

Long-term effects of burning *Festuca* and *Stipa-Agropyron* grasslands

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Abstract

The effects of early spring burning on current year standing crop, litter, and total standing crop (current year standing crop plus litter) were examined in *Festuca*- and *Stipa-Agropyron*-dominated communities in central Saskatchewan over an 11-year period in a paired design with burned sites compared to adjacent control sites that were not burned. In *Festuca* communities current year standing crop was reduced in the first and third years ($P = 0.010$) after burning. Burning *Stipa-Agropyron*-communities tended to reduce current year standing crop, but the differences were not significant ($P < 0.050$) compared to control. Increasing precipitation stimulated current year standing crop after burning *Festuca* ($P < 0.001$, $r^2 = 0.33$) and *Stipa-Agropyron* ($P < 0.001$, $r^2 = 0.55$) communities. Litter and current year standing crop were correlated ($R^2 = 0.24$, $P = 0.002$) for *Festuca* indicating beneficial and detrimental effects of litter on production at low and high amounts, respectively. Litter and current year standing crop were not correlated ($P = 0.964$) for *Stipa-Agropyron*. In both communities total standing crop increased until about the eighth year after burning while the mass of litter appeared to reach a plateau around 11 years.

Key Words: *Agropyron dasystachyum*, Fescue Prairie, *Festuca hallii*, fire, litter, Northern Mixed Prairie, primary productivity, *Stipa curtisetata*, total standing crop

Prescribed burning is useful for achieving many conservation goals in grasslands. Beneficial effects of burning on production have been demonstrated in mesic grasslands such as Tallgrass Prairie where C4 grasses dominate (Wright and Bailey 1982, Collins and Wallace 1990). By contrast in the Northern Mixed Prairie and in Fescue Prairie dominated by C3 grasses, primary production is often reduced after burning (Redmann et al. 1993). For example, peak green biomass in Fescue Prairie recovered 2 to 3 years after burning, while in Mixed Prairie dominated by western porcupine grass (*Stipa curtisetata* Hitchc.) and northern wheatgrass (*Agropyron dasystachyum* [Hook.] Scribn.), recovery was delayed 4 to 5 years. Total graminoid biomass (green plus standing dead) in areas previously burned was comparable to unburned sites 3 to 4 years after burning, but recovery of litter took much longer in the Northern Mixed Prairie of western North Dakota (Dix 1960).

Litter alters the microenvironment of grasslands and affects productivity (Willms 1988, Facelli and Pickett 1991). Whereas excessive litter reduces productivity in Tallgrass Prairie (Vogl 1974, Boerner 1982), litter has positive effects on herbage production apparently by reducing evaporation and making more

Resumen

Se examinaron los efectos de la quema a inicios de primavera sobre la cosecha en pie actual, mantillo y cosecha en pie total (cosecha en pie del año actual + mantillo) de comunidades de *Festuca* y comunidades dominadas por *Stipa-Agropyron* situadas en la región central de Saskatchewan. El estudio se llevó a cabo en un período de 11 años en un diseño apareado con sitios quemados adyacentes a sitios control que no fueron quemados. En las comunidades de *Festuca* la cosecha en pie actual se redujo en el primer y tercer años ($P = 0.010$) después de la quema. La quema de comunidades de *Stipa-Agropyron* tendió a reducir la cosecha en pie del año actual, pero las diferencias no fueron significativas ($P < 0.050$) en comparación con el control. El aumento en la precipitación estimuló la cosecha en pie del presente año después de la quema en las comunidades de *Festuca* ($P < 0.001$, $r^2 = 0.33$) y *Stipa-Agropyron* ($P < 0.001$, $r^2 = 0.55$). El mantillo y la cosecha en pie actual estuvieron correlacionadas ($R^2 = 0.24$, $P = 0.002$) en la comunidad de *Festuca*, indicando efectos benéficos y perjudiciales del mantillo en la producción en cantidades bajas y altas respectivamente. El mantillo y la cosecha en pie actual no estuvieron correlacionadas ($P = 0.964$) en la comunidad de *Stipa-Agropyron*. En ambas comunidades la cosecha en pie total se incrementó hasta aproximadamente el octavo año después de la quema mientras que la masa de mantillo pareció alcanzar su máximo nivel alrededor de los 11 años.

water available for plant growth especially in xeric Northern Mixed Prairie (Willms et al. 1986, 1993). Herbage production increased slightly with litter removal in Fescue Prairie but reductions in production occurred in Mixed Prairie (Willms et al. 1986). Climatic effects, particularly the amount of precipitation, also strongly influence primary productivity of Northern Mixed Prairie (Smoliak 1986) and Fescue Prairie (Bork et al. 2001).

Understanding the dynamics of standing crop of plants after burning is relevant to developing strategies for conserving *Festuca*- and *Stipa-Agropyron*-dominated grasslands. The purpose of this study was to examine the effects of burning over an 11-year period on current year standing crop, and the recovery over time of litter and total standing crop in Fescue Prairie and Northern Mixed Prairie dominated by western porcupine grass and northern wheatgrass.

Study site

This study was conducted at the University of Saskatchewan, Kernen Prairie located 1 km east of Saskatoon, Saskatchewan (52°10'N, 106°33'W; elevation 510 m). This 130-ha remnant

grassland has been relatively undisturbed since the 1930s except for periodic mowing on portions of it until 1976 (Pylypec 1986). Since 1986 various parts of the prairie have been burned by prescribed fires, and the impacts of these fires on the vegetation have been described in Redmann et al. (1993), Romo et al. (1993), Grilz and Romo (1994, 1995), Archibold et al. (1998) and Ripley and Archibold (1999).

Kernen Prairie lays in an ecotone between the Northern Mixed Prairie and the Boreal Forest. Therefore, the *Festuca*-dominated plant communities at Kernen Prairie are near the southern extent of their distribution while the *Stipa-Agropyron* communities are northerly extensions of typically more southern grasslands. Plains rough fescue (*Festuca hallii* [Vasey] Piper) dominates the more mesic sites with clayey glaciolacustrine soils within Kernen Prairie whereas western porcupine grass and northern wheatgrass dominate the more xeric sites at slightly elevated topographic positions with sandy loam soils (Baines 1973). A complete floristic inventory of Kernen Prairie is given in Pylypec (1986). Climate in this area has been described by Walter and Lieth (1960–1967) as Type VIII (VII), Boreal (Arid, with cold season). The mean annual temperature is 2.0° C, ranging from a January mean minimum of -22.9° C to an average maximum of 25.4° C in July (Environment Canada 1993). Normal annual precipitation is 347 mm of which 185 mm falls during the growing season (April–July).

Methods

A different portion of Kernen Prairie ranging from 4 to 16 ha was burned in the first 2 weeks of April each year from 1991 to 1997. At the time of burning prairie crocus (*Anemone patens* [Bess.] Koch) was in early stages of blooming. Burn areas included representative plant communities of Fescue Prairie (Coupland and Brayshaw 1953) and also of Northern Mixed Prairie (Coupland 1950), and were adjacent to similar controls where no fire has been recorded for the past eight decades.

Except for 2000, aboveground plant biomass at each burn site and the adjacent control area was sampled each year from 1991 to 2001 in late July to mid-August after green biomass had peaked. Previous studies in grasslands of this region have shown that peak standing crop is reached in late July to early August (Redmann et

al. 1993, Zhang and Romo 1994, Kowalenko and Romo 1998). Four, 50- by 50-cm quadrats were randomly located along a 20 m transect in *Festuca*- and *Stipa-Agropyron*-dominated communities in each burn area and were compared to 4 quadrats of the same size in unburned control sites located within 20 m of the burns. In each quadrat, biomass was clipped at ground level and sorted into graminoids, forbs and shrubs. Fallen litter was collected from the surface by hand. All samples were oven-dried at 80° C for 24 hours and weighed. A subsample of the graminoids that comprised the bulk of the samples was then separated into green biomass, current year dead biomass and dead biomass from previous years; these subsamples were weighed and their proportions were applied to the entire sample. Graminoids comprised about 95% of the samples in *Festuca*-dominated communities and about 99% in *Stipa-Agropyron*-dominated communities. Current year standing crop was represented by the total of green biomass and current year dead biomass (Redmann 1992). Litter was determined as the sum of fallen, detached, and standing dead biomass from previous years. Total standing crop was the total of litter and current year standing crop.

Means of current year standing crop in control and burned plots were compared with 2-sample t-tests (Snedecor and Cochran 1980) within years after burning ($P \leq 0.050$). Regression analysis (Neter et al. 1990) was used to evaluate the relationships between: annual precipitation (August through July), growing season precipitation (April through July) and current year standing crop; litter and current year standing crop, and; the number of years since burning versus litter and total standing crop. Lack-of-fit tests ($P < 0.050$) (Snedecor and Cochran 1980) were used to select the best-fit regression equations.

Results and Discussion

Precipitation

Annual precipitation during the 11 years of study ranged from 18% less to 38% more than the normal of 347 mm. Precipitation was at least 10% greater than normal in 4 years, 90% or less than normal in 5 years, and within 10% of normal in 2 years. Thus, by repeating this study through time, responses of *Festuca*- and *Stipa-Agropyron*-dominated communities to burning were evaluated over wide-ranging amounts of precipitation in many combinations among years. Responses of cur-

rent year standing crop, litter and total standing crop after burning discussed here are therefore applicable to a wide range of precipitation conditions.

Current year standing crop

Annual precipitation and current year standing crop were positively correlated ($P < 0.001$) after burning the *Festuca* and *Stipa-Agropyron* communities (Fig. 1). Correlations between current year standing crop and growing season precipitation were significant but lower than the correlation between annual precipitation and current year standing crop for *Festuca* ($Y = 82.5 + 0.40X$, $r^2 = 0.21$, $P < 0.001$) and *Stipa-Agropyron* ($Y = 20.2 + 0.53X$, $r^2 = 0.50$, $P < 0.001$). Increasing current year standing crop with precipitation was expected because precipitation constrains production in North American grasslands (Sims and Singh 1978). Herbage production also increases with precipitation in *Stipa-Bouteloua*-dominated grasslands (Smoliak 1986), grazed Fescue Prairie (Bork et al. 2001) and Tallgrass Prairie (Briggs and Knapp 1995). The variation in current year standing crop within precipitation amounts is attributed to harvesting being done in areas burnt in different years and they were therefore in different chronological stages of recovery after burning. Differences in production potential among burned areas likely also contributed to the variation in current year standing crop.

Burning mesic grasslands often stimulates production where conditions are often light- or nutrient-limited (Old 1969, Knapp 1984, Town and Owensby 1984, Abrams et al. 1986). However, current year standing crop in *Festuca* communities was reduced ($P < 0.050$) in the first and third years after burning (Table 1). A trend of less current year standing crop was observed after burning, but there was no difference ($P < 0.050$) compared to the control in the second year and after the third year. The longevity of reduced current year standing crop in the *Festuca* communities is close to a 2 to 3 year reduction reported by Redmann et al. (1993). On the other hand, current year production of plains rough fescue was not affected by burning in early April in Alberta (Gerling et al. 1995).

Despite a trend of less current year standing crop after burning, differences were not significant ($P < 0.050$) between control and burned *Stipa-Agropyron* communities within all years (Table 1). That burning had no effect on current year standing crop in *Stipa-Agropyron*-domi-

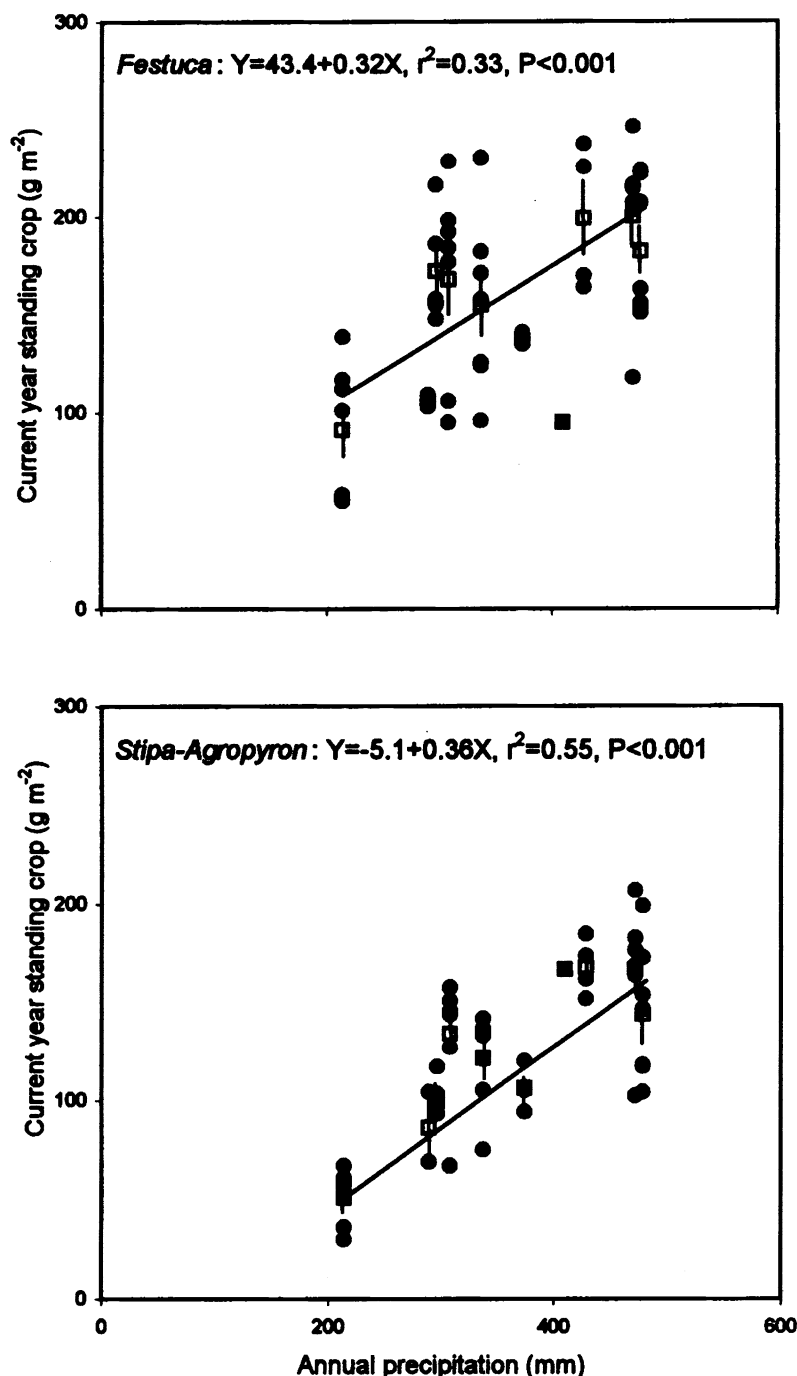


Fig. 1. Fitted regression lines and observed values for current year standing crop versus annual precipitation (August through July) in *Festuca*- and *Stipa-Agropyron*-dominated plant communities. Solid circles are observed current year standing crop and open squares with vertical lines are means \pm SE for the control. Solid squares represent overlapping values for current year standing crop in control and after burning.

nated grasslands is at odds with earlier studies where productivity was reduced by burning (Redmann 1978, Engle and Bultsma 1984, Whisenant and Uresk 1989). Burning during a drought reduced current year standing crop of *Stipa-Agropyron*-dominated grasslands for 4 to 5 years (Redmann et al. 1993). Since the

present study was conducted over a number of areas and years, and current year standing crop was measured over a wide range of environmental conditions, it is likely that variation in current year standing crop within years after burning masked the variation between control and burning. A similar response was also

noted in Tallgrass Prairie (Briggs and Knapp 1995). Inherent differences among burned areas undoubtedly also contributed to variability in production within years after burning.

Current year standing crop after burning *Festuca* communities was correlated with the amount of litter ($Y = 83.5 + 0.71X - 0.0013X^2$, $R^2 = 0.24$, $P = 0.002$) (Fig. 2), but they were not correlated ($P = 0.964$) for *Stipa-Agropyron*. Deviation among observed current year standing crop is attributed to sampling being done during different years after burning and thus different growing conditions. The regression line in Fig. 2 suggests that low amounts of litter benefit production, large amounts are a detriment to production, and production is greatest at intermediate amounts. Willms et al. (1986) also noted increased total standing crop in Fescue Prairie after litter removal, and litter inhibits production in Tallgrass Prairie (Knapp and Seastedt 1986).

Altering the litter layer by burning may indirectly impact current year standing crop of *Festuca* communities by changing the microenvironment. Litter insulates the soil against incident solar radiation (Rauzi 1960, Willms et al. 1986, 1993) thereby reducing evaporation (Weaver and Rowland 1952, Hopkins 1954) and increasing soil water. Litter also insulates the soil, creating cooler temperatures in summer and warmer temperatures in winter (Johnston et al. 1971). Burning removes litter which in turn causes cascading effects of reduced soil water, increased plant water stress, and reduced production in Fescue Prairie (Redmann 1978, Redmann et al. 1993, Romo et al. 1993, Grilz and Romo 1994). We concur with Willms et al. (1986) that large amounts of litter appear to inhibit production and outweigh benefits of more soil water in *Festuca* communities. Even though our findings suggest that litter influences production in *Festuca* communities, additional studies are needed to elucidate relationships.

Production in drier parts of the Northern Mixed Prairie is associated with amounts of litter; production is maximized with maximum amounts of litter (Willms et al. 1986, 1993). Dix (1960) also concluded that litter does not inhibit production in Northern Mixed Prairie. In the present study, evidence suggests no improvement or reduction of current year standing crop in *Stipa-Agropyron* communities due to litter. The independence of current year standing crop and litter in *Stipa-Agropyron* indicates other factors, such as

Table 1. Current year standing crop in control and burned *Festuca*- and *Stipa-Agropyron*-dominated grasslands over the 11 years of study.

Growing seasons after burning	<i>Festuca</i>					<i>Stipa-Agropyron</i>					n
	Control		Burned		P	Control		Burned		P	
	Mean	SE	Mean	SE			Mean	SE	Mean		SE
	-----(g m ⁻²)-----		-----(g m ⁻²)-----			-----(g m ⁻²)-----		-----(g m ⁻²)-----			
1	197a ¹	19.3	126b	10.5	0.01	144a ¹	6.5	114a	12.8	0.07	7
2	208a	23.8	152a	19.8	0.10	150a	14.5	116a	15.0	0.13	7
3	233a	13.7	167b	16.2	0.01	158a	15.8	131a	13.6	0.22	7
4	230a	12.3	192a	15.4	0.09	159a	13.0	142a	12.2	0.34	6
5	198a	24.6	190a	27.2	0.83	134a	16.1	121a	21.5	0.64	6
6	202a	31.7	163a	28.2	0.39	156a	28.1	142a	25.4	0.73	5
7	204a	13.5	171a	25.4	0.31	135a	20.6	131a	22.5	0.88	4
8	187a	29.8	131a	10.2	0.22	124a	37.7	131a	39.9	0.90	3
9	169a	46.5	146a	7.0	0.72	112a	66.0	86a	32.0	0.78	2
10	67	----	112	----	----	103	----	58	----	----	1
11	175	----	55	----	----	70	----	36	----	----	1

¹Means followed by similar letters in the same row and plant community are not significantly different ($P < 0.050$) between the control and burned plots.

precipitation, place greater controls on production than does litter.

Litter

Litter averaged 391 g m^{-2} ($\text{SE} \pm 12.4$) in the *Festuca* control and 254 g m^{-2} ($\text{SE} \pm 8.6$) in the control for *Stipa-Agropyron*. During the 11-year period litter increased in both *Festuca*- and *Stipa Agropyron*-dominated communities, with 79 and 78% of the variation in litter accounted for by years since burning (Fig. 3). Unexplained variation among observed values probably includes differences in production, transfer to litter, and decomposition among burn areas because observed amounts of litter are grouped by growing seasons after

burning. In both *Festuca*- and *Stipa-Agropyron*-dominated communities, litter was reaching a plateau at the end of our study indicating about 11 years are required for the mass of litter to reach levels comparable to unburned sites. For the Northern Mixed Prairie in North Dakota it is estimated that mass of litter stabilizes in 11–16 years, depending on the plant community (Redmann 1975). At another location in North Dakota, litter recovered 4 years after burning *Stipa*-dominated communities while litter recovery took longer in *Agropyron*-dominated communities (Dix 1960).

Total standing crop

Over the 11-year period total standing crop in the control averaged 595 g m^{-2} ($\text{SE} \pm 14.5$) in *Festuca*- and 398 g m^{-2} ($\text{SE} \pm 10.9$) in *Stipa-Agropyron*-dominated communities. Total standing crop increased for about 7 to 8 years after burning before reaching a plateau in both communities (Fig. 4). The number of growing seasons since burning explained 67% and 58% of the variation in total standing crop in *Festuca* and *Stipa-Agropyron* communities, respectively. The unexplained variation in total standing crop is attributed to differences in production and decomposition among burn areas because total standing crop is categorized by growing seasons after burning. Redmann et al. (1993) reported total standing crop recovered to unburned levels 3 to 4 years after burning.

Return intervals of fires are an important consideration when including fire in the conservation of *Festuca*- and *Stipa-Agropyron*-dominated grasslands. Burning *Festuca*- and *Stipa-Agropyron* communities reduced or had no effect on current year standing crop. Although not definitive, our results also suggest that limited or excessive amounts of litter can hinder production in *Festuca*-dominated grasslands. Limiting litter accumulation by burning *Festuca* too frequently would limit production, as would burning infrequently and allowing large amounts (greater than about 350 g m^{-2}) of litter to accumulate. In comparison our findings suggest precipitation places greater controls on production than amounts of litter in *Stipa-Agropyron* communities.

Aside from the changes in current year standing crop, litter and total standing crop after burning, it is imperative that other conservation goals be considered for *Festuca*- and *Stipa-Agropyron*-dominated grasslands. Annual burning in these grass-

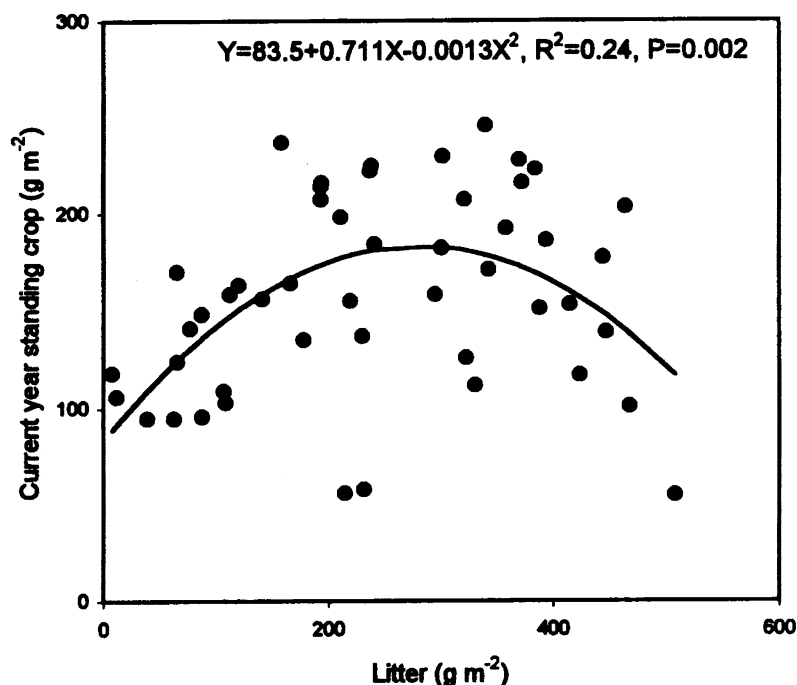


Fig. 2. The fitted regression line and observed values (solid circles) for current year standing crop and litter in burned *Festuca*-dominated plant communities.

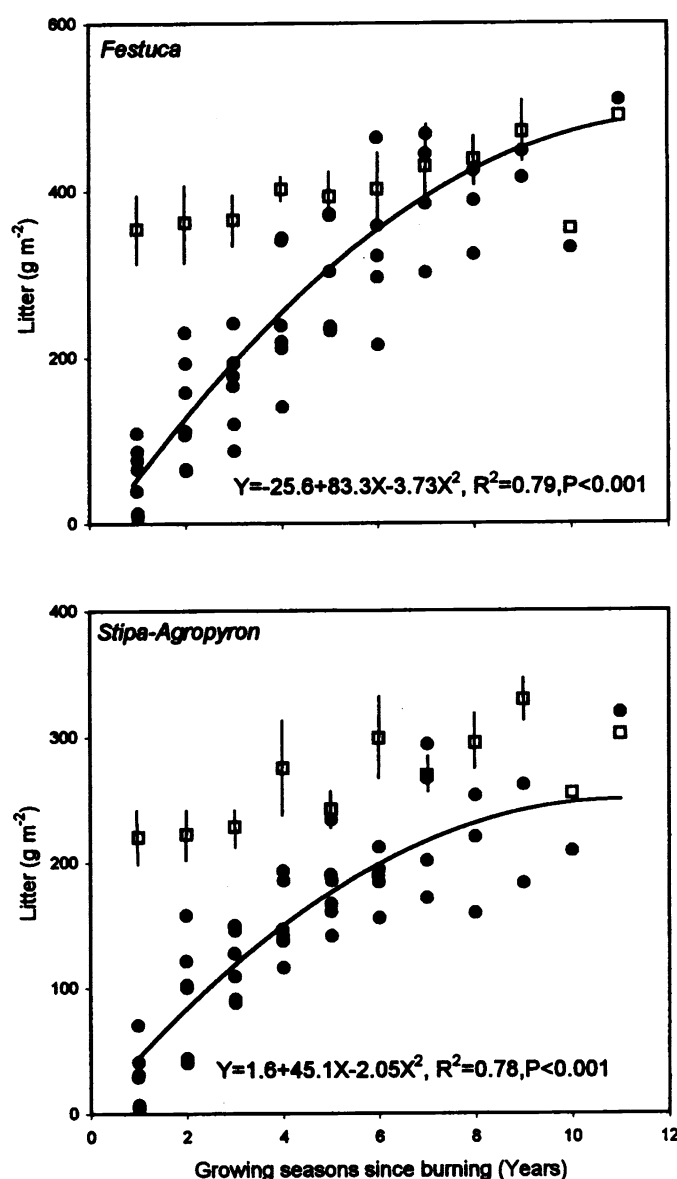


Fig. 3. Fitted regression lines and observed values for litter and growing seasons since burning in *Festuca*- and *Stipa-Agropyron*-dominated plant communities. Solid circles are observed litter after burning and open squares with vertical lines are means \pm SE for the control.

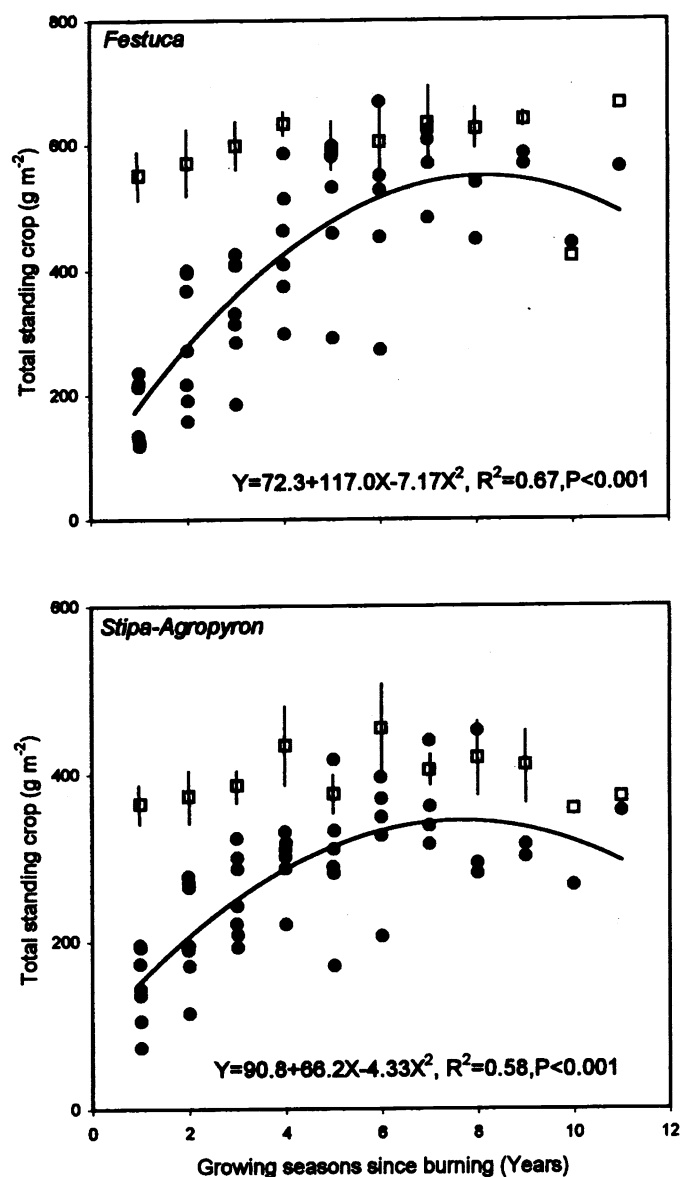


Fig. 4. Fitted regression lines and observed values for total standing crop versus growing seasons since burning in *Festuca*- and *Stipa-Agropyron*-dominated plant communities. Solid circles are total standing crop observed after burning and open squares with vertical lines are means \pm SE for the control.

lands changes the structure in these grasslands by favoring species of warmer and drier conditions (Anderson and Bailey 1980). Furthermore Redmann (1991) argued that losses of nitrogen to volatilization by burning can exceed nitrogen inputs by 3- to 6-fold, and burning more frequently than every 4 years could cause a negative nitrogen balance in these grasslands.

Eighty-two percent of the native prairie in Saskatchewan has been cultivated for growing annual crops (Saskatchewan Agriculture and Food 1998), and about 5% of the prairie dominated by plains rough

fescue remains (Grilz and Romo 1995). Prairie remnants such as Kernen Prairie are important habitats for many species of wildlife, and are especially valuable as developed agricultural and urban lands often surround these remnant prairies. For example, certain species of birds require grasslands that have recovered from burning while others are most abundant when plant communities are in various states of recovery after burning (Pylypec 1991, Madden et al. 1999, 2000). Conservation goals of grasslands may also require significant amounts of dead plant material to

provide nesting cover and foraging sites for wildlife. Burning should be infrequent (11 years or longer) when maintenance of large amounts of litter or total standing crop are concerns in both *Festuca* and *Stipa-Agropyron* communities. Five- (Trottier 1985) to 10 (Wright and Bailey 1982) year return intervals have also been proposed for Fescue Prairie. Barrett (1997, 1999) estimated fire return intervals averaged about 10 to 26 years and ranged from 1 to 60 years in Fescue Prairie in the foothills of the Rocky Mountains in Montana. The actual frequencies of burn-

ing needed to achieve conservation goals must be adjusted for management objectives and prevailing conditions of the prairie remnant under consideration. In practice, conservationists should probably strive to maintain a mosaic of burned patches within remnants of *Festuca*- and *Stipa-Agropyron*-dominated grasslands, each in various states of recovery.

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