THE USE OF HERBICIDES FOR BRUSH CONTROL IN PASTURES OF EAST-CENTRAL SASKATCHEWAN

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ABSTRACT

One of the main problems encountered with most methods of pasture improvement is the control of regrowth of young trees and shrubs which compete with grasses and legumes for moisture, nutrients, and sunlight. This paper reports on results from three timing experiments that used combinations of 2,4-D and dicamba and different patterns of herbicide application to control regrowth of woody plants in pastures of east-central Saskatchewan. The main woody plant species were aspen poplar, prickly rose, and western snowberry. The experiments were conducted during 1981 to 1989 in a community pasture located on a Waitville loam soil. The area had been cleared of trees and shrubs by bulldozing in the winter of 1979-80, prior to the start of the tests. In June of 1981 2,4-D ester or 2,4-D amine at 2.2 kg ha^{-1}, plus dicamba at 1.5 kg ha^{-1}, were foliar applied at full leaf expansion of the aspen poplar. Some treatments received repeated sprayings in the first year, second year, or in two consecutive years after the initial herbicide application. Other treatments studied included the application of 2,4-D tank mixtures with higher rates of dicamba, using a combination of fertilizer and herbicide, and using fertilizer alone. The results showed that herbicides were an effective method for controlling brush regrowth on pastures. The production of woody plant material was reduced by 52 to 98%, while the production of grasses was increased nearly three-fold compared to untreated areas. When mixed with dicamba, application of 2,4-D ester was more effective for controlling undesirable plant species than the 2,4-D amine formulation. Using repeated herbicide applications improved the control of woody plants and improved the yields useable herbage. The highest yields of forage were obtained when herbicides and fertilizers were used in combination. Economic returns from brush control were generally highest for the one-time application of 2,4-D ester plus dicamba. Repeated herbicide applications, and application of a higher rate of dicamba, were not economically justified unless the value assigned to forage was very high. Under the conditions of this study, improving pasture productivity through application of fertilizer and herbicides in combination, or fertilizer alone, were less profitable than a one-time application of 2,4-D ester plus dicamba.

INTRODUCTION

In the Parkland region of Saskatchewan, aspen poplar is the dominant woody plant species that occupies rangeland areas (Looman and Best 1979). Other trees and shrubs often grow in association with aspen poplar, such as balsam poplar which is found in moister areas, prickly rose found in drier areas, and western snowberry found in dry to moist areas. These species reproduce from seed and either rhizomes or shallow lateral roots. Together, they can cause large reductions in the amount of useful herbage available for grazing by beef cattle through competition with grasses for moisture, nutrients, and sunlight (Bailey and Gupta 1973; Bailey and Wroe 1974).

The traditional method of controlling woody plants in pastures is to bulldoze, pile, and burn them. The trees and larger shrubs are often bulldozed when the soil is frozen, leaving the soil surface relatively undisturbed and the root systems intact. This, combined with the ability of aspen poplar and associated brush species to sprout vigorously from shallow roots and seed, permits rapid re-invasion of the areas unless subsequent action is taken to control their regrowth (Bailey 1972).

Mechanical methods such as rotary mowing, prescribed burning, and heavy grazing by cattle have been used alone and in combination to provide short-term control of brush regrowth (Bailey 1986). Selective herbicides have also been used effectively in many parts of North America for control of woody and herbacious weeds in pastures (Bailey 1972; Bowes 1975, 1976; Norris et al. 1982). In Canada, 2,4-D and dicamba are the main foliar herbicides registered for control of woody plants on permanent grassland areas (Saskatchewan Agriculture and Food 1990).

The objective of this study was to determine the effect of multiple 2,4-D and dicamba herbicide combinations for control of brush regrowth on change in forage yields and economic returns for pastures in east-central Saskatchewan.

MATERIALS AND METHODS

Experimental Data

Three experiments were conducted simultaneously from 1981 to 1989 in a community pasture located 190 km northeast of Regina, Saskatchewan. The soil was classified as a Waitville loam (Mitchell et al. 1944); the topography was undulating - rolling to rolling with sloughs and marshy depressions common. Surface drainage was impeded but profile drainage was adequate in most areas. The area was originally dominated by aspen poplar. The trees were bulldozed and piled during the winter of 1979-80 when the soil was frozen. Trees were sheared off at the soil surface, leaving the root systems intact. After the bulldozer treatment, the area was left undisturbed and was invaded by native forbs, grasses, and woody plant species. Aspen poplar was the dominant woody species which re-invaded rapidly. In 1982, forbs comprised about 16%, grass and legume species 59%, and woody plants under 0.5 m in height 24% of the total above ground dry matter.

The areas selected for the tests had uniform stands of regrowth aspen

Table 1. Summary of brush control treatments

Experiment/Treatment	Description (Year of application)	Rates	Code
a) Experiment I		(kg ha^{-1})	
1	Check	---	Check
2	2,4-D Ester + Dicamba (1981)	2.2 + 1.5[+]	ED1Y1
3	2,4-D Ester + Dicamba (1981, 82)	2.2 + 1.5	ED1Y12
4	2,4-D Ester + Dicamba (1981, 83)	2.2 + 1.5	ED1Y13
5	2,4-D Ester + Dicamba (1981, 82, 83)	2.2 + 1.5	ED1Y123
6	2,4-D Amine + Dicamba (1981)	2.2 + 1.5	AD1Y1
7	2,4-D Amine + Dicamba (1981, 82)	2.2 + 1.5	AD1Y12
8	2,4-D Amine + Dicamba (1981, 83)	2.2 + 1.5	AD1Y13
9	2,4-D Amine + Dicamba (1981, 82, 83)	2.2 + 1.5	AD1Y123
b) Experiment II			
1	Check	---	Check
2	N + P_2O_5 Fertilizer[§]	40 + 40	F
3	2,4-D Ester + Dicamba (1981) + N + P_2O_5[§]	2.2+1.5+40+40	ED1Y1F
4	2,4-D Ester + Dicamba (1981)	2.2 + 1.5	ED1Y1
5	2,4-D Ester + Dicamba (1981)	2.2 + 1.75	ED2Y1
6	2,4-D Amine + Dicamba (1981)	2.2 + 1.5	AD1Y1
7	2,4-D Amine + Dicamba (1981)	2.2 + 1.75	AD2Y1
c) Experiment III			
1	Check	---	Check
2	2,4-D Ester + Dicamba (1983)	2.2 + 1.5	ED1Y1
3	2,4-D Ester + Dicamba (1983, 84)	2.2 + 1.5	ED1Y12
4	2,4-D Ester + Dicamba (1983, 85)	2.2 + 1.5	ED1Y13

[+] Herbicide rates are in units of active ingredient.

[§] Fertilizer N and P_2O_5 were broadcast in fall of 1981, and in the spring of 1984, 1985, 1986, 1987 and 1989.

poplar and variable stands of prickly rose and western snowberry. Balsam poplar was a minor component and was restricted to moist areas. Subject to treatment specifications (Table 1), 2,4-D ester or 2,4-D amine, in combination with dicamba, were applied as soon as possible after full leaf expansion of aspen poplar, usually in early to mid June of each application year. All experiments have some treatments in common. Experiment III, which was comprised of a subset of treatments from experiment I, was initiated to determine whether effects on pasture productivity were dependent upon weather conditions in the starting year. Untreated check plots were included in each experiment. All herbicides were applied in water at 225 L ha^{-1} with a small hand-held compressed air sprayer. In experiment II, fertilized treatments received 40 kg ha^{-1} N plus 40 kg ha^{-1} P_2O_5 broadcast in mid May, except in 1983 and 1988 when no fertilizer was applied. The treatments for each experiment were arranged in randomized complete block designs with four replicates. The size of each plot was 59 m^2.

The test areas were grazed during 1980 and 1981. In spring of 1982, an electric fence was built around the sites to exclude cattle from grazing. Control of the woody species was determined by measuring the leaf canopy in mid August of each year which intercepted two 10-m line transects. The total canopy width of each species which intercepted the line transect was expressed as a percentage of the total length of the line. Yield of total plant material was determined by collecting randomly selected samples from four 0.5 m^2 areas per plot in late June or early July of each year. All samples were clipped at the level of the litter layer, placed in plastic bags, and frozen. Later the samples were separated into grasses, legumes, forbs, and woody material, and then oven dried at 100 C for 48 h before weighing. The production of consumable herbage (forage) for beef cattle was taken as the yield of grasses plus one-half the yield of forbs.

Growing season precipitation was estimated as the mean of recordings from weather stations near Yorkton and Kelliher.

Annual yields of wood, forbs, grasses, forage (grass plus one-half forbs), and undesirable plant species (woody material plus one-half of forbs) were statistically analyzed using analysis of variance (SAS Institute, Inc. 1985). Duncan's New Multiple Range Test was used to rank treatment means.

Economic Analysis

The economic performance of treatments within each experiment was assessed using capital budgeting procedures (Doll and Orazem 1978) to discount the annual net cash flows associated with the increase in useable herbage production over that of the check treatment. This involved computing the net present value (NPV) of the additional revenues and costs for each treatment based on the following formula:

$$NPV_i = \sum_{t=1}^{T} \left[(V^* \Delta Y_{it} - H_{it} - F_{it}) \frac{1}{(1 + r)^t} \right]$$

where, ΔY = dry matter forage yield increase over check (kg ha^{-1}) for treatment i in year t,

V = value of forage (\$ kg-1),

H = herbicide plus application cost for treatment i in year t (\$ ha^{-1}),

F = N fertilizer plus application cost for treatment i in year t (\$ ha^{-1}),

r = discount rate (%), and

T = length of study period (years).

A positive NPV (\$ ha^{-1}) is interpreted to mean that the brush control treatment is profitable relative to the check. The most profitable treatment is the one that provides the highest positive NPV. However, this should not be interpreted as an indication of the overall profitability of beef production since only costs that differed between treatments have been included.

The analysis was conducted using 1989 costs for herbicides, fertilizer, and machine operation (University of Saskatchewan 1989) (Table 2). Further, since the treatments were not grazed by cattle, the value of the additional forage was taken as being equivalent to that of standing hay (expressed on a dry weight basis). No allowance was made in the analysis for loss of herbage production because of grazing restrictions since the restrictions for grazing beef cattle on pastures sprayed with 2,4-D and dicamba when applied as described above are relatively minor (Saskatchewan Agriculture and Food 1990). Each treatment was evaluated for forage prices of 25, 50, and 75 \$ t^{-1} (dry weight basis), and for discount rates of 0, 5, and 10%. The discount rates, which adjust the net cash flows for the opportunity cost or time value of money, reflect an inflation free situation, adjusted for risk.

Two approaches were used to estimate the future forage yield benefits of the treatments beyond 1989. In the first instance, multiple regression was used to relate annual forage yield increases for each treatment to level of growing season precipitation and time (or years); however, in nearly all cases the estimated coefficients for the time variables were nonsignificant ($P>0.05$), and this approach was discarded. In the second approach, it was assumed that the pastures reached steady-state conditions by year five from the initial herbicide application (Novak and Lerohl 1986). The mean forage yield increase over check for each treatment, calculated for the remainder of the study period (i.e., 1986-89 for experiment I and II, and 1988-89 for experiment III), was used as an estimate of the future yield benefit. These estimates, based on findings of Ethbridge et al. (1984), and Novak and Lerohl (1986), were assumed to: i) continue at a constant level for 5 years beyond 1989, ii) continue at a constant level for 10 years beyond 1989, iii) decline linearly over 5 years into the future, and iv) decline linearly over 10 years into the future. In addition to NPV, breakeven or threshold forage prices were computed for each treatment and future forage benefit scenario. These breakeven prices represent the minimum value that must be obtained from utilization of the forage (as standing hay) in order to just offset the costs of the brush control treatments. When the actual forage utilization value is less than the breakeven price, it implies that the brush control treatment is unprofitable, and vice versa.

Table 2. Summary of economic parameters[+]

Item	Value	Unit[§]
Herbicides		
2,4-D Ester	8.00	$ kg^{-1}
2,4-D Amine	7.50	$ kg^{-1}
Dicamba	48.03	$ kg^{-1}
Fertilizers		
N	0.55	$ kg^{-1}
P_2O_5	0.60	$ kg^{-1}
Herbicide Application	7.50	$ ha^{-1}
Broadcast Fertilizer	4.00	$ ha^{-1}

+ Taken from University of Saskatchewan (1989).

§ For herbicides, units are active ingredient.

RESULTS AND DISCUSSION

Weather Conditions

Average growing season precipitation (May 1 to August 31) received during 1982-89 was similar to the long-term mean of 235 mm (Table 3). Growing season precipitation was less than 75% of average in 1988 and 1989, and more than 20% above average in 1983 and 1986. Precipitation received in May and June was uniformly distributed from year to year, but precipitation received in July was highly variable across years. August precipitation was below average in all years except 1985.

Effect of Herbicide Treatments on Yields of Plant Material

Mean annual yields of total above ground plant material did not differ greatly among most treatments within an experiment (Table 4); however, yields of woody material and forbs declined significantly ($P<0.05$) with application of 2,4-D plus dicamba herbicide. Herbicides reduced the mean annual production of woody material by 52 to 98%, in agreement with findings of other studies (Bowes 1975, 1976). By reducing the competitive effect of woody plants, yields of grasses were increased from one to four fold relative to the check, with the average yield increase being about 2.9 fold. The application of herbicide mixtures reduced the presence of forbs but this was more than offset by an increase in the presence of grasses. On check plots the proportion of useable herbage (grasses plus one-half forbs) averaged 47 to 54% of total dry matter production, while on plots that received herbicide the proportion of useable herbage averaged 66 to 96%.

Table 3. Summary of precipitation received

Year	May	June	July	August	Growing Season+
	(mm)				
1982	43	52	138	34	267
1983	65	107	140	28	340
1984	60	90	31	20	201
1985	63	98	21	70	252
1986	63	60	125	34	282
1987	41	57	98	38	234
1988	40	53	33	24	150
1989§	62	52	30	48	182
Mean	55	71	76	37	239
LT Avg.ƒ	48	69	59	59	235

+ May 1 to August 31

§ Estimated using precipitation measurements from weather stations at Yorkton and Kelliher.

ƒ Long-term (1951-89) average for Yorkton.

The application of 2,4-D ester in a mixture with dicamba was generally more effective than 2,4-D amine in reducing yields of undesirable plants and increasing yields of grasses (Table 4). Yields of grasses averaged about 20% higher on plots that received the ester versus amine formulation. The use of repeated herbicide applications in consecutive years further reduced the production of woody material and forbs, and permitted increased yields of grasses. In most instances, there was little difference ($P>0.05$) in the yield of grasses regardless of whether the repeat sprayings occurred in the first year, second year, or in both years following the initial spraying.

In experiment II, the application of N and P fertilizer alone increased yields of wood by 72% and yields of grasses by 145% (Table 4). On areas that received 2,4-D ester at the start of the experiment, fertilizer increased yields of grasses by 29% but had no affect on the yields of wood and forbs. By comparison, application of fertilizer and herbicide increased grass yields by 245%, and reduced yields of wood and forbs by 72% and 20%, respectively, relative to the check treatment. These results are similar to those reported by Bowes (1981) wherein yields of grasses were often highest when herbicides and fertilizers were used in combination. Also in experiment II, the application of a higher rate of dicamba (1.75 vs 1.5 kg ha^{-1}) in combination with 2,4-D tended to further reduce yields of undesirable and increase yields of desirable plants, but often the forage yield benefits were nonsignificant ($P>0.05$). Finally, comparison of experiment I with experiment III showed little evidence that treatment effects were influenced by the year in which the herbicides were applied.

Table 4. Mean annual dry matter plant production

Experiment/Treatment	Total	Wood	Forbs	Grasses	Proportion of Useable Herbage[+]
	------------	(kg ha^{-1})	-------		(%)
a) Experiment I[§]					
Check	1479	582	582	315	47
ED1Y1	1448	135	484	830	75
ED1Y12	1327	30	269	1028	88
ED1Y13	1286	16	168	1101	92
ED1Y123	1315	11	77	1227	96
AD1Y1	1371	281	482	608	66
AD1Y12	1376	162	330	904	77
AD1Y13	1265	61	240	964	85
AD1Y123	1263	36	141	1085	91
Mean	1350	146	308	896	80
$S\bar{x}$	43	31	16	30	
b) Experiment II[§]					
Check	1297	350	606	342	50
F	2092	601	654	837	58
ED1Y1F	1761	98	482	1180	81
ED1Y1	1514	101	496	917	77
ED2Y1	1393	63	383	947	81
AD1Y1	1406	167	526	713	69
AD2Y1	1353	119	419	815	75
Mean	1545	214	509	821	70
$S\bar{x}$	39	26	19	34	
c) Experiment III[ƒ]					
Check	1277	323	577	377	54
ED1Y1	1284	62	247	975	85
ED1Y12	1317	21	148	1149	93
ED1Y13	1282	29	149	1104	92
Mean	1290	109	280	901	81
$S\bar{x}$	36	22	15	30	

+ Includes grasses and one-half forbs.
§ 1982-89.
ƒ 1984-89.

Table 5. Forage yield of check and forage yield increase from brush control+

Experiment/Year — Yield Increase Over Check — (kg ha^{-1})

a) Experiment I

Experiment I	Check	ED1Y1	ED1Y12	ED1Y13	ED1Y123	AD1Y1	AD1Y12	ADY13	AD1Y123	Mean	S$\bar{x}$
1982	403	629	185	492	711	338	307	468	423	444	113
1983	632	619	651	347	408	314	596	117	371	428	121
1984	679	453	662	630	668	220	724	758	789	613	120
1985	919	331	484	798	614	243	223	414	564	459	102
1986	603	253	573	616	556	250	327	457	635	458	76
1987	500	368	497	422	619	126	319	332	393	387	80
1988	503	431	498	484	616	140	400	372	385	416	75
1989	608	641	901	849	1085	321	808	908	858	796	120
Mean	606	466	556	580	660	244	463	478	552	500	

b) Experiment II

Experiment II	Check	F	ED1Y1F	ED1Y1	ED2Y1	AD1Y1	AD2Y1	Mean	S$\bar{x}$
1982	526	316	601	531	617	451	470	498	146
1983	910	120	358	330	402	175	219	267	146
1984	627	552	1017	566	786	633	864	736	151
1985	933	873	1113	299	495	167	209	526	84
1986	606	629	848	396	330	315	294	469	117
1987	475	562	902	399	338	180	264	441	102
1988	474	283	470	360	326	268	261	328	55
1989	605	820	902	1287	654	461	457	764	124
Mean	645	519	776	521	494	331	380	504	

c) Experiment III

Experiment III	Check	ED1Y1	ED1Y12	ED1Y13	Mean	S$\bar{x}$
1984	473	383	318	342	348	95
1985	909	510	636	290	479	82
1986	783	460	688	681	610	91
1987	499	369	413	416	399	76
1988	503	406	543	487	479	99
1989	828	469	740	864	691	206
Mean	666	433	556	513	501	

+ Includes grasses plus one-half of forbs.

On an annual basis, forage yields on herbicide treated plots exceeded those on check plots in all years (data not shown). For most treatments, the forage yield increases over check tended to rise during the first three or four years after the initial sprayings, then they declined and leveled off (Table 5). This early period effect partly reflects more favorable precipitation, but also greater invasion of the areas by grasses and legumes as the competition from woody plants was reduced. The yield of wood on herbicide treated plots showed little tendency to increase with time after the herbicide applications were stopped (data not shown). By comparison, yields of forbs tended to increase, while yields of grasses showed some tendency to decline in later years of the study (data not shown).

Effect of Herbicide Treatment on Net Present Value (NPV)

Forage price, nature of the future forage yield benefit, and discount rate had major effects on NPV for the brush control treatments (Tables 6, 7, and 8). In general, NPV for the treatments increased with forage price and the magnitude and duration of future forage yield benefits, and decreased with the discount rate.

As with forage yields, 2,4-D ester herbicide combinations generally provided higher NPV than the comparable 2,4-D amine herbicide combinations. Treatments that received repeated herbicide applications were generally less profitable (or had higher economic losses) than those receiving a single herbicide application at the start of the experiment, except when forage prices were high. This implies that the increased forage yields obtained with repeated sprayings were often insufficient to pay for the extra herbicide costs. Further, in experiment I repeated sprayings in the second year after the initial herbicide application tended to be more profitable than repeated sprayings in the year immediately following the initial herbicide application, and it was more profitable than repeated sprayings in two consecutive years following the initial sprayings. In experiment III there was little difference in profitability between ED1Y12 and ED1Y13, but here the treatments were in place for fewer years.

Under the conditions of this study, improving pasture productivity by applying herbicides alone was consistently more profitable than applying fertilizer alone, or applying a combination of fertilizer and herbicide. Applying a higher rate of dicamba (1.75 vs 1.5 kg ha^{-1}) was generally profitable when combined with 2,4-D amine, but it was not profitable when combined with 2,4-D ester. These latter results reflect the greater control of woody plants that was obtained with 2,4-D ester versus the amine formulation.

At a forage price of 25 \$ t^{-1} and with no consideration of a forage yield benefit beyond 1989 (discount rate = 5%), all brush control treatments resulted in economic losses. However, when the forage yield benefits were assumed to continue into the future, treatments ED1Y1 and ED2Y1 (to a lesser degree) became profitable to undertake. At this low value for forage, the treatments with the greatest economic loss were those that received fertilizer or repeated herbicide applications. At a forage price of 50 \$ t^{-1}, nearly all brush control treatments were profitable when future forage benefits were considered. The treatment ED1Y1 generally provided the highest NPV in all experiments. At still higher forage prices, the profit-

Table 6. Net present value of brush control treatments in experiment I[+]

Forage Value/Treatment	1981 to 1989 Only	Constant Future Effect[§] 5 Year	Constant Future Effect[§] 10 Year	Declining Future Effect[f] 5 Year	Declining Future Effect[f] 10 Year
	($\$\ ha^{-1}$)				
a) Forage Value = $25\$t^{-1}$ DM					
ED1Y1	- 21	10	34	- 2	11
ED1Y12	-102	- 56	- 21	- 73	- 54
ED1Y13	- 93	- 49	- 15	- 65	- 47
ED1Y123	-173	-120	- 79	-140	-117
AD1Y1	- 56	- 41	- 29	- 47	- 40
AD1Y12	-113	- 79	- 53	- 92	- 78
AD1Y13	-107	- 69	- 40	- 84	- 67
AD1Y123	-186	-145	-112	-160	-143
Mean	-107	- 69	- 39	- 83	- 67
b) Forage Value = $50\$t^{-1}$ DM					
ED1Y1	55	117	165	93	120
ED1Y12	- 14	77	148	42	82
ED1Y13	0	87	155	54	91
ED1Y123	- 68	37	120	- 3	43
AD1Y1	- 16	15	39	3	16
AD1Y12	- 39	29	82	3	32
AD1Y13	- 32	44	104	15	48
AD1Y123	- 98	- 15	50	- 47	- 11
Mean	- 27	49	108	20	53
c) Forage Value = $75\$t^{-1}$ DM					
ED1Y1	131	224	296	188	228
ED1Y12	74	210	316	158	217
ED1Y13	92	222	324	173	229
ED1Y123	37	195	319	135	203
AD1Y1	24	70	106	53	73
AD1Y12	35	137	217	98	142
AD1Y13	44	158	247	115	164
AD1Y123	- 10	115	213	67	121
Mean	53	166	255	123	172

+ Discount rate = 5%.

§ Assumes 1986-89 mean forage yield increase over check persists into the future for 5 and 10 years, respectively.

f Assumes 1986-89 mean forage yield increase over check disappears linearly in the future over 5 and 10 years, respectively.

Table 7. Net present value of brush control treatments in experiment II+

Forage Value/Treatment	1981 to 1989 Only	Constant Future Effect§ 5 Year	Constant Future Effect§ 10 Year	Declining Future Effect*f* 5 Year	Declining Future Effect*f* 10 Year
	($ ha^{-1})				
a) Forage Value = 25$ t^{-1} DM					
F	-163	-121	- 88	-137	-119
ED1Y1F	-217	-160	-115	-182	-157
ED1Y1	- 15	29	65	12	32
ED2Y1	- 29	2	25	- 10	3
AD1Y1	- 42	- 20	- 2	- 28	- 19
AD2Y1	- 46	- 23	- 4	- 31	- 21
Mean	- 85	- 37	- 15	- 63	- 35
b) Forage Value = 50$ t^{-1} DM					
F	- 81	3	69	- 29	7
ED1Y1F	- 93	21	111	- 22	27
ED1Y1	67	156	226	122	161
ED2Y1	52	112	160	89	116
AD1Y1	12	56	92	40	59
AD2Y1	16	63	100	45	65
Mean	- 4	69	126	41	73
c) Forage Value = 75$ t^{-1} DM					
F	1	127	225	79	133
ED1Y1F	31	203	337	138	212
ED1Y1	148	283	388	232	290
ED2Y1	133	223	294	189	228
AD1Y1	66	133	186	107	136
AD2Y1	78	149	203	122	152
Mean	76	186	272	145	144

+ Discount rate = 5%

§ Assumes 1986-89 mean forage yield increase over check persists into the future for 5 and 10 years, respectively.

f Assumes 1986-89 mean forage yield increase over check disappears linearly in the future over 5 and 10 years, respectively.

Table 8. Net present value of brush control treatments in experiment III[+]

Forage Value/Treatment	1983 to 1989 Only	Constant Future Effect[§] 5 Year	Constant Future Effect[§] 10 Year	Declining Future Effect[ƒ] 5 Year	Declining Future Effect[ƒ] 10 Year
	($ ha^{-1})				
a) Forage Value = 25$t^{-1} DM					
ED1Y1	- 42	- 7	21	- 20	- 5
ED1Y12	-120	- 68	- 27	- 88	- 65
ED1Y13	-122	- 67	- 24	- 88	- 64
Mean	- 95	- 47	- 10	- 65	- 45
b) Forage Value = 50$t^{-1} DM					
ED1Y1	13	83	139	56	87
ED1Y12	- 50	54	135	14	59
ED1Y13	- 58	51	137	10	57
Mean	- 32	63	137	27	68
c) Forage Value = 75$t^{-1} DM					
ED1Y1	68	174	257	133	179
ED1Y12	20	175	297	116	183
ED1Y13	6	169	298	107	178
Mean	31	172	284	119	180

+ Discount rate = 5%.

§ Assumes 1988-89 mean forage yield increase over check persists into the future for 5 and 10 years, respectively.

ƒ Assumes 1988-89 mean forage yield increase over check disappears linearly in the future over 5 and 10 years, respectively.

ability of treatments that received repeated sprayings with 2,4-D ester and dicamba were often equal or greater than that of treatment ED1Y1.

Increases in the interest rate or opportunity cost of capital, substantially reduced the profitability of all brush control treatments, but it had relatively little effect on the economic rankings of the treatments. An increase in discount rate from 5 to 10% reduced the NPVs by 20 to 40 \$ ha^{-1} when forage price was 25 \$ t^{-1}, by 25 to 60 \$ ha^{-1} when forage price was 50 \$ t^{-1}, and by 50 to 110 \$ ha^{-1} when forage price was 75 \$ t^{-1} (data not shown). Treatments that received one application of herbicide at the start of the experiment suffered the smallest drop in NPV, while treatments that received three sprayings and/or fertilizer suffered the greatest drop. Reducing the discount rate had the opposite effect, making investment in brush control economically attractive at lower forage prices (data not shown).

Breakeven Forage Values

The minimum price for forage that is needed to just offset the costs of brush control follow the reverse patterns as for NPV (Table 9). Treatment ED1Y1 had the lowest breakeven forage prices under all economic scenarios, while treatments with repeated sprayings or the application of fertilizer had the highest. These figures imply that if the utilization value of the additional forage obtained from brush control is greater than these breakeven prices, then producers can increase net returns by investing in brush control. However, the figures also imply that if a producer can obtain access to forage of equilvalent nutritional value for grazing beef cattle at less cost than the breakeven prices (e.g., through leasing, renting, or purchasing additional pasture land, or placing cattle in community pastures), then it will be more cost effective (at least in the short-run) to use these alternate grazing sources than to improve forage productivity on an existing pasture through brush control. In the long-run, however, the producer must also be cognizant of the impact on future pasture productivity due to a build-up of undesirable plant species as a result of foregoing brush control.

As for NPV, changes in the discount rate impact on the breakeven forage prices. Increasing the discount rate from 5 to 10%, increased the breakeven forage prices by an average of 6 \$ t^{-1} for treatments with one herbicide application, 11 \$ t^{-1} for treatments with two sprayings, and 15 \$ t^{-1}, for treatments with three sprayings (data not shown). At a zero discount rate, the breakeven forage prices were reduced by generally similar amounts (data not shown).

CONCLUSIONS

Results of up to eight years of study from three experiments conducted simultaneously have shown that the use of 2,4-D plus dicamba herbicides is an effective method for controlling brush regrowth on pastures in east-central Saskatchewan. The application of 2.2 kg ha^{-1} of 2,4-D ester or 2,4-D amine, tank mixed with 1.5 kg ha^{-1} of dicamba, reduced dry matter production of woody materials by 52 to 98%. By reducing the competitive effect of woody plants, the production of grasses was increased by an average of 2.9 fold relative to the check. When mixed with dicamba, an

Table 9. Breakeven forage values[+]

Experiment/Treatment	to 1989 Only	Constant Future Effect[§] 5 Year	Constant Future Effect[§] 10 Year	Declining Future Effect[ƒ] 5 Year	Declining Future Effect[ƒ] 10 Year
	($ t^{-1})				
a) Experiment I					
ED1Y1	26	17	12	20	16
ED1Y12	44	26	18	31	25
ED1Y13	42	26	18	30	25
ED1Y123	55	33	23	39	32
AD1Y1	49	32	24	37	31
AD1Y12	52	32	23	38	31
AD1Y13	50	30	21	36	29
AD1Y123	65	40	29	47	38
b) Experiment II					
F	75	49	39	57	49
ED1Y1F	69	47	38	54	46
ED1Y1	30	19	15	22	19
ED2Y1	34	25	20	27	24
AD1Y1	45	32	26	35	31
AD2Y1	43	32	26	35	31
c) Experiment III					
ED1Y1	44	27	21	32	26
ED1Y12	68	39	29	47	38
ED1Y13	73	39	29	48	38

[+] Discount rate = 5%.
[§] Assumes 1988-89 mean forage yield increase over check persists into the future for 5 and 10 years, respectively.
[ƒ] Assumes 1988-89 mean forage yield increase over check disappears linearly in the future over 5 and 10 years, respectively.

application of 2,4-D ester was more effective for controlling undesirable plant species than the 2,4-D amine formulation. Using repeated herbicide applications in subsequent years provided somewhat better control of woody plants, and contributed to still higher yields of grasses. The highest yields of useable herbage were obtained when herbicides and fertilizers were used in combination.

Economic returns from brush control varied greatly among treatments and depended on the value assigned to forage, the longevity and nature of the future forage yield benefit from brush control, and the interest rate used to discount the streams of returns and costs. In general, the most profitable brush control treatment was the one-time application of 2,4-D ester plus dicamba. Repeated herbicide applications were economically justified only when forage prices were high. Under the conditions of this study, improving pasture productivity through application of herbicides for brush control was more profitable than application of fertilizer and herbicides in combination, or application of fertilizer alone.

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