Productivity of Four Annual Legumes as Green Manure in Dryland Cropping Systems

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ABSTRACT

Integration of green manuring as fallow replacement in dryland cereal production requires selection of well-adapted legumes. The objectives of this study were to (i) analyze vegetative growth of annual legumes and (ii) assess the relative merits of each legume as short-term green manure crop. Inoculated black lentil (*Lens culinaris* Medikus), Tangier flatpea (*Lathyrus tingitanus* L.), chickling vetch (*Lathyrus sativus* L.), and feedpea (*Pisum sativum* L.) were tested on an Orthic Brown Chernozem soil (Aridic Haploborolls) at Swift Current, SK, Canada, from 1984 to 1990. Legume species and years differed significantly in dry matter (DM) production of shoots, roots, and nodules; DM partitioning; growth habit; relative growth rate; and weediness. Total legume DM ranged from 601 to 3961 kg ha^{-1}, with 6-yr means of 1669 kg ha^{-1} for black lentil, 1486 for Tangier flatpea, 2230 for chickling vetch, and 3008 for feedpea. Nodulation was most abundant with chickling vetch and least with Tangier flatpea; nodule DM ranged from 2 to 329 kg ha^{-1}. Coefficients of determination between nodule and legume DM were $r^2 = 0.93$* for chickling vetch and $r^2 = 0.78$*** for feedpea, indicating their ability to benefit from symbiosis with *Rhizobium*. Nodulation was greatly influenced by soil mineral N and soil water. Average DM allocation to roots as a percentage of total legume biomass averaged ≈7% for chickling vetch and feedpea and 12% for black lentil and Tangier flatpea. Feedpea canopy height was double to triple that of black lentil. The degree of decumbency (stem length/canopy height) was 1.09 for black lentil, 1.19 for chickling vetch, 1.21 for feedpea, and 1.29 for Tangier flatpea. Growth rate analysis identified chickling vetch as an early-developing legume. Feedpea and chickling vetch were definitely more suited to green manuring in semiarid climates than black lentil and Tangier flatpea. Feedpea has good growth habits and greatest DM production. Chickling vetch also seems promising for marginal soils.**

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In the drier regions of the Canadian Prairies and the U.S. Northern Great Plains, soil organic matter concentrations and reserves of mineralizable N have been depleted under the conventional cropping system utilizing wheat (*Triticum aestivum* L.) and fallow (Haas et al., 1957; Campbell and Souster, 1982; Lamb et al., 1985). Thus, summer fallowing can no longer release enough available N to produce a profitable wheat crop. Frequent fallowing also increases soil loss and degradation by wind and water erosion and encourages the spread of salinization (Campbell et al., 1990). Some soil degradation can be reversed by extended cereal cropping with increased fertilization (Biederbeck et al., 1984; Janzen, 1987a), but recent droughts and low grain prices have made these alternatives uneconomical (Campbell et al., 1990).

Replacement of fallow with forage, grain, or green manure legumes protects the soil from loss and degradation and adds valuable N for improved fertility and subsequent cereal cropping (Welty et al., 1988; Wright, 1990; Campbell et al., 1991, 1992). Consequently, legumes are expected to play an increasingly important role in dryland cereal cropping systems of the USA (Sims and Slinkard, 1991) and the Canadian Prairies (Biederbeck, 1990). However, few grain growers in the Northern Plains have included forage, grain, or green manure legumes in their rotations. The aversion to green manuring was particularly strong in the more drought-prone Brown (Aridic Haploborolls) and Dark Brown (Typic Borolls) soil zones (Bieder-

Abbreviations: DM, dry matter; RGR, relative growth rate. *** Significant at the 0.001 probability level.

Table 1. Precipitation and evaporation during the study period at Swift Current, SK.

Year	Growing season precipitation (May 1–July 31)		Growing season Class A pan evaporation†	Annual total precipitation
	mm	%‡	mm	mm
1984	100	60	844	262
1985	73	44	908	279
1986	205	123	705	383
1987	129	78	802	256
1988	143	86	1085	287
1989	210	127	695	430
1990	179	108	699	296
Mean	148	89	819	313
Long-term mean (105 yr)	166	100	740†	357

† 31-yr mean for pan evaporation.
‡ Percent relative to long-term (105 yr) average.

beck and Looman, 1985). Here perennial legumes, such as alfalfa (*Medicago sativa* L.), produce insufficient biomass and fix a limited amount of N in the first year. When grown longer, perennial legumes will deplete soil water, so that yields of subsequent cereals are depressed (Janzen, 1987b). Biennial sweetclover (*Melilotus* spp.), underseeded in a cereal, severely restricts chemical weed control in the cereal crop, and, in the second year, it severely depletes soil moisture unless it is turned under early (Foster, 1990). Other reasons for not including legume green manures in cereal rotations are high seed cost and resultant reduced cash flow, establishment difficulties, and poor competition with weeds. These factors led Army and Hide (1959) and Brown (1964) to conclude in earlier reviews that legumes such as alfalfa and sweetclover should not be used for production of wheat in short rotations on drought-prone soils with the cultural techniques available at that time. The lack of acceptance of legume green manuring on grain farms in the drier regions was more recently ascribed largely to underdeveloped agronomic practices, lack of proper equipment, and inadequate weed control (Power and Biederbeck, 1991). In addition to declining soil fertility, past agricultural policies acted as external constraints (Sims, 1989).

The availability of improved crop production and soil management systems such as the use of tall stubble strips to increase snow retention (Steppuhn and Nicholaichuk, 1986), advances in applied N_2 fixation technology (Rice and Olsen, 1990), and concerns about energy shortages and declining soil fertility in the 1970s have spawned renewed scientific interest in green manures for dryland agriculture. This new research on green manures indicated that several annual legume species may have good potential to replace fallow in dryland cropping systems (Auld et al., 1982; Power, 1987, 1990).

Successful integration of green manuring into dryland cereal production requires selection of the best adapted legume species and development of the most effective legume management practice. However, relatively little information is available on the performance of annual legumes as green manures in the more drought-prone regions of the Northern Plains. Results from grain legume–cereal rotations are not applicable to green manuring because legume dry matter (DM) production, a key feature of green manure crops, and legume seed yield, the main criterion of cash crops, behave largely as independent variables (Somaroo, 1988). The need for identification of suitable legume species in field experiments is also indicated by greenhouse studies that show great differences in growth rate in response to soil temperature and moisture changes (Zachariassen and Power, 1991).

To be effective for fallow replacement in a semiarid environment, an annual legume for green manure or forage production must meet several major criteria (Biederbeck and Looman, 1985). These criteria are fast emergence to provide an early ground cover; high rate of N_2 fixation and biomass production; high water use efficiency (i.e., equal to or better than wheat); resistance to insects and diseases; and high potential for an emergency source of high protein forage in dry years. Various species of *Lupinus*, *Lathyrus*, *Trifolium*, and *Vicia* were screened at the Research Station in Swift Current, SK (Biederbeck and Looman, 1983), and preliminary results suggested that a lentil cultivar and a pea cultivar and two species of *Lathyrus* may be able to meet the requirements for green manuring in drought-prone regions. The overall objective of a comprehensive, multiyear experiment with these four annual legumes, initiated in 1984, was to evaluate their suitability as green manures in dryland cropping systems. The specific objectives of the work reported here were to (i) analyze the vegetative shoot and root growth of annual legumes seeded into wheat stubble and (ii) assess the relative merits of each legume for use as a short-term green manure crop in the Brown (Aridic Haploborolls) soil zone. The water use, N gain, legume management, and soil quality aspects of this study plus the effects of green manuring on yield and quality of subsequent wheat will be reported in forthcoming papers.

MATERIALS AND METHODS

Experimental Design

The field experiment was conducted at the Research Station in Swift Current, SK, on a Swinton silt loam (Ayers et al., 1985), which is an Orthic Brown Chernozem (Aridic Haploborolls), from 1984 to 1990. The legume species grown for green manure in rotation with 'Leader' spring wheat were 'Indianhead' black lentil; 'Tinga' Tangier flatpea; Morden Research Station Accession no. NC8a-3 chickling vetch (also known as grasspea or grassy peavine), and 'Sirius' feedpea. In 1984, Austrian winter pea [*Pisum sativum* subsp. *arvense* (L.) Poir. cv. Melrose] was used instead of feedpea. In 1985, chickling vetch seed was unavailable and it was replaced by a 1:1 mixture (by seed count) of feedpea and Tangier flatpea. Continuous wheat, fertilized with N and P according to soil test, and a wheat–fallow rotation were included as control treatments with low and high soil water storage, respectively. The same experimental design was established at two adjacent sites; one was seeded to green manure crops and the other was seeded to wheat in a given year. This arrangement ensured that both rotational phases were present each year. The four legume–wheat rotations and the two check treatments were arranged in a randomized complete block design with four replicates. The treatments were planted in plots measuring 6.75 by 18 m, with rows spaced 0.25 m apart.

Agronomic Practices

The legumes were seeded into wheat stubble. Snow trapping was practiced during the previous season by leaving four rows of head-clipped wheat stubble along the west side of each plot. The long-term average seeding rate was 43 kg ha^{-1} for black lentil, 74 for Tangier flatpea, 100 for chickling vetch, and 132 for feedpea, to provide target populations of ≈50 plants m^{-2} for the three large-seed legumes and 120 plants m^{-2} for the small-seed black lentil. The actual rates were adjusted every year for the level of seed germination. Commercial peat-base inoculants (Nitragin Co. products, now Liphatech Inc., Milwaukee, WI) and an effective sticking agent (NutriGum from the Nitragin Co.) were used at double the recommended rate for inoculation of the various legume seeds with the appropriate strains of *Rhizobium leguminosarum* bacteria. Seeding at a depth of 4 to 6 cm was usually completed between late April and early May. In the first year, seeding depth was only 2 cm and seeding date was delayed until 17 May. At legume seeding, P fertilizer (0–45–0 N–P–K) was side-banded, according to soil test. All plots received 24.2 kg P ha^{-1} in the first year and 0 to 6.5 kg ha^{-1} in the following years. Weed control was practiced since 1985 by preplant application of granular trifluralin (Treflan QR5; α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine; Dow Elanco, Indianapolis, IN) at a rate of 1.1 kg ha^{-1} a.i. with a Barber spreader (Barber Engineering Co., Spokane, WA) and incorporation to a 5-cm depth with a cultivator and attached spring tooth harrows. The green manure species were all incorporated on the same date with a tandem disk as soon as all legumes had reached the full bloom stage, usually in early July (8–10 wk after seeding).

Sampling Procedure

Measurement of legume stand densities were made at full bloom from 1984 to 1989. Canopy height and stem length were measured on plants in a defined one meter portion of row at intervals during the growing season from 1985 to 1987. Prior to green manure incorporation, aboveground DM production of legumes and associated weeds was determined separately by hand sampling in two 1.0-m^2 rectangles in each plot, followed by drying the plant material at 70 °C. Weeds were not sampled in 1984. From 1984 to 1989, the legume roots, their nutrient content, and their nodulation were also measured. Roots and soil were excavated to a 30-cm depth from a portion within each rectangle and soaked for 24 h in water to disperse the soil before recovering the root material by manual washing. All nodules were counted and carefully severed from the roots with a scalpel prior to drying of nodules and roots at 70 °C. The root and nodule weight per plant was measured on 10 and 20 plants of large-seed legumes and black lentil, respectively. Weather conditions were recorded at a meteorological site 0.2 km north of the experimental block. Data on potential evaporation were measured by a Class A pan device (Table 1). Gravimetric soil moisture content and soil nutrients, including nitrate, exchangeable ammonium and bicarbonate extractable phosphate, were determined on samples taken in five segments from two 120-cm-deep cores per plot prior to legume seeding (Table 2).

Calculations and Statistical Analysis

Root DM production in the top 30 cm of the soil was estimated from the product of mean root weight per plant multiplied by mean plant density. This root DM estimate was expressed as a percentage of the total legume shoot and root DM. The ratio of stem length to canopy height (degree of decumbency) was used to characterize the growth habit of the legumes. The stem length data were also used for seasonal growth analysis. Data recorded after growth intervals of different duration were normalized by computing the relative growth rate (RGR) on a daily basis for each observation interval. The

Table 2. Reserves of soil water and available plant nutrients at legume seeding in spring at Swift Current, SK.

Year	Soil water 0–120 cm	NH_4–N 0–30 cm	NH_4–N 0–120 cm	NO_3–N 0–30 cm	NO_3–N 0–120 cm	PO_4–P 0–120 cm	P fertilization rate
	ha cm	kg ha^{-1}					
1984	21.4	50	130	20	94	116	24.2
1985	20.0	33	134	18	89	95	4.4
1986	17.4	15	88	22	72	71	0.0
1987	20.3	40	169	25	127	105	0.0
1988	16.4	17	93	47	125	103	3.3
1989	17.6	16	87	74	219	100	6.5
1990	16.3	16	95	18	102	85	3.3
Mean	18.5	27	114	32	118	96	—
LSD (0.05)	—	3	11	9	45	12	—

RGR (% d^{-1}) was calculated by applying the growth analysis concept proposed by Lambers (1987), to the stem length records in the following manner:

$$\mathrm{RGR} = [(1/L)\, \mathrm{d}L/\mathrm{d}t] \times 100$$

where L is the stem length (cm) of the investigated plants at full bloom, and dL is the stem length increment (cm) during the interval dt (d).

The CoStat software package (Cohort Software, Berkeley, CA) was used to calculate analyses of variance, least significant differences for mean comparisons, and linear regressions between selected plant parameters as outlined by Little and Hills (1978). In addition to analyzing the annual performance of the different green manure species, the results of all years were combined as a split-plot design, with green manure species as main plots and years as subplots.

RESULTS AND DISCUSSION

Weed Competition

Weed DM, as percent of total aboveground DM, averaged 36% for Tangier flatpea, 31% for black lentil and for chickling vetch, and 18% for feedpea (Table 3). Comparison among years showed that all crops became severely weed infested during and after the drought of 1988. Under this extreme drought, the weed component—primarily flixweed (*Desurainia sophia* L.); stinkweed, also known as field pennycress (*Thlaspi arvense* L.); and wild buckwheat (*Polygonum convolvulus* L.)—was as high as 70% of the total aboveground plant growth. The severe weed infestation in 1990 was not due to weather conditions, but to legume stand densities that were less

Table 3. Weed dry matter as percent of total aboveground plant dry matter for four annual legume green manure crops at the full bloom stage (1985–1990, Swift Current, SK).

Year	Black lentil	Tangier flatpea	Chickling vetch	Feedpea	LSD (0.05)
	%				
1985	12	11	4	—	9
1986	12	16	—	1	8
1987	1	6	1	0	3
1988	59	70	38	33	24
1989	61	63	55	23	16
1990	38	52	59	33	17
Mean	31	36	31	18	—
LSD (0.05) year = 7					

than half of normal as a result of difficulties with a new drill at seeding time. The generally high weediness of our plots must also be ascribed partly to weed infestation pressure caused by adjacent experimental plots that allowed crop and weed growth until seed maturity and partly to the wide spacing between rows, which delayed closure of the legume canopy. Therefore, the absolute data on weediness in our experiment are not fully representative and should not be generalized. However, the relative performance of the four legumes confirms the finding by Wall et al. (1988) that chickling vetch is a poor weed competitor. Our 6-yr means demonstrate that Tangier flatpea and black lentil must also be classified as extremely poor weed competitors, while the feedpea is relatively competitive (Table 3).

Crop Establishment, Growth Habit, and Seasonal Development

All four legumes emerged within 10 to 14 d of seeding and reached full bloom within 6 to 7 wk after emergence. From 1984 to 1989, the crops established at average stand densities of 140 plants m^{-2} for black lentil, 56 for Tangier flatpea, 55 for chickling vetch, and 62 for feedpea (Table 4). The actual annual values, with the exception of 1990, ranged within ≈25% of the 6-yr mean for stand densities and were close to the target populations of 50 plants m^{-2} for the three large-seeded legumes and 120 m^{-2} for black lentil. Black lentil establishment was very poor in the drought year of 1988. The establishment of feedpea and Tangier flatpea was below average in 1989, while chickling vetch did not establish well in the first year due to poor seed quality.

The type of growth habit affects the suitability of a crop for green manuring; e.g., a high degree of decumbency provides good ground cover for soil protection against wind and water erosion. Tall, erect-growing crops are more effective in over-winter snow trapping under a no-tillage system if green manure growth would be chemically terminated at the full-bloom stage of development. In the 3 yr from 1985 through 1987, the canopy height of feedpea was two- to threefold that of black lentil; canopy height was intermediate for Tangier flatpea and chickling vetch (Fig. 1). Although the general growth pattern of stem length was similar to that indicated by canopy height, marked differences occurred in the degree of decumbency among the four legumes. On a 3-yr average, the decumbency degree at full bloom was 1.09 for black lentil, 1.19 for chickling vetch, 1.21 for feedpea, and 1.29 for Tangier flatpea. These ratios indicate that black lentil has an erect growth habit, while Tangier flatpea has a more decumbent growth habit. Feedpea appeared to have a growth habit suitable for green manuring, since it produced both a tall and a decumbent canopy (Table 5).

Table 4. Stand density of four annual legumes at full bloom (Swift Current, SK).

Year	Black lentil	Tangier flatpea	Chickling vetch	Feedpea	LSD (0.05)
	plants m^{-2}				
1984	162	72	41	—	20
1985	150	70	—	78	22
1986	139	46	53	57	19
1987	132	43	66	66	17
1988	111	63	65	60	31
1989	146	41	50	48	15
Mean	140	56	55	62	

Growth curves for feedpea and chickling vetch best fit a sigmoid curve starting at a low postemergence growth rate, continuing at a steadily increasing rate toward full bloom, reaching a maximum at the podding stage, and tapering off toward plant maturity (Jensen, 1987; Wesselmann and Caesar, 1989). In our study, all four green manure crops fulfilled the early postemergence growth paradigm at a daily RGR ranging from 0.6 to 2.1%. Later in the growing season, the growth patterns differed among crops and years according to weather conditions (Fig. 2). Tangier flatpea consistently exhibited a nonlinear development, with pronounced fluctuations in RGR. The marked decline in RGR by all legumes, except feedpea, during advanced growth in 1986 was caused by a prolonged decrease in air temperature. The feedpea always responded more to precipitation and less to temperature than did the other three legumes. In contrast to the sharp growth fluctuations in the wet year (1986), development of black lentil and chickling vetch was more gradual in dry years (1985, 1987). Thus, by applying the sigmoid growth paradigm to our RGR results, chickling vetch and the flatpea can be identified as early-developing crops that reach their full growth potential in a shorter period than black lentil and feedpea. These data corroborate our field observations from this and other locations that chickling vetch generally reached full bloom (i.e., green manure maturity) at least 1 wk earlier than black lentil. Earliness reduces soil water depletion, rendering chickling vetch more suitable for fallow replacement green manuring (Somaroo, 1988).

Nodulation

Nodules form the reactor that supplies legumes with atmosphere-derived N_2 through symbiotic fixation. Nodule numbers and DM provided an estimate of the potential N_2–fixing capacity of these four annual legumes (Table 6). Differences in nodulation among green manures were not consistent. However, chickling vetch and Tangier flatpea were definitely the best and the least nodulated legumes, respectively, both in terms of nodule counts and mass. Variation among crops may be caused to some extent by differences in crop development. Root nodulation by chickling vetch was not only more abundant, but it also extended much farther beyond the crown region. Thus, chickling vetch had a higher potential for biological N_2 fixation than the other legumes in this study. The year comparisons showed the same nodulation pattern for all four legumes, with high nodulation in the wet years (1986 and 1989) and poor nodulation in the drought year of 1988 (Tables 1 and 6). The response to weather conditions was very strong for Tangier flatpea and chickling vetch, while feedpea and black lentil responded only moderately. The data suggest that legume growth was severely limited by dry growing conditions, greatly reducing the number and mass of nodules and, thus, the potential N_2 fixation (Bremer et al., 1988; Sprent, 1976). However, in some years nodulation was also inhibited

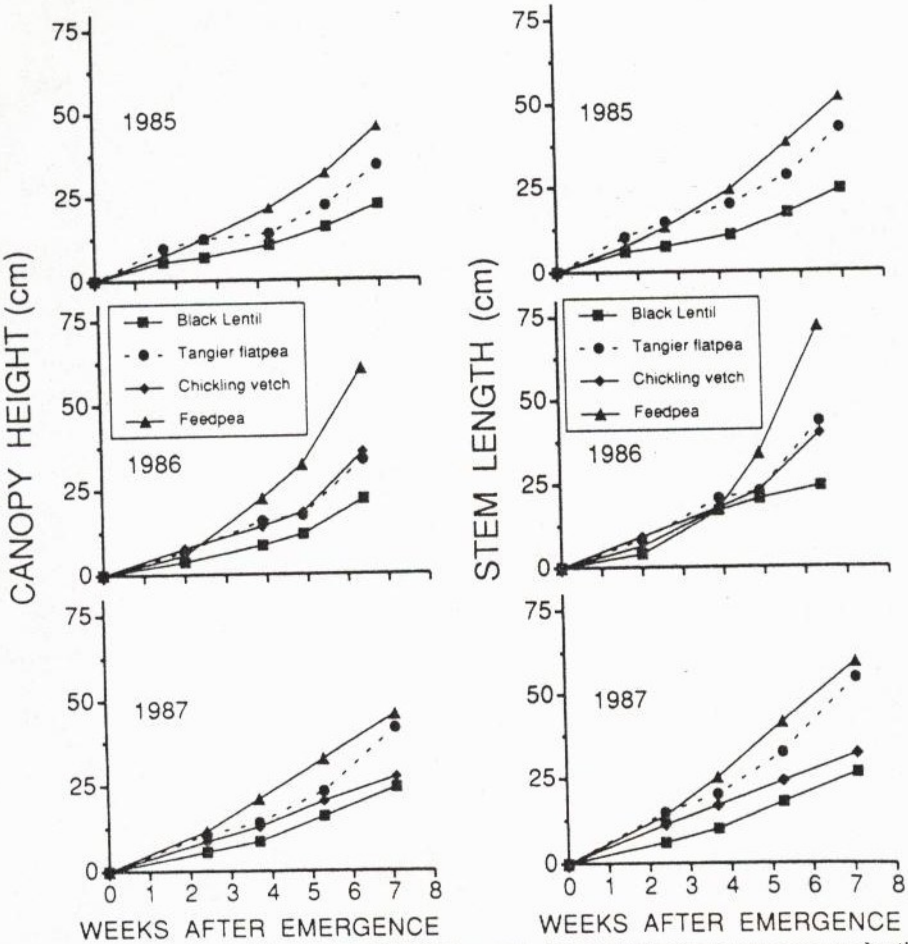

Fig. 1. Growth characteristics of four annual legumes at Swift Current, SK, during green manure production (1985–1987).

2 and 6). This is in agreement with the report by Bremer et al. (1988) that the proportion of N assimilated from the atmosphere by lentil and pea growing under drought stress in Saskatchewan declined sharply with increasing soil nitrate levels ($r^2 = -0.95^{***}$), and also confirmed Liebhard's (1989) observation with peas that nodule counts were negatively influenced by ascending mineral N supply.

Aboveground Dry Matter

Green manure yields varied significantly among legumes and even more among years (Table 7). The aboveground DM yields produced by legumes ranged from 519 to 3602 kg ha^{-1}, while the yields produced by legumes plus associated weeds ranged from 1718 to 4623 kg ha^{-1}. Yields were usually high for feedpea and chickling vetch and markedly lower for black lentil and Tangier flatpea. The poor performance of all legumes in the first year must be attributed to inappropriate agronomic practices and limited knowledge of seeding technology at the beginning of the experiment. In 1984, seeding was delayed, seeds were placed too shallow into dry soil, and weed control was not practiced. In the extreme drought year of 1988, DM production by all legumes was significantly depressed. Compared with the wet years of 1986 and 1989, the productivity of feedpea and Tangier flatpea in the extreme drought year of 1988 was decreased by ≈70% and that of black lentil and chickling vetch by ≈50%, indicating a higher drought sensitivity for the former two crops.

In most years, legume top growth was positively correlated with the recorded nodulation pattern (Table 8), confirming similar findings by Sprent (1976) with soy-

Table 5. Growth habit of four annual legumes in terms of canopy height and degree of decumbency at the full bloom stage (1984–1987, Swift Current, SK).

Year	Black lentil	Tangier flatpea	Chickling vetch	Feedpea	LSD (0.05)
		Canopy height, cm			
1984	23.9	35.4	26.5	—	6.1
1985	22.4	34.2	—	45.7	2.7
1986	22.0	33.4	35.7	60.4	2.4
1987	24.2	41.4	27.3	45.6	5.3
Mean	23.1	36.1	29.8	50.6	—
LSD (0.05) year = 2.5					
		Degree of decumbency†			
1984	1.07	1.28	1.28	—	0.19
1985	1.08	1.24	—	1.13	0.08
1986	1.10	1.30	1.12	1.19	0.06
1987	1.10	1.32	1.18	1.32	0.15
Mean	1.09	1.29	1.19	1.21	—
LSD (0.05) year = 0.06					

† Degree of decumbency is the ratio of stem length to canopy height.

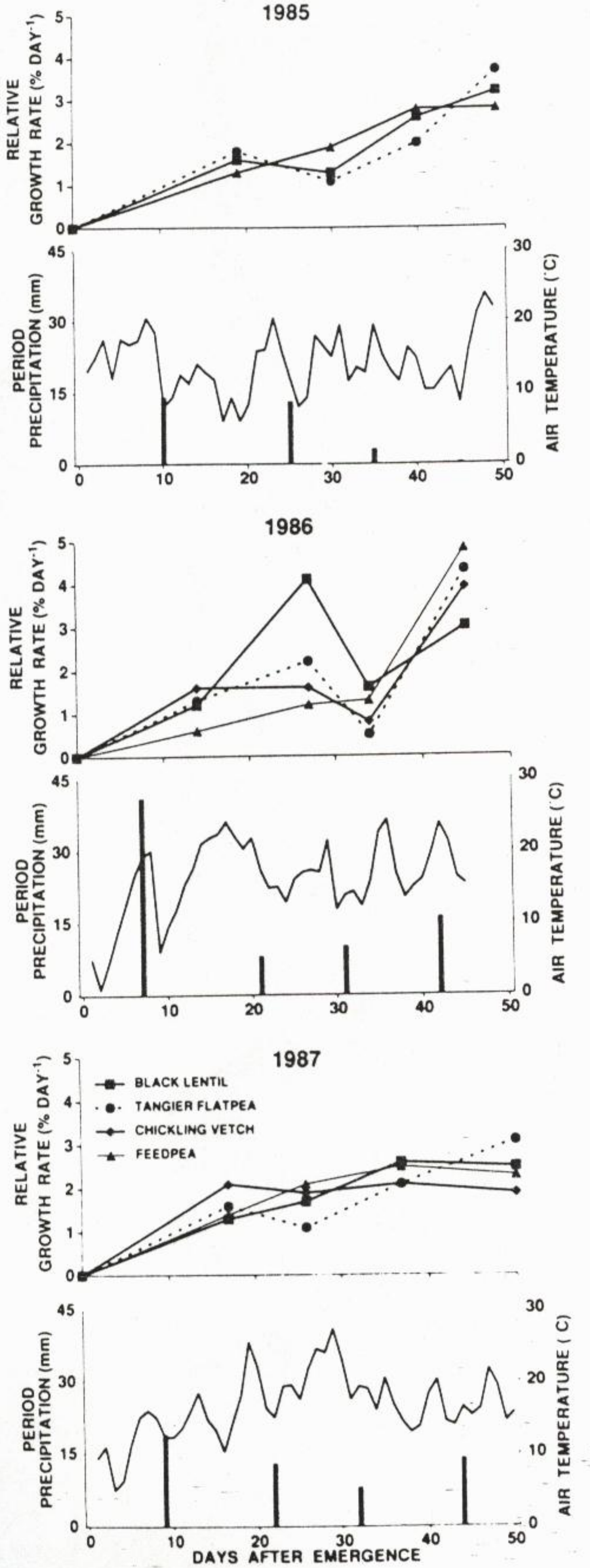

Fig. 2. Relative growth rate of four green manure legumes at Swift Current, SK, during four periods from emergence to full bloom as influenced by weather conditions. Mean daily temperature = (max + min)/2.

Table 6. Nodulation of four annual legumes at full bloom (Swift Current, SK).

Year	Black lentil	Tangier flatpea	Chickling vetch	Feedpea	LSD (0.05)
			Nodule number†		
			nodules plant⁻¹		
1984	22	11	86	—	32
1985	27	18	—	70	14
1986	46	40	163	73	15
1988	30	4	39	11	6
Mean	31	18	96	51	—
LSD (0.05) year = 8					
			Nodule mass†		
			kg ha⁻¹		
1984	15	10	28	—	NS
1985	13	24	—	48	23
1986	92	207	329	105	52
1987	16	8	17	24	11
1988	5	2	6	5	NS
1989	62	40	77	100	NS
Mean	34	48	91	56	—
LSD (0.05) year = 17					

† Nodule numbers and nodule mass within 0–30 cm soil depth.

bean. All four legumes produced high DM yield with intensive nodulation and low DM yield with poor nodulation. Although significant relationships existed for all four legumes, the correlation between nodule and legume DM was much closer for chickling vetch and feedpea than for the other annual legumes. This suggests that chickling vetch and feedpea were able to benefit more extensively from seed inoculation and the resultant symbiosis than the other annual legumes. The curvilinear relationship between legume DM yield and nodulation mimics a typical crop response to N fertilizer. The regression of legume DM on nodule DM was greatly improved by excluding the atypical 1987 data, which reflected unusually high mineral N levels in the soil which, in turn, have been reported to depress nodule function (Bremer et al., 1988; Pate and Atkins, 1983). The close linkage between top growth and nodulation is corroborated by the findings of Keck et al. (1984) that specific nodule activity (acetylene reduction) and top growth were enhanced by increasing water supply. Growth of the annual green manure legumes in this study was limited by insufficient water supply, resulting in greatly reduced nodulation and potential N_2 fixation and utilization of mineral soil N.

In 1989, more humid growing conditions (Table 1) and extremely high soil N availability (Table 2) resulted in high aboveground DM production by all four legumes, as well as high associated weed growth (Table 7). These high yields must be largely attributed to enhanced weed growth with black lentil, Tangier flatpea, and chickling vetch (Table 3). Dry matter yields of these legume species excluding weeds were significantly lower in 1989 than in 1986, the other wet year (Tables 1 and 7). The relatively low response of legume growth to enhanced soil N availability suggests that the weeds were more competitive than these legumes in utilizing soil N. A comparison of the two dry years (1985 and 1987) with much lower weed infestation showed significantly higher DM production for all four legumes in the year (1987)

Table 9. Relative root dry matter allocation of four annual legumes as percentage of total shoot plus root biomass (Swift Current, SK).

	Relative root dry matter				
Year	Black lentil	Tangier flatpea	Chickling vetch	Feedpea	LSD (0.05)
	%				
1984	6	7	6	—	NS
1985	9	5	—	4	2
1986	24	30	12	10	5
1987	9	3	5	5	1
1988	15	15	10	10	4
1989	10	10	10	7	2
Mean	12	12	8	7	—
LSD (0.05) year = 2					

the low-fertility year 1986 were much more pronounced than the difference in the aboveground DM production for all legumes except feedpea (Tables 1, 2, and 7). Our findings support the concept of a *functional equilibrium* between shoot and root growth in response to environmental conditions (Brouwer, 1983). This concept assumes that shoot and root do not respond to the size of the other plant part to maintain a *morphological equilibrium*, but rather to the effectiveness with which basic needs are obtained from the environment by these complementary organs (Van Noordwijk and De Willigen, 1986). Thus, in 1986 many more assimilates were allocated into the root compartment to satisfy the plant nutrient, presumably phosphate (Table 2), demand at a lower soil fertility level than in 1989. The same functional equilibrium concept also applies to the dry years of our field study. Under a relatively uniform soil fertility regime, root DM allocation reached a maximum in 1988, when the moisture supply was most limited (Tables 1 and 8). This finding corroborates observations with soybean showing an increase in root growth rate and a decrease in shoot growth as a result of water stress (Hoogenboom et al., 1986). However, the root DM data demonstrate clearly that the biomass contribution of the root behaves to a large extent independent of the top growth. Therefore, the process of selecting adequate green manure crops can be misleading if the suitability of green manure legumes is based solely on aboveground DM production.

SUMMARY AND CONCLUSIONS

Field observations of crop development and data on DM production revealed significant differences in the performance of four annual legumes in response to dry and erratic growing conditions and to soil fertility regime in the semiarid Northern Great Plains. We also demonstrated that the inclusion of root DM and nodulation measurements can greatly enhance the understanding of the legume performance and should, therefore, become part of further green manure screening trials. In our study, the overall picture presented the feedpea and chickling vetch as more suitable for green manuring than black lentil and Tangier flatpea in semiarid climates. Feedpea consistently outproduced the other three legumes and was the most suitable green manure crop. This was true not only in terms of organic matter contribution, but also because the tall and decumbent growth habit of feedpea rendered it more effective for soil conservation. High weed competitiveness is another striking agronomic advantage of feedpea over the other legumes. However, for green manuring to replace fallow on marginal soils, the chickling vetch with its earliness of flowering, high drought tolerance, abundant nodulation, and weaker response to indigenous soil fertility could be the legume of choice.

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