mean ratio for this 12-week period is 4.5:1. If one considers in addition to this evapotranspiration stress the fact that plant available soil moisture to 90-cm depth at legume seeding was just below half of the soil water storage capacity (cf. Fig. 4) then one can comprehend more fully the severity of the drought conditions suffered during the summer of 1984.

Legume Nodulation and Growth

On average, all five legume crops emerged by May 30, that is within 13 days of seeding. The average date for first visible root nodulation on the inoculated legumes was June 11, i.e., 12 days after emergence. First bloom occurred on June 29 with chicken vetch, July 5 with black lentils and July 11 with Tangier flatpeas (TFP), Austrian winter peas (AWP) and the TFP/AWP mixture, corresponding to a period of 30, 36 and 42 days, respectively, after emergence.

Under normal growing season weather conditions, the nodulation of these annual legumes would be expected to increase sharply between four weeks after emergence and full bloom and then begin to decline with the onset of pod formation. However, under the severe drought conditions of last summer only the chicken vetch nodulation followed this pattern (Figure 2), reaching a maximum of 83 nodules/plant at eight weeks after emergence. The number of nodules on AWP and on black lentils did not increase further after five weeks from emergence and at full bloom (i.e., 8 weeks after emergence) it was much lower than the number on chicken vetch. Nodulation of the Tangier flatpeas was very poor and did not change significantly between four and eleven weeks after emergence (Fig. 2). The inadequate nodulation of TFP was obviously a result of greater susceptibility of this legume to drought stress because 'Tinga' will nodulate very well under good soil moisture conditions, such as existed in 1982, when TFP nodulation reached a maximum of 86 nodules/plant at full bloom (cf. Biederbeck and Looman 1983).

The very abundant and persistent nodulation on chicken vetch, despite the severe drought stress, was remarkable. Although the number of nodules decreased by 28% between eight and eleven weeks after emergence the total dry weight of nodules declined only by 7% during the same three-week period, indicating that most chicken vetch nodules were still active and still growing in size after the plant had reached full bloom.

This unusual persistence of nodule activity does provide the most plausible explanation for our observation that only inoculated chicken vetch plants were still green and turgid and actively growing in late August when all other inoculated legumes, on the unincorporated plot segments, had already turned brown and shrivelled up under the continued rigors of the drought.

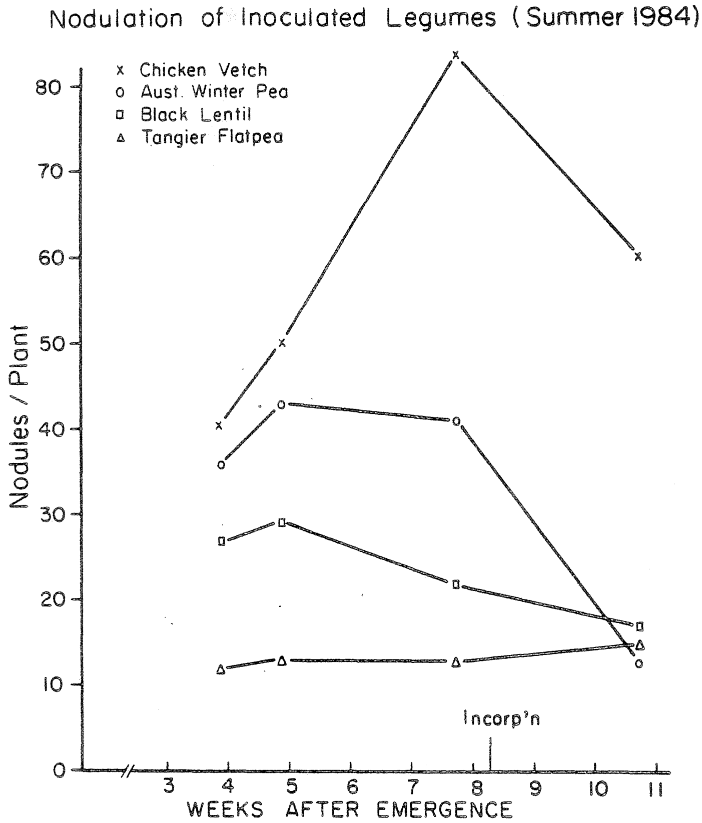


Figure 2.

In our plot experiment to evaluate green manure legumes the desired stand density for all large-seed legumes is 50 plants/m^2 and for the small-seed legumes, such as black lentil, it is about 110 plants/m^2. Consequently, the seeding rates are adjusted each year according to the germination percentage of the available seed and according to soil moisture conditions at seeding time. The average stand density of inoculated plants, at the time of green manure incorporation, was 41, 97, 72, 162 and 89 plants/m^2 for chicken vetch, AWP, TFP, black lentil and the TFP/AWP mixture, respectively. Thus, except for chicken vetch, the actual stand densities of these green manure legumes were considerably higher than the desired target densities. Inoculation had no effect on stand density for four of the five legume crops. Only the inoculated

AWP plots had a significantly higher (p.05) plant density than the corresponding uninoculated plots.

As it was impossible to obtain enough fresh seed of NC8-3, the most promising line of chicken vetch, for the required eight plots, several lots of one-, two-, three- and four-year-old seed had to be bulked for the spring seeding. Some of this seed was damaged, very low in germination and low in seedling vigor. Thus the chicken vetch stands were much thinner than expected in spite of the greatly increased seeding rate (i.e., 136 kg/ha).

By the time of green manure incorporation the uninoculated legumes had produced an average top growth of 665 kg dry matter/ha and there were no significant differences in yield between the five legume crops. At the same time the inoculated legumes had produced an average of 1,334 kg dry matter/ha, again with no significant yield difference among the five legume crops. Thus, despite the very severe drought stress, seed inoculation and the resultant root nodulation and symbiotic N_2-fixation had effected an average increase of 102% in dry matter production during the eight-week growth period (Figure 3). This overall increase in top growth was significant (p.05) and so was the treatment effect for four of the five legume crops. Only with Tangier flatpeas was the yield increase due to incoulation not quite significant, but the N content of the inoculated flatpeas was significantly higher than that of the uninoculated plants.

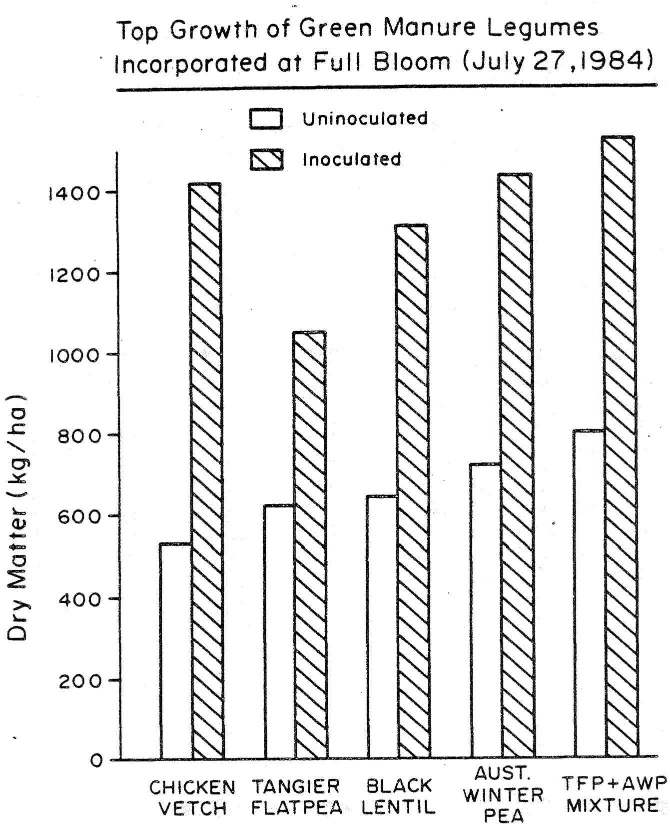


Figure 3.

As expected, the boost in plant growth was greatest with the legume that had developed the most abundant and active root nodulation. Thus the inoculated chicken vetch produced 166% more top growth than did the uninoculated plants (Fig. 3). Consequently, it is not surprising that inoculation effected only a 69% yield increase with the Tangier flatpea (Fig. 3), the legume with the poorest nodulation (cf. Fig. 2).

Most of the legume plots were rather weedy due to the drought conditions and the inability to effectively compete with weeds, primarily broadleaf weeds, which is known to be a general weakness of annual legumes. At green manure incorporation the average top growth of weeds amounted to 344 kg dry matter/ha in uninoculated and 399 kg dry matter/ha in inoculated legume plots. Thus the proportion of weeds within the total top growth of plants effectively decreased from an average of 34% to an average of 23% as a result of legume seed inoculation.

Although the growth of weeds is undesirable for obvious reasons and cannot add N through fixation, it does -- in the context of green manuring -- provide some additional organic matter for soil incorporation. A comparison of average total top growth (legumes + weeds) on plots of annual legumes, i.e., 1743 kg/ha, with the average total top growth (legumes + weeds) on plots with 3-year-old stands of inoculated alfalfa (cultivars 'Beaver', 'Drylander' and 'Anchor'), i.e., 1127 kg/ha, grown on the same Brown loam under the same drought conditions, indicates that some annual legumes are able to produce significantly more biomass for green manuring than is being produced by well-established stands of perennial legumes, such as alfalfa, in the frequently dry summers of southwestern Saskatchewan.

Water Use Efficiency and N_2-Fixation

Monitoring of soil moisture depletion and determination of the efficiency of water use by these annual legumes, while growing under drought stress, is rather crucial because these measurements are, without doubt, the key criteria for assessing the potential of these annuals as fallow substitute-green manure crops in the Brown soil zone. In the fallowed soil of the control plots plant available water remained constant from early May until late July, at just above half of the soil water storage capacity, then it decreased by 2 cm in late summer and between early September and late October the fallowed soil gained 3 cm from fall rains and early snowfalls (Figure 4). Between seeding and green manure incorporation (i.e., July 27) available soil water decreased by an average of 5 cm under uninoculated legumes, by 6 cm under inoculated legumes and by 8 cm under spring wheat (cv. 'Canuck'). By this time the considerably deeper root system of the wheat had completely exhausted all available soil water within the 0- to 90-cm depth reaching the 'true lower limit' (i.e., 0 availability) which was 3.5 cm lower than the conventionally defined permanent wilting point (i.e., PWP = H_2O at 1500 kPa).

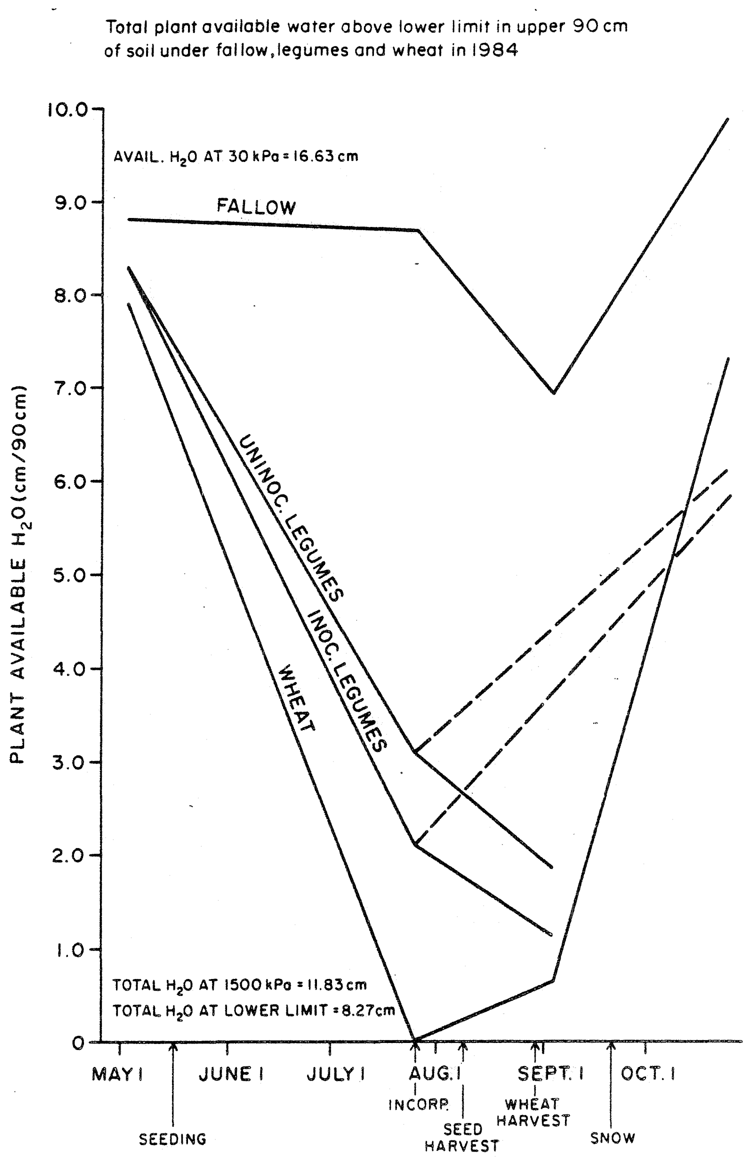


Figure 4.

After the legumes were disced in, the soil in the inoculated plots regained almost 4 cm of water (see hatched line in Fig. 4) from early and late fall precipitation, while moisture recharge in the uninoculated plots was only slightly lower (Fig. 4). Where the legumes were left unincorporated to grow to maturity available soil water declined by one more cm between late July and early September. The soil under spring wheat gained about 7 cm of available water between grain harvest and late October (Fig. 4). Some of the higher water recharge in the wheat plots as compared to the disced-in legume plots was due to more late fall snow being held (trapped) by the wheat stubble than remained on the bare soil of the disced plots. A comparison of the available water status by late fall shows that soil moisture reserves under wheat stubble were 2.5 cm less and under green manured legumes 3.75 cm less than in the fallowed control soil. However, relative to the amount of soil water that had been available at seeding time the legume and the wheat plots had been recharged to 73% and 92%, respectively, of the initial moisture reserve.

As the inoculated legumes produced about twice as much biomass as the uninoculated legumes, while using only one more cm of available soil water, their water use efficiency (WUE) of dry matter production was also greatly increased (Figure 5). On average, the uninoculated legumes required 1422 kg H_2O to produce 1 kg dry matter and there were no significant differences in WUE (at p.05) between the five legume crops. The inoculated legumes required, on average, only 874 kg H_2O per kg D.M. produced and there were significant differences between the legume crops as the TFP/AWP mixture was much more efficient in water use than any of the other green manure crops.

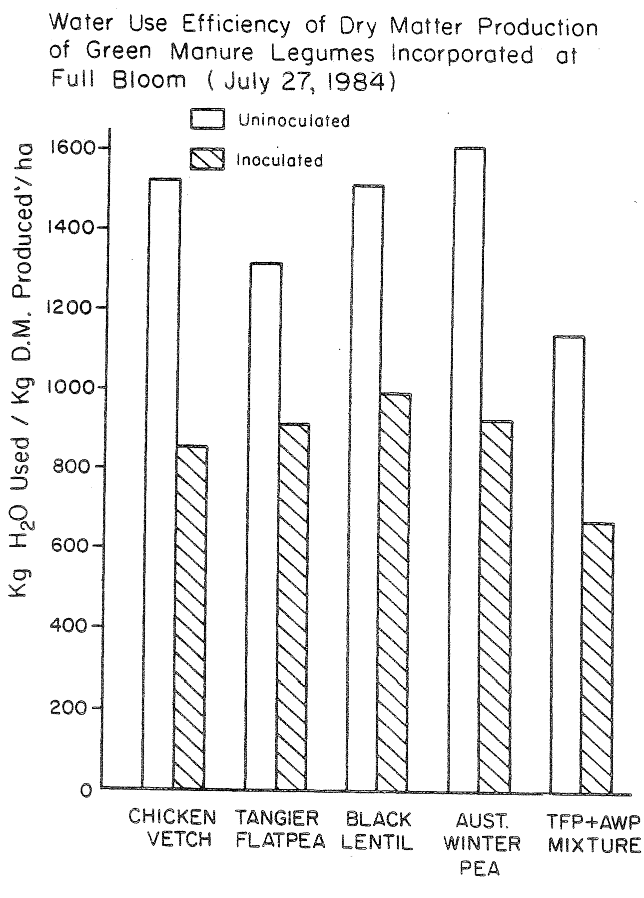


Figure 5.

Thus inoculation and the resultant symbiotic N_2-fixation had effected an average 63% increase in the efficiency of water use by these annual legumes (Fig. 5). This overall increase in WUE was significant (at p.05) and so was the individual inoculation effect on WUE for four of the five legume crops, with the exception being the black lentil.

In comparison to the inoculated legumes, the WUE of dry matter production by stubble-seeded spring wheat (cv. 'Canuck') up to July 27, 1984 was considerably lower, averaging about 1400 kg H_2O used/kg D.M. produced, i.e., an efficiency level very similar to the average WUE of the uninoculated legumes.

It was possible to assess cumulative N_2-fixation by inoculated legumes with reasonable accuracy by means of the difference method because the soil in the field where the plots were located was essentially free of indigenous cells of Rhizobium leguminosarum (pea rhizobia) and because cross contamination of uninoculated plots with R. leguminosarum from the planting of inoculated seeds into the other plots was very minimal since frequent root excavations revealed very few nodulated plants (generally fewer than 3%) in uninoculated plots. Our estimates show that all five legume crops were able to obtain, despite the severe drought stress, between half and three-quarters of their tissue-N through symbiotic N_2-fixation. As expected, the proportion of plant-N originating from fixation was greatest, at 78%, with chicken vetch, the most heavily nodulated legume, and it was lowest, at 51%, with Tangier flatpea (Table 2), the least nodulated legume.

Table 2. N_2-Fixation by Inoculated Green Manure Legumes Prior to Incorporation (July 27, 1984)

Legume	Plant-N derived from atmosphere*, %	Total N fixed, tops & roots, kg/ha	Proport'n of total fixed N in tops, %
Chicken vetch	78	33	94
Black lentil	64	21	95
TFP/AWP mixture	57	17	90
Aust. winter pea	59	15	90
Tangier flatpea	51	10	96

*Determined by the difference method.

This range of % plant-N derived from the atmosphere is several-fold greater than the 8 to 24% range estimated by Townley-Smith and Slinkard (1984) for lentils, field peas, Tangier flatpeas and faba beans grown on a Dark Brown soil under more favorable moisture conditions in 1983.

Although the total amounts of N fixed by the legume green manures were generally very low (Table 2), due to the severe drought conditions, the 33 kg N/ha gained with chicken vetch must be considered as adequate to meet the N-fertilizer requirements of a following cereal crop in the Brown soil zone when compared to the stubble fertilization range of 15-45 kg N/ha currently recommended by provincial guidelines (Saskatchewan Agriculture 1984).

As these annual legumes do not develop a very extensive root system as compared to that of perennial legumes, it was not surprising to find that between 90 and 96% of the total fixed N was contained in the above-ground legume growth (Table 2). This suggests that reasonable estimates of cumulative N_2-fixation by these green manure crops can be obtained by the difference method without the bother of a lot of laborious plant excavations and time-consuming root and nodule washings, provided that the uninoculated control legumes remain essentially nonnodulated until they are turned under or chemically desiccated.

Table 3. Water Use and Water Use Efficiency of N-Fixation by Green Manure Legumes and Wheat from May 3 to July 26, 1984

Crop	Water used by Uninoculated	Water used by Inoculated	Water use efficiency of N_2-fixation, mg N fixed/kg H_2O used
	cm H_2O	cm H_2O	
Chicken vetch	7.8	11.8	28
Black lentil	8.9	12.9	17
TFP/AWP mixture	9.2	10.0	17
Aust. winter pea	11.4	13.2	12
Tangier flatpea	8.2	9.7	10
Wheat	17.3	--	--

A comparison of total water consumption (Table 3) indicates that spring wheat used about double the amount of water that was consumed, on average, by the uninoculated legume crops. It also shows that inoculated green manure crops used, on average, only 26% more water while producing double the biomass of the uninoculated crops. Furthermore, these water consumption data emphasize again the very efficient use of water by the TFP/AWP mixture that tended to be the most productive of the five legume crops tested. The water use efficiency of N_2-fixation with chicken vetch was about threefold greater than with Tangier flatpea (Table 3). In general, the efficiencies obtained with these green manure legumes under severe drought stress were somewhat higher than the 3 to 16 mg N/kg H_2O range reported by Townley-Smith and Slinkard (1984) for four similar annual legumes when grown on a Dark Brown soil with better moisture conditions.

SUMMARY AND CONCLUSIONS

The period from September 1983 to August 1984 was the third driest on record at Swift Current. Thus it was not surprising that annual legumes seeded into wheat stubble with tall stubble trap strips produced very little biomass for green manure in the 8 weeks between emergence and soil incorporation at full bloom. However, it was promising to note that rhizobial inoculation and the resultant symbiotic N_2-fixation effected a 102% increase in top growth D.M. from a mean of 665 kg/ha for uninoculated to a mean of 1334 kg/ha for inoculated legumes. Inoculation also produced, on average, a 63% increase in the efficiency of water use and the TFP/AWP mixture, with a WUE of 675 kg H_2O used/kg D.M. produced, was significantly more efficient than any of the other green manure crops. The total amount of water used by uninoculated and by inoculated legumes corresponded to about half and two-thirds, respectively, of the amount consumed by stubble-seeded spring wheat during the same period. Due to the greater water use efficiency the leaves of nodulated legumes remained green and turgid for at least 10 days longer than those of nonnodulated legumes and of stubble-grown wheat during the most severe period of drought stress. Although the inoculated legumes were able to obtain between half and three-quarters of their plant-N from the atmosphere the average amount of N fixed by the five green manure crops was only 19 kg/ha, due to the extensive drought. However, the chicken vetch proved to be a remarkable N_2-fixer as this legume developed, despite poor seed quality and severe drought stress, by far the most abundant and persistent root nodulation and fixed an average of 33 kg N/ha, i.e., an amount that can well be considered adequate to cover the N-fertilizer requirement of a following wheat crop in the Brown soil zone.

The results of this study show that there are annual legumes and mixtures of legumes which could be used, when combined with bio-resource efficient management (e.g., inoculation, snow trapping), as fallow substitute-green manure for soil improvement and N-fertilizer saving in support of grain production even in the rather drought-prone Brown soil zone. Although green manuring with annual legumes appears to be agronomically feasible the major question to be addressed next is: "Can it also be managed to become an economically viable proposition for grain growers in southern Saskatchewan?"

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