Seeding rate affects establishment of *Native Perennial Legumes* in the upper midwestern US

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ABSTRACT

In Minnesota, perennial native legumes (Fabaceae) differed in population and yield response to seeding rates of 14, 67, 135, 275, and 538 pure live seeds (PLS)/m^2 (1.3, 6.3, 12.5, 25, and 50 PLS/ft^2) when seeded in cultivated seedbeds with little bluestem (*Schizachryium scoparium* (Michx.) Nash [Poaceae]). Average seeding-year populations were greatest for Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM. ex B.L. Robins. & Fern.) (131 plants/m^2); intermediate and similar for false indigo (*Amorpha fruticosa* L.), wild blue indigo (*Baptisia australis* (L.) R. Br), and wild senna (*Senna hebecarpa* (Fern.) H.S. Irwin & Barneby) (average of 72 plants/m^2); and least for purple prairie clover (*Dalea purpurea* Vent) (27 plants/m^2). Seeding-year populations of all legumes increased linearly as seeding rate increased. Second-year biomass yield of legumes in mixture with little bluestem ranged from 1.1 Mg/ha (0.5 tons/ac) for purple prairie clover to 5.6 Mg/ha (2.5 tons/ac) for Illinois bundleflower.

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KEY WORDS
biomass yield, plant populations, false indigo, wild blue indigo, Illinois bundleflower, purple prairie clover, wild senna, Fabaceae

NOMENCLATURE
USDA NRCS (2005a)

Agriculture in the upper midwestern US is currently dominated by the production of corn (*Zea mays* L. [Poaceae]) and soybean (*Glycine max* L. [Fabaceae]). This annual cropping system is dependent upon annual tillage, chemical control of weeds and pests, fossil-fuel-powered traction, and application of synthetic fertilizers. Although highly productive, this cropping system leaks nitrogen (N) into the Gulf of Mexico (Rabalais and others 2002), contaminates surface and groundwater with pesticide residues (Hayes and others 2002), and reduces biodiversity on the agricultural landscape. Improving the environmental, economic, and social sustainability of agriculture in the upper midwestern US requires a move from a few annual row crops to perennial forage and grain crops (Cox and others 2002; Sheaffer and Seguin 2003).

Perennial legumes were once integral components of prairie ecosystems of the midwestern US (Weaver 1954). They are now components of conservation and restoration plantings but also have agronomic potential as forage and grain crops (CAST 1999). Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM. ex B.L. Robins. & Fern. [Fabaceae]), a widely distributed legume, has forage quality similar to alfalfa (*Medicago sativa* L.) (Fischbach and others 2005) and seed yield similar to soybean (Kulakow and others 1990; DeHaan and others 2003). Another legume, purple prairie clover (*Dalea purpurea* Vent [Fabaceae]) has high forage quality and has been evaluated for use in mixture with warm-season grasses (Washburn and Barnes 2000).

Despite the agronomic potential of perennial legumes native to the upper midwestern US, little research has evaluated their biomass or seed yield. A major roadblock to this research has been lack of dependable and cost-effective establishment techniques that produce vigorous stands. Warm-season grasses and legumes are notoriously difficult and costly to establish due to competition from annual weeds and the high cost of seeds (Masters 1997). Many seed suppliers recommend small quantities of native legumes in mixtures for landscape restoration but research is scarce that evaluates seeding rates for establishment of native legumes in midwestern US. Wildflower nurseries and prairie restoration companies often recommend seeding rates of 135 pure live seeds (PLS)/m^2 or less for wildflower and forb plantings (for example, USDA NRCS 2005b; Prairie Moon Nursery 2005). Posler and others (1993) used a seeding rate of 275 PLS/m^2 for establishing Illinois bundleflower. The recommended seeding rate for alfalfa in Minnesota is 538 PLS/m^2 (Sheaffer and others 2003).

Our objective was to evaluate the effect of seeding rate on establishment and biomass yield of native legumes (Fabaceae) including Illinois bundleflower, wild senna (*Senna hebecarpa* (Fernald) H.S. Irwin & Barneby), false indigo (*Amorpha fruticosa* L.), wild blue indigo (*Baptisia australis* (L.) R. Br), and purple prairie clover when seeded with the native grass little bluestem (*Schizachryium scoparium* (Michx.) Nash [Poaceae]). We selected these legumes based on preliminary trials that showed their potential to produce forage or grain. We grew these legumes with little bluestem because they are not usually grown in monoculture and the grass has potential to enhance winter cover and suppress weeds while providing minimal competition for light.

MATERIALS AND METHODS

Identical field experiments were established at Rosemount, Minnesota (44°53'N, 93°13'W), in 1999 and 2000 on a Tallula silt loam (coarse-silty, mixed, mesic Typic Hapludoll) with pH of 6.9 and phosphorus = 30 mg/kg (ppm) and potassium = 67 mg/kg (ppm). The sites were tilled and seeded on 19 Jun 1999 and on 7 Jun 2000. The previous crop for each experiment was soybean.

The experiment was a randomized complete block design with treatments in a split-plot arrangement with 4 replications. Whole plots were false indigo, wild blue indigo, Illinois bundleflower, purple prairie clover, and wild senna. Each whole plot was divided into five, 1.8 m x 6 m (6 ft x 20 ft) subplots with seeding rate treatments of 14, 67, 135, 275, and 538 PLS/m^2 (1.3, 6.3, 12.5, 25, and 50 PLS/ft^2). Legume seeds were obtained from the University of Minnesota Native Perennial Legume Collection. Seeds were from plants grown from seed collected from native stands in Minnesota.

All seeds were mechanically scarified with sandpaper and inoculated with 10 g/kg seed (0.16 oz/lb) of legume inoculant using 30 ml/kg seed (0.46 oz/lb) of a 10% sucrose solution as an adhesive. Seeds were drilled with a 10-row plot seeder with 15-cm (6-in) row spacing. Following seeding of legumes, all plots were immediately broadcast seeded with 323 PLS/m^2 (30 PLS/ft^2) of 'Badlands' little bluestem purchased from a Minnesota seed producer.

To control weeds, experiments were mowed to 15 cm (6 in) on 2 and 25 August 1999 for the 1999 seeding, and on 14 and 25 July 2000 for the 2000 seeding. Both seedings were sprayed with 0.65 l ai/ha (0.07gal/ac) pendimethalin (Prowl 3.3EC, *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine, American Cyanamid Company, Parsippany, New Jersey) in late October of the seeding year to eliminate legume seedling recruitment because we wanted to evaluate the impact of the initial seeding. No weed control was applied in the year following seeding.

Legume populations in the establishment year and the year following seeding were determined by counting plants in two 0.25 m^2 (2.7 ft^2) quadrats per subplot. Counts were taken for the 1999 seeding on 19 July 1999 and 15 May 2000 and for the 2000 seeding on 1 August 2000 and 26 June 2001. Biomass yield was determined, in the year following seeding on about 10 August in 2000 and 2001 when all legumes were flowering, by harvesting a 0.9 m x 3 m (3 ft x 10 ft) strip to a 15 cm (6 in) residual height from the center of each subplot using a flail harvester. Random 1 kg (2.2 lb) subsamples of the harvested biomass from each subplot were weighed, dried at 60 °C (140 °F) for 48 h, weighed again, and used to determine dry matter (DM) yield.

Legume, little bluestem, and weed abundance were visually estimated immediately prior to harvest. To calibrate the visual estimates, a random 1-kg sample from each plot in one replication was hand-clipped prior to harvest; separated into legume, little bluestem, and weed components; and dried to determine DM composition.

Analyses of variance (ANOVA) were performed using the PROC ANOVA function of SAS (SAS Institute 2001) to test for differences in DM yield and stand counts due to year, native legume species, seeding rate, and legume by seeding rate interactions. Treatment effects were considered significant at $P < 0.05$. Years, native legumes, and seeding rates were considered independent variables in the ANOVA. For selected data, significant differences ($P \leq 0.05$) among treatments were separated with the least significant difference procedure. To describe the relationship of plant populations and biomass yield with seeding rate, regression analysis was conducted (SAS Institute 2001).

RESULTS AND DISCUSSION

Air temperatures and rainfall for 1999, 2000, and 2001 are shown in Table 1. Air temperatures were near normal each month with some minor departures. Rainfall, a critical factor

TABLE 1

Weekly temperature and rainfall departures and 30-y average for weeks within each month of the growing season for 1999, 2000, and 2001 at Rosemount, Minnesota.

	May		Jun				Jul				Aug				Sep		
	3 [z]	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Temperature (°C)																	
(departure 1999)	0.9 [y]	0.8	0.9	2.4	-4.1	3.2	-1.7	-0.2	1.5	2.1	2.4	-1.3	-1.5	0.1	2.6	3.8	0.1
(departure 2000)	-0.2	0.3	-2.7	-0.3	-3.1	-0.3	-1.7	0.4	1.1	-5.2	-1.2	-0.8	1.2	-0.8	1.1	1.1	-0.5
(departure 2001)	6.3	-5.7	-0.3	-2.2	1.3	-1.2	4.2	-0.2	1.4	3.4	0.3	4.5	3.3	-0.1	2.4	1.3	3.6
30-y average	14.3	16.2	16.6	18.7	19.8	20.7	21.5	21.5	22.4	22.5	22.4	21.8	21.5	20.3	19.7	18.5	17.2
Precipitation (mm)																	
(departure 1999)	31 [y]	-24	-10	25	-23	-2	57	-9	-22	-8	90	-18	39	-1	-23	-13	10
(departure 2000)	22	-6	22	13	2	-6	-3	180	-19	-21	-19	-5	7	11	-15	-13	-22
(departure 2001)	-22	43	-8	-6	43	-19	-24	-23	-23	-8	-4	-8	-23	2	-22	4	-1
30-y average	23	24	25	26	26	26	25	24	23	23	23	23	23	23	23	23	22

[z] Weeks within months.
[y] Conversions: 1 inch = 0.04 mm; °F = 1.8(°C) + 32

in seedling establishment, was inconsistent with the 30-y average. Rainfall in 1999 was often below the 30-y average for most weeks in June, July, and August. In 2000, rainfall was near normal in June but below normal until early August except for a 180-mm (7.1-in) rainfall event in the second week of July. In June, July, and August 2001 rainfall was below normal. During September, concurrent with declining air temperature, legume growth rate had decreased. The first frosts that occurred by mid-October terminated all growth.

Legume Populations

Populations in both establishment years were greatest for Illinois bundleflower and least for purple prairie clover (Table 2; Figure 1). Populations of all legumes except purple prairie clover were initially greater for the 1999 than for the 2000 seeding. Establishment-year populations of all legumes increased with seeding rate. The response to increasing seeding rate was similar (that is, year x treatment interactions were not statistically significant, $P = 0.05$) for the 1999 and 2000 seedings and is shown as an average in Figure 1. The relationship of seeding rate to plant population was linear ($P < 0.001$) for all legumes with population changes in response to seeding rate greatest for Illinois bundleflower and least for purple prairie clover. For all legumes, the highest percentage of seeds developing into plants occurred at the 14 PLS/m^2 seeding rate and the lowest occurred at the 538 PLS/m^2 seeding rate (Table 3). For Illinois bundleflower and false indigo, 100% of the planted seeds emerged and successfully established at the 14 PLS/m^2 rate. Launchbaugh and Owensby (1970), working with several native grasses, also observed a negative association between increasing seeding rate and plant establishment.

TABLE 2

Average populations (plants/m²) of native legumes in the seeding year and the year following seeding. Data averaged for 5 seeding rates.

Seeding year	Data year	Plants/m² False indigo	Wild blue indigo	Illinois bundlefower	Purple prairie clover	Wild senna	LSD (0.05)
1999	Establishment	89 [z]	93	189	22	63	37
	Year after seeding	45	48	161	58	108	33
2000	Establishment	60	68	131	50	59	21
	Year after seeding	58	40	84	60	86	15

[z] Conversion: $(plants/m^2)/10.8 = plants/ft^2$

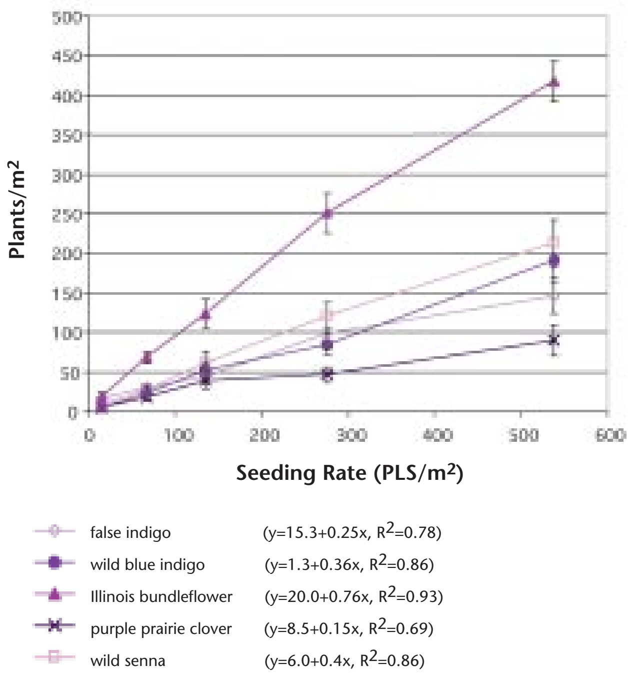

Figure 1. Seeding rate affects seeding year (July) populations of native legumes. Data are averaged for 1999 and 2000. Regression equations and R^2 values describing the relationship between seeding rate and plant population are shown in parentheses for each legume. Standard error bars are shown for each data point.

CONVERSIONS

PLS/m²	PLS/ft²
14	1.3
67	6.3
135	12.5
275	25.0
538	50.0

Populations of false indigo, wild blue indigo, and Illinois bundleflower declined from the establishment year to the year after seeding; whereas, populations of purple prairie clover and wild senna were the same or increased slightly. We speculate that the population decline may have occurred because of disease or winter injury whereas the population increase could be attributed to seedlings that emerged after the initial count.

Second-year populations of all native legumes increased ($P < 0.05$) with seeding rate in both the 1999 and 2000 experiments; however, in contrast to the seeding year, the response in the second year differed ($P < 0.05$) for the 2 experiments (Figures 2 and 3). The range in plant population among legume species the year after seeding was much greater for the 1999 seeding than for the 2000 seeding. For the 1999 experiment, the second-year response was linear for all legumes with Illinois bundleflower having greater populations than the other legumes at the 275 and 538 PLS/m² seeding rates, but similar populations as wild blue indigo, false indigo, and wild senna at the 14, 67, and 135 PLS/m² rates. Purple prairie clover populations were lower than for the other legumes at all seeding rates. For the 2000 experiment, Illinois bundleflower and wild senna were among the legumes with the greatest populations at all seeding rates while false indigo, wild blue indigo, or purple prairie clover were among the legumes with the lowest populations. The response of false indigo, Illinois bundleflower, and wild senna populations to seeding rate was best defined by a logarithmic function whereas the responses for the other legumes were linear.

Biomass Yield

Seeding rate x legume interactions ($P < 0.05$) for second-year biomass yield occurred for both the 1999 and 2000 experiments. For the 1999 seeding, Illinois bundleflower and wild senna had greater yields than the other 3 legumes at all seeding rates (Figure 4). Illinois bundleflower had greater yield than wild senna at the 275 PLS/m² seeding rate, but the legumes had

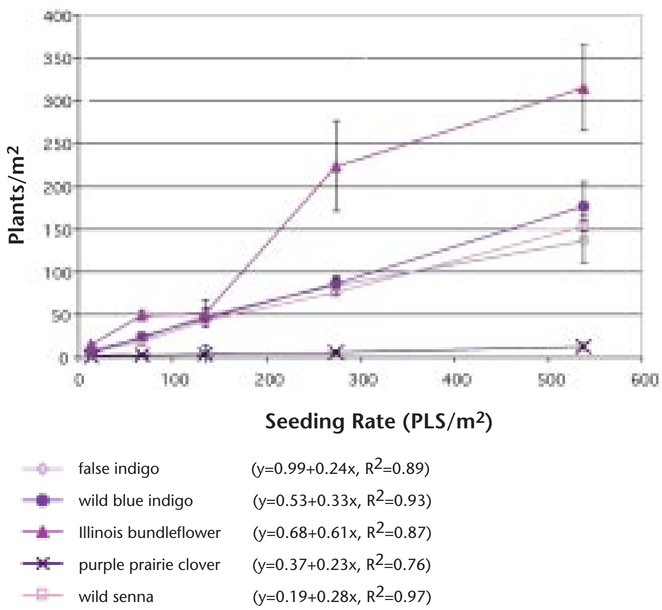

Figure 2. Seeding rate affects populations of 5 native legumes in May 2000 following the 1999 seeding. Regression equations and R^2 values describing the relationship between seeding rate and plant population are shown in parentheses for each legume. Standard error bars are shown for each data point.

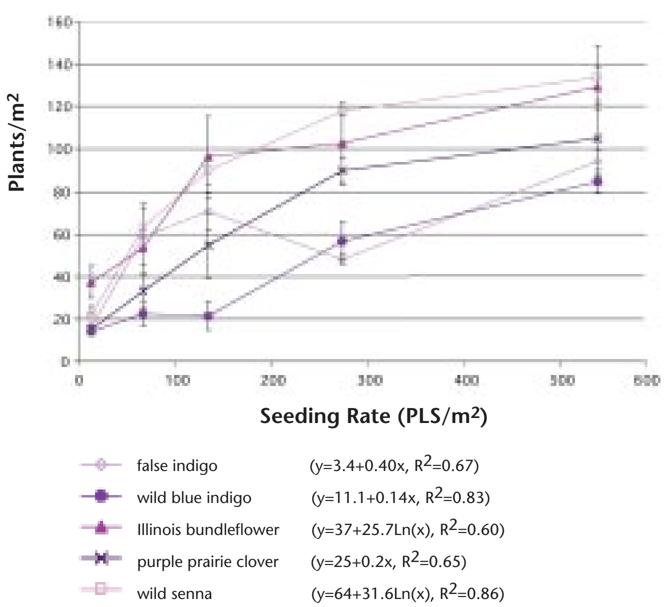

Figure 3. Seeding rate affects populations of 5 native legumes in May 2001 following the 2000 seeding. Regression equations and R^2 values describing the relationship between seeding rate and plant population are shown in parentheses for each legume. Standard error bars are shown for each data point.

TABLE 3

Percentage of seeds developing into plants in the seeding year. Data averaged for 1999 and 2000 seeding years.

Seeding rate	False indigo	Wild blue indigo	Illinois bundleflower	Purple prairie clover	Wild senna
PLS/m² (ft ²) ᶻ			%		
14 (1.3)	100	45	100	35	64
67 (6.3)	44	36	100	26	42
135 (12.5)	33	40	92	28	45
275 (25)	37	32	93	17	45
538 (50)	27	35	78	16	40
LSD (0.05)	23	11	20	9	17

z PLS = pure live seeds

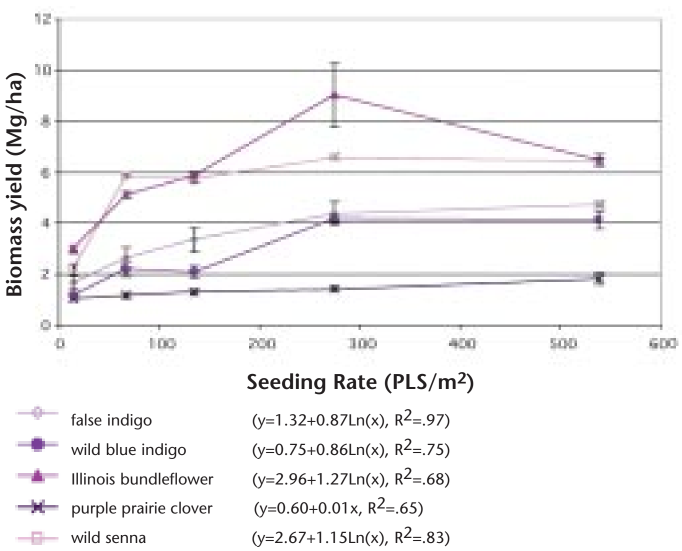

Figure 4. Seeding rate affects biomass yield of 5 native legumes in August 2000 following a 1999 seeding. Regression equations and R^2 values describing the relationship between seeding rate and plant population are shown in parentheses for each legume. Standard error bars are shown for each data point.

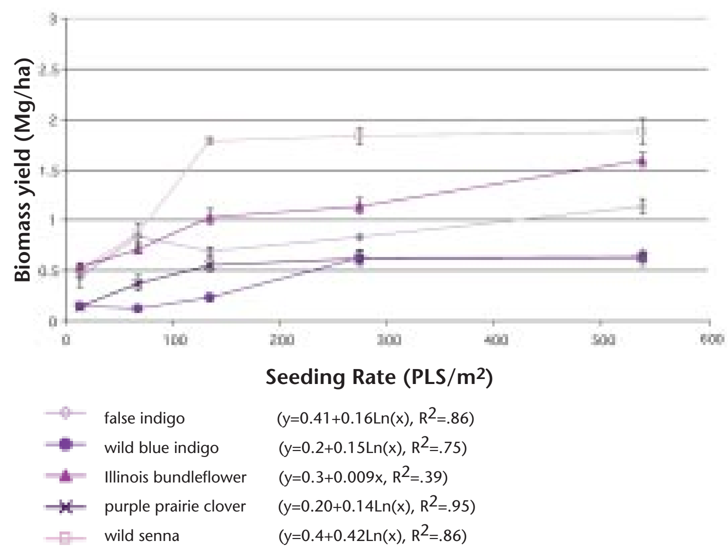

Figure 5. Seeding rate affects biomass yield of 5 native legumes in August 2001 following a 2000 seeding. Regression equations and R^2 values describing the relationship between seeding rate and plant population are shown in parentheses for each legume. Standard error bars are shown for each data point.

similar yields at all other rates. False indigo had greater yield than wild blue indigo at the 135 PLS/m² seeding rate, but yields were similar for the 2 legumes at all other seeding rates. Not unexpectedly, purple prairie clover was the lowest yielding legume at all seeding rates because of its relatively short stature and marginal stands even at high seeding rates

For the 2000 seeding, wild senna had the highest biomass yields at the 135, 275, and 538 PLS/m² seeding rates but had similar yields as false indigo and Illinois bundleflower at the two lowest seeding rates (Figure 5). Illinois bundleflower had higher yields than false indigo at 135, 275, 538 PLS/m² and higher yields than purple prairie clover and wild blue indigo at all seeding rates. Purple prairie clover and blue wild indigo had similar yields at 275 and 538 PLS/m², but wild blue indigo had lower yields than purple prairie clover at the 3 lowest seeding rates. Purple prairie clover and wild blue indigo did not compete with overseeded little bluestem or weed growth as well as the other legumes (Table 4). In the year after seeding for both experiments,

TABLE 4

Second year biomass harvest composition for 5 native legumes. Data average for 5 seeding rates.

Seeding year	Biomass component	Biomass composition (% of total DM)					LSD (0.05)
		False indigo	Wild blue indigo	Illinois bundleflower	Purple prairie clover	Wild senna	
1999	Legume	38	30	66	3	65	17
	Little bluestem	7	10	2	15	2	4
	Weed	55	60	32	82	33	25
2000	Legume	28	13	39	16	52	12
	Little bluestem	41	48	37	49	26	8
	Weed	31	39	23	35	21	7

purple prairie clover contributed less than 20% to the total biomass yield and wild blue indigo contributed 30% or less. In comparison, wild senna and Illinois bundleflower contributed from 40% to 65% to the total biomass yield.

Second-year biomass yield response of purple prairie clover for the 1999 experiment was best described by a linear function. For all other legumes in 1999 and all legumes in 2000, a logarithmic polynomial function in which yield increased until 67 or 135 PLS/m^2 and thereafter plateaued with further seeding rate increases best described the relationship. Seeding-year biomass yield response to increasing plant density is typically asymptotic where there is no gain or loss beyond a critical plant density (Gardner and others 1985). Above the critical plant density, there is often no gain in biomass yield because 100% of the most limiting resources (often solar energy) is utilized. We observed this same response for second-year biomass yield although the response was more dramatic for legumes with the greater biomass yield. Native legume biomass yields were lower for the 2000 experiment than for the 1999 experiment due to lower plant populations. Biomass yields of all legumes were significantly ($P < 0.05$) positively correlated with plant populations each year. Correlation coefficients were 0.90 or above for all legumes in 2001 and for false indigo, wild blue indigo, and purple prairie clover in 2000. In 2000, correlation coefficients for Illinois bundleflower and wild senna were 0.70 and 0.62, respectively.

In the year after seeding, little bluestem comprised a much greater proportion of the total biomass yield in the 2000 seeding compared to the 1999 seeding (Table 4). Greater rainfall deficits in many weeks of late June and July of 2001 versus 2000 may also have contributed to the lower second-year biomass yields for the 2000 seeding. The higher legume yields for the 1999 seeding, despite a higher percentage of weed biomass, suggests that weather conditions in 2000 were more conducive for plant growth in general, and, thus, resulted in higher legume yields.

SUMMARY

Illinois bundleflower and wild senna had the most vigorous seedlings and consequently the greatest plant populations and often the greatest biomass yields of the 5 native legumes. Good seedling vigor associated with large seed size allowed these legumes to compete effectively with weeds and little bluestem. These legumes have greater potential for use as biomass or forage crops than purple prairie clover or wild blue indigo. Purple prairie clover had less successful establishment and less biomass yield than the other legumes, indicating a lack of seedling vigor and suggesting that purple prairie clover may not be suitable for agronomic production.

In the seeding year and the year after seeding, populations of all legumes increased with increased seeding rates. Seeding-year population responses to increased seeding rate were linear for all legumes, but in the year following seeding responses to increased seeding rates differed among legumes and between years. Nonlinear responses imply that environmental resources limit plant persistence. A seeding rate from 135 to 275 PLS/m^2 achieved maximum biomass yields in August of the year following seeding for most legumes.

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