

Reevaluation of row spacing/plant density of seeded pasture grasses for the semiarid prairie

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Jefferson, P. G. and Kielly, G. A. 1998. **Reevaluation of row spacing/plant density of seeded pasture grasses for the semiarid prairie.** *Can. J. Plant Sci.* **78**: 257–264. Previous research in the semiarid prairie at Swift Current, Saskatchewan, indicated that optimum row spacing for forage production was 60 or 90 cm for crested wheatgrass (*Agropyron cristatum* [L.] Gaertner) and Russian wild ryegrass (*Psathyrostachys juncea* [Fisch.] Nevski). However, recent research suggested that harvest method affects forage yield estimates from row spacing experiments. An experiment with three row spacings of mixtures of alfalfa (*Medicago sativa* L.) with crested wheatgrass and Russian wild ryegrass was harvested mechanically and by hand. Yield differences between methods of harvesting were affected by row spacing; larger differences were observed at 15 cm than at 60 cm spacing, particularly for Russian wild ryegrass. The highest hand-harvested forage yield estimates were observed in the narrowest row spacing. In a second experiment, plant density was evaluated for the same grasses using square grid spacings of 30, 45, 60, 75 and 90 cm. Decreasing plant density was associated with decreased hand-harvested forage yield in both species. In a third experiment, 60- and 90-cm row spacing resulted in more seed heads and lower leaf content than 30-cm row spacing. Leaf digestibility increased slightly with increased row spacing. These results suggest that 30-cm row spacing should be recommended to producers for sustainable pastures in the semiarid prairie region.

Key words: Forage yield, forage quality, leaf:stem ratio, plot technique

Jefferson, P. G. et Kielly, G. A. 1998. **Nouveau regard sur l'écartement des lignes et sur la densité de peuplement des graminées à pâturage semé dans la zone semi-aride des Prairies.** *Can. J. Plant Sci.* **78**: 257–264. Les recherches antérieures réalisées à Swift Current, Saskatchewan dans la zone semi-aride des Prairies établissaient à 60 ou à 90 cm, l'écartement optimal des lignes d'agropyre à crête (*Agropyron cristatum* [L.] Gaertner) et de l'élyme de Russie (*Psathyrostachys juncea* [Finch.] Nevski) pour la production fourragère. Des recherches plus récentes suggèrent cependant que la méthode de récolte influe sur les rendements fourragers calculés à partir des expériences sur la largeur des interlignes. Nous avons donc réalisé une expérience à trois largeurs d'interligne sur des associations de luzerne (*Medicago sativa* L.) et d'agropyre à crête ou d'élyme de Russie dans laquelle la récolte se faisait soit à la machine soit manuellement. Les différences de rendement attribuables aux méthodes de récolte variaient selon la largeur de l'interligne, elles étaient plus prononcées à l'écartement de 15 cm qu'à celui de 60 cm, en particulier pour l'élyme de Russie. Le plus fort rendement de fourrage récolté à la main allait à l'écartement le plus étroit. Dans une deuxième expérience, la densité de peuplement était évaluée sur ces mêmes graminées, utilisant pour chaque espèce des espacements équidistants de 30, 45, 60, 75 et 90 cm entre les plantes. Une diminution de la densité de peuplement était associée chez les 2 espèces à une baisse de rendement fourragère récolté à la main. Dans une troisième expérience, les écartements de 60 et de 90 cm entre les lignes donnaient lieu à une plus abondante production d'inflorescences et à une moindre proportion de feuilles dans le fourrage que l'écartement de 30 cm. La digestibilité des feuilles augmentait légèrement à mesure que l'interligne s'élargissait. Il ressort de ces observations que 30 cm est la largeur d'interligne qu'il faudrait recommander aux producteurs de cette zone semi-aride désireux de maintenir des pâturages durables.

Forage management literature generally recommends narrow rows, or broadcast seeding at high seedling density, to maximize forage yield (Vough et al. 1995). However, wide (≥ 45 cm) row spacings for introduced grasses such as crested wheatgrass (CWG) (*Agropyron cristatum* [L.] Gaertner) and Russian wild ryegrass (RWR) (*Psathyrostachys juncea* [Fisch.] Nevski) have been recommended in the semiarid (Brown soil) zone of southern Saskatchewan and Alberta (Kilcher 1961).

At Swift Current, Saskatchewan, maximum forage yields of RWR and CWG were found in 60- and 90-cm row spacings, respectively (Kilcher 1961; Leyshon et al. 1981). Lawrence and Heinrichs (1968) concluded that the optimum row spacing for RWR forage yield was 60 cm, but for seed yield the optimum was 90 cm. For alfalfa (*Medicago sativa*

L.), highest forage yields were reported for 45- to 60-cm (Kilcher and Heinrichs 1969) or 90-cm row spacings (Irvine and Jefferson 1984). Mixtures of grass/alfalfa yielded the most forage in 60-cm row spacing when seeded in either cross- or alternate-row patterns (Kilcher and Heinrichs 1971).

Results from other arid or semiarid locations have not supported the conclusions regarding wide row spacing obtained at Swift Current. For example, on arid foothill range in Utah, wide row spacing (70 cm) resulted in less

Abbreviations: AWR, Altai wild ryegrass; CWG, crested wheatgrass; DM, dry matter; OMD, organic matter digestibility; RWR, Russian wild ryegrass; SEM, standard error of the mean; SWG, slender wheatgrass

CWG forage than narrow row (17.5) spacing (Cook et al. 1967). In Colorado, CWG forage yield was greater in 30- to 40-cm than in 52- or 76-cm row spacings (McGinnies 1960, 1970).

In the study by Cook et al. (1967), they noted greater shrub invasion as row spacing increased. Kilcher (1961) noted several agronomic deficiencies of wide row spacings: weed invasion, soil erosion and elevated crowns that result in the “washboarding” of fields. He also suggested that heavily stocked, rotationally grazed fields should be seeded at narrow row spacings to “withstand excessive trampling”.

Despite the large number of agronomy experiments conducted on row spacing at Swift Current, only one was reported in which forage was harvested by grazing cattle. Kilcher et al. (1976) grazed RWR sown at 20, 40 and 60 cm row spacings with steers. Forage yields increased with row spacing, being 751, 864 and 1328 kg ha⁻¹ for the three spacings, respectively. However, liveweight gains per hectare were unaffected by row spacing.

Grazing ruminants tend to select leaf tissue and avoid seed heads and stems (Stoddart et al. 1975; Ganskopp et al. 1992). But wider row spacing favours increased seed production of CWG (McGinnies 1971) and RWR (Lawrence and Heinrichs 1968). Therefore, forage quality and utilization may be decreased in wide row spacings if the composition of the sward is shifted to more seed heads and stems in place of leaf production. The reports of Cook et al. (1967) and McGinnies (1970) noted that increased seed production was an undesirable response with wide row spacing. Further, this issue is often voiced as a concern about wide row spacing by producers on the Canadian prairies (N.W. Holt, personal communication).

Row spacing affected the proportion of RWR biomass that could be harvested by machine (Leyshon et al. 1990). At 15-cm row spacing only 27% of the biomass was collected by machine compared with 54% in 60-cm spacing. Hand-harvested biomass estimates from this study indicated that RWR forage yield was not significantly affected by row spacing. While not described in all reports, previous row spacing studies likely used machine-harvested forage yield estimates. The possibility that the effect of row spacing on forage yield might be an artifact of harvesting method caused us to re-examine the row spacing question. The objectives of this study were: 1) to evaluate the hypothesis that forage yield response to row spacing of three species, alfalfa, CWG, and RWR, was affected by harvest method (hand vs. machine); 2) to determine optimum plant density for CWG, RWR and Altai wild ryegrass (AWR) (*Leymus angustus* [Trin.] Pilger), from equidistant grid spacing planting; 3) to determine the effect of row spacing on proportion of leaf tissue, grass seed head density, and leaf organic matter digestibility (OMD) for CWG, RWR, AWR and slender wheatgrass (SWG) (*Elymus trachycaulus* [Link] Gould ex Shinnars).

MATERIALS AND METHODS

Three experiments were conducted at the Semi-arid Prairie Agricultural Research Centre at Swift Current Saskatchewan (50°16'N, 107°44'W, elevation 825 m). The soil type is classified as a Swinton loam (Ayres et al. 1985)

Table 1. Growing season (April–August) precipitation and evaporation at Swift Current, Saskatchewan from 1979 to 1984 and from 1987 to 1994

Year	Precipitation (mm)	Evaporation (mm)
1979	194	949
1980	195	948
1981	226	952
1982	295	758
1983	227	1018
1984	129	1179
1987	185	988
1988	175	1377
1989	306	920
1990	218	967
1991	386	910
1992	251	862
1993	340	883
1994	201	934
109 yr mean	233	–
34 yr mean	–	986

or a fine, silty, mesic, aridic Haploboroll in the USDA classification. The mean (109 yr) annual precipitation is 360 mm and the mean growing season precipitation (April–August) is 233 mm. Low precipitation combined with high evaporation resulted in dry growing seasons in 1984 and 1988 (Table 1). Higher precipitation and lower evaporation resulted in wet growing seasons in 1982, 1989, 1991, 1992, and 1993.

Forage yield harvesting occurred at flowering stage (mid- to late June) for first harvest and about mid-August for regrowth. Subsamples of harvested forage were weighed, dried at 60°C and reweighed to determine DM content. Dry matter content was used to calculate forage DM yield (g m⁻²). Treatment differences were tested with a Type I error rate of $P = 0.05$.

Alfalfa/Grass Mixture Experiment

This experiment was seeded on 28 April 1987. Factors tested included three alfalfa synthetic populations, three mixture treatments (alfalfa monoculture, alfalfa-crested wheatgrass, and alfalfa-RWR) and three row spacings (15, 30 and 60 cm). The grass-alfalfa mixtures were grown in alternate row arrangement so that each species had its own “space” within the sward. The experimental design with six replications was a split-split plot with row spacings as the main plots, forage mixtures as the subplots and synthetics as the sub-subplots. From 1989 to 1994, two row segments (1 m length) of each plot was harvested by hand and a 0.6 × 4 m area harvested by flail plot harvester (Thompson 1972). Dry matter yields were determined for each methods and the difference between methods (Hand minus machine), resulting in three yield variables. Clipping by hand is the most common method for forage biomass or yield estimation in range and pasture research (Cook and Stubbendieck 1986). We assumed that the difference variable would estimate the relative precision of machine-harvest estimates compared with hand-harvest. We also assumed that the flail machine-

Table 2. Effect of row spacing on total forage yield measured with a flail plot harvester (MACH), hand-harvested (HAND) and the difference (HAND-MACH) between methods for the period 1989 to 1993 at Swift Current, Saskatchewan

Year	MACH				HAND				HAND-MACH			
	Spacing (cm)			SEM	Spacing (cm)			SEM	Spacing (cm)			SEM
	15	30	60		15	30	60		15	30	60	
	(g m ⁻²)											
1989	325	321	353	NS ^a	563	490	395	NS	238	169	42	19
1990	128	130	156	NS	571	357	248	55	443	228	92	48
1991	560	457	520	NS	923	654	492	55	363	198	-28	40
1992	142	111	102	8	168	133	148	10	26	22	45	6
1993	189	131	166	NS	221	186	224	NS	32	55	58	NS
\bar{x}	269	230	259		489	364	301		220	134	42	

^aNS = not significant at $P = 0.05$.

harvest estimate would be similar to that from commercially available farm equipment used for hay or silage harvesting. Grass and alfalfa components of the mixtures were separated manually from hand-harvested samples to determine their yields. This proportion of grass and alfalfa was used to calculate component yield values for the machine-harvested data. These data were analyzed using the GLM procedure of the SAS Institute, Inc. (1985). Replicate and spacing effects were tested by their interaction. Mixture and spacing \times mixture interaction effects were tested by Rep(spacing \times mixture) term. The alfalfa synthetics and remaining interaction effects were tested by the residual error term. When analyzing the species component yields, the alfalfa monoculture treatment was removed from the data.

Plant Density Experiment

Plants of CWG, RWR, and AWR were seeded in soil and grown to the fifth leaf stage in the greenhouse. After clipping about 50% of the aboveground growth, they were transplanted to the field in the spring of 1979. Twenty-five plants per experimental unit were transplanted at 30, 45, 60, 75, 90 cm equidistant grid spacing for each species. The experimental design was a randomized block with 3 species, 5 grid spacings, and 10 replications. Any missing plants due to failure of transplants were replaced with new seedlings in 1980 and all established plants were trimmed to allow for yield stabilization. From 1981 to 1984, the spring growth of the centre plant from each experimental unit was harvested by hand and dry matter yield determined. In 1981, the AWR was not harvested as it was deemed to have not completely established. Regrowth forage of AWR was never sufficient to permit harvesting. In 1982 there was inadequate regrowth of RWR to permit harvesting. In 1982 and 1983, N concentration (Kjeldahl N) was determined on both spring and regrowth forage samples.

Statistical analysis of variance was conducted on the randomized block model and the spacing effect separated into linear, quadratic, cubic and residual components by means of contrasts (SAS Institute, Inc. 1985). While there was differing number of species for some ANOVAs, it was possible to examine the spacing effect on eight harvests over 4 yr.

Grass Row Spacing Experiment

This split plot experiment with six replications was seeded on 20 June 1988. The main plots were three row spacings (30, 60 and 90 cm) and the subplots were experimental lines or cultivars of grasses. The entries included two cultivars of CWG, two cultivars of AWR, one cultivar and one breeding line of RWR and one cultivar of SWG. From 1990 to 1993, the proportion of leaf biomass and counts of seed heads m⁻² were determined from hand-harvested material. From 1991 to 1993, in vitro OMD of leaves (Troelsen 1970) were determined. Values for these characteristics were averaged over species and effect of row spacing assessed in this report. The analysis of variance by the GLM procedure of the SAS Institute, Inc. (1985) was specified for the split-plot design. The replicate and spacing effects be tested by their interaction and the grass and grass \times spacing interaction was tested by the residual error term.

RESULTS AND DISCUSSION

Alfalfa/Grass Mixture Experiment

In general, hand-harvested total forage yield declined as row spacing increased but machine-harvested yield was generally not affected by row spacing (Table 2). The difference between harvesting methods was significantly affected by row spacing in most years. During the first 3 yr, hand-harvested yields exceeded the machine-harvested yields but the difference declined as row spacing increased. In 1992, the difference between methods was small and increased as row spacing increased.

For the mixture components, the difference between methods of harvest was significant from 1989 to 1991 for the alfalfa component and from 1990 to 1992 for the CWG component and from 1989 to 1993 for the RWR component (Table 3). This was due to higher forage yield estimates for hand-harvesting than for machine-harvesting at the 15- and 30-cm row spacing than at 60 cm for all three species. The largest difference between methods occurred for RWR at 15 cm in 1990. The smallest (negative) difference occurred for CWG at 60-cm row spacing in 1991. The difference between methods of harvesting declined as row spacing increased. However, in 1992 and 1993 for RWR and in 1992 for CWG, the differences increased with row spacing.

Table 3. Effect of row spacing on component forage yield estimates from grass-alfalfa mixtures measured with a flail plot harvester (MACH), hand-harvested (HAND) and the difference between methods (HAND-MACH) during the period 1989–1993 at Swift Current, Saskatchewan

Year	MACH				HAND				HAND-MACH			
	Spacing (cm)			SEM	Spacing (cm)			SEM	Spacing (cm)			SEM
15	30	60	15		30	60	15		30	60		
<i>Alfalfa (g m⁻²)</i>												
1989	160	131	171	NS ^a	291	217	197 ^y	10	131	86	18 ^y	7
1990	46	44	42	NS	206	124	76	25	160	80	34	19
1991	311	245	303	NS	489	339	298	36	178	94	-5	14
1992	48	39	50	NS	58	46	46	NS	10	7	-4	NS
1993	86	65	93	NS	105	93	116	NS	19	28	23	NS
\bar{x}	130	105	132		230	164	147		100	59	13	
<i>Crested wheatgrass^y (g m⁻²)</i>												
1989	125	142	98	NS	236	197	141	NS	113	55	35	NS
1990	97	93	68	6	380	224	120	35	283	132	52	36
1991	252	226	197	NS	365	248	132	36	113	22	-65	32
1992	99	88	39	6	112	102	82	6	12	13	43	5
1993	91	88	84	NS	107	105	113	NS	16	17	30	NS
\bar{x}	133	127	97		240	175	118		107	48	15	
<i>Russian wild ryegrass^y (g m⁻²)</i>												
1989	148	195	221	16	302	370	246	NS	154	175	25	22
1990	96	124	215	10	437	326	241	39	341	202	26	35
1991	200	209	242	NS	376	364	241	NS	176	155	-1	33
1992	75	56	60	NS	86	69	100	NS	11	13	40	5
1993	93	49	66	NS	104	74	115	NS	11	25	49	7
\bar{x}	122	127	161		261	241	189		139	114	28	

^aNS = not significant at $P = 0.05$.

^yEstimated from missing plot.

This experiment was conducted over a time period that included four “wet” growing seasons: 1989, 1991, 1992, and 1993 (Table 1). It could be argued that these results have been skewed due to the favourable precipitation that occurred during the experiment. It is notable, however, that a large difference between harvest methods occurred in both a wet year, 1989, and an average year, 1990. This suggests that the effect of harvest method was independent of growing season precipitation.

Our machine-harvested yield results tend to support the conclusions of previous workers (Kilcher 1961; Lawrence and Heinrichs 1968; Kilcher and Heinrichs 1971) in that RWR forage yields were greater when seeded in the wider rows. However in contrast to previous reports (Kilcher 1961; Kilcher and Heinrichs 1969; Irvine and Jefferson 1984), row spacing had no effect on machine-harvested CWG and alfalfa yields.

The hand-harvested yield results confirmed the conclusions of Leyshon et al. (1990) indicating that RWR does not respond to row spacing. We observed a row spacing effect on RWR yield in 1 of 5 yr, but the yield declined with increased row spacing.

The difference between harvesting methods variable was greatest at narrow row spacing for 3 of 5 yr for alfalfa, 2 of 5 yr for CWG, and 3 of 5 yr for RWR. The difference was greater at wider row spacings in 1 out of 5 yr for CWG and 2 of 5 yr for RWR. In the latter case, the differences were much smaller than were observed in the former case. The calculated yield differences may be subject to consistent

error(s) when these values approach zero. These results indicate that forage yield in row spacing experiments cannot be accurately estimated with a flail plot harvester due to the interaction of row spacing with the relative precision of the two methods.

The reason(s) for the yield bias of the flail harvester was not examined in our research. We speculate that the proportion of decumbent biomass below 6 cm cutting height may be greater for the narrower row spacing. Stoddart et al. (1975) showed there were growth form differences between *Agropyron spicatum* and *Festuca idahoensis* and the distribution of aerial biomass at height increments. The *F. idahoensis* had proportionally more biomass between 0 and 5 cm height than *A. spicatum*. We observed that decumbent grass tillers were gathered and held upright during hand-harvesting but were missed by the flail cutting mechanism of the forage harvester. We also noted that grass tillers in wide rows were larger and more upright than those in the narrow row spacing. Thus a greater proportion of the forage sward in the 60-cm row spacings would be available for removal by the machine compared with forage from 30-cm rows. McGinnies (1970) suggested that:

“An advantage that might be gained from wider row spacing and the resulting taller plants would occur where the grass is cut for hay. Even in years of abundant rainfall the low-growing herbage obtained from the 15 cm (narrow) spacing would be difficult to mow and bale; the taller herbage from the wider spacings would be easier to harvest.”

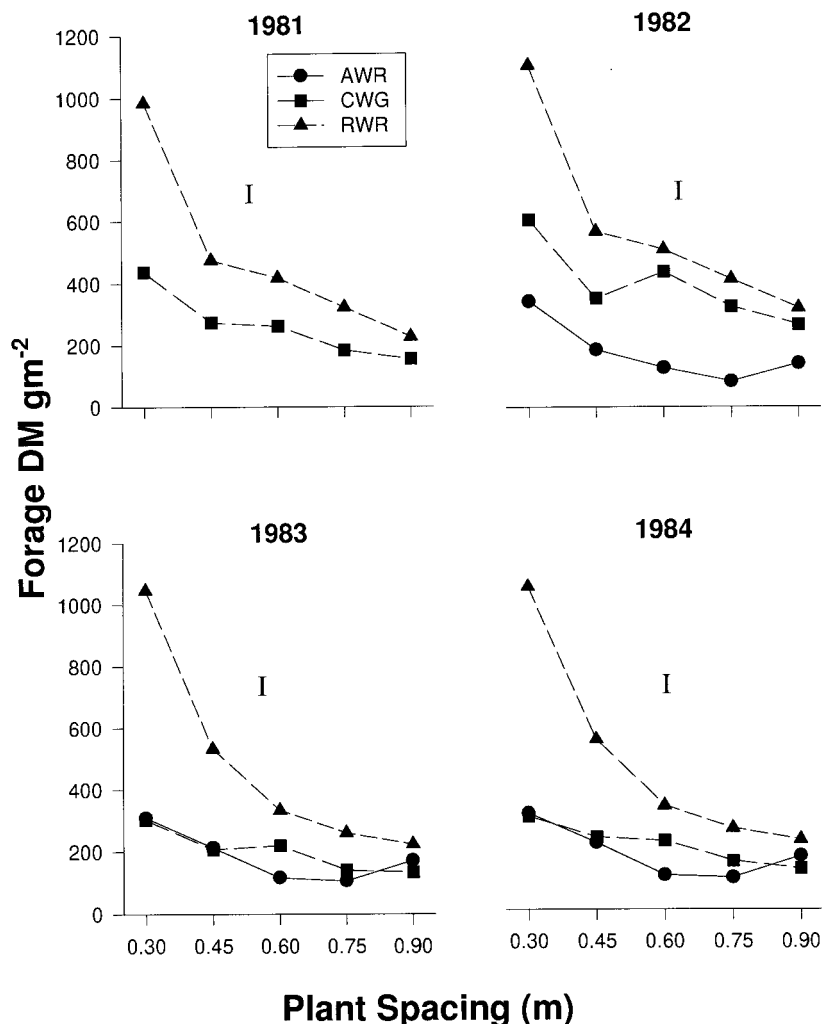


Fig. 1. Spring forage yield of Russian wild ryegrass (RWR), Altai wild ryegrass (AWR) and crested wheatgrass (CWG) from five plant densities over 4 yr at Swift Current, Saskatchewan. Bars indicate standard error of the mean. The grass species \times spacing interaction was significant in all 4 yr ($P = 0.006$, $P = 0.002$, $P = 0.0001$, and $P = 0.0001$ for 1981 to 1984, respectively).

This proposition was supported by our results also. More detailed experimentation will be necessary to examine the hypothesis that plant density affects the angle or decumbency of grass tillers or alfalfa stems.

Plant Density Experiment

Plant spacing had a highly significant effect on spring forage yield over the 4 yr of this trial (Fig. 1). There were linear and quadratic components to the spacing effect with significant contrasts for all harvests (data not shown). The grass \times spacing interaction was significant for each harvest (Fig. 1) because RWR exhibited a quadratic decline while CWG and AWR declined linearly with increased spacing (decreased plant density). The grass \times spacing interaction term was also significant for regrowth forage yield in 1983 and 1984 (data not shown). A similar pattern was observed in regrowth forage yield as for spring growth with a larger proportional decline in forage yield for RWR than CWG as spacing was increased. The heterogeneous nature of the plants used for sampling may have contributed to high coef-

ficients of variation in this study (49 to 72%) but the yield responses to row spacing were consistent over all 4 yr.

Kilcher (1961) concluded that: "When few grass plants use a limited amount of soil moisture they grow larger and yield more than crowded plants." The four growing seasons of the plant density experiment included one "wet" year (1982) and one "dry" year (1984). Our results did not support Kilcher's (1961) thesis.

Forage N concentration varied among grass species in 1982 and 1983 but generally not with plant density except for spring growth in 1983 (data not shown). The interaction of spacing and grass species was not significant for any harvest. The N concentration of AWR, CWG, and RWR in spring growth was 1.56, 1.60 and 1.55%, respectively, averaged over 2 yr. Altai wild ryegrass had higher N content than CWG or RWR in 1982 but lower N content in 1983 (data not shown). The N concentration of CWG and RWR regrowth was 1.06 and 1.50%, respectively. For spring growth in 1983, the N concentration was 1.69, 1.67, 1.74, 1.83, and 1.79% for the 30, 45, 60, 75, and 90 cm plant spac-

Table 4. Effect of row spacing on the proportion of leaves for AWR, CWG, RWR and slender wheatgrass (SWG) from 1990 to 1993 at Swift Current, Saskatchewan

Year	Spacing (cm)	Grass				\bar{x} and SEM
		AWR ^y	CWG ^y	RWR ^y	SWG	
1990	30	0.81	0.30	0.41	0.51	0.51
	60	0.69	0.27	0.34	0.51	0.45
	90	0.59	0.26	0.28	0.47	0.40
	\bar{x}	0.70	0.28	0.34	0.50	SEM=0.04 ^z
1991	30	0.82	0.25	0.81	0.63	0.63
	60	0.81	0.24	0.60	0.66	0.43
	90	0.70	0.22	0.55	0.48	0.49
	\bar{x}	0.78	0.24	0.65	0.59	SEM=0.04
1992	30	0.96	0.50	0.93	0.61	0.75
	60	0.93	0.39	0.73	0.57	0.66
	90	0.87	0.36	0.72	0.52	0.62
	\bar{x}	0.92	0.42	0.79	0.57	SEM=0.03
1993	30	0.78	0.35	0.57	0.38	0.52
	60	0.68	0.29	0.42	0.37	0.44
	90	0.66	0.33	0.35	0.33	0.42
	\bar{x}	0.71	0.32	0.45	0.36	SEM=0.05

^z SEM = standard error of grass species \times spacing means. The probability of the grass species \times spacing interaction was 0.6203, 0.0137, 0.0074 and 0.3465 for 1990, 1991, 1992 and 1993, respectively. The grass species and row spacing effect were significant in each year.

^yAWR = Altai wild ryegrass, CWG = crested wheatgrass, RWR = Russian wild ryegrass.

ings, respectively. This increased N concentration at low plant density would be expected if decreased density resulted in less competition for mineralized soil N or yield dilution of N at high plant density. While McGinnies (1970) reported a decline in CWG forage N content with increased row spacing, we did not observe a consistent effect of plant density on N concentration in this experiment

Grass Row Spacing Experiment

As row spacing increased from 30 to 60 cm, the proportion of leaf tissue declined significantly in all 4 yr (Table 4). The grass species differed in proportion of leaves with AWR being the most leafy and CWG the least leafy. The grass \times spacing interaction was significant in 1991 and 1992. In 1991 the interaction can be attributed to the lack of CWG response in contrast to the other grasses. In 1992 AWR and SWG exhibited only a small decline in leaf proportion as row spacing increased while CWG and RWR exhibited a marked decline. Less leaf on CWG plants in wide spacing compared with narrow rows had been noted at other locations (Cook et al. 1967; McGinnies 1970).

Seed head density increased with increased row spacing for all four species (Table 5). In each year the CWG seed head density doubled or more than doubled as row spacing increased from 30 to 90 cm. Even in 1991 when CWG leaf proportion was not affected by row spacing (Table 4), CWG seed head density increased in wider rows. With the exception of 1993, SWG exhibited low seed head density. However, SWG stem material made up 40 to 50% of the biomass in 1990 to 1992 even though very few seed heads were present. Russian and Altai wild ryegrasses had the lowest seed head density and highest leaf proportions at 30-cm row spacing. The significant grass \times spacing interactions observed in 1991 to 1993 can be attributed to the large increase in seed head density for CWG and RWR and no significant increase for AWR or SWG.

In the long-term (15 yr) data presented by Lawrence and Heinrichs (1968), forage yield was fourfold greater (1838 kg ha⁻¹) in the 7 yr with seed production than in the 8 yr without seed production (472 kg ha⁻¹). This suggests that the increased forage yields reported for wide row spacing may be partly the result of increased seed head density and the contribution of stems and seed heads to measured yield.

Leaf OMD varied among species for all 3 yr; RWR had the highest and SWG the lowest leaf OMD in each year (Table 6). Leaf OMD increased with row spacing in 1991 and 1992. The increase was 3.6 and 3.0 OMD units for the 2 yr, respectively. These results contrast with those of Cook et al. (1967) where whole-plant forage quality was less in wider row spacings.

Increased row spacing will result in reduced leaf proportions and increased seed head density of the species we tested, similar to the results of Cook et al. (1967). Cook et al. (1967) also noted higher cellulose and lignin contents of forage from wide row spacing and attributed this to lower leaf proportion. Cattle grazing CWG will select leaf tissue and avoid stem and stem heads in semiarid pastures (Stoddart 1975; Ganskopp et al. 1992). Ungrazed plants continue to produce inflorescences and experience decreasing grazing pressure until "wolf plants" are created (Romo 1994). Further research should examine the relationship between wolf plant frequency and row spacing.

Vegetative tillers of AWR and RWR have basal leaves, and these species produce few seed heads when grown in narrow row spacing. This results in a high leaf proportion. In the semiarid prairies, the wild ryegrasses have been used for fall and winter grazing with stock-piled pasture systems. Stock-piled pastures in semiarid regions refer to areas where grazing is excluded during the growing season and forage is grazed during the dormant period. The high leaf content of these two species should be particularly valuable in these systems. While increased row spacing resulted in higher leaf

Table 5. Effect of row spacing on seed head density for AWR, CWG, RWR and SWG from 1990 to 1993 at Swift Current, Saskatchewan

Year	Spacing	Grass				\bar{x}
		AWR ^y	CWG ^y	RWR ^y	SWG ^y	
		count m ⁻²				
1990	30	9	240	84	0	83
	60	22	410	132	0	141
	90	49	496	194	7	186
	\bar{x}	27	382	137	2	SEM=27 ^z
1991	30	6	221	11	0	60
	60	10	482	52	0	136
	90	35	650	98	0	196
	\bar{x}	17	451	54	0	SEM=33
1992	30	5	41	2	0	12
	60	2	174	32	10	54
	90	10	228	38	17	73
	\bar{x}	6	148	24	9	SEM=13
1993	30	8	76	55	77	54
	60	24	244	146	155	142
	90	40	206	200	151	149
	\bar{x}	24	175	134	128	SEM=22

^zSEM = standard error of mean for grass species × spacing interaction. The probability of species × spacing interaction was 0.0518, 0.0002, 0.0001 and 0.0030 in 1990, 1991, 1992 and 1993, respectively. The grass species effect and row spacing effect are significant in each year.

^yAWR = Altai wild ryegrass, CWG = crested wheatgrass, RWR = Russian wild ryegrass, SWG = slender wheatgrass.

Table 6. Effect of row spacing on leaf OMD^x for CWG, AWR, RWR and SWG from 1991 to 1993 at Swift Current, Saskatchewan

Year	Spacing	Grass				\bar{x}
		AWR ^y	CWG ^y	RWR ^y	SWG ^y	
		(%)				
1991	30	62.6	60.0	66.7	53.7	60.8
	60	65.0	64.3	67.6	57.0	63.5
	90	64.4	63.8	70.2	59.4	64.4
	\bar{x}	64.0	62.7	68.2	56.7	SEM=1.0 ^z
1992	30	62.1	58.6	63.4	54.9	59.8
	60	62.7	64.4	65.6	58.4	62.8
	90	61.4	62.1	65.8	57.5	61.7
	\bar{x}	62.1	61.7	64.9	56.9	SEM=1.0
1993	30	54.3	56.0	59.5	50.5	55.1
	60	54.4	54.4	60.7	50.4	55.0
	90	53.6	55.9	60.5	49.1	54.8
	\bar{x}	54.1	55.4	60.2	50.0	SEM=1.1

^zSEM = standard error of mean for grass species × spacing interaction. The probability of species × spacing interaction effect was 0.6810, 0.2203 and 0.0779 for 1991, 1992 and 1993, respectively. The grass species effect was significant for all 3 yrs. The row spacing effect was significant in 1991 and 1992, only.

^yAWR = Altai wild ryegrass, CWG = crested wheatgrass, RWR = Russian wild ryegrass, SWG = slender wheatgrass.

^xOMD = organic matter digestibility.

OMD, the effect was small compared with the decrease in the proportion of leaves. Our results suggest CWG and RWR plants should be seeded in narrow rows for pasture production in this semiarid region.

The grazing results of Kilcher et al. (1976) are counter-intuitive. They reported that forage yields were higher in wide row spacing compared with narrow row spacing but that cattle gains were similar across row spacings. However, their forage estimates were machine harvested (M.R. Kilcher, personal communication) which would have underestimated the available forage in narrow row spacing. We need to repeat the livestock production research of Kilcher et al. (1976) using hand-harvested estimates of forage yield.

CONCLUSIONS

We concluded that RWR, CWG and alfalfa forage yields reported previously as responses to increased row spacing could be artifacts related to the harvesting method employed. The previous row spacing research results would only be valid for dryland hay stands where mechanical harvesting is used. The extrapolation of machine-harvested yields to pasture situations will underestimate forage production of narrowly seeded rows of these species resulting in erroneous recommendations to producers. Sustainable pasture systems of seeded forage species in the semiarid prairie should have high plant density, or narrow row spacings, contrary to the previous reports that had been extrapo-

lated from machine-harvested results. This will achieve higher forage dry matter production and quality and may have the potential to reduce weed invasion and soil erosion. Researchers should carefully consider the growth form of the forage species of interest before selecting the harvesting technique. More research is needed to calibrate pasture yield estimates taken by machine plot harvesters versus hand-harvest estimates in semiarid pastures.

ACKNOWLEDGEMENTS

The technical support of Russell Muri, Cliff Ratzlaff, Neil McCrie, Fran Juffinger, Ed Birkedal, Darwin Wilms, Brian Neudorf, Stan Greenwood, and many summer students is gratefully acknowledged. Many stimulating discussions with Dr. Neal Holt on row spacing and pasture quality contributed significantly to this manuscript and we thank him. The authors acknowledge J. McElgunn and the late T. Lawrence for initiating two of the experiments.

Ayres, K. N., Acton, D. F. and Ellis, J. G. 1985. The soils of the Swift Current Map Area (72J) Sask. Saskatchewan Institute of Pedology, Saskatoon, SK. Publ. S6. Extension Publ. 481, 226 pp.

Cook, C. W. and Stubbendieck, J. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317 pp.

Cook, C. W., Stoddart, L. A. and Sims, P. L. 1967. Spacing and intensity of seeding on the development of foothill range grass stands. Bull. 467 Utah Agric. Exp. Stn. Utah State University, Logan, UT.

Ganskopp, D., Angell, R. and Rose, J. 1992. Response of cattle to cured reproductive stems in a caespitose grass. J. Range Manage. **45**: 401–404.

Irvine, R. B. and Jefferson, P. G. 1984. Alfalfa (*Medicago sativa* L. and *M. falcata* L.) cultivar × row spacing interaction on yield at a semiarid environment in southwestern Saskatchewan. Can. J. Plant Sci. **64**: 895–900.

Kilcher, M. R. 1961. Row spacing affects yields of forage grasses in the Brown soil zone of Saskatchewan. Publ. 1100. Research Branch, Canada Department of Agriculture, Ottawa, ON.

Kilcher, M. R. and Heinrichs, D. H. 1969. Influence of row spacing on yield and creeping root development of Rambler alfalfa in a semiarid region. Can. J. Plant Sci. **49**: 307–311.

Kilcher, M. R. and Heinrichs, D. H. 1971. Stand patterns for alfalfa-grass hay production in a dry climate. Can. J. Plant Sci. **51**: 317–322.

Kilcher, M. R., Heinrichs, D. H. and Lodge, R. W. 1976. Row spacings of Russian wildrye for fall pasture in southern Saskatchewan. J. Range Manage. **29**: 237–240.

Lawrence, T. and Heinrichs, D. H. 1968. Long-term effects of row spacing and fertilizer on the productivity of Russian wild rye-grass. Can. J. Plant Sci. **48**: 75–84.

Leyshon, A. J., Cutforth, H., Waddington, J. and Rhymes, P. C. 1990. Effect of row spacing on biomass production and aboveground harvestability of Russian wildrye. Can. J. Plant Sci. **70**: 555–558.

Leyshon, A. J., Kilcher, M. R. and McElgunn, J. D. 1981. Seeding rates and row spacings for three forage crops grown alone or in alternate grass-alfalfa rows in southwestern Saskatchewan. Can. J. Plant Sci. **61**: 711–717.

McGinnies, W. J. 1960. Effects of planting dates, seeding rates, and row spacings on range seeding results in western Colorado. J. Range Manage. **13**: 37–39.

McGinnies, W. J. 1970. Effects of seeding rate and row spacing on establishment and yield of crested wheatgrass. Agron. J. **62**: 417–421.

McGinnies, W. J. 1971. Influence of row spacing on crested wheatgrass seed production. J. Range Manage. **24**: 387–389.

Romo, J. T. 1994. Wolf plant effects on water relations, growth and productivity in crested wheatgrass. Can. J. Plant Sci. **74**: 767–771.

SAS Institute, Inc. 1985. SAS user's guide: Statistics Version Fifth ed. SAS Institute Inc., Cary NC. 959 pp.

Stoddart, L. A., Smith, A. D. and Box, T. W. 1975. Range management. McGraw-Hill Book Company, New York, NY. 532 pp.

Thompson, J. L. 1972. The Swift Current forage plot harvester IV. Can. J. Plant Sci. **52**: 859–860.

Troelsen, J. E. 1970. Digestible energy in forage by in vivo and in vitro assays. Can. J. Anim. Sci. **50**: 557–562.

Vough, L. R., Decker, A. M. and Taylor, T. H. 1995. Forage establishment and renovation. Pages 29–43 in R. F. Barnes, D. A. Miller, and C. J. Nelson, eds. Forages. 5th ed. Volume II. The science of grassland agriculture. Iowa State University Press, Ames, IA.