REJUVENATION OF TAME FORAGES

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Herbert A. Lardner

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Examining Committee:

Dr. J.T. Romo	~~Dean's Associate Dean~~ Dean's Designate, Chair College of Graduate Studies and Research
Dr. G.I. Christison	Chair of Advisory Committee, Department of Animal and Poultry Science
Dr. R.D.H. Cohen	Co-supervisor, Department of Animal and Poultry Science
Dr. S.B.M. Wright	Co-supervisor, Western Forage/Beef Group, Lacombe, AB
Dr. D.A. Christensen	Department of Animal and Poultry Science
Dr. J.J. McKinnon	Department of Animal and Poultry Science
Dr. P. Jefferson	Agriculture and Agri-Food Canada, Swift Current, SK
Mr. P. Curry	Ducks Unlimited Canada, Melfort, SK

External Examiner:

Dr. R. Horton
B.C. Ministry of Forests Research Branch
3015 Ord Road
Kamloops, B.C. V2B 8A9

Rejuvenation of Tame Forages

Studies were conducted at five sites in Saskatchewan over three years to determine the effect of spiking (SP), burning (B), mowing (M), deep-banding (slicing) (DB) and liquid and granular fertilizer on dry matter yield (DMY), crude protein (CP), calcium (Ca) and phosphorous (P) content, and botanical composition of primarily smooth bromegrass (*Bromus inermis* Leyss.) alfalfa (*Medicago sativa* Pers.) and Kentucky bluegrass (*Poa pratensis* L.) pastures. All treatments were applied spring 1994 as a randomized complete block split-plot. Liquid fertilizer (DBLIQ) was deep-banded at 350 kg ha^{-1} (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}). Split-plot treatments were granular fertilizer (+F), broadcast at 0 and 350 kg ha^{-1} (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}). Burning increased ($p<0.05$) DMY in yr 1 and 2 at the Gray-Wooded soil site while spiking decreased ($p<0.05$) DMY in 1994. DB and M had only minimal effects on production. In 1994, DBLIQ+F (200 kg N ha^{-1}) increased DMY, 84 to 185% over control plots at all sites, with no carry over effect in 2nd or 3rd year. Mechanical treatments (DB, M and SP) + F increased ($p<0.05$) DMY and herbage CP in 1994. Liquid fertilizer deep-banded showed a greater response for DMY at all sites than did granular fertilizer. DBLIQ+F increased ($p<0.05$) CP content of 1994 forage samples however, CP of 1995 and 1996 samples were similar to control. Broadcast fertilizer (C+F) affected CP and P only in 1994. Forage phosphorous increased ($p<0.05$) with fertilizer plus SP, DB, M and B in 1994, but not with SP, B, DB or M alone. Spiking reduced grass and legume composition, but increased ($p<0.05$) presence of weeds and bare ground. Burning increased ($p<0.05$) alfalfa composition and decreased ($p>0.05$) bluegrass (*Poa pratensis* L.) composition only in 1994. Broadcast fertilizer, (C+F) increased ($p<0.05$, 1994; $p<0.10$, 1995-96) smooth bromegrass component each year but decreased alfalfa component ($p<0.05$). Broadcast fertilizer

combined with DB, M, SP or B increased (p<0.05) smooth bromegrass and decreased bluegrass, weeds and bare ground.

Nutrient digestibility and dry matter intake (DMI) of rejuvenated hay was determined in a feeding trial using ram lambs. Hay was harvested from DBLIQ+F, B and control plots at two maturity dates from two soil zone sites. As maturity advanced, DMI $(g d^{-1} kg^{-0.75})$ and digestible organic matter intake (DOMI) decreased (p<0.05) for all diets (except fertilizer) harvested from the Gray-Wooded site. DMI and DOMI were greater (p<0.05) for hay (early and late harvest) from rejuvenated plots than from control plots. Digestibilities of dry matter and organic matter were greater (p<0.01) for early harvested forage from control at the Gray-Wooded soil site than for hay from fertilized plots. Metabolizable energy (ME) content was higher (p<0.05) for early harvested hay from burn and fertilized plots (Black soil site) than hay from control plots. These same hays were analyzed using *in vitro* gas production (mL/200 mg DM) to predict ME (MJ kg^{-1} DM) and *in vitro* digestibility (IVDMD) to predict *in vivo* dry matter digestibility (DMD). Predicted ME values using *in vitro* gas production data were different (p<0.03) from *in vivo* ME values. A high correlation (r=0.87) was found between *in vitro* and *in vivo* dry matter digestibility. Predicted average daily gains of steers consuming B+F and control hay from two soil zones were generated using NRC (1996) Computer Model Level I. Energy was the most limiting nutrient for ADG. Rejuvenated hay from Gray-Wooded and Black soil sites backgrounded 52 and 44% more steers, respectively than did control hay.

VITAE

Herbert Andrew Lardner was born in Salmon Arm, British Columbia, Canada on August 30, 1957 to Winnifred Alice and Harold Alfred Lardner. His family farmed in the Okanogan Valley of British Columbia until they moved to the Peace River area in 1970 where they purchased a mixed farm near Dawson Creek, B.C. The author was actively involved with farming and the agricultural community until completing high school. Over the next ten years he was employed in the livestock industry in western Canada, working in the cow-calf, feedlot and animal health sectors. In 1982 he entered the animal health diploma program at Fairview College in northern Alberta, which he completed in the spring of 1984. In the fall of 1984 the author came to Saskatoon and began studying for a degree in agriculture at the University of Saskatchewan. After completing a year of studies he returned to Alberta and was employed in the bovine embryo transfer industry. In 1989, after deciding to finish his education, he returned to Saskatoon completing his Bachelor of Science in Agriculture in 1991. After completing his Bachelors degree he pursued an M.Sc. studying irrigated grass species for grazing ruminants. After receiving his Master of Science degree the author spent a year at Lethbridge Community College, Lethbridge, Alberta instructing Animal Science courses in the Agricultural Technology program. In May of 1994 he returned to Saskatchewan and began a Ph.D. program working on rejuvenation of tame forage pasture. The author has always maintained an active interest in the beef and forage industry of western Canada and is currently employed by the Sustainable Production Branch of Saskatchewan Agriculture and Food.

ABSTRACT

Field studies were conducted at five different sites throughout central Saskatchewan over three years to determine the effect of spiking (SP), burning (B), mowing (M), deep-banding (slicing) (DB) and liquid and granular fertilizer on dry matter yield (DMY), crude protein (CP), calcium (Ca) and phosphorous (P) content, and botanical composition of primarily smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago sativa* Pers.) pastures. All mechanical and fertilizer treatments were applied in the spring of 1994 as a randomized complete block split-plot design. Liquid fertilizer (DBLIQ) was deep-banded at 350 kg ha^{-1} (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}). Split-plot treatments were granular fertilizer (+F) broadcast at 0 and 350 kg ha^{-1} (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}). Responses to rejuvenation treatments in DMY and forage quality varied from no response (DB and M) to 185% above control for liquid and granular fertilizer (200 kg N ha^{-1}) in 1994. Burning increased ($p<0.05$) DMY in yr 1 and 2 at the Gray-Wooded soil site while spiking decreased ($p<0.05$) DMY in 1994. DB and M had only minimal effects on production, decreasing DMY in 1994 and showing only a varied response in the second and third years. In 1994, DBLIQ+F (200 kg N ha^{-1}) increased DMY, 84 to 185% over control plots at 4 sites. This effect carried over into the second year at 4 sites ($p<0.05$) but not the third year of the study. Mechanical treatments (DB, M and SP) combined with broadcast fertilizer significantly ($p<0.05$) increased forage yields in 1994. Fertilizer deep-banded in the liquid form showed a greater response for DMY at all sites than did granular fertilizer.

200 kg N ha^{-1} (DBLIQ+F) increased ($p<0.05$) CP content of 1994 forage samples however, CP of 1995 and 1996 samples were similar to control levels for this treatment. The impact of broadcast fertilizer (C+F) on quality ocurred only in the year of

application (1994). Herbage CP in 1994 increased (p<0.05) with broadcast fertilizer combined with SP, DB, M and B but returned to control levels by 1996. Broadcast fertilizer combined with SP, DB, M and B decreased forage calcium (Ca) content. Burning tended to increase herbage Ca after 3 years. Forage phosphorous increased (p<0.05) with fertilizer combined with SP, DB, M and B in 1994, but not with SP, B, DB or M alone. Spiking reduced grass and legume composition, but increased (p<0.05) the presence of annual weeds (4 sites) and bare ground (1 site). Burning increased (p<0.05) alfalfa composition and decreased (p>0.05) bluegrass (*Poa pratensis* L.) composition only in 1994. Broadcast fertilizer, (C+F) increased (p<0.05, 1994; p<0.10, 1995-96) smooth bromegrass component each year but decreased alfalfa component (p<0.05). Broadcast fertilizer combined with DB, M, SP or B increased (p<0.05) smooth bromegrass and decreased bluegrass, weeds and bare ground.

A digestibility and intake trial was designed to determine nutrient digestibility and dry matter intake (DMI) by growing lambs of sun-cured hay harvested from DBLIQ+F, B and control plots at two maturity dates from two soil zone sites . As maturity advanced, DMI (g d^{-1} kg$^{-0.75}$) and digestible organic matter intake (DOMI) decreased (p<0.05) for all diets (except fertilizer) harvested from the Gray-Wooded site. DMI and DOMI (g d^{-1} kg$^{-0.75}$) were greater (p<0.05) for hay (early and late harvest) from rejuvenated plots than from control plots. Apparent digestibilities of dry matter (DMD) and organic matter (OMD) were greater (p<0.01) for early harvested forage from control plots at the Gray-Wooded soil site than for hay from fertilized plots. Metabolizable energy (ME) content was higher (p<0.05) for early harvested hay from burn and fertilized plots at the Black soil site than hay from control plots. These same diets were analysed using *in vitro* gas production (mL/200 mg DM) to predict ME (MJ kg^{-1} DM) and *in vitro* digestibility (IVDMD) to predict *in vivo* dry matter digestibility (DMD). For all samples DMD and ME *in vivo* was determined with sheep fed at a maintenance level. Predicted ME values

using *in vitro* gas production data were different (p<0.03) from *in vivo* ME values, having a coefficient of variation (CV) of 8.1%. A high correlation (r=0.87) was found between *in vitro* and *in vivo* dry matter digestibility. The IVDMD technique accurately predicted digestibility of the hays, having a CV of 0.5%.

Steer average daily gain (ADG) was predicted using nutritive data of B+F and control hay samples from two soil zones, entered into the NRC (1996) Computer Model Level I. In all predictions, energy was the most limiting nutrient for ADG. Predicted mean animal ADG was greater for rejuvenated hay harvested from the Black soil site. Rejuvenation of tame hay on Gray-Wooded and Black soils backgrounded 52 and 44% more steers than control hay.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

ADF	-	acid detergent fiber
ADICP	-	acid detergent insoluble crude protein
ADL	-	acid detergent lignin
B	-	burn
B+F	-	burn + broadcast granular fertilizer
C	-	control
C+F	-	control + broadcast granular fertilizer
CP	-	crude protein
DB	-	deep-band
DB+F	-	deep-band + broadcast granular fertilizer
DBLIQ	-	deep-banded liquid fertilizer
DBLIQ+F	-	deep-banded liquid + broadcast granular fertilizer
DM	-	dry matter
DMD	-	dry matter digestibility
DMI	-	dry matter intake
DMY	-	dry matter yield
DOMI	-	digestible organic matter intake
EE	-	ether extract
M	-	flail mow
ME	-	metabolizable energy
M+F	-	flail mow + broadcast granular fertilizer
NDF	-	neutral detergent fiber
NDICP	-	neutral detergent insoluble crude protein
NPN	-	non-protein nitrogen
NSC	-	non-structural carbohydrates
SCP	-	soluble crude protein
SP+F	-	spike + broadcast granular fertilizer
SP	-	spike
OMD	-	organic matter digestibility

APPENDIX TABLES

Chapter 1

1.0 INTRODUCTION

The amount of land occupied by perennial forages in Saskatchewan has increased since 1986 to 7.5 million ha of which 1.4 million ha are improved hay and pasture land. Land reclamation, wildlife conservation, fluctuating grain prices, beef markets and the Permanent Cover Program all have contributed to the continuing trend of increased forage area.

Once a forage stand has been established, yearly maintenance costs are relatively low. However, productivity tends to decline over time as nutrients become bound up in the plant biomass and other less productive species invade the stand. This process becomes a challenge to producers, wildlife conservationists and land reclamation programs. Traditional renovation of these areas involves breaking and reseeding, resulting in the loss of valuable wildlife habitat and is an expensive technique that can increase the risk of soil erosion and degradation.

Less costly rejuvenation methods utilizing perennial forage species and minimal disturbance to the area are an attractive alternative. These minimal disturbance methods can reduce herbicide, fuel and energy inputs and prevent erosion through elimination of breaking and subsequent summerfallowing.

It is important that rejuvenation have both continued and carryover effects on forage production and quality. To consider any rejuvenation method of tame forages, information regarding yield, quality and the effect on botanical composition are

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required. There is also a need for data on animal response to changes in forage composition and nutritive value.

This study was undertaken to provide information about dry matter yield, quality and botanical composition of rejuvenated forages over a three-year period. In addition, the effects of rejuvenation on voluntary intake, total tract digestibility and nutritive value of forages harvested from rejuvenated forage plots were investigated. The ability of rejuvenated forages to meet the nutrient requirements of beef cattle was also studied using the National Research Council (1996) computer simulation model Level I.

Chapter 2

2.0 REVIEW OF THE LITERATURE

2.1 Rejuvenation and renovation of forages

2.1.1 Introduction

Graber (1927) first successfully undertook to burn, disk, fertilize and re-seed unproductive, unplowable pastures in Wisconsin with drought resistant legumes and it was this procedure that he termed 'renovation' or 'rejuvenation'. Today, many problems are associated with rejuvenation practices; and good answers to the "when, where and how" questions are not available. Choosing the best economic alternative can be very difficult. The decision to renovate, delay harvest date, and/or add nitrogen fertilizer to unproductive stands is influenced by yield, cost, alternative hay prices, forage supplies and forage demand (Barnhart, 1995b). Results from pasture renovation are varied (Pearen and Koeghan, 1982) and more information is needed on site x treatment interactions and how different rejuvenation treatments affect the micro-environment and associated vegetational response.

Mechanical rejuvenation treatments have been imposed on western Canadian range and pasture land to increase herbage production for nearly 50 years. These rejuvenation and renovation practices have included numerous variations and combinations of a wide range of chemically and mechanically imposed surface modification techniques. To be effective on native or tame pasture, a treatment

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should increase water infiltration and storage and reduce competition from unwanted vegetation to allow more desirable cool or warm-season species to become established.

2.1.2 Mechanical rejuvenation techniques

Removal of annual and perennial grassy weeds with herbicides can cost more than $40/ha, therefore one or two tillage operations would cost considerably less (Welty *et al.*, 1988). Mechanical land treatments such as contour furrowing, pitting, ripping, discing and spiking have been applied for more than 60 years in an effort to improve forage production and control erosion. Mechanical disturbances of native sod causes the release of plant nutrients through soil weathering and decomposition of organic matter (Wight and White, 1974). The initial response to soil disturbance is due to nutrient enrichment of the soil, plus reduced competition for available nutrients.

2.1.2.1 Contour furrowing

Contour furrowing creates variably-spaced furrows using a lister-type shovel which forms flat-bottomed furrows approximately 60 cm wide and 5 to 8 cm deep at 1.5 to 1.8 m intervals. This technique imposes major soil disturbance because of the corrugated surface that is created. It also effectively increases water infiltration, ameliorates physical and chemical characteristics of panspot (Solonetzic) soils while increasing production of present forage species (Soiseth *et al.*, 1974). Rangelands that have been contour furrowed have shown long-term forage production improvement of two to four times that of untreated pastures (Kartchner *et al.*, 1983; Wight *et al.*, 1978). Branson *et al.* (1966) evaluated seven kinds of mechanical

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treatments on rangeland in Montana, Wyoming, Colorado, Utah, New Mexico and Arizona and found the most effective was contour furrowing at intervals of 1 to 1.5 m and depths of 20 to 25 cm. The authors also reported that average soil water storage was nearly 8% greater in contour-furrowed soils than in unfurrowed soils. Kartchner *et al.* (1983) reported that over a 4-year period, average annual herbage production on native range was 603 kg ha^{-1} compared to 1350 kg ha^{-1} on contour-furrowed range interseeded with alfalfa (*Medicago sativa* L.). The results of this work showed that interseeding alfalfa into contour furrows produced forage sufficient to double beef production per unit of area as compared to untreated native range. However, Heitschmidt *et al.* (1993) reported no significant treatment effects relative to steer daily gains, total gain steer^{-1} or gain ha^{-1} when evaluating contour furrowing on native Montana rangeland.

2.1.2.2 Spiking or ripping

Spiking, ripping, chiseling, sub-soiling and deep plowing are all terms applied to a similar treatment and these techniques can vary according to equipment and results. The objective of the treatment is to fracture the soil, especially the sub-soil which may have a 'hardpan' and to impose a disturbance within the root zone of the pasture. Schuman and Rauzi (1985) used a single ripping treatment where chisels removed sod strips 10 to 12 cm wide and 12 to 15 cm deep on 40 cm spacing. This single ripping treatment removed an average of 28 percent of the existing vegetation (20-35%), as determined by direct measurement in 1 m^2 quadrats. A double ripping treatment was also accomplished by ripping the area twice at right angles, resulting in 60 percent removal (52-70%) of the native sod.

In Montana, Welty *et al.* (1988) applied tillage treatments using a field cultivator (International 45 Vibra-Shank®) equipped with spring-loaded 4 cm shanks

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spaced every 15 cm along the tool bars. Two tillage depths, 5 cm (shallow) and 10 cm (deep) were imposed on six-year-old alfalfa stands for one, two and three consecutive years. A single deep tillage of 10 cm stimulated alfalfa growth and vigor in swards where perennial grasses were present. Deep tillage for two consecutive years tended to decrease grass yields. Webb and Guthery (1983) used spring discing to alter species composition of mesquite rangeland as part of a habitat management program for game birds. Forbs, which are important wildlife foods, showed increases of 170 and 225% during two summers.

Peat and Bowes (1995) used two rejuvenation treatments on a 20-year-old crested wheatgrass stand at Neudorf, Saskatchewan. Spiking treatments were 5 cm and 10 cm width shovels attached to a cultivator. The authors reported a surface roughness problem with the severity of the spike treatment, therefore a 3-tiered float (leveler) was dragged behind the cultivator. Spiking produced lower yields during the treatment year, however increases of 128%, 89%, 50% and 27% were observed for the next four years.

Erickson and Currie (1985) describe a Rangeland Improvement Machine (RIM) which they developed specifically for renovation of semi-arid pastures. The machine prepares the soil by rotary tillage, forms a vee-trough seedbed and plants or fertilizes in a single-machine, single-pass operation. The RIM unit is operated with a 80-120 kW tractor which provides power for the rototiller, drawbar pull and hydraulic controls. The RIM prototype is 305 cm wide and has a field capacity of 5 ha h^{-1}. The authors reported that RIM treated pastures produced more forage in a hot, dry year than control pastures, even though treatment initially resulted in a 33% disturbance of the ground surface.

Feistmann (1979) described a rangeland disk designed to follow the severe land contours and terrain of British Columbia. The double offset gang disk has a tillage width of 3.6 m and weighs 9 tonne. The disk is pulled by a 140 horsepower

Caterpillar® D-6C crawler tractor. Over 2000 ha of rangeland had been renovated with this equipment, and under reasonably good operating conditions, up to 14 ha d^{-1} can be renovated at a cost of $65 per ha.

2.1.2.3 Pitting

Pitting has long been used as a renovation treatment on the rangelands of the western United States. Implements used in pitting are of two general types, the eccentric disc and the spike tooth or 'rotary pitter'. Pits made with the eccentric disc vary in size according to the machine used; but are usually .6 to 1.8 m long, 15 to 20 cm wide, 8 to 15 cm deep and spaced 40 to 106 cm apart. Spike tooth or rotary pitters usually make pits 25 to 46 cm in depth and spaced 8 to 15 cm apart (Branson et al., 1966).

This treatment causes major soil disturbance using equipment such as modified discs on a one-way plow, leaving 'pits' or furrows averaging 112 cm long, 14 cm wide and 10 cm deep. Because pitting creates major surface depressions, the resulting surface is harder to seed than a contour furrowed surface and is not as effective at providing a desirable seeding micro-climate or in retaining surface water. Ryerson et al. (1970) found that pitting and interseeding increased herbage production on range sites infested with clubmoss (Selaginella densa), and that interseeding usually was more effective than pitting.

Rauzi (1974) reported that herbage yields and botanical composition were largely influenced by precipitation as much as renovation by pitting alone. It was estimated that longevity of range pitting in southeast Wyoming was about 15 years.

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2.1.2.4 Roller chopping

Roller chopping is a relatively inexpensive brush management technique whereby a crawler-type tractor pulls a drum fitted with blades (Bozzo *et al.*, 1992a). This method is used mainly on brush and browse pastures to allow for late summer or early fall availability of more nutritious forage. Reynolds *et al.* (1992) and Bozzo *et al.* (1992b) described the technique as using a 6.4-m-wide (about 27,300 kg) roller chopper pulled by a crawler tractor. The authors compared results from a pattern of roller-chopped and non-treated strips and reported that roller chopping in early July increased crude protein of guajillo (*Acacia berlandieri* Benth.) and blackbrush (*A. rigidula* Benth.) during the late summer and early fall nutritional stress period. Bozzo *et al.* (1992a) found that roller chopping reduced brush canopy cover and increased herbaceous cover on south Texas pastures.

2.1.2.5 Mowing

The litter (dead plant material) component of pastures affects the structure and function of the plant community through its impact on the chemical and physical environment. Litter also acts as a physical barrier to heat and water flow at the soil surface, altering the micro-environment of the plant and soil (Weaver and Rowland, 1952). Litter conserves soil moisture by reducing evaporation from the soil but reduces input from rainfall by intercepting water equivalent to about twice the weight of litter (Naith *et al.*, 1991). Renovation by mowing is recommended to remove senesced tissue and maintain a vegetative growth response in those more productive species. This activity removes biomass, eliminates individual plants and influences the distribution, abundance and competitive balance between species (Parish *et al.*, 1990).

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Mowing date may be important because of its affect on plant vigor and productivity. Hazell (1965) reported late fall mowing of native pasture reduced forage production and composition compared to late spring mowing. Plants seemed to recover better from spring mowing, resulting in greater plant vigor and recovery. Weaver and Rowland (1952) stated yields of big bluestem (*Andropogon gerardi* Vitman.) in June, July and August were 53, 26 and 29% less from mulch covered stands than those from mowed mulch stands.

Cotter *et al.* (1983) used a sickle mower or a rotary shredder to remove dead material allowing new tillering in the core centers of grasses. On native grassland, Willms *et al.* (1993) used a rotary mower set at 3 and 7-cm cutting heights so as not to disturb the crown of plants. They reported that removing litter had no effect on herbage yield but did influence plant height and tiller weight on some species. Hodel and Pittenger (1994) found that mowing groundcover species caused an unfavorable response. Quality was reduced and mowing significantly (P<0.05) reduced height, thatch and density. To control Canada thistle (*Cirsium arvense* L.) in alfalfa stands, Schreiber (1967) mowed the pastures and reported a reduced density of thistle plants and increased forage yield of 2.2 tonne ha^{-1} over control.

2.1.3 Chemical techniques

A problem with some of the current techniques for pasture improvement is the relatively long period required to produce a grazeable stand of improved perennial grasses after tillage and reseeding. In addition, there is a severe erosion hazard with a clean tillage operation. Renovation techniques involving suppression by non-residual herbicides on an established sward have been tried (Sprague, 1952; Jones, 1962; Douglas, 1965; Bowes and Friesen, 1967; Waddington and Bowren, 1976; Samson and Moser, 1985; Moyer and Smoliak, 1987; Malik and Waddington, 1990). The use

of herbicides has provided grassland managers with a wide range of options in manipulating and changing vegetation. The wide variety of herbicides available today includes chemicals that destroy practically all vegetation, approaching the action of a plow. Other herbicides are selective, affecting one or more components of the sward and having little influence on others (Van Keuren *et al.*, 1985).

The degree of success depends on the herbicide used, timing of application of the herbicide in relation to sod-seeding and the duration of suppression of the sward and the competing weeds. A disadvantage with this method is that no forage can be harvested during the establishment period. This period of deferred production is assumed to be two years if improved grasses are seeded, and only part of the seeding year if alfalfa is planted (Barnard *et al.*, 1985). However, the benefits include reduced time to attain optimal stocking rates and improved establishment control, but these may be offset by higher initial costs (Frengley and Andersen, 1989).

2.1.3.1 Atrazine

Many hectares of land within the Tall Grass prairie states of Kansas, Nebraska and Wyoming were historically warm-season grass dominated. Much of this land was plowed under for the production of grain crops. During the last 40 years, many of these areas have once again been seeded to warm-season forages. Due to the effects of overgrazing, older pastures have seen the invasion of and dominance by annual bromegrass (*Bromus tectorum* L.) and Kentucky bluegrass (*Poa pratensis* L.).

Earlier researchers determined that application of atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-di-amine] benefited vegetation on shortgrass range in three ways. Atrazine controlled annual plants (Houston, 1977), increased crude protein content 53 percent in grasses (Houston and Van der Sluijs, 1973) and

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reduced blue grama (*Bouteloua gracilis* [H.B.K.] Lag. ex Griffiths) susceptibility to drought mortality (Hyder *et al.*, 1976).

Samson and Moser (1982) showed the effectiveness of a spring application of atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] in shifting the composition of seeded warm-season pastures to C_4 species by suppression of cool-season competition. This herbicide worked very well in suppressing Kentucky bluegrass and smooth bromegrass (*Bromus inermis* L.), permitting successful establishment of sod-seeded atrazine-resistant grasses such as switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* var. *gerardii* Vitman) (Lawrence *et al.*, 1995).

In Wyoming, Rauzi (1975) treated native pasture with strip sprayed atrazine in combination with a rotovator and reported a 300% increase of the five-year average yield. Dill *et al.* (1986) reported that a single, spring application of atrazine (3.3 kg/ha) could renovate smooth brome dominated, seeded warm-season pastures when C_4 remnant species are present. The use of atrazine is a relatively inexpensive, fast method to convert an abused, seeded warm-season pasture from cool-season dominance to warm-season dominance. The authors suggested applying the herbicide to small areas protected from grazing before treating entire pastures. Atrazine is currently not registered for use in Canada due to environmental concerns.

2.1.3.2 Glyphosate

One of the most frequently used non-selective herbicides used for direct seeding is Roundup© or glyphosate [N-(phosphonomethyl) glycine]. Glyphosate is reported to suppress resident vegetation more effectively than nontranslocated herbicides and its use has increased since the expiration of the glyphosate patent in 1990 (Malik and Waddington, 1990). Fall applied herbicides appear to act faster and

reduce competition longer compared to spring applications. The action of glyphosate also appears to be enhanced when the plants are translocating a major portion of photosynthates to roots and rhizomes in late summer (Samson and Moser, 1982). For glyphosate to be effective on sod, 9 to 12 cm of grass growth should be present for sufficient leaf coverage (Barnhart, 1995a). In New Zealand, Leonard et al. (1989) found that glyphosate was very effective against certain perennial grasses such as paspalum (*Paspalum dilatatum* Poir). Hurto and Turgeon (1979) found that Kentucky bluegrass thatch containing paraquat inhibited perennial ryegrass (*Lolium perenne* L.) establishment, but glyphosate-treated thatch did not.

Campbell (1974) evaluated glyphosate at 0, 1.5, and 4.5 kg active ingredient ha^{-1} on the germination and establishment of alfalfa, subterranean clover (*Trifolium subterraneum* L.) and perennial ryegrass sown on bare soil or an established pasture before spraying with glyphosate. The herbicide had little or no effect on germination of seeds but had deleterious effects on establishment and growth of legumes. The residual effects were less severe at a low rate and disappeared 35 d after spraying. Campbell concluded that the seed and herbicide should not come in contact and that the herbicide should be applied prior to seeding. Welty et al. (1983) reported a 14 to 28-day spray-plant interval was needed for good establishment of ladino clover (*Trifolium repens* L.) or alfalfa.

Olsen et al. (1981) indicated that foliage dessication was very effective using glyphosate at the rate of 1.8 kg active ingredient ha^{-1}, suppressing grass top-growth for up to 8 weeks. They reported that this chemical was desirable in cases where it was important to severely reduce or completely eliminate grass competition. In Utah, Barnard et al. (1985) applied 2.3 L ha^{-1} glyphosate to kill quackgrass (*Elytrigia repens* Syn.) and, approximately 10 d later, planted alfalfa. Yield increases from 1.36 t ha^{-1} of grass hay to 3.2 t ha^{-1} of alfalfa were seen in the first year and the authors estimated the alfalfa stand to last at least seven years. Johnson (1988) reported that

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three applications of 2.2 kg active ingredient ha^{-1} applied in May, June and August was more effective than a single application when renovating bermudagrass (*Cynodon dactylon* [L.] Pers.) in turfgrass areas.

2.1.3.3 Paraquat

Gramoxone© or paraquat (1, 1'-dimethyl-4, 4'-bypyridinium ion) is used as a sod suppression to allow establishment of legume seedlings (Douglas, 1965; Kunelius, 1981). In addition to predictable herbicide activity, its main features are inactivation on contact with soil and its selectivity toward white clover (*Trifolium repens* L.) (Leonard *et al.*, 1989), creeping bentgrass (*Agrostis stolonifera* L.) and rough-stalked blue grass (*Poa trivialis* L.) (Jones, 1962). It is rapidly absorbed by the foliage and produces a quick desiccation of above ground parts, however, it only has a short term effect as it does not kill perennial plants. Usually when there is less than 25-30% grass in the sod, paraquat can be used effectively (Robinson and Winch, 1985). Recommended rates are 0.6 to 1.1 kg of active ingredient per hectare to allow effective control of grass species (Bowes and Friesen, 1967; Evans, 1980).

The value of tall fescue (*Festuca arundinacea* (Schreb.) Wimm.) as a pasture grass is diminished when infected with the fescue endophyte. For the control of infected tall fescue pastures, prior to planting fungus-free seed, paraquat is labeled at 0.3 to 0.6 kg ha^{-1} (Smith, 1992). Waddington and Bowren (1976) reported that paraquat and glyphosate broadcast at 2.2 kg ha^{-1} gave 70% control of a cool-season sod 6 weeks after a June application. Paraquat provided satisfactory sward suppression when applied either banded or broadcast, preferably in a drier year (Barnhart and Wedin, 1981). Paraquat banded over the seeded row enhanced legume stands only when grass stands were dense and growth was rapid (Taylor *et al.*, 1969). Band spraying this herbicide at the time of drilling resulted in variable establishment

of clovers and alfalfa, therefore it is important to spray at least 10 days prior to drilling (Kunelius, 1981). When sprayed on grass/clover pastures in New Zealand, low rates of paraquat (675-900 L ha⁻¹ active ingredient) applied in late spring produced summer clover dominance. In 1983, a special paraquat/diquat product called Spraygrow© was introduced for use on pasture, however not much information is available on this product (Leonard *et al.*, 1989). Bowes and Friesen (1967) recommended that fall applications of paraquat were not effective in suppressing the resident vegetation; thus seeding a legume the following spring would fail to establish an adequate stand.

2.1.3.4 Dalapon

Dalapon is an effective systemic grass herbicide which controls perennial grasses but does not affect broadleaf weeds. One disadvantage of its use is that seedlings are sometimes stunted, particularly in a dry year (Robinson and Winch, 1985). Taylor *et al.* (1969) reported that banding dalapon (2, 2-dichloropropionic acid) over a seeded row increased stands and seedling size of alfalfa sod-seeded into vigorously growing Kentucky bluegrass. Martin *et al.* (1983) evaluated dalapon, and when broadcast sprayed at 3.5, 5.6 and 9.0 kg ha⁻¹ was the most effective herbicide in comparison to glyphosate and paraquat for suppressing grass and increasing alfalfa yields.

2.1.4 Other techniques

2.1.4.1 Sod-seeding

Effective methods of pasture renovation have been the partial destruction of

the existing sward by mechanical tillage plus liming, fertilization and seeding as

required to establish or re-establish desirable forage without an intervening crop.

Sod-seeding is a popular alternative technique either carried out by itself or in

combination with fertilizing or tillage. Other common names given to this technique

are inter-seeding, range furrowing or no-till pasture renovation. Sod-seeding grass or

legumes into existing forage communities is not a new concept (Harrington and

Washko, 1962). Range inter-seeding, accomplished by catching windblown seed in

plowed furrows, was attempted in Texas late in the 19th century (Bentley, 1899).

Consequently the technique of sod-seeding has been used to renovate pastures in

Canada and the United States for many years. In recent years, work in China on

pasture improvement with sod-seeded grasses or legumes has also been studied

(Michalk *et al.*, 1993a; Michalk *et al.*, 1993b).

Research has indicated that zero tillage pasture renovation is a feasible

alternative for pasture improvement. This technique requires seeding equipment that

maintains the existing vegetation for erosion and moisture control, while placing the

seed into an ideal seed bed for optimum germination and long term establishment.

Many systems and types of equipment are available for zero-till renovation

(Hultgreen and Leduc, 1993).

Often inter-seeded legumes do not require chemical suppression of the sod

unless the grass stands are dense and growth is rapid. Therefore, reduction of

perennial grass competition during legume establishment is an important management

step in sod-seeding. Sod suppression can be accomplished through the use of

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herbicides alone or in combination with pre- and post-seeding grazing (Martin *et al.*, 1983; Evans *et al.*, 1985). Alfalfa, birdsfoot trefoil (*Lotus corniculatus* L.) and crownvetch (*Coronilla varia* L.) have all been successfully established in existing pasture swards via reduced-tillage renovation techniques such as glyphosate band-applied to reduce competition (Wheaton and Meinke, 1975; Barnhart and Wedin, 1981). Welty *et al.* (1981) suggested a 14 d interval was needed between spraying glyphosate and sod-seeding alfalfa, alsike clover (*Trifolium hybridum* L.) or tall fescue to allow for adequate seedling establishment and vigor. Volesky *et al.* (1996) interseeded stands of Old World bluestem [*Bothriochloa ischaemum* (L.) Keng.] with two nitrogen-fixing legumes, rose clover (*Trifolium hirtum* All.) and hairy vetch (*Vicia villosa* Roth.), improving both crude protein and *in vitro* digestibility of the forage.

Tall fescue pastures in southeastern United States can become infected with a fungus (*Acremonium coenophialum*) and poor performance is observed by animals that consume these infected plants, therefore renovation of these pastures is needed. Pasture renewal may involve merely seeding a legume into an infested stand, or it may involve totally destroying the stand and reseeding with fungus-free seed with or without legumes (Burns, 1978; Standaert, 1986). Taylor *et al.* (1979) offered the following guidelines for renovation and improvement of tall fescue-based pastures with legumes. Old sod grass growth and competition can be reduced by herbicides, minimum tillage in needed for seedbed preparation and sod-seeding with legumes may be either broadcast, or with conventional drills or pack-seeders. The authors also reported that compared with sods not receiving high rates of nitrogen fertilizer, the addition of adapted forage legumes to tall fescue stands improved productivity and animal performance.

When introducing grasses or legumes in renovated pastures it may be necessary to modify the competitive environment. In New Zealand, Thom *et al.*

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(1986a) found that ryegrass introduced into areas with a high component of paspalum, suffered from establishment losses. After 2 years, ryegrass plants experienced 20% losses due mainly to 'animal effects' or pulling up plants. Thom *et al.* (1986b) reported that when ryegrass seedlings were fertilized with 48 to 67 kg N ha^{-1} and rotationally grazed, large growth responses in yield (50-350%) influenced ryegrass survival. Clipping resident herbage surrounding the introduced grass, irrigation and shorter grazing intervals over spring-summer are necessary to enhance ryegrass seedling persistence (Thom *et al.*, 1986c).

Even with herbicide use many problems have been encountered with direct sod-seeding. Welty *et al.* (1981) observed that in many situations where herbicides provided adequate sod control, forage stand establishment was inadequate. They concluded that factors other than sod control were limiting successful establishment of small-seeded legumes and grasses. Suspected reasons for poor establishment are residual toxicity of non-selective herbicides and/or allelopathic effects of decaying swards on germination, emergence and growth of legumes and grasses.

2.1.4.2 Fertilization

Fertilization as a means of rejuvenating production yield of pastures has been studied (Brown *et al.*, 1960; Dodds and Van Der Puy, 1985; Ukrainetz *et al.*, 1988; Fairey, 1991).

The decision to fertilize with a rejuvenation program must be based on the yield potential of the soils and the degree of pasture deterioration. Generally, soils with low water-holding capacities such as coarse-textured sands and sandy soils respond poorly to fertilizer application when compared with applications on heavier-textured soils unless they have a high water table or rainfall is above normal.

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Pastures should first be soil tested for availability of nitrogen (N), phosphorous (P), potassium (K) and sulfur (S).

Nitrogen is the primary nutrient limiting forage production, but phosphorous also may be limited in some soils (Sedivec and Manske, 1990; Berg and Sims, 1995) and in areas where S may be limiting (such as Gray Luvisolic soils) S may also be required (Ukrainetz *et al.*, 1988). Nitrogen will stimulate grass production and can be used as a management tool when needed. However, nitrogen fertilization for grass production has been shown to be uneconomical when moisture is limiting as commonly occurs on Brown soils in south-western Saskatchewan (Campbell *et al.*, 1986). On a smooth bromegrass-crested wheatgrass pasture in central Saskatchewan, Cohen *et al.* (1987) reported nitrogen response (kg N ha^{-1} yr^{-1}) was dependent on rainfall. Prediction equations were computed showing rainfall as a significant covariate (P<0.001) on total forage production (TFP), animal average daily gain (ADG) and total livestock production (TLP)

$$TFP = 285 + 3.17N + 12.9R \qquad (RSD = 80.8) \qquad (2.1)$$

$$ADG = 48.6 + 0.39N + 0.48R \qquad (RSD = 27.0) \qquad (2.2)$$

$$TLP = 20.23 + 0.32N + 0.13R \qquad (RSD = 23.0) \qquad (2.3)$$

where N = nitrogen and R = mm rainfall. On Gray-wooded and Black soils where available moisture is generally greater, annual applications of 100 kg N ha^{-1} have increased dry matter yield by greater than 300% when P, K, and S were non-limiting (Ukrainetz and Campbell, 1988). On a Gray Luvisolic soil, Ukrainetz *et al.* (1988) reported dry matter production of smooth bromegrass was greater over an 8-year period for annual (0, 50, 100 and 200 kg ha^{-1} rates) versus single (0, 100, 200, 400

and 800 kg ha^{-1} rates) N applications and on Dark Brown soil over a 4-year period, annual applications resulted in up to 37% more dry matter than a single application (Ukrainetz and Campbell, 1988).

Spring application will give a greater yield response than fall, although fall applied fertilizer will benefit herbage production and economic costs (Lavin, 1967). Of the N sources available, ammonium nitrate produces higher dry matter and protein yield than urea when broadcast on surface, but the effectiveness of urea can be improved by disc-banding below the soil surface (Campbell *et al.*, 1986; Mahli *et al.*, 1993). The major response to N will be in the first 6-8 weeks after application and it is recommended to use 56-84 kg ha^{-1} of available nitrogen (140-336 kg ha^{-1} of ammonium nitrate or 100-150 kg ha^{-1} of urea) to get a good response on tame pasture (Van Keuren, 1980). Hart *et al.* (1980) reported a linear response between hay yield and nitrogen rate up to 180 kg ha^{-1} on tame grass pastures.

Renovations of smooth bromegrass and crested wheatgrass pasture with nitrogen applied at 67 kg ha^{-1} active ingredient yielded 40% greater dry matter than control pasture (Sedivec and Manske, 1990). Dodds and Van Der Puy (1985) reported rates of 100 kg actual nitrogen per hectare tripled average forage yields of crested wheatgrass pastures in North Dakota. On a Luvisolic (Gray Wooded) soil, Nuttall *et al.* (1991) applied N fertilizer at 0, 45 and 90 kg ha^{-1} in combination with P applied at 0 and 20 kg ha^{-1}. Two additional treatments combined 90 N + 20 P (kg ha^{-1}) with 23 S and 45 S (kg ha^{-1}). Over the 12-year study, N increased average herbage yield from 1.99 to 2.95 t ha^{-1}; P, from 2.23 to 3.05 t ha^{-1}; and S from 3.48 to 4.19 t ha^{-1}, respectively. However, the authors also reported yield was positively related to total precipitation and negatively to mean maximum temperatures for May, June and July. Response of pinegrass (*Calamagrostis rubescens* Buckl.) and a seeded tame grass mixture on the forested slopes of British Columbia was favorable to a single application of factorial combinations of nitrogen, phosphorous and sulfur. Nitrogen

was applied at 100, 200, 300 and 400 kg N ha^{-1}; phosphorous at 25 and 50 kg P ha^{-1} ; and sulphur at 55 kg S ha^{-1}. Nitrogen fertilization increased (P<0.05) standing crop and pinegrass crude protein (CP) content. Addition of P to N applications increased (P<0.05) pinegrass and other grass standing crop. Addition of S to N applications enhanced total yields compared to controls (Wikeem et al., 1993).

Both grasses and legumes respond well to P and K fertilization. Forages generally range from about 0.2-0.5 percent P and 1.3-3.5 percent K, depending on species and stage of maturity. If legumes are the primary components of a sward, high amounts of phosphorous fertilizer are usually applied to generate a yield response of the pasture. Alfalfa requires high annual applications of P and K, at a ratio of one part P_2O_5 to three of K_2O. Springer (1992) deep-banded 115 kg ha^{-1} of 12-51-0 on 8 year old stands of alfalfa and reported a 6% increase in yield compared to control. Bittman et al. (1991) applied 18 kg ha^{-1} P which increased total yield (6-year average) from 1.47 t ha^{-1} in control plots to 2.52 t ha^{-} in fertilized plots. Van Keuren (1980) suggested renovating old stands of grass-legume pasture with 23 to 45 kg ha^{-1} P_2O_5 and 67 to 112 kg ha^{-1} K_2O.

Fertilization of rangeland or native species is approached differently from fertilizing tame forages. High or moderate levels of phosphorous on native range will decrease or eliminate mycorrhizal fungi that have a symbiotic relationship with desirable grasses. Nitrogen in excess of 56 kg ha^{-1} has negative effects on the soil microorganisms, causes a reduction in symbiotic rhizosphere activity and allows selective advantage to plants that are not dependent in soil organisms. In a complementary practice of study, Dodds and Van Der Puy (1985) found a ninety-two percent increase in yield on native pasture where herbicide was used first followed by fertilizing with nitrogen at 80 kg ha^{-1}. Fertilizing with nitrogen at 56 kg ha^{-1} along with soil tillage increased herbage production 40% on native Montana rangeland averaged over eight years (Haferkamp et al., 1993). At rates of 34 and 168 kg ha^{-1},

nitrogen fertilizer increased herbage yields over a 5-year period on mixed grass prairie in Wyoming 25 and 163 percent, respectively (Rauzi, 1978; Rauzi and Fairbourn, 1983). Berg and Sims (1995) found that steer gain averaged 220 kg ha^{-1} yr^{-1} and 3.3 kg per kg N applied at a rate of 34 kg ha^{-1} yr^{-1} on Oklahoma pastures where the primary species was Old World bluestem. Steer gain in unfertilized paddocks averaged 110 kg ha^{-1} yr^{-1}. Berg (1995) stated that N fertilization of mixed native warm-season grass stands on marginal land can result in substantial yield increases, however, some of the increased yield may be from weedy species.

Fertilization has been combined with other renovation techniques to study the compounded effects on production and profitability. Hart *et al.* (1995) examined the effect of nitrogen fertilizer and atrazine on herbage production and steer gain in a 9-year study in Colorado. The authors reported all treatments increased total fall standing crop and blue grama standing crop. Nitrogen increased cool-season grass and forbs; atrazine nearly eliminated cool-season grasses but did not affect forbs. Atrazine and/or N appeared to increase gain ha^{-1}, but not average daily gain. They concluded that under optimum stocking rates and grazing strategies, N or atrazine but not both together might increase economic returns.

Cost of fertilizer application on tame pastures needs to be justified if diminishing returns to N-fertilization occur. At Brandon, McCaughey and Simons (1996) indicated nitrogen use efficiency on grass pastures should range from 14 to 35 kg herbage kg^{-1} N applied. This theory was based on 1995 N-fertilizer prices ($330 t^{-1} for 46-0-0) and standing hay valued from $20-$50 tonne^{-1}. In comparison, Rubio *et al.* (1996) indicated that on native Mexican rangeland, the best rate in terms of economic return was ammonium nitrate at 120-30-0 kg ha^{-1} producing 4065 kg ha^{-1} with a marginal return rate of 377 percent.

In conclusion, Fairey (1991) stated that herbage productivity and quality of Parkland pastures were influenced more by crop-management factors (harvesting

frequency, N fertilizer supply) than by the species composition, particularly when soil-N was not limiting crop growth.

2.1.4.3 Burning

The history and influence of fire on forest and grassland ecosystems has been studied in detail (Arno and Gruell, 1983). Prescribed burning of forages or rangelands requires less increase in returns than herbicides or spiking and may offer benefits not possible with other rejuvenation methods. Season of burning can have a major effect on pasture response to fire. The majority of research on fire focuses almost exclusively on dormant season fires, primarily winter and spring (Engle *et al.*, 1993). Late spring burns are often prescribed to benefit cattle production (Hilmon and Hughes, 1965; McMurphy and Anderson, 1965; Vogl, 1965; Anderson, *et al.*, 1970; Owensby and Smith, 1979), because they favor the matrix grasses over forbs, low-seral grasses and woody species. Late spring burns are less detrimental to plants however, there is reduced infiltration rate, soil moisture and forage yield when compared to unburned range. There can also be an increase of key productive species, control of invasive bluegrass (*Poa* spp.) and other less desirable plants (McMurphy and Anderson, 1965; Owensby and Anderson, 1967). Spring burning, fertilization and atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] have been used to manipulate botanical composition and improve herbage productivity of warm-season grasses in southern and central Great Plains tallgrass prairies (Gillen *et al.*, 1987; Masters *et al.*, 1992).

Conditions are extremely important for burning rangeland or pasture. Gay and Dwyer (1965) stated conditions for an early spring burn of native range. Plots were burned against a NE wind of 10 to 15 miles per hour under overcast conditions. Soil surface was moist and air temperature was 68.5 °F and relative humidity was

thirty-three percent. Approximately 1500 to 1800 pounds of dead vegetation per acre was burned.

Cotter *et al.* (1983) returned stands of weeping lovegrass (*Eragrostis curvula* L.) decadent from non-use, to a productive high quality state. Dormant season burning removed previous years' top growth. Additional material was removed through the activities of livestock. The authors reported that average daily gains increased from 0.35 to 0.80 kg in five years using a short duration grazing system. Gay and Dwyer (1965) found positive effects with fire and fertilizer combination. Forage production on native grass plots burned and fertilized at 110 kg ha^{-1} increased yield 59% over control and 54% over un-burned fertilized plots. In Wisconsin, burning increased native herbage from 865 kg ha^{-1} on unburned areas to 2363 kg ha^{-1} on burned plots in the first season. Burned areas maintained high productivity of grasses and forbs the second year (Vogl, 1965).

Fire can also be used for brush control with a follow-up herbicide treatment. Engle *et al.* (1993) compared two herbicide treatments (atrazine and 2,4-D) after late-summer burning for brush control and reported that little bluestem [*Schizachyrium scoparium* (Michx.) Nash], other perennial grass and total herbage were significantly reduced. However, tallgrass, annual grasses and forb standing crop on burned plots averaged about twice that of unburned plots. A spring burn on an Aspen Parkland pasture in north-west Saskatchewan decreased yields of herbaceous species while increasing browse dramatically due to suckering of aspen and understory shrubs. However, livestock density was increased two-fold from previous years (Jorgenson and Bjorge, 1993). Rasmussen *et al.* (1983) used fire to control heavy canopy covers of huisache (*Acacia farnesiana*), a thorny shrub which seriously reduces production of desirable, warm season bunchgrasses and hinders effective management of livestock. Burning usually killed 90% of the plants, however all burned huisache plants sprouted following treatment, regardless of season or intensity of burning.

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In Nebraska, Masters *et al.* (1993) used spring burning in combination with fertilization and atrazine to study the effect on seed production in big bluestem (*Andropogon gerardii* Vitman var. *gerardii* Vitman) and indiangrass (*Sorghastrum nutans* (L.) Nash). Number of germinable seed produced by the grasses was influenced by treatment when precipitation was adequate. Burning mid-May increased seed number from 333 to 724 and 202 to 481 germinable seed m^{-2} for big bluestem and indiangrass, respectively.

2.2 Forage species

2.2.1 Introduction

The production of perennial forages has a vital role to play in diversifying the agricultural economy of the prairies and maintaining the productivity of the soil. Farming in the Aspen Parklands of Western Canada would benefit considerably if more forages were included in cropping programs. This is especially true for land that is difficult to work or that regularly experiences spring flooding, a short frost-free period or serious soil erosion. Pasture forages in the Aspen Parklands of Saskatchewan are typically established as grass-legume mixtures, mainly smooth bromegrass and alfalfa.

2.2.2 Grasses

2.2.2.1 Smooth bromegrass

Smooth bromegrass (*Bromus inermis* Leyss.) is commonly grown with alfalfa for hay and pasture in the Aspen Parklands of western Canada. This grass is valued

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in pasture mixtures because it yields well and is hardy. Rapid elongation of tillers, especially reproductive tillers, contributes significantly to spring yield, but slow regrowth often limits forage availability in the summer and fall. Also, smooth bromegrass spreads by way of rhizomes so that it encroaches upon alfalfa and its tall canopy often suppresses alfalfa in mixtures, especially at locations where it grows rapidly in spring (Pearen et al., 1995). For example, annual alfalfa yield in smooth bromegrass mixtures was 1,830 kg ha^{-1} higher at drier or infertile sites than at moist fertile ones. Short growing seasons of about 110 d, poor legume persistence, and invasion of less productive species, however, limit productivity and quality of smooth bromegrass-alfalfa mixtures (Pearen et al., 1995). At 3 sites in the Aspen Parkland, Pearen and Baron (1996) reported that over three years, annual smoothbrome-alfalfa yields under a 4-cut system, declined 52 to 67%.

2.2.2.2 Kentucky bluegrass

Kentucky bluegrass (*Poa pratensis* L.), a cool-season, sod-forming, perennial, occurs primarily as a pasture species in the Aspen parkland of Saskatchewan, but is also used for lawns and turf (Alberta Agriculture, 1981). Bluegrass makes up a large proportion of the permanent pastures of the Black and Gray-Wooded soil zones of Saskatchewan. Although not generally seeded in pasture mixtures, it volunteers easily and eventually will take over old stands (Smith, 1981). In Alberta, Willms *et al.* (1996) reported that grazing rough fescue (*Festuca campestris* Rydb.) dominated rangeland, modified the species composition by causing a shift to a Parry oat grass (*Danthonia parryi* Scribn.) - Kentucky bluegrass stand.

While Kentucky bluegrass, generally found on drier sites, is an important component of hayland and pastures, the nutritive value compared to smooth bromegrass was ranked lower by Horton and McElroy (1977). *In vitro* dry matter

digestibility (IVDMD), ruminal trichloracetic acid-insoluble nitrogen (TCA-N) and rumen volatile fatty acid (VFA) concentrations were higher for smooth brome hay than for Kentucky bluegrass.

In a grazing study comparison by Martin *et al.* (1983), smooth bromegrass pastures in Minnesota yielded more total animal unit months ha^{-1} than did Kentucky bluegrass pastures, 15.8 and 11.6, respectively.

2.2.3 Legumes

2.2.3.1 Alfalfa

Alfalfa (*Medicago sativa* L.) is a high quality pasture for all classes of livestock (Barnes and Sheaffer, 1995) and a valuable legume in agriculture due to high yields, excellent forage quality and adaptation to a wide range of edaphic and climatic conditions (Wolf and Allen, 1990). This legume is a dependable and economical protein source for the grazing animal because its production is independent of soil nitrogen. Alfalfa is an excellent source of calcium, magnesium, phosphorous, carotene and vitamin D. Alfalfa allows greater flexibility for the producer than other pasture legumes, as it withstands grazing fairly well provided it is not overgrazed (Alberta Agriculture, 1981). Because of its upright growth habit and rapid recovery, it lends itself to harvest as hay, silage, or as pasture. Its drought resistance provides a more uniform seasonal growth pattern that of most legumes or grasses (Van Keuren and Matches, 1988).

In the Aspen Parklands of western Canada, alfalfa is commonly grown in mixtures with smooth bromegrass for hay and pasture. In Saskatchewan, alfalfa is grown on about 2.8 M ha as a component of forage mixtures in combination with grasses. Alfalfa is valued in mixtures because it yields well, fixes atmospheric

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nitrogen and has high nutritive value for ruminants (Van Keuren and Matches, 1988). Mixtures are also compatible because they reduce the hazard of bloat, facilitate field drying when harvested as hay, improve the feeding value of the grass and reduce losses should the alfalfa winter kill (Alberta Agriculture, 1981). In legume-grass mixtures on the Canadian Prairies, the grass component is usually the aggressor and dominates the legume after a few growing seasons. It is difficult to maintain a desirable balance of legume in legume-grass mixtures. (Chamblee and Collins, 1988). On productive alfalfa-meadow bromegrass (*Bromus biebersteinii*)/Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski.] pastures in south-western Manitoba, season-long average daily gains ranged from 0.7 to 1.5 kg d^{-1} in long-term grazing trials, depending on stocking rate and grazing system (Popp *et al.*, 1998).

There has been relatively little work in western Canada to investigate the response of alfalfa to fertilizer. When phosphorous (P) and potassium (K) are applied to alfalfa stands, they are normally broadcast on the soil surface. Phosphorous and K are both relatively immobile in the soil, moving only short distances from the site of application. Applied P (35 kg ha^{-1}) increased total annual forage yield on a clay loam soil in Manitoba by 1.53 t ha^{-1} (47%), averaged over a 4 yr study. Potassium application resulted in minor or no increases in forage yield (Simons *et al.*, 1995).

2.2.4 Other species

Weeds are often a major contribution to pasture or hayland yield (Gill and Arshad, 1995) but should not always be considered anti-quality factors. Weed densities will increase and species composition will change in perennial crops over time. Common weed populations include; lambs quarters (*Chenopodium album* L.), field pennycress (*Thlaspi arvense* L.), dandelion (*Taraxacum officianale* Weber), perennial sow thistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium arvense* L.), wild

buckwheat (*Polygonum convolvulus* L.), yarrow (*Achillea millefolium* L.), narrow-leaved hawk's-beard (*Crepis tectorum* L.) and wild mustard (*Brassica kaber* L.) (Blackshaw *et al.*, 1994).

A common species along roads, uncultivated fields, pastures and haylands in the Parklands of Saskatchewan is dandelion (*Taraxacum officinale* Weber). These natural infestations provide a continual source of seeds, which infest nearby seeded grass pastures and hay crops. This plant also can contribute up to 30% of the forage yield depending on composition. Popolizio *et al.* (1994) stated that bare ground increased significantly (P<0.01) and dandelion densities were three times greater in long-term grazed areas. Bergen *et al.* (1990) reported that protein increased for dandelion harvested June 3 and July 7 from 13.8 to 22.8%, respectively. Crude protein and mineral (Ca, Mg, K and Se) contents of this species were at levels consistent with the established requirements of beef cattle (NRC, 1996). Dry matter digestibility was reported to be equivalent to that of perennial ryegrass (Derrick *et al.*, 1993).

Grasses can be deficient in some elements, including N, P, Mg, Na and, sometimes Ca, for animal production purposes. Wilman and Derrick (1994) examined mineral levels of five common weeds and compared these values to perennial ryegrass. Chickweed (*Stellaria media* (L.) Vill.) was particularly high in P and K, dandelion in K and Mg, dock (*Rumex obtusifolius* L.) in Mg, ribwort (*Plantago lanceolata* L.) in Ca and spurrey (*Spergula arvensis* L.) in Mg and Na, relative to perennial ryegrass.

Carex species, particularly thread-leaved sedge [*Carex filifolia* Nutt.] and beaked sedge [*Carex rostrata* Stokes], along with Baltic rush [*Juncus balticus* var. montanus Engelm.] are common on heavily grazed sites characterized by water seepage from adjacent uplands onto riparian meadows. Conversely, low everlasting [*Antennaria aprica* Greene], Kentucky bluegrass, and common dandelion

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[*Taraxacum officinale* Wiggers] are common species of grazed sites with shallow soils (Popolizio *et al.*, 1994).

Canada thistle (*Cirsium arvense* L.), which can reproduce vegetatively as well as from seed, is a major weed species in pasture and hayland. Schreiber (1967) reported that after 4 years, Canada thistle density approached one plant/ft^2 in an alfalfa stand. It was reported that mowing after each grazing period every year would eliminate Canada thistle presence.

Perennial sow thistle (*Sonchus arvensis* L.) was introduced into North America from Europe and Asia and is distributed widely throughout the Canadian provinces (Lemna and Messersmith, 1990). *Sonchus arvensis* is acceptable as a livestock feed and has equal IVDMD and crude protein compared to alfalfa (Martin *et al.*, 1987). Traditional control methods in perennial forage crops has been tillage during the emergence phase (March-May) and late summer to significantly reduce seed bank numbers (Hutchinson *et al.*, 1984).

Finally, narrow-leaved hawk's-beard occurs across most of Canada but is particularly abundant in the parkland zone of Alberta, Saskatchewan and Manitoba. *Crepis tectorum* presents the greatest problem in established perennial forage crops, seedling stands of perennials and annual cereal and oilseed crops (Najda *et al.*, 1982).

2.3 Botanical composition

Many methods of measuring and surveying vegetation have been reviewed by Brown (1954), however, they differ by the attributes sampled, techniques and numbers. Sampling methods include areas of various sizes and shapes, lines or transects and points (Poissonet *et al.*, 1973). Brown (1954) has shown that most techniques assess forage species by one of four criteria, which she defined as the area

covered by a species, the weight of a species, the number of individuals and the frequency of occurrence of a species.

Botanical composition , as expressed in percentage cover area, is one of the best means of studying ecological changes (succession) and trends in development of a pasture (Heslehurst, 1971). Botanical composition of grass-legume mixtures greatly influences the productivity and quality of the sward and is therefore an important variable in many agronomic studies. Research studies designed to assess the effects of various treatments on grass-legume mixtures require a reliable technique for quantifying botanical composition (Moore *et al.*, 1990). A number of indirect methods for estimating botanical composition of mixtures of grasses and legumes have been developed. Some common methods are hand separation (Sprague and Myers, 1945; Petersen and Chamblee, 1955; Marten, 1964) , visual estimation (Marten, 1964; Tanner *et al.*, 1966; Tiwari *et al.*, 1963), point quadrat methods (Leasure, 1949; VanKeuren and Ahlgren, 1957a; Radcliffe and Mountier, 1964a), the dry-weight rank method (t' Mannetje and Haydock, 1963; Walker, 1970) and line intercept (Walker, 1970).

2.3.1 Methods of estimating botanical composition

2.3.1.1 Hand separation

An accurate measurement of botanical composition can be obtained by hand separating species clipped from a sward from an entire plot area. This technique involves random sampling from yield strips of forage plots. Samples are typically separated into legume or grass components or they can be frozen until time allows sorting at a later date. Separation values are expressed as percentage by weight of seeded species on a dry matter basis (Tiwari *et al.*, 1963; Marten, 1964; Olsen and

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Tiharuhondi, 1972). Separation is, however, a laborious and time consuming procedure, especially when large samples are involved (Sprague and Myers, 1945; Tiwari et al., 1963). The hand separation method is the standard with which all other methods are compared.

Petersen and Chamblee (1955), using a plot size of 5 x 25 ft, reported that the most efficient size of subsample for estimating botanical composition by hand separation was about 10% of a yield-strip sample 2 x 23 ft. Tanner et al. (1966) used a 1000 g random sample of fresh forage from a 3 x 18 ft yield strip, and Tiwari et al. (1963) collected an 800 g random sample of green forage from a 3 x 8 ft area for hand separation. Marten (1964) used random samples of approximately 500 g of green forage taken from duplicated 3.5 x 12 ft yield strips of plots measuring 12 x 30 ft.

2.3.1.2 Visual estimation

Visual estimation of botanical composition involves estimating percentage by weight of seeded species in standing crop. Estimates are made once each in the morning and afternoon. This reduces any possible bias, due to the difference of early or late day sunlight reflecting off leaf surfaces. Plots are examined randomly with a different randomization for morning and afternoon estimates (Marten, 1964). Tiwari et al. (1963) proposed a type of double-sampling procedure for correcting visual estimates of botanical composition by establishing the relationship between these estimates and a limited number of hand separation measurements.

Visual estimates of percentage composition by weight permit an increase in the number of samples. Good agreement between visual estimates and plant count data (Sheaffer et al., 1990) or hand-separation methods has been reported (Leasure, 1949; Tanner et al., 1966). However, Van Keuren and Ahlgren (1957a) reported that the visual estimation method had greater variation than the point quadrat method. As

well, Marten (1964) indicated that visual estimations of legume in two-component legume-grass mixtures should be restricted to comparisons of treatments where similar varieties are involved as the degree and direction of bias may be influenced by variety and species growth habits.

2.3.1.3 Quadrat counting

A count is made of individual vegetation units inside a frame quadrat with the most suitable vegetation unit being the tuft. As the number of tillers differs radically between species, results using tiller counts have very little meaning (Walker, 1970). The two factors that most influence the validity of density estimates by quadrat counting are the size and number of quadrats used. Walker (1970) reported that a preliminary trial with quadrats showed a 20 x 40 cm quadrat to be the most suitable for most vegetation types. He suggested a minimum of 90 quadrats be recorded at each site.

2.3.1.4 Point frame

The point contact method or point quadrat was originally developed by Levy and Madden (1933), first with the pins in a vertical position (vertical point quadrat), and later with the pins at an angle of 45 degrees (inclined point quadrat). This "inclined point quadrat" method was shown by Tinney *et al.* (1937) to have some advantages: the accuracy was increased because of the longer path through the vegetation and it was easier to use, particularly in taller swards. The principle of the method is based on the concept that a point represents a unit area, *i.e.*, the limiting value of an area becoming progressively smaller is a point. Therefore, the point quadrat method records at each station the vegetation at linearly arranged unit areas or

"point quadrats" (Tinney *et al.*, 1937). This technique is considered more sensitive than dry-weight analysis or tiller counts (Mountier and Radcliffe, 1964).

The point quadrat method of evaluating botanical composition of grass-legume swards has been used extensively in New Zealand and Australia (Crocker and Tiver, 1948) and has been used in the determination of composition and density of short grass and mixed grass range types in Canada by Clarke *et al.* (1942) and Coupland (1950). Comparative studies on the point quadrat and other methods of determining botanical composition have illustrated both the consistency and rapidity of the point quadrat analysis (Tinney *et al.*, 1937; Heslehurst, 1971).

The point apparatus used by Levy and Madden (1933), Whitman and Siggeirsson (1954), and VanKeuren and Ahlgren (1957a; 1957b) was a wooden frame with the pins held in the inclined position at an angle of 45° to the vertical. Pins were spaced 2 inches (5.1 cm) apart on the frame and the technique can be used in two ways. The first system was designated the "all-contacts" system. In this system all contacts of the point with the vegetation as the pin is projected downward are recorded by species, irrespective of the number of times any species is hit. The second was designated the "basal-contact" system where a plant is hit when the point of a pin touches its base and only basal contacts of vegetation are recorded. Where no vegetation is hit, bare ground is recorded. This method is ideal for the determination of botanical composition in terms of "percentage cover", which is given by :

$$\frac{\text{Number of times a species is hit}}{\text{Total vegetation hits recorded}} \quad \text{X} \quad (100 - \text{percentage of bare ground}) \quad (2.4)$$

The authors reported the intensity of sampling to be 3000 points and with this intensity the point quadrat method provided sampling errors of 5 percent or less for total density.

Amy and Schmid (1942) made determinations when growth was 6-8 inches (15-20 cm) tall and as each of the 10 needles of the quadrat apparatus pushed down through the vegetation the species name for each hit was recorded. Sprague and Myers (1945) took readings at 3 stations with 10 needles (hits) per station. The plots were divided by estimation into 3 parts and location of station in each part of the plot was at random. All the vegetation hit by each needle until it reached the ground or went out of sight was recorded. Proportion of species was considered to be the percentage of vegetative hits of that species. Glatzle *et al.* (1993) reported percentage contribution, analyzed by clipping and separating was significantly correlated (r=0.92) with percentage of sward, analyzed using point-intercept method.

The most valuable features of this technique are that it permits quantitative determination of botanical composition in terms of cover which may be the most suited ecological way of expressing recorded change, it is objective and more rapid than other equivalent methods, it provides for randomization and ample replication of sampling, it permits close examination of all species present and it does not depend entirely on random distribution of pasture species or in any way interfere with the vegetation (Crocker and Tiver, 1948). Criticisms of this method by Walker (1970) are that it increases the variance of an estimate due to the points being closer than the mean plant area and location of single points by the step-point approach is subject to excessive operator bias. However, the point method as generally used is most suited to a measurement of area rather than volume (Radcliffe and Mountier, 1964a).

2.3.1.5 Wheel-point

The wheel-point method of Tidmarsh and Havenga (1955) involves regular spacing of points, and is free of the criticisms of the point frame technique, as it reduces operator bias. The instrument consists of a wheel made with 6.5 mm

diameter silver steel rods. The circumference of the wheel is 3 m and, as only one spoke is used as a point, this is the distance between points. Three people are required for maximum speed of operation; one to pull the apparatus, one (the operator) to observe and one to record. One drawback of the wheel-point is that it is not a point, and estimates are biased upwards (Walker, 1970).

2.3.1.6 Line transect interception

This technique originally developed by Stone and Fryer (1935) was called the 'string method' which consisted of counting all the plants of each species whose crowns (not stems or leaves) are vertically beneath or touching a string 72 inches long stretched between two stakes. This method is essentially one of percentage frequency giving no information as to productivity or sward quality (Tinney *et al.*, 1937).

The line intercept method was later modified and used by Canfield (1941, 1950). Whitman and Siggeirsson (1954) reported the line interception method had been used extensively in a number of range research studies.

In the line interception method, a 10 m line with intercepts measured to the nearest 0.5 cm was used by Whitman and Siggeirsson (1954). The line was given a width of 1 cm, i.e., 0.5 cm, on either side of the wire. This arbitrary value of 1 cm was allowed for the intercept of all species. The authors suggested a minimum of 23 line transects to provide for reasonable estimates of 3 major vegetation components. Walker (1970) used 60 lb breaking strain fishing wire stretched tightly between two pegs, as close as possible to the surface of the soil. The operator stood astride the line and indicated to the recorder which plants to measure. Only rooted plant material directly beneath the line was recorded. In a comparison study, Poissonet *et al.* (1973) recorded species presence using a 64 m line with 25 cm segments recording 4 lines on

pasture areas in France. It was suggested that the line transect allowed fast sampling for species composition by a relatively simple method.

2.3.1.7 Dry-weight rank

This method gives an estimate of the percentage contribution of each species to the total yield of a pasture. In each of the quadrats an estimate is made as to which species occupy the first, second and third positions according to weight. The proportions of first, second and third ratings allocated to each species are then weighted by three previously determined constants, and the sum of these values, for each species, gives the percentage contribution of the species to the total weight of the sward ('t Mannetje and Haydock, 1963). The size of the quadrat to be used is not critical, provided that it is large enough to ensure that at least three species will be included in most positions. Anderson (1994) used 100 16x16 inch quadrats systematically located at five-pace intervals over a distance of 0.5 mile to estimate cover on native Arizona rangeland.

The maximum percentage of a species on a dry matter basis that can be estimated is 70.2% as species at high levels of dominance will likely receive all the first rankings. Advantages with this method are that the pasture is not disturbed and large sample numbers are possible. 't Mannetje and Haydock (1963) proposed this technique to be an alternative to the hand-separation method where the labour involved with hand-separation usually imposes a severe restriction on sample numbers.

2.3.1.8 Constituent differential

Copper et al. (1957) developed an indirect method for predicting botanical composition (dry matter basis of binary mixtures of grasses and legumes based on differences in chemical composition. The technique involves taking a large sample of the mixture and smaller sub-samples of each species in the mixture. The concentration of a chemical constituent is determined for each sample and the proportion of each species is calculated based upon these concentrations using an appropriate formula. Dry matter, calcium and crude protein were constituents used in this technique and the authors reported constituent differential method was more efficient than hand separation. Johnson et al. (1982) demonstrated that neutral detergent fiber (NDF) could be used to predict the proportion of legume in mixtures consisting of tall fescue (*Festuca arundinacea* Schreb.) and alfalfa, red clover (*Trifolium pratense* L.) or white clover (*Trifolium repens* L.) using the constituent differential method. Moore et al. (1990) also reported that NDF was the most reliable constituent for predicting botanical composition compared to crude protein (CP). Solving the differential equation for a constituent gave acceptable estimates at boot stage, but gave unreliable estimates at later maturities.

2.3.1.9 Near infrared reflectance spectroscopy

A more recent development has been the use of near infrared reflectance spectroscopy (NIRS) for predicting species composition of forage mixtures (Coleman et al., 1985). Determination of species composition by hand separation for sown pastures is laborious and separation times for samples from indigenous pasture are often longer. NIRS has also been used to predict the chemical constituents, digestibility and intake of forages by animals (Shenk et al., 1979; Shenk et al., 1981).

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As well, near infrared reflectance spectroscopy has been used successfully to predict the proportion of alfalfa grown in mixtures with smooth bromegrass (Moore *et al.*, 1990).

Dried and ground forage samples representing species proportions of 20 to 100% are analyzed spectrally using a near infrared reflectance scanning monochromator and software developed specifically for this technique. Reflectance data (log 1/R) is recorded between 1100 and 2500 nm wavelengths at 2 nm intervals. Empirical calibration equations are developed by regressing spectra of 40 samples against known proportions of a pure species. The remaining samples are then used to validate the calibration equation.

Coleman *et al.* (1985) predicted percentage of species regressed on the spectra using a modified stepwise regression procedure. Calibration equations for eight grasses had coefficients of determination (R^2) and standard errors of difference (SED) ranging from 0.94 to 0.99 and 1.9 to 6.8%, respectively. Moore *et al.* (1990) reported that the NIRS method was the most reliable method for predicting alfalfa proportion over all maturities.

2.3.1.10 Point-centred quarter method

Distance measuring methods are based upon the thesis that the measurement of the distances between plants is a more efficient sampling tool than area methods of direct density measurement. This is true in vegetation where difficulty is often encountered in identifying individual plants and high densities make direct counting of single plants impractical. The point-centered quarter method was developed by Cottam and Curtis (1956) for use in sampling of tree and sapling compositions of woodlands. Dix (1961) states that point-centered quarter is a method which offers a means of taking rapid, quantitative samples, yielding both species composition and

density data. In applying the method, a point is objectively established and the area around the point is divided into four quadrants. In each quadrant of the sampling unit, the distance to the closest living shoot is measured and species and distance recorded. Each unit consists of four measured distances to four shoots. Individual species densities are calculated from the measured distances and an importance value (relative frequency + relative density) which is independent of the measured distances is determined (Dix, 1961).

Heyting (1968) showed that the number of points required for a valid estimate of the relative density of a species rises sharply as the relative density decreases, indicating that about 250 points gave a meaningful result for the dominant species.

2.4 Forage yield

Forages may be evaluated for traits related to production such as yield, chemical composition, digestibility and animal performance. When measuring forage production the most suitable method will depend on the type of vegetation, area to be sampled and its topography and whether samples will be botanically or chemically analyzed (t' Mannetje, 1978). Replication helps to estimate experimental error (Steel *et al.*, 1997), and environmental replication estimates environmental variation and environment x treatment variation. Both the survey and the literature consider environmental replication essential for measuring dry matter yield (Cherney and Volenec, 1992).

2.4.1 Methods of estimating forage yield

Methods for the estimation of forage production have been studied (Brown, 1954; Michalk and Herbert, 1977; t' Mannetje, 1978; Cook and Stubbendieck, 1986).

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Most methods are classed as either direct or indirect techniques of forage yield estimation. Clipping to determine herbage weight is probably the most common direct method. Clipping provides an objective index of pasture yield which is accurate, sensitive and reliable, provided that sampling is adequate (Brown, 1954). This technique however, does not emulate the effects of herbivore grazing behavior. Indirect or estimate techniques rely on factors relatively easy to measure and highly related to herbage weight, which are then used to predict herbage weight (Haydock and Shaw, 1975; Cook and Stubbendieck, 1986).

Since herbage weight is often determined from quadrats by estimation or direct clipping, the choice of quadrat size and shape are very important. A quadrat of standard size should be selected for ease of conversion to yield. Weight is multiplied by a given factor to obtain kg ha^{-1} or lb ac^{-1} (Cook and Stubbendieck, 1986). Hume and Shirriff (1995) reported that when small quadrats are used for sampling crops, sampling is best done using rectangular quadrats. In a review of seventy-seven publications (1988-1994), quadrat shape used in sampling was appropriate in only fourteen instances. The authors also stated that inappropriately shaped quadrats (square or circular) could result in errors of up to 25% in estimates of crop related variables, such as yield. It was suggested when writing a paper to include a description of quadrat shape and area under materials and methods.

2.5 Methods of forage quality evaluation

Forages are the base source of nutrients for ruminants and recently there is an interest in using forages to supply a greater proportion of those nutrients. There is a need to know the productive capacity of forages. This productive capacity depends upon the availability of nutrients present in the forage consumed and the efficiency of utilization of the ingested nutrients (Coelho *et al.*, 1988). The feeding of a forage is

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the most accurate method of forage evaluation at a single point in time. While the accuracy of feeding and digestion trials can not be denied, they are time consuming, expensive and very slow.

The true value of a feed depends on the amount of nutrients that an animal can use after digestion and therefore feed evaluation procedures must incorporate some measure of nutrient digestibility. Although the *in vivo* method is the most accurate way of determining the digestibility, it is costly and unsuitable for screening large numbers of samples.

2.5.1 *In vivo* intake and digestibility of forages

Reliable procedures for estimating voluntary intake and digestibility are imperative for evaluation of the nutrition of ruminants. Comparative studies involving the digestibility and intake of forage crops has been investigated (Neathery, 1972; Bae *et al.*, 1979.; Deinum *et al.*, 1984; Prigge *et al.*, 1984; Petit *et al.*, 1985; Cochran *et al.*, 1986; Holechek *et al.*, 1986; von Keyserlingk and Mathison, 1989; Howard *et al.*, 1992).

Indoor feeding trials are advantageous because accurate direct measurements of individual animal feed consumption and digestibility are obtained, characteristics of the forage can be obtained, the environment can be controlled and trials can be run any time of the year (Heaney *et al.*, 1969). *In vivo* digestibility trials are thought to accurately reflect the feeding value of total diets but are limited in that they are laborious and time consuming. Feed intake can be determined by conventional hand-fed methods (Schneider and Flatt, 1975.). Traditionally, there is a week of adaptation by the animals which are randomly assigned to the various treatments. Most studies have shown that 6 to 8 days are sufficient for adjustment periods when ordinary forages are fed; longer preliminary periods are desirable with feeds such as silage,

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straws and ground or pelleted hays (Heaney et al., 1969). Schneider and Flatt (1975) concluded that a 5-day adjustment period was adequate to clear previously fed diets from the digestive tract. During the first 14 days, feeds are offered ad libitum. Voluntary intake (per $kg^{0.75}$) is determined in the second week. During weeks three and four, feed is restricted to 90% of voluntary intake. Then, during the last week, samples of forage offered and orts are taken daily. Ten percent aliquots of feces are collected daily and frozen for subsequent analyses (Petit et al., 1985).

Estimation of in vivo digestibility of forage-based diets has been studied using internal markers. Cochran et al. (1986) reported that digestion coefficients from in vitro neutral and acid detergent fiber were similar (P>0.10) to in vivo coefficients. Acid detergent lignin (ADL) was not acceptable to use as an internal marker in forages due to positive (>100%) and incomplete recovery results. Fecal components (DM, N, ether extract, crude fiber and acid soluble ash) have also been related to forage intake and digestibility (Holloway et al., 1981). Prigge et al. (1984) reported that digestibility differences between steers and whethers were 6 percentage units at the ad libitum level of intake and 1 unit at the restricted level of intake. Crude protein digestibility tended to be greater (P<0.10) for sheep.

2.5.1.1 Prediction of voluntary intake

Improved predictions of voluntary intake of forages by ruminants are needed in order to improve both the balancing of rations of animals and the strategic planning of forage conservation. Use of linear regression analyses of total nitrogen (N), ammonia nitrogen (NH_3-N) and volatile fatty acids (VFAs) on dry matter intake (DMI) (Rook and Gill, 1990), principal component and ridge regression analyses of NH_3-N and VFA on DMI (Rook et al., 1990a) and alternative prediction models using ridge regression have been studied (Rook et al., 1990b).

2.5.2 Laboratory analyses

2.5.2.1 Crude protein

Values for crude protein (CP) and ruminally undegradable CP content are now required in feed evaluation systems currently used in North America. The determination of forage CP content is a standard procedure for most laboratories as it is relatively easy to measure (Hoffman *et al.*, 1993).

2.5.2.2 *In vitro* techniques

Several laboratory techniques are widely used in forage evaluation to predict intake and digestibility of roughages. Among the most popular are fiber analysis (Van Soest and Wine, 1967), the two stage *in vitro* method of Tilley and Terry (1963), the gas production technique of Menke *et al.* (1979) and the rumen incubation *in situ* method of Mehrez and Ørskov (1977) or Ørskov and Ryle (1990).

2.5.2.2.1 *In vitro* dry matter digestibility

To reduce the cost and time involved in *in vivo* forage evaluation, laboratory procedures have been developed. Dry matter digestibility (DMD) can be estimated by procedures using rumen microorganisms (Tilley and Terry, 1963; Van Soest *et al.*, 1966).

Digestibility is often estimated by *in vitro* rumen systems that simulate the digestion process. *In vitro* systems can be more accurate, because *in vivo* techniques are sensitive to factors that can influence rate and extent of digestion. Tilley and Terry (1963) developed a technique which involves two stages: 48 h digestion with

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rumen organisms followed by 48 h digestion with pepsin in weak hydrochloric (HCl) acid (about pH 2). The residue is composed of undigested plant cell wall and bacterial debris and yields values comparable to *in vivo* apparent digestibility (Van Soest, 1994).

The modified Tilley and Terry (1963) two-stage rumen fermentation *in vitro* procedure as outlined by Goering and Van Soest (1970) or Van Soest (1994) is recognized generally as the most widely used of the *in vitro* procedures for the estimation of digestibilities *in vivo* (Van Soest, 1994). Significant correlations between the two-stage method and *in vivo* dry matter digestibility (r=0.94) (Scales *et al.*, 1974) and organic matter digestibility (r=0.88) (Aerts *et al.*, 1977) have been published. This technique can evaluate multiple samples at the same time, however the main disadvantage is the long time required to do the analysis and the numerous steps involved (Van Soest, 1994). Further variations reported are that a 60 h fermentation time was optimal for warm-season perennials and 36 h was optimal for annuals, legumes and cool-season perennials (Nelson *et al.*, 1975). Also, Coelho *et al.* (1988) stated that dry matter intake and DMD was associated with *in vitro* dry matter disappearance ($r^2 = 0.78$ and $r^2 = 0.90$).

2.5.2.2.2 Nylon bag

The *in situ* rumen dry matter (DM) disappearance technique (Mehrez and Ørskov, 1977; Ørskov and McDonald, 1979; Ørskov *et al.*, 1988) evaluates forages for their rate and extent of fermentation in the rumen. Bags containing the feed being studied are incubated with ruminal microbial flora for different set incubation times in the rumen of animals, and variations in degradation rate among feeds are then only attributable to the specific characteristics of the feeds (Nozière and Michalet-Doreau, 1996). The method is widely used as the technique is simple and generates data

without resorting to highly technical and expensive laboratory procedures. A further advantage of the *in situ* DM disappearance technique is that it may afford a means of predicting intake (Ørskov *et al.*, 1988) and degradability characteristics of forage dry matter and protein (von Keyserlingk *et al.*, 1996). However, the technique has some limitations. First, it is a very invasive technique and may be subject to great criticism by animal welfare groups and second, the technique is incapable of evaluating large numbers of samples at a given time (Sileshi *et al.*, 1996). Also, sample preparation prior to incubation may affect dry matter digestibility (López *et al.*, 1995) and fibrolytic activities were lower in bag residues than in rumen digesta with differences ($P<0.05$) greater at 2 h than after 23 h incubation time (Nozière and Michalet-Doreau, 1996).

To estimate the degradability of protein supplements in the rumen Ørskov and McDonald (1979) proposed the use of a single exponential model:

$$p = a + b\,(1 - e^{-ct}) \qquad (2.5)$$

where p represents the potential dry matter disappearance at incubation time t (h^{-1}), ($a + b$) are fitted constants, a the soluble fraction and b the degradable part of insoluble fraction, and c is the fractional rate of dry matter disappearance (% h^{-1}) of fraction b. For low degradable feeds, McDonald (1981) revised this model to deal with the presence of lag times as follows:

$$p = a + b\,(1 - e^{-c(t-t_o)}) \qquad (2.6)$$

where p represents the potential dry matter disappearance, t is lag time (h^{-1}), ($a + b$) are fitted constants, a the soluble fraction or wash value, b the degradable part of

insoluble fraction, and c is the fractional degradation rate (% h^{-1}) of fraction b (Dhanoa, 1988).

A pre-treatment of sodium hydroxide (NaOH) and cellulase on roughage samples (pea husk, maize stover, orchard grass hay and rice straw) incubated *in situ* increased ($P<0.05$) dry matter and cell wall digestibility (Adebowale and Nakashima, 1992). Comparisons between the *in sacco* and *in vitro* technique by Mbwile and Udén (1991) found that accuracy of predicting *in vivo* digestibility was lower ($R^2 =$ 0.91)with both methods when samples were incubated at 72 h and highest ($R^2 = 0.93$) when samples were incubated at 48 hours. This is similar to the results of von Keyserlingk and Mathison (1989), who reported that predictions of digestibility and intake from *in situ* results were most accurate at 24 and 36 hours, $R^2 = 0.92$ and 0.86, respectively. Neathery (1972) also reported lower digestible values for Bermudagrass (*Cynodon dactylon* [L.] Pers) when incubated with nylon bag method and compared to conventional digestion trials.

2.5.2.2.3 *In vitro* gas production

The digestion of feedstuffs by ruminal microorganisms produces gas, and gas measurements have long been used to measure the extent and kinetics of fiber digestion *in vitro* (Menke *et al.*, 1979; Pell and Schofield, 1993). This anaerobic fermentation of feeds by ruminal microbes produces volatile fatty acids, carbon dioxide, methane and traces of hydrogen (Hungate, 1966). Rumen fermentors are mainly cellulolytic bacterial and protozoal species (Hidayat *et al.*, 1993).

Gas produced in fermentation is generally proportional to microbial metabolism and therefore a possible endpoint for estimating digestibility. A system was developed by Menke *et al.* (1979) and Menke and Steingass (1988) using large-bore syringes as the measuring device and is referred to as the Hohenheimer Gas Test.

Gas is collected at atmospheric pressure and its volume determined directly. Gas volume can be explained by the volatile fatty acids produced and their proportions. About 50% of the gas volume consists of CO_2 and CH_4 arising from fermentation, the remainder being CO_2 released from the buffer solution (Blummel and Ørskov, 1993). This system has been successful in predicting digestibility and metabolizable energy (ME) by relating expected gas production to organic matter fermented (Van Soest, 1994). The volume of gas produced in 24 h from incubating 200 mg food dry matter (DM) was used together with the concentration of crude protein, crude fat, crude fiber and ash in the sample to predict metabolizable energy. Additional measurement of these constituents to predict ME could be considered a disadvantage of the gas technique (Khazaal et al., 1995.).

Using the (a + b) and (c) of gas production, intake was predicted accurately (r = 0.87; P < 0.01) (Khazaal et al., 1995). Blummel and Ørskov (1993) reported gas production of barley and wheat straw was correlated with intake (0.88), digestible dry matter (0.93) and growth rate (0.95) of steers using a multiple regression model. Mir et al. (1997) reported total in vitro gas production was higher for alfalfa than fenugreek (Trigonella foenum-graecum L.), however, lag time prior to initiation of gas production was shorter for alfalfa. In vitro gas production has been used to compare digestibility of leguminous fodder trees, which are used as livestock forage, in sub-Saharan Africa. Siaw et al. (1993) reported that Sesbania spp. produced more gas and had greater degradation characteristics than Acacia, Erythrina or Cajanu species. Andrighetto et al. (1992) measured in vitro digestibility of sixty-six native Italian forages using gas production and three other techniques, to predict digestible organic matter in dry matter (DOMD) in vivo using multiple linear, step-wise regression analyses. The final regression equation with an R^2 of 0.68 could increase the precision of predicting DOMD in vivo, required only a restricted number of laboratory determinations.

Pell and Schofield (1993) used a different approach which allows the gas to accumulate in a fixed volume container, and the volume is calculated by transducers measuring pressure changes allowing continuous recording by computer software. This technique can measure rate and extent of fermentation in a single flask, in contrast to batch fermentors and nylon bags which require collection of replicate samples at specified time intervals to describe rate and extent (Van Soest, 1994). Schofield and Pell (1995a) further reported that gas measurements based on pressure increases in a fixed volume container appear to offer a valid alternative to methods based on gas collection at atmospheric pressure. Theodorou *et al.* (1994) also developed a simple gas production technique (PTT), using a pressure transducer, to assess the fermentation kinetics of forages incubated *in vitro* with rumen liquor. The authors reported that PTT has the potential to evaluate rumen fermentation characteristics of large numbers of samples at a given time. Sileshi *et al.* (1996) predicted in situ dry matter disappearance parameters of two warm-season grasses, napier grass (*Pennisetum purpureum* Schumach) and pigeon grass (*Heteropogon whitei*) and a cool season grass, reed canarygrass (*Phalaris arundinacea* L.) from *in vitro* gas production parameters using the technique of Theodorou *et al.* (1994). Overall fractional rate of dry matter disappearance of forages was correlated (P<0.01) with fractional rate of gas production. More precise procedures have been studied measuring fermentation of substrate fractions and fitting the data to a modified Gompertz model or single and dual pool logistic equations (Beuvink and Kogut, 1993; Schofield *et al.*, 1994; Schofield and Pell, 1995b). It was reported that collection bottle size had an slight effect on pH, but was not associated with changes in any other characteristics measured.

Various studies have utilized this technique to compare the effects of different inocula (reconstituted sheep feces vs. rumen fluid) (Nsahlai and Umunna, 1996) on gas production, and to compare the rates of fermentation of energy supplements

(Krishnamoorthy et al., 1991). Gerson et al. (1988) suggested rate of gas production per g of fermentable feed particle is influenced by particle size. Rate was approximately 30% lower with 1-2 mm particles than with 0.1-0.4 mm particles. Beuvink and Spoelstra (1994) investigated fermentation kinetics of silages treated with different cell wall degrading enzymes using the gas test and Naga and Harmeyer (1975) studied the relationship between production of gas or volatile fatty acids and the synthesis of microbial protein *in vitro*.

The gas production technique has been adapted by reading the increase in gas production at a series of chosen time intervals and using the exponential equation of Ørskov and McDonald (1979):

$$p = a + b \, (1 - e^{-ct}) \qquad (2.7)$$

This equation describes the gas production characteristics of forages, where p represents the percent degradation at incubation time t (h^{-1}), a, b and c are constants, a the soluble fraction and b the degradable part of insoluble fraction, and c is the fractional rate of dry matter disappearance (% h^{-1}) of fraction b.

Another kinetic derivation of this model was presented by France et al. (1993) which demonstrates how its parameters can be used to calculate the extent of degradation in the rumen:

$$p = A\{1 - \exp[-b \, (t - T) - c \, (\sqrt{t} - \sqrt{T})]\} \qquad (2.8)$$

Where p denotes cumulative gas production (ml), t incubation time (hr), and A, b, c, and T are parameters and lag time, respectively. Khazaal et al. (1993), concluded that prediction of intake and digestibility of leguminous hays from their degradation characteristics was slightly more accurate using the *in situ* method (r = 0.79 to 0.83)

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than the gas production method (r = 0.73 to 0.80). Nsahlai and Umunna (1996) found the relationship between gas production and intake to be strongest (R^2 = 0.41) at 12 h of incubation for roughages.

2.5.2.3 Fiber analysis

The detergent system provides a rapid procedure for determining the insoluble cell wall matrix and estimating hemicellulose, cellulose and lignin. Extraction of forage with a neutral (pH 7) solution of sodium lauryl sulfate and ethylenediaminetetraacetic acid (EDTA) leaves a neutral detergent fiber (NDF) residue which recovers the major cell wall components: lignin, cellulose and hemicellulose (Van Soest, 1994). The value of NDF for forages has been shown to be highly correlated (r = 0.76) with voluntary intake (Van Soest *et al.* (1978).

A low-nitrogen residue that recovers lignin and cellulose is obtained from strong acid solutions of quaternary detergents. The acid-soluble fraction includes primarily hemicelluloses and cell wall proteins, while the residue recovers lignin, cellulose and the least digestible noncarbohydrate fractions. Acid detergent fiber (ADF) is widely used as a quick method of estimating the fiber in a forage sample. There is also a highly correlated statistical relationship between ADF and feed digestibility (r=0.75) (Van Soest, 1994).

2.6 Prediction of animal requirements using computer models

The Weende system for proximate analysis and the total digestible nutrient (TDN) system have been used for over a century to predict energy and protein in feedstuffs. Further to this net energy (NE) systems were developed to account for methane, urinary and heat increment losses (NRC, 1986). However, tabled NE values

are usually calculated from TDN and are representative of the average value for a group of feeds. Computer application models such as Cornell Net Carbohydrate and Protein System (CNCPS) and the National Research Council (NRC) 1996 computer program can accurately estimate fermentation and passage of feed carbohydrate and protein fractions based on a ruminal fermentation model using voluntary intake, feed composition and degradation rates of feed protein and carbohydrate as inputs. Feed dietary protein and carbohydrate are fractionated using laboratory analyses according to Sniffen *et al.* (1992).

The development of the NRC (1996) computer program arose from the need to account for variation in factors observed in the field that influence performance of cattle consuming forages. A primary purpose in developing models is to improve nutrient management through intensive animal feeding. Predicting requirements accurately results in minimized overfeeding of nutrients, increased efficiency of nutrient utilization, maximized performance and reduced excess nutrient excretion.

2.6.1 Prediction of beef cattle requirements using NRC 1996 application model

The NRC Computer Model is a two level system. Level 1 is used when limited information on feed composition is available and the user is not familiar with how to use, interpret and apply the inputs and results of level 2. It is an aggregate system designed to provide information on maintenance, growth, lactation and pregnancy attributable to the feedstuffs.

Level 2 is designed to obtain additional information about ruminal carbohydrate and protein utilization and amino acid supply and requirements. A series of papers were included to supply more mechanistic submodels. The NRC (1996) Nutrient Requirement Series application model is based on equations and validation published by Russell *et al.* (1992), Sniffen *et al.* (1992), Fox *et al.* (1992),

O'Connor *et al.* (1993), Fox *et al.* (1995), and Pitt *et al.* (1996). NRC 1996 computer model can be used as a teaching tool to evaluate interactions of feed composition, feeding management and animal requirements in varying conditions; to develop feed tables; to predict requirements and balance for nutrients in a more detailed system; as a tool for extending research results to farm conditions; and as a diagnostic tool to evaluate feeding programs and to account for more variation in performance in a specific production setting (Fox *et al.*, 1995).

2.7. Objectives

The objectives of this thesis are:

1. To evaluate the effect of rejuvenation of grass-legume pastures by spiking, burning, mowing, deep-banding and applications of N, P, K and S liquid and granular fertilizer on forage dry matter yield and quality components.

2. To evaluate the effect of rejuvenation of grass-legume pastures by spiking, burning, mowing, deep-banding and applications of N, P, K and S liquid and granular fertilizer on botanical composition.

3. To examine ruminant total tract digestibility and voluntary intake responses to changes in forage composition as a result of three methods of rejuvenation, harvesting date and soil zone.

4. To compare *in vivo* apparent digestibility with *in vitro* dry matter digestibility and predicted metabolizable energy (ME) from *in vitro* gas production data with *in vivo* ME of twelve hays harvested the year following three rejuvenation treatments, at two stages of maturity from two soil zones.

5. To predict potential animal performance using National Research Council's (NRC) Nutrient Requirement Series computer software and three years of nutritive data from hays harvested from two rejuvenation treatments.

Chapter 3

The Effects of Rejuvenation of Grass-Legume Pastures:

I. Dry Matter Yield and Quality

3.1 Abstract

A three year study was conducted on Black and Gray Wooded soils at five sites in the Aspen Parkland region of Saskatchewan to determine the effect of spiking, burning, mowing, deep-banding and applications of N, P, K and S liquid and granular fertilizers on dry matter yield (DMY) and forage quality of primarily smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago media* Pers.) pastures. Fertilizer was blended to provide 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1} in either liquid or as granular broadcast at 0 and 350 kg ha^{-1}. All mechanical and fertilizer treatments were applied in the spring of 1994. Interaction effects of Trt x Yr and Fert x Yr were significant ($P<0.05$) indicating a wide range of response to the rejuvenation methods among years. Deep-banding (slicing) and mowing had only minimal effects on production. Spiking showed increased yield over 3 yr at only one site. Burning increased ($P<0.05$) DMY in yr 1 and 2 only at the Gray-Wooded site. In yr 1, liquid plus granular fertilizer (200 kg N ha^{-1}) (deep-banded liquid fertilizer (DBLIQ at 100 kg N ha^{-1}) + broadcast fertilizer (+F at 100 kg N ha^{-1})) increased DMY at 4 sites, 84 to 185% over control plots. This effect carried over into 1995 at 4 sites, but not 1996. Mechanical treatments (deep-banding, mowing and spiking) combined with broadcast fertilizer increased ($P<0.05$) forage

yields in yr 1 of the study. Spiking plus fertilizer and mowing plus fertilizer increased DMY (P<0.05) at 4 sites in the second year. The high rate of nitrogen (200 kg N ha^{-1}) of the DBLIQ+F increased crude protein content of yr 1 forage 55%, 14.63% compared to 9.52% for control samples. However, crude protein content of the 1995 and 1996 samples was similar to control values for this treatment. Mean concentrations of forage calcium and phosphorous were 0.85% and 0.11%, respectively. Broadcast fertilizer combined with mechanical rejuvenation methods decreased calcium content of the pasture. Burning tended to increase calcium content of the herbage after 3 years. Phosphorous content increased with combination fertilizer treatments but not with spiking, burning, deep-banding or mowing. Results of this study suggest that mechanical rejuvenation methods such as spiking, mowing, deep-banding or burning have minimal effects on yield and quality. An application of broadcast or liquid fertilizer alone or combined with mechanical treatments will produce a significant effect on herbage yield and quality but only short term.

3.2   Introduction

Tame forage in Saskatchewan covers more than 3 million hectares. Since 1989, over 280,000 ha were seeded to forages under the PFRA Permanent Cover Program, of which 120,000 ha were seeded in the Parkland area of Saskatchewan. The majority of forages and all of the Permanent Cover acreage has been seeded on primarily marginal land. In the Aspen Parkland, most forages are commonly established as mixtures of smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago sativa* L.). Over time the productivity and carrying capacity of these pastures has declined, because of invasion of unpalatable or less productive species, over-grazing and poor soil fertility. Soil fertility decreases because available nitrogen is locked up in the carbon:nitrogen ratio. The dominant invasive species infesting

these areas after 5 to 10 yr are Kentucky bluegrass (*Poa pratensis* L.), Canada

bluegrass (*Poa compressa* L.), dandelion (*Taraxacum officinale* L.), yarrow (*Achillea*

millefolium L.), Perennial sow thistle (*Sonchus arvensis* L.) and Canada thistle

(*Cirsium arvense* L. Scop.).

There is limited information on the effect of rejuvenation treatments applied to

pastures grown on Black and Luvisolic (Gray Wooded) soils of western Canada

(Bowes and Freisen, 1967; Mahli *et al.*, 1995; Peat and Bowes, 1995). No long-term

experiments with grass-legume pastures have been conducted to study the effects of

rejuvenation on dry matter production and forage quality. With long-term

experiments, temperature and precipitation patterns are likely to vary over a greater

range, with a corresponding effect on pasture herbage yield, composition and quality.

The concentration of N, P and Ca in ungrazed mature pasture herbage, particularly

grasses, are commonly below optimum for efficient animal performance (Minson,

1990). Therefore, it is important to know the effects of rejuvenation, such as

fertilizing, on the contents of these elements so that the effects can be considered

when managing the sward.

Conventional systems of renovation generally involve breaking up the stand

with several tillage operations and reseeding the land back to forages. These systems

are costly and increase the potential for erosion, nitrogen leaching and resalinization

on marginal land. Therefore, there is a need to study less costly rejuvenation methods

utilizing present forage species with minimal nitrogen loss and disturbance to the

area. The objectives of this study were to evaluate the effects of rejuvenation

treatments on dry matter yield (DMY) and forage quality components of long

established grass-legume stands located within the Black and Gray-Wooded soil

zones of parkland Saskatchewan.

3.3 Materials and Methods

Field experiments were conducted from 1994 to 1996 at five sites located throughout central and north-eastern Saskatchewan. All sites were within the Aspen Parkland and represented two soil types (Appendix, Table A.1). Before treatments were applied in the spring of 1994, pH, organic matter (OM) and available soil nitrogen (N), phosphorous (P), potassium (K) and sulphur (S), were determined at all sites from soil samples taken to a depth of 30 cm in the soil profile. Samples were analyzed at Plains Innovative Laboratory Services (PILS) in Saskatoon, Saskatchewan. The fertilizer blend for this study was formulated and applied according to initial soil test results and studies conducted on Gray-Wooded (Gray Luvisol) and coarse textured Black soils in the parkland area of Saskatchewan (Nuttall *et al.*, 1991).

3.3.1 *Sites, Soils and Location*

Pathlow

Pathlow site (52° 46' N; 104° 54' W), was a 20 yr old pasture located approximately 30 km southwest of Melfort, Saskatchewan. The topography is gently sloping to nearly level (2 to 5% slope), and the soil is mapped as a Gray-Wooded Podzolic, Waitville-Northern Light loamy glacial till (Saskatchewan Soil Survey, 1992). The soil is developed on a mixture of loamy glacial till and shallow, silty lacustrine materials underlain by glacial till with 2-3% organic matter. Mean annual precipitation at Melfort (52° 49' N; 104° 36' W), the nearest permanent weather station, averages 426 mm with nearly 68% occurring during the growing season (Environment Canada, 1994).

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Initial buffer pH ranged from 7.2 to 7.9, available N ranged from 2 to 5 kg ha^{-1} (very low), available P ranged from 5 to 13 kg ha^{-1} (low), available K ranged from 297 to 653 kg ha^{-1} (very high), and exchangeable S ranged from 10 to 21 kg ha^{-1} (average) (PILS).

Prince Albert

Two sites were established on the same section, Delayed Hay Cut (DHC) and Dense Nesting Cover (DNC) (53° 10' N; 104° 38' W), both located approximately 15 km southeast of Prince Albert, Saskatchewan. Both sites had been established hayland for over 40 years. DHC (NW$_{1/4}$, 14-47-26 W2nd) was managed with a delayed hay cut in mid-July to allow young waterfowl to move off the nesting area, and the DNC site (NE$_{1/4}$, 14-47-26 W2nd) was unmanaged and left as a dense nesting cover (DNC) for waterfowl species.

The topography was hummocky with mostly rolling low and high spots (5 to 15% slope) within the experimental area. The soil at both sites was Chernozemic, Black Orthic Hamlin-Blaine Lake, a mixture of sandy loam and silty lacustrine material (Saskatchewan Soil Survey, 1992) with 5-7% organic matter. Mean annual precipitation at Prince Albert (53° 13' N; 105° 41' W), the nearest permanent weather station, averages 406 mm with nearly 69% occurring during the growing season (Environment Canada, 1994).

Initial buffer pH ranged from 6.8 to 7.6, available N ranged from 4 to 15 kg ha^{-1} (very low), available P ranged from 4 to 24 kg ha^{-1} (low), available K ranged from 358 to 967 kg ha^{-1} (very high), and exchangeable S ranged from 21 to 47 kg ha^{-1} (high) (PILS).

Rama

The Rama site (51° 40' N; 103° 2' W) was a 4 yr old hayfield located 57 km southeast of Wadena, Saskatchewan. Site topography was undulating with a sequence of gentle slopes extending from smooth rises to gradual hollows. The soil is a Chernozemic, Black Orthic Meadow-Crooked Lake (Saskatchewan Soil Survey, 1992), a poorly drained loamy to gravelly loam with 2 to 5% slope and 7-8% organic matter. Mean annual precipitation at Margo (51° 50' N; 103° 20' W), the nearest permanent weather station, averages 388 mm with nearly 68% occurring during the growing season (Environment Canada, 1994).

Initial buffer pH ranged from 7.9 to 8.3, available N ranged from 24 to 59 kg ha^{-1} (low), available P ranged from 5 to 16 kg ha^{-1} (low), available K ranged from 542 to 1142 kg ha^{-1} (very high), and exchangeable S ranged from 48 to 96 kg ha^{-1} (very high) (PILS).

Insinger

The Insinger site (51° 45' N; 102° 56' W) was a 6 yr old hayfield located 35 km southeast of Foam Lake, Saskatchewan, with an elevation of 518 m and a mean annual precipitation of 420 mm. Topography was also undulating with 2 to 5% slope. The soil is typed as Chernozemic Meota-Whitesand with 7% organic matter. This is a Black soil formed from a mixture of fluvial materials with a texture of loamy sand to gravelly sandy loam. Mean annual precipitation at Insinger (51° 32' N; 102° 59' W), the nearest permanent weather station, averages 431 mm with nearly 70% occurring during the growing season (Environment Canada, 1994).

Initial buffer pH ranged from 7.5 to 8.1, available N ranged from 43 to 84 kg ha^{-1} (moderate), available P ranged from 10 to 20 kg ha^{-1} (low), available K ranged

from 573 to 993 kg ha^{-1} (very high), and exchangeable S ranged from 22 to 107 kg ha^{-1} (very high) (PILS).

At all five sites, the study was conducted on established stands of smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago sativa* L.) (cultivar unknown). Perennial grasses invading the stands were Kentucky bluegrass (*Poa pratensis* L.), Canada bluegrass (*Poa compressa* L.), quackgrass (*Elytrigia repens* Syn.) and green foxtail (*Setaria viridis* (L.) Beauv.). The sites were infested with broadleaf weeds such as dandelion (*Taraxacum officinale* Weber), perennial sow thistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), narrow-leaved hawk's-beard (*Crepis tectorum* L.), yarrow (*Achillea millefolium* L.) and other lesser species. All sites were harvested as hay the year prior to treatment application.

A split-plot arrangement of a randomized complete block design with four replicates was used. Each replication (block) was represented by a 0.63 ha area (90 m x 70 m). Six main treatment plots (whole plots) were arranged at random in 10.8 x 90 m strips across each block and separated by 1-m borders. All treatments were applied late April of 1994. Treatments established at all sites were (i) control, (ii) deep-banded liquid fertilizer, (iii) deep-band without liquid fertilizer, (iv) burn, (v) flail mow, and (vi) spiking. Split-plot treatments were two rates of broadcast granular fertilizer, 0 and 350 kg ha^{-1}. The fertilizer was blended to provide 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1} in 350 kg of fertilizer/ha. The source of N fertilizer was urea, the P source was diammonium phosphate, the K source was muriate of potash (potassium chloride) and the S source ammonium sulphate.

The control area (C) was the experimental check. These plot areas were left untouched (no treatment applied). Deep-band liquid fertilizer (**DBLIQ**) was applied using an 8 nozzle, 2.4 m liquid fertilizer applicator pulled by an 80 hp International tractor. Coulter/nozzle injector units were spaced 30 cm apart and liquid fertilizer

was nozzle injected at a depth of 7 cm behind fluted coulters which opened up the soil profile. This same applicator unit was used for deep-banding without liquid fertilizer (**DB**). As the applicator with attached fluted coulter units was applied across the test area, the slicing effect of the coulter unit resulted in minimal disturbance of the soil profile. Nevertheless, the DB treatment was included in order to detect and separate the effect of the slicing from fertilizer on plant productivity.

The burn treatment (**B**) was initiated with a controlled spring burn. The prescribed burn was contained within plot areas using first a wet line, followed by drip torches which were then used to burn off all above ground senesced plant material. On plots where there was a shortage of plant fuel, drip torches were used more frequently.

The mowing treatment (**M**) was applied using a 2.0 m John Deere rotary flail mower. Forage material was mowed to a height of 1-2 cm, opening up the plant canopy and exposing basal material to more light and moisture penetration. Mowed forage material was spread on plot areas but was negligible due to harvesting from the previous year.

The spike treatment (**SP**) used a 3.7 m John Deere DT100 deep tillage cultivator attached with 2 cm anhydrous applicator knives. Cultivator shanks were spaced 30 cm apart and initial depth was set at 8 cm which varied due to flexing of the shank spring release mechanism.

Additionally, each whole plot was split and topdressed with a granular blend of fertilizer (**+F**) applied at 0 or 350 kg ha^{-1} (providing 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) using a Valmar air flow fertilizer spreader.

3.3.2 *Data collection and analysis*

Herbage production estimates were made when major species of the plant community were approaching maturity. Forage dry matter yield (DMY) was determined mid-July each year by clipping from within each replicate (block), five randomly placed 0.25 m² quadrats (0.25 m x 1.0 m), to a 1.5 cm stubble height. The sample material was then dried in a forced air oven at 65°C for 48 h, weighed and converted to kg/ha. The herbage from each site was harvested for three successive production years, 1994-96, according to the following schedule. Pathlow plots were harvested on 13 July/94, 17 July/95 and 16 July/96. Prince Albert-DHC plots on 14 July/94, 17 July/95 and 17 July/96. Prince Albert-DNC plots on 14 July/94, 17 July/95 and 22 July/96. Rama plots on 25 July/94, 18 July/95 and 18 July/96. Finally, Insinger plots were harvested on 25 July/94, 18 July/95 and 18 July/96. All dried forage samples were retained for further laboratory analysis.

Prior to analyses all samples were ground through a 1 mm screen using a Wiley mill. Lab tests for forage quality including crude protein (CP, Kjeldahl N X 6.25), calcium and phosphorous were conducted on five composited forage subsamples from each site-year. Samples were analyzed for Kjeldahl nitrogen (semi-automated method No. 976.06), according to the procedures of the Association of Official Analytical Chemists (AOAC, 1990) using a Technicon GTPC Auto Analyzer II. Digested sample solution was then further analyzed for calcium and phosphorous with the Technicon Auto Analyzer II using a method adapted from Hambleton (1976).

Data were first analyzed using the GLM procedure of the SAS Institute, Inc. (1989) including year, site, replicate, treatment and fertilizer in the model and testing for interactions. Due to non-homogeneity of variances (Bartlett's Test, Steel *et al.*, 1997) between site-years, and year x site, year x treatment and year x fertilizer

interactions (P<0.05) (Appendix, Table A.9), the experiment was analyzed separately for each site-year combination and no attempt was made to sort out these interactions. The interactions, year x site, year x treatment and year x fertilizer were anticipated prior to this study (Cherney and Volenec, 1992).

The five sites (Pathlow, DHC, DNC, Rama and Insinger) were studied in separate but similar experiments due to environmental (year) x site, site x treatment and site x fertilizer interactions, therefore site data were not pooled. However, the experiments at each site were identical in design and treatments. Each experiment was set up as a randomized complete block in a split-plot arrangement of treatments with four replications. In each experiment, six rejuvenation treatments were assigned randomly to the main plots (10.8 x 90 m) in each replication, and two broadcast fertilizer treatments were assigned randomly to the sub-plots (5.4 x 90 m) in each main plot. Dry matter yield and forage quality data at each site within each year were calculated and analyzed using a split-plot ANOVA (SAS, 1989) in a randomized complete-block design with rejuvenation treatments as the main plots, broadcast fertilizer as the split-plot, and 4 replications (Blocks). The experimental model was:

$$Y_{ijk} = \mu + B_i + R_j + F_k + (RF)_{ij} + (BRF)_{ijk} + e_{ijk} \qquad (3.1)$$

where Y = DMY of the ith block, jth rejuvenation treatment, and kth fertilizer rate, and B = block, R = rejuvenation treatment, F = fertilizer rate, and e = experimental error. Main plot effects (rejuvenation treatments) were tested against the block x treatment term and sub-plot effects were tested against the experimental error term. Whole plot and split-plot means were tested for differences using Fisher's protected LSD test (Steel et al., 1997).

3.4 Results and Discussion

3.4.1 *Weather Data*

At all sites in 1994, April and May mean monthly temperatures were above the long-term average while in 1995 and 1996, these monthly temperatures were below long-term averages (Appendix, Table A.2). July and August temperatures were close to the long-term average at all sites in all 3 years; however growing season temperatures were slightly higher than the 30-yr average. In 1994 at all sites, spring precipitation was below average, but rainfall in May, June, July and August resulted in one-half to twice the long-term average (Appendix, Table A.3). Precipitation during the May to July period was well below average in 1995, above or near long-term average in 1994, and variable in 1996. In August of 1995 rainfall was two to three times greater than average at all sites. This occurred again in July of 1996. Total annual precipitation was below average at Pathlow in 1994 and above average at the other sites that same year, but near average in 1995 and 1996 at Pathlow and DHC/DNC sites. Rama and Insinger received greater than normal annual precipitation and over the 3 years recorded, Rama received 115% and Insinger 116% of the long-term average.

3.4.2 *Dry Matter Yield*

The amount and distribution of precipitation in 1994 during the growing season may have influenced fertilizer response in herbage production. Above average rainfall was observed at DHC, DNC, Rama and Insinger.

All four, three and two-way interactions involving treatment, fertilizer, site and year, were significant ($P<0.05$) (Appendix, Table A.9). Therefore yield and

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quality data were analyzed within each year and site. The Trt x Yr interaction effect

on dry matter yield was significant (P<0.05) when measured over 1994 to 1996. The

interaction effects of Yr x Site, Yr x Fert and Trt x Fert were all significant (P<0.05)

(Appendix, Table A.9) over the 3-yr period.

The dry matter yield of total herbage varied with years and treatments (Tables

3.1 to 3.5). The significant Year by Treatment interaction suggested that herbage

responded substantially more to fertilizer in 1994 than in 1995 or 1996, as expected.

Indeed, the lowest dry matter production was from C+F (granular fertilizer) plots at

DHC in 1995 yielding 2211 kg ha^{-1} and the greatest production was 7257 kg ha^{-1} on

the DBLIQ+F (liquid + granular fertilizer) plots (DNC, 1994) (Tables 3.2 and 3.3).

The effect of liquid fertilizer plus broadcast fertilizer (700 kg ha^{-1} providing 200 kg N

ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1} and 24 kg S ha^{-1}) greatly increased yield of

total herbage at all sites in the first year and total production after 3 years. This

treatment was twice the normal recommended rate of fertilizer for these soils.

Carryover effect of this treatment was observed on the DBLIQ+F plots in each of four

sites (Pathlow, DHC, Rama and Insinger) where increased DMY was significantly

(P<0.05) different from control for year's 1 and 2 of the experiment. On the

DBLIQ+F plots, application of 200 kg ha^{-1} actual N increased (P<0.05) DMY ranging

from 84 to 185% in 1994 at 4 sites, Pathlow, DNC, DHC and Rama. The Insinger

site produced the smallest increase in DMY (34%) compared to control for this

treatment in 1994.

At Pathlow in 1994, DMY increases (P<0.05) over control were observed for

the DB+F, C+F, M+F, B+F, DBLIQ and DBLIQ+F treatments. However, in 1995

and 1996, yield differences were greatly reduced, due to the low response to fertilizer

(liquid or granular) or rejuvenation treatments combined with granular fertilizer. This

is similar to the findings of Misselbrook *et al.* (1996) who reported injection of slurry

fertilizer (80 kg ha^{-1}) on a ryegrass (*Lolium perenne* L.)/white clover (*Trifolium*

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Table 3.1. Effect of rejuvenation treatments and fertilizer on dry matter yield of grass-legume plots at Pathlow site. (kg/ha)

Year	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994	3209f	5161cde	2510g	3692f	4543e	5696bc	3337f	4843de	6215ab	6391a	3394f	5265cd	235
1995	2350cd	2913ab	2852abc	2951ab	3278a	2906ab	2536bc	2808abc	2236d	2970ab	2846abc	3113a	180
1996	2159a	3052a	2258a	2816a	2394a	2992a	2480a	3116a	2617a	3091a	2061a	2925a	225
Total	7718	11126	7620	9459	10215	11594	8353	10767	11068	12452	8301	11303	

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹)
ySEM = Standard error of the mean
a-g Values in a row followed by the same letter do not differ significantly at the 0.05 level

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Table 3.2. Effect of rejuvenation treatments and fertilizer on dry matter yield of grass-legume plots at Prince Albert delayed hay cut (DHC) site. (kg/ha)

Year	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEM[y]
	NF[z]	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994	3320de	4613bc	2638e	3938cd	3454d	5005b	3329de	4835b	6085a	6113a	2607e	4614bc	284
1995	1850c	2211abc	2383abc	2679ab	2208abc	2471abc	2056bc	2395abc	2222abc	2597ab	2216abc	2752a	245
1996	3028a	2991a	3266a	3105a	2814a	3096a	2596a	2908a	3149a	3048a	2955a	3046a	254
Total	8198	9815	8287	9722	8476	10572	7981	10138	11456	11758	7778	10412	

[z]NF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1}, 12 kg S ha^{-1})

[y]SEM = Standard error of the mean

a-e Values in a row followed by the same letter do not differ significantly at the 0.05 level

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Table 3.3. Effect of rejuvenation treatments and fertilizer on dry matter yield of grass-legume plots at Prince Albert dense nesting cover (DNC) site. (kg/ha)

Year	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994	3799gh	5084de	3534h	4776ef	4611efg	6644ab	3678h	5427de	6329bc	7257a	4130fgh	5676cd	286
1995	2762ab	2781ab	2611b	2968ab	2804ab	3245a	2873ab	3029ab	2895ab	2811ab	2866ab	2986ab	225
1996	2836a	3522a	3168a	3413a	3123a	2986a	3402a	3425a	3057a	3668a	3009a	3032a	285
Total	9397	11387	9313	11157	10538	12875	9953	11881	12281	13736	10005	11694	

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha-1, 45 kg P_2O_5 ha-1, 23 kg K_2O ha-1, 12 kg S ha-1)

ySEM = Standard error of the mean

a-h Values in a row followed by the same letter do not differ significantly at the 0.05 level

Table 3.4. Effect of rejuvenation treatments and fertilizer on dry matter yield of grass-legume plots at Rama site. (kg/ha)

Year	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994	2468*d*	5355*b*	2032*d*	4482*c*	2212*d*	5509*b*	2419*d*	5045*b*	4950*bc*	7037*a*	2259*d*	5552*b*	247
1995	2254*g*	4330*abc*	2278*fg*	4160*abcd*	2285*fg*	4676*a*	2282*fg*	3389*de*	4142*abcd*	4372*ab*	2573*efg*	3125*ef*	290
1996	2570*ab*	2619*ab*	2291*b*	2819*ab*	2594*ab*	2554*ab*	3018*ab*	3300*a*	2633*ab*	3214*ab*	2509*ab*	3081*ab*	286
Total	7292	12304	6601	11461	7091	12739	7719	11734	11725	14623	7341	11758	

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha-1, 45 kg P_2O_5 ha-1, 23 kg K_2O ha-1, 12 kg S ha-1)
ySEM = Standard error of the mean
a-g Values in a row followed by the same letter do not differ significantly at the 0.05 level

Table 3.5. Effect of rejuvenation treatments and fertilizer on dry matter yield of grass-legume plots at Insinger site. (kg/ha)

Year	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994	4136cd	4761bc	3337ef	4668bc	3832de	5214ab	3046f	4840abc	5548a	5540a	3326ef	5323ab	270
1995	4540bc	5367ab	5473ab	5859a	4191c	6470a	4057c	5428ab	6101a	6071a	4000c	6272a	286
1996	2340d	3909ab	4389a	3788ab	2297d	3869ab	3846ab	3459bc	3989ab	2901cd	3438bc	3615abc	285
Total	11016	14037	13199	14315	10320	15553	10949	13727	15638	14512	10764	15210	

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1}, 12 kg S ha^{-1})

ySEM = Standard error of the mean

a-fValues in a row followed by the same letter do not differ significantly at the 0.05 level

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repens L.) sward resulted in significantly lower yields in the second compared with the first year of the experiment. Fertilizer responses were minimal at Pathlow in the second and third year of this study, suggesting that much of the inorganic N was lost due to denitrification, utilized by soil microorganisms or leached from the soil profile. Precipitation was also below the long-term average during May and June of those years (Appendix, Table A.3) suggesting that perhaps moisture was the first limiting nutrient. This was not the case however, on a Black soil in southern Manitoba (McCaughey and Simons, 1996), where yields increased steadily (compared to control) on grass pastures fertilized with 160 kg ha^{-1} of nitrogen two years after application, or an Oxbow Black soil in central Saskatchewan (McCaughey, 1989), where yields were nearly double the control two years after application of 100 kg/ha.

A decrease in DMY ranging from 2 to 20% at three sites (Rama, DHC and Insinger) was consistent in yr 1 but not in yr 2 or 3, following spring litter removal by mowing. These losses may have resulted from microenvironment changes on plots rather than direct effects on the plants due to mowing because the treatment was applied when plants were senescent. Wikeem *et al.* (1989) also reported that dormant season removal of litter reduced spring forage yields by 25 and 29% in 1981 and 1984, respectively, on a bluebunch wheatgrass (*Pseudoroegneria spicatum* [Pursh] A. Löve subsp. *spicata*)-Sandberg's bluegrass (*Poa sandbergii* Vasey) site in southern British Columbia. At all sites in the first year, there was a positive response of dry matter yield when mowing was combined with broadcast fertilizer. Increased DMY (P<0.05) was 29% at Insinger, 40% at DHC and DHC, 64% at Pathlow and 125% at Rama compared to control. This response in DMY was reduced in the second and third year. In 1995, DMY ranged from an 8% increase at DNC to a 55% increase at Insinger in 1996 over control plots. These results agree with those of Parish *et al.* (1990) who found that orchardgrass (*Dactylis glomerata* L.) production was

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decreased by mowing however, when mowing was combined with fertilizer, grass production increased with abundance.

DMY from the deep-band (DB) or minimal disturbance plots, was not generally different (P>0.05) from control at Pathlow, DHC, DNC and Rama in each year except at Insinger (1996) where a significant (P<0.05) increase over control was observed. This may have been due to above average rainfall in July of that year (Appendix, Table A.3) at that site. The only positive response from the DB treatment in yr 1 was a 4% numeric increase over control at the Pathlow site. A range of 4 to 11% increase was observed at three sites (DHC, DNC and Pathlow) the following year, however yield increases ranging 15 to 64% over control were observed in 1996 at four sites (DNC, Insinger, Rama and Pathlow). Based on the data from this treatment, first year DMY increases are lower than those reported by Davies *et al.* (1989), who stated that slitting increased perennial ryegrass (*Lolium perenne* L.) pasture production by 33%.

Burning DMY was not different (P>0.05) from control plots over the three years in each of four sites (DHC, DNC, Rama and Insinger). At Pathlow (Gray-Wooded) site, DMY of burn plots was 42 and 40% greater (P<0.05) than control in 1994 and 1995, respectively. Vogl (1965) reported a 178% increase in herbage production the first season after burning tall grass native range. In this study, burning plus broadcast fertilizer (100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) showed a positive response in forage yield. Yields on B+F plots were significantly greater (P<0.05) than the control in yr 1 at DHC and DNC sites, in yr 1 and 2 at Rama and Pathlow sites, and in all 3 yr at the Insinger site (Tables 3.1 to 3.5). With the addition of broadcast fertilizer, production increased markedly, a range of 51 to 123%, 18 to 94% and 5 to 65% was observed at all sites in 1994, 1995 and 1996, respectively. This is similar to the results of Gay and Dwyer (1965) who reported increased herbage yields of 59% over control from burning and fertilizing native

range. In contrast, Jorgenson and Bjorge (1993) found that grass yields decreased and forbs increased after controlled burning of bush pasture in northwestern Saskatchewan.

Spiking reduced (P<0.05) DMY at Pathlow and Insinger in 1994, but not significantly (P>0.05) at DHC, DNC and Rama in that same year. The effect of spiking on DMY showed only a slight increase over control in 1995 at all sites. When spiking was applied as a single mechanical treatment, a range of 7 to 22% reduction in DMY was observed in yr 1 at all sites; however, the combination of spiking plus broadcast fertilizer (providing 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) resulted in increased production at all five sites in all three years, ranging from 13 to 82% in 1994, 8 to 85% in 1995 and 3 to 62% in 1996. The response was greatest at the Rama site, an 82 to 85% increase (P<0.05) in the first and second year, respectively. These increases were greater than yields observed for spiking alone in yr 1 and 2, which showed only a negative response in 1994 and only a 20 to 29% increase in 1995 at all sites. These second year results differ from Peat and Bowes (1995) who reported a 15% reduction in yield in the treatment year after spiking crested wheatgrass (*Agropyron pectiniforme* R. & S.) stands, followed by increases of 128%, 89%, 50% and 27% for the next four years.

Fertilizing control plots with a granular rate of 350 kg ha^{-1} (providing 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) (C+F) saw a positive response in DMY in yr 1 at Pathlow and Rama, a 61 and 117% increase (P<0.05) over no fertilizer (C). In 1995 at the Rama site, the carryover effect of fertilizer resulted in a 92% increase (P<0.05) over control, but only a 2% numeric increase in 1996. At Pathlow in 1995 and 1996, yields were 20 and 40% greater than control. The DMY and response to N, P, K and S fertilizer observed in this study is similar in magnitude to findings on Gray-wooded soils in Saskatchewan (Ukrainetz *et al.*, 1988) and Black soils in Alberta (Mahli *et al.*, 1993) receiving a single application of

fertilizer. Sedivec and Manske (1990) also reported increased yields of domestic grass pastures fertilized (70 kg ha^{-1} N + 45 kg ha^{-1} P) annually over a 5-yr period in North Dakota.

When the response of DMY to either liquid or granular forms of fertilizer applied at 350 kg ha^{-1} (providing 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) was compared, the liquid form showed a consistently greater yield response at Pathlow, DHC, DNC and Rama in 1994; a 20 to 50% increase in production over the granular application. This may have been a direct result of deep-banding the liquid form directly into the root zone (7 cm depth) allowing quick utilization by plants during spring growth. Yield response to either form of fertilizer was similar in the second and third years of this study.

Total cumulative yield data (Tables 3.1 to 3.5) showed the greatest difference in yield for burn (32% over control) at the Gray-Wooded site (Pathlow). The burning plus fertilizer total at the Rama site was 75% greater than control, a three year total yield response to rejuvenation on a younger (4 year) stand. Spiking, mowing and deep-band treatments had total yields lower than or similar to control plots at all five sites. The exception was at Insinger site (younger stand), where total yield for spiking after 3 year was 20% greater than control plots. Total (3 year) DMY for granular fertilizer (C+F) ranged from 20% (DHC) to 69% (Rama) greater than control for all sites. Deep-banded liquid fertilizer (DBLIQ) had a range of 30% (DNC) to 61% (Rama) increase over control. The liquid + granular fertilizer treatment (DBLIQ+F) total DMY at all sites were very similar to the single liquid application (DBLIQ), except Rama site where total production over the 3 years was twice the control level.

After 3 years, DMY for mechanical treatments (M, SP and DB) and B was less than or only slightly greater than control levels. The exception was Insinger site, showing good production for all three treatments even in 1996. This may have been

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due to the younger forage stand (6 year) at this site or above average precipitation during the 1996 growing season. These treatments combined with granular fertilizer showed a greater response in 1996 at all sites, ranging from a 7 to 55%, 3 to 65%, 3 to 62% and 5 to 65% increase for M+F, C+F, SP+F and B+F, respectively, compared to control plots. Because late-spring burning plus fertilizer greatly increased yield across all sites in year 1 and 2, and showed a very high 3 yr total cumulative yield on the younger stand at Rama, this treatment, or other mechanical + fertilizer combinations may be viable alternatives to breaking and reseeding, but only short term. After the first year there was a moderate yield response to the 350 kg ha^{-1} granular fertilizer application (C+F) (compared to control) as a single treatment or combined with DBLIQ, B, M and SP, a limited response with DBLIQ and DB treatments and no response until third year with SP and DB treatments. Perhaps the cost of high applications of fertilizer (200 kg N ha^{-1}) and/or losses due to leaching or unavailability may discourage applying the DBLIQ+F treatment.

3.4.3 *Forage Quality*

3.4.3.1 *Crude Protein*

The crude protein content of the herbage in 1994 was increased significantly (P<0.05) in each of 4 sites by applied broadcast fertilizer in combination with mechanical rejuvenation but declined by the third year of the study to control levels (Tables 3.6 to 3.10). Values were highest in 1994 samples due to heavy applications of fertilizer in the spring or a combination of fertilizer and rejuvenation treatment. Crude protein values ranged from 80.7 (DB) to 135.9 g kg^{-1} (SP+F) from Pathlow samples; 99.1 (B) to 168.6 g kg^{-1} (SP+F) from DHC samples; 90.4 (DB) to 146.7

Table 3.6. Effect of rejuvenation treatments on forage nutrient components - Pathlow site (g kg⁻¹ DM).

	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994													
Crude Protein	80.8c	126.7ab	105.7b	135.9a	80.9c	108.0b	80.7c	121.6ab	87.9c	122.0ab	81.0c	123.3ab	5.6
Calcium	5.6a	6.3a	6.2a	6.2a	6.1a	5.6a	5.2a	5.7a	4.9a	5.2a	5.6a	5.8a	0.4
Phosphorous	1.6c	2.1ab	2.0abc	2.4a	1.6c	2.3a	1.8bc	2.2a	1.8bc	2.1ab	1.6c	2.4a	0.1
1995													
Crude Protein	99.1a	113.8a	110.1a	111.8a	110.5a	99.8a	101.4a	108.4a	100.3a	117.0a	117.3a	120.4a	6.7
Calcium	7.0a	7.4a	8.6a	9.1a	10.4a	9.4a	7.0a	8.3a	6.7a	7.6a	10.2a	9.7a	0.8
Phosphorous	1.6a	1.8a	1.7a	1.7a	1.6a	1.7a	1.7a	1.9a	1.8a	1.9a	1.8a	1.8a	0.1
1996													
Crude Protein	97.8a	103.5a	99.0a	105.2a	114.9a	102.9a	99.0a	101.9a	99.1a	109.4a	106.0a	107.4a	5.8
Calcium	7.2ab	6.6ab	7.2ab	8.2ab	12.1a	7.9ab	8.3ab	8.2ab	5.2b	7.8ab	7.6ab	8.6ab	0.9
Phosphorous	1.6a	1.8a	1.8a	1.7a	1.7a	2.0a	1.8a	1.9a	1.8a	2.0a	2.0a	1.8a	0.1

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹)

ySEM = Standard error of the mean

a-c Values in a row followed by the same letter do not differ significantly at the 0.05 level

Table 3.7. Effect of rejuvenation treatments on forage nutrient components - Prince Albert DHC site (g kg⁻¹ DM).

	Control NF[z]	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep-band NF	Deep-band F	Deep-band liquid fertilizer NF	Deep-band liquid fertilizer F	Mow NF	Mow F	SEM[y]
1994													
Crude Protein	105.5cd	146.6b	124.6c	168.6a	99.1d	147.8b	113.0cd	147.2b	105.0cd	143.5b	107.0cd	150.8b	4.9
Calcium	8.7ab	6.8ab	8.4ab	7.0ab	8.4ab	7.6ab	8.5ab	8.2ab	5.6b	5.9ab	9.3a	7.3a	0.7
Phosphorous	1.5b	2.3a	1.7b	2.4a	1.5b	2.4a	1.7b	2.3a	1.8b	2.5a	1.5b	2.4a	0.1
1995													
Crude Protein	106.0a	105.2a	110.2a	105.7a	107.4a	103.4a	114.3a	113.6a	105.9a	111.7a	118.6a	113.5a	6.6
Calcium	10.7a	9.1a	10.2a	9.0a	10.3a	9.9a	10.2a	10.2a	8.8a	7.7a	12.6a	10.6a	0.8
Phosphorous	1.1a	1.2a	1.2a	1.2a	1.1a	1.5a	1.2a	1.3a	1.3a	1.4a	1.2a	1.3a	0.1
1996													
Crude Protein	107.3a	114.3a	95.3a	92.9a	107.6a	99.8a	114.6a	106.3a	97.7a	100.9a	105.4a	103.4a	5.1
Calcium	8.6a	8.1a	6.0a	5.4a	8.4a	6.9a	9.3a	8.8a	6.9a	6.3a	8.5a	7.3a	0.7
Phosphorous	1.1b	1.3ab	1.2ab	1.3ab	1.3ab	1.4ab	1.4ab	1.5ab	1.4ab	1.6a	1.2ab	1.4ab	0.1

[z]NF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P₂O₅ ha⁻¹, 23 kg K₂O ha⁻¹, 12 kg S ha⁻¹)
[y]SEM = Standard error of the mean
a-d Values in a row followed by the same letter do not differ significantly at the 0.05 level

Table 3.8. Effect of rejuvenation treatments on forage nutrient components - Prince Albert DNC site (g kg⁻¹ DM).

	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFz	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994													
Crude Protein	95.2c	135.9a	110.2bc	146.7a	94.0c	132.9a	90.4c	139.9a	112.7bc	146.3a	97.5c	127.8ab	5.2
Calcium	9.0a	6.5a	9.2a	7.6a	9.0a	8.0a	7.4a	7.6a	6.9a	6.5a	8.8a	7.5a	0.8
Phosphorous	1.1e	1.9ab	1.4de	2.0ab	1.2e	1.9bc	1.1e	2.1ab	1.6cd	2.2a	1.2e	1.9bc	0.1
1995													
Crude Protein	102.5a	97.8a	102.4a	98.6a	85.0a	95.3a	94.9a	105.1a	91.3a	110.5a	91.7a	104.9a	6.9
Calcium	7.6a	6.8a	7.5a	5.8a	7.6a	6.4a	8.5a	7.2a	6.7a	6.4a	7.9a	6.9a	0.8
Phosphorous	0.9ab	1.0ab	0.9ab	1.0ab	0.7b	1.1ab	0.9b	1.1ab	0.9ab	1.3a	0.8b	1.1ab	0.1
1996													
Crude Protein	116.3a	116.6a	100.2a	92.4a	105.1a	98.6a	111.6a	101.1a	107.2a	114.3a	111.7a	118.5a	6.2
Calcium	6.5a	7.3a	6.9a	5.5a	8.7a	6.4a	8.7a	6.6a	5.5a	5.7a	7.9a	6.9a	0.8
Phosphorous	1.4c	1.6abc	1.4c	1.5bc	1.3c	1.6abc	1.4c	1.6abc	1.7abc	1.9a	1.6bc	1.8ab	0.1

zNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹)
ySEM = Standard error of the mean
a-c Values in a row followed by the same letter do not differ significantly at the 0.05 level

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Table 3.9. Effect of rejuvenation treatments on forage nutrient components - Rama site (g kg⁻¹ DM).

	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMy
	NFᶻ	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994													
Crude Protein	95.7cd	112.4bcd	112.5bc	118.6bc	103.2bcd	119.9bc	104.0bcd	118.2bc	123.4b	139.8a	92.1d	111.6bcd	5.6
Calcium	10.3ab	9.2ab	10.2ab	11.2ab	12.3a	10.3ab	10.5ab	10.0ab	9.8ab	8.4b	8.9b	10.5ab	0.7
Phosphorous	0.8d	1.5bc	0.9d	1.8ab	0.9d	1.6bc	0.8d	1.6bc	1.3c	2.1a	0.8d	1.6bc	0.1
1995													
Crude Protein	80.2a	84.7a	89.4a	86.9a	89.6a	79.6a	85.8a	88.6a	77.2a	91.8a	89.7a	94.1a	5.1
Calcium	8.4a	7.9a	8.6a	8.1a	9.3a	8.1a	9.2a	8.4a	7.0a	6.7a	9.6a	9.3a	0.7
Phosphorous	0.5a	0.7a	0.6a	0.8a	0.7a	0.6a	0.5a	0.8a	0.5a	0.9a	0.6a	0.9a	0.1
1996													
Crude Protein	93.4a	102.4a	92.0a	98.6a	97.4a	103.4a	90.5a	91.7a	95.4a	86.9a	85.3a	98.2a	5.7
Calcium	9.8ab	9.4ab	8.8ab	10.9a	9.9ab	9.4ab	9.1ab	8.9ab	8.1ab	7.5b	8.3ab	8.6ab	0.6
Phosphorous	0.9a	1.1a	0.9a	1.2a	1.1a	1.1a	0.9a	1.0a	1.0a	1.2a	0.9a	1.1a	0.1

ᶻNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹)
ySEM = Standard error of the mean
a-d Values in a row followed by the same letter do not differ significantly at the 0.05 level

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Table 3.10. Effect of rejuvenation treatments on forage nutrient components - Insinger site (g kg⁻¹ DM).

	Control		Spike		Burn		Deep-band		Deep-band liquid fertilizer		Mow		SEMʸ
	NFᶻ	F	NF	F	NF	F	NF	F	NF	F	NF	F	
1994													
Crude Protein	104.8c	131.7ab	126.4b	141.4ab	98.7c	128.3b	103.0c	132.7ab	126.4b	153.4a	96.6c	134.5ab	5.5
Calcium	9.0a	9.2a	10.1a	10.3a	8.6a	9.5a	8.1a	9.4a	10.0a	8.9a	7.6a	10.1a	0.7
Phosphorous	0.9c	1.4ab	1.1bc	1.6a	0.9c	1.7a	0.8c	1.5ab	1.3ab	1.7a	0.7c	1.6a	0.1
1995													
Crude Protein	84.5a	88.0a	97.9a	95.9a	91.8a	96.4a	89.7a	86.7a	101.6a	101.2a	86.5a	96.9a	6.0
Calcium	8.9a	8.2a	9.0a	7.6a	8.3a	7.9a	8.4a	6.9a	9.5a	8.1a	7.3a	7.2a	0.7
Phosphorous	1.3a	1.1a	1.2a	1.2a	1.0a	1.1a	1.0a	0.9a	1.0a	0.9a	1.0a	0.9a	0.1
1996													
Crude Protein	101.7a	125.8a	114.7a	129.2a	112.8a	119.8a	104.3a	113.5a	115.4a	100.6a	99.0a	111.1a	5.7
Calcium	9.6a	7.7a	9.4a	9.7a	11.5a	9.9a	8.0a	8.2a	8.4a	7.2a	8.0a	8.4a	0.6
Phosphorous	1.1a	1.1a	0.8a	1.2a	1.2a	1.2a	0.8a	1.0a	1.0a	1.2a	0.9a	1.2a	0.1

ᶻNF = unfertilized, F = fertilized (broadcast granular at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹)
ʸSEM = Standard error of the mean
a-c Values in a row followed by the same letter do not differ significantly at the 0.05 level

80

g kg^{-1} (SP+F) from DNC samples; 92.1 (M) to 139.8 g kg^{-1} (DBLIQ+F) from Rama samples; and 96.6 (M) to 153.4 g kg^{-1} (DBLIQ+F) from Insinger samples.

Crude protein concentrations of 1995 and 1996 samples from any treatment did not differ significantly from those of the control treatment on any sites. Samples from 1995 and 1996 at all sites only differed by 13 to 30 g kg^{-1} units. Values ranged from 99.1 (C) to 120.4 g kg^{-1} (M+F) at Pathlow; 103.4 (B+F) to 118.6 g kg^{-1} (M) at DHC; 91.3 (DBLIQ) to 110.5 g kg^{-1} (DBLIQ+F) at DNC; 77.2 (DBLIQ) to 94.1 g kg^{-1} (M+F) at Rama; and 84.5 (M) to 101.6 g kg^{-1} (DBLIQ) at Insinger. Forage crude protein concentration in the control treatment varied from 80 g kg^{-1} in 1995, to 116 g kg^{-1} in 1996.

The crude protein content of all DBLIQ+F (200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1} and 24 kg S ha^{-1}) samples in each of 4 sites in 1994 was consistently greater ($P<0.05$) than control sample protein levels. This effect was also observed by Ukrainetz et al. (1988) who reported that applications of high rates (>200 kg N ha^{-1}) of N fertilizer increased forage nitrogen concentration. This fertilizer effect was also observed for all mechanical treatments (M, SP, DB and B) combined with broadcast fertilizer
(100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) at all sites except Rama. Increased CP content in the forage due to the high rate (200 kg N ha^{-1}) of fertilizer of DBLIQ+F may not economically justify its application. Heavy losses of N occurred in 1995 perhaps due to high dry matter production in 1994 or increased denitrification. Finally, Ukrainetz et al. (1988) stated that when N was applied annually at $\geq$ 200 kg ha^{-1}, NO$_3$-toxicity occurred in smooth bromegrass and became a problem in later years as soil mineral N accumulated.

3.4.3.2 *Calcium and Phosphorous*

Average concentrations of Ca and P of the forage samples from rejuvenation treatments are shown in Tables 3.6 to 3.10. Compared to burn plots, application of high rates of granular plus liquid fertilizer (200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1} and 24 kg S ha^{-1}) significantly decreased (P<0.05) Ca levels in the forage at Rama. Overall, any fertilizer treatment (N-P-K-S) reduced the calcium level numerically in the forage. Calcium concentration of the forage was lower numerically in samples from the Gray-wooded soil site (Pathlow) compared to the Black soil sites. Forage calcium content was also lower in samples from the second and third years at the unmanaged DNC site. Applying nitrogen fertilizer to grass/legume swards reduces the Ca concentration of mixed forages due to a depression in the legume content of the mixed pasture (Rodger, 1982). However, burning increased calcium content of forage at Pathlow (Gray-Wooded site) from 6.4 g kg^{-1} in 1994 to 12.1 g kg^{-1} in 1996. This suggests that the increased alfalfa component in these plots (Figure 4.1, Chapter 4) could cause an increased Ca concentration in the herbage.

Phosphorous content (45 kg ha^{-1}) in the blend of applied fertilizer significantly (P<0.05) increased P concentration in first year forage samples at each of five sites. In 1994, percent P in forage samples from all sites, ranged from 0.8 to 1.6 g kg^{-1} for the control (Tables 3.6 to 3.10), and 1.4 to 2.3 g kg^{-1} when P was applied to forage plots (C+F) which received 45 kg P ha^{-1} as a single application. The presence of P in the fertilizer blend resulted in this positive effect, whereas straight N application tends to cause a decrease in P content in grasses (Wilman and Mzamane, 1982). Phosphorous concentration in the control (C) and other treatments (M, DB, SP, B) was lowest at all sites in 1995, the year following the highest dry matter production year (Tables 3.6 to 3.10). In the first year (1994) all rejuvenation treatments

combined with broadcast fertilizer (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) increased P concentration compared to the control (P<0.05). In the third year only the DBLIQ+F treatment (90 kg P ha^{-1}) significantly (P<0.05) increased P concentration at each Prince Albert site, DHC and DNC. Phosphorous applied at 45 kg P ha^{-1} increased forage P content in the first year only, doubling the phosphorous concentration in the fertilizer suggests a carryover effect, resulting in increased P content of the forage beyond the first year.

Dry matter yield and quality of dryland pastures showed varying responses to both mechanical (spike, deep-band, mow), chemical (liquid and granular fertilizer) and burning rejuvenation methods. Results of this 3-yr study at 5 sites in the Black and Gray-Wooded soil zones of parkland Saskatchewan suggest that a single application of blended broadcast fertilizer (100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) alone or combined with spiking, burning, deep-band or mowing gives a better response than a combination of deep-banded liquid fertilizer plus broadcast fertilizer (200 kg N ha^{-1}, 90 kg P$_2$O$_5$ ha^{-1}, 46 kg K$_2$O ha^{-1} and 24 kg S ha^{-1}). However, this response may only show an effective increase in forage production for one or two years. The impact of broadcast fertilizer on quality was only in the year of application. Spiking, mowing or deep-banding as single treatments failed to show a lasting significant effect on forage yield or quality at Pathlow, DHC, DNC or Rama. The younger stand at Insinger site showed significant yield increases in the third year for spike, deep-band and mow.

Fertilizer deep-banded in the liquid form showed a greater response for DMY at each of the five sites than broadcasted granular fertilizer. Not only was the dry matter production generally higher for the liquid fertilizer treatment in the first year (1994), but total cumulative yield after three years was also higher for each site.

Although differences occurred between rejuvenation treatments and fertilizer rates and combinations of both within site-years, these differences were not consistent

83

at each site with different treatments or combinations ranking highest in dry matter yield on at least one occasion. Some rejuvenation methods showed high to sufficient productivity in the year of treatment, however production returned to the control level in the second and third year.

Fertilizing, deep-band liquid (DBLIQ) or broadcast granular (C+F), will increase yield significantly and affect forage quality in the year of treatment. It will also affect yield and quality combined with mechanical treatments (SP+F, DB+F, M+F, B+F) in the first year. In the year following treatment and on a young forage stand, carryover effects of rejuvenation may result. Those methods which result in sustained increased production after 3 or more years along with an increased effect on mineral and crude protein content are suggested as alternatives to breaking and reseeding a forage stand. Classified by dry matter production and forage quality the treatments grouped into: highly effective (deep-band liquid fertilizer, broadcast fertilizer), moderately effective (burn and fertilizer, spike and fertilizer, mowing and fertilizer, deep-banded liquid fertilizer and fertilizer) and minimally effective (mow, burn, spike, deep-band, deep-band and fertilizer). In conclusion, herbage productivity and quality initially were influenced more by fertilizer treatments (both liquid and granular) alone or in combination with mechanical treatments in the year of application. Factors such as residual effects due to heavy applications of nitrogen were not evident the year following treatment. The effects of rejuvenation were not apparent even after three years except at the site with a younger forage stand.

Chapter 4

The Effect of Rejuvenation of Grass-Legume Pastures:
II. Botanical Composition

4.1   Abstract

A 3 year study was conducted at five sites to determine the effect of spiking, burning, mowing, deep-banding and applications of N, P, K and S liquid and granular fertilizers on changes in botanical composition of predominantly smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago media* Pers.) pastures established on Black, Chernozemic (Orthic silty-loam) and Gray-Wooded, Podzolic (Waitville loam) soils in central Saskatchewan. Fertilizer was applied at 350 kg ha^{-1} to provide 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23 kg K$_2$O ha^{-1} and 12 kg S ha^{-1}. All mechanical and fertilizer treatments were applied in the spring of 1994. An additional split-plot treatment was granular fertilizer, broadcast at 0 and 350 kg ha^{-1}. Mowing and deep-banding had minimal effects on botanical composition. Spiking reduced ($P>0.05$) grass and legume composition, and increased ($P<0.05$) the presence of annual weeds (1 site, 1994) and bare ground ($P<0.05$) (4 sites, 1994-95). Burning increased ($P<0.05$) alfalfa composition

(1 site, 1995; 2 sites, 1996) and decreased ($P>0.05$) bluegrass composition. Broadcast fertilizer, at 100 kg N ha^{-1} decreased ($P>0.05$) alfalfa composition in all years and increased ($P<0.05$) the smooth bromegrass component (2 sites, 1995; 1 site, 1996). Fertilizer (granular or liquid) alone or combined with mechanical treatments (deep-

band, mow, spike or burn) increased (P<0.05) the composition of smooth bromegrass (1 site, 1995-96; 2 sites, 1994-96) and decreased (P<0.05) the composition of bluegrass, weeds and bare ground in the year of application.

4.2   Introduction

More than 3 million ha of land in Saskatchewan are used for pasture for beef cattle. In the Aspen parkland, pastures are commonly established as a mixture of smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago media* Pers.) as the primary species. Over time, the productivity and carrying capacity of these pastures declines because of invasion of unpalatable and less productive species, over-grazing and poor soil fertility. Available nitrogen becomes locked up in the carbon:nitrogen cycle reducing stand vigour and productivity. The main invasive species infesting these pastures after five to ten years are Kentucky bluegrass (*Poa pratensis* L.), Canada bluegrass (*Poa compressa* L.), dandelion (*Taraxacum officinale* L.), yarrow (*Achillea millefolium* L.), Perennial sow thistle (*Sonchus arvensis* L.) and Canada thistle (*Cirsium arvense* L. Scop.).

There is little information on the effect of rejuvenation treatments applied to pastured grasses and legumes grown on Black and Luvisolic (Gray Wooded) soils of western Canada. Studies done include spiking crested wheatgrass stands in Saskatchewan (Peat and Bowes, 1995) and discing rangeland in British Columbia (Feistmann, 1979). No long-term experiments with grass-legume pastures have been conducted studying the effects of numerous rejuvenation techniques. With long-term experiments, temperature and precipitation patterns are likely to vary over a greater range, with a corresponding effect on pasture species botanical composition.

Traditional methods of breaking, fallowing and reseeding are costly and in some areas not feasible because of rough landscape, stones, or risk of erosion.

Moreover, these grazing areas are limited during the renovation period. Therefore, there is a need to study less costly rejuvenation methods utilizing present forage species with minimal disturbance to the area. The objectives of this 3-year study were to evaluate rejuvenation effects on botanical composition of long established grass-legume pastures located within the Black and Gray-Wooded soil zones of Saskatchewan.

4.3 Materials and Methods

4.3.1 *Sites, Soils and Location*

Materials and methods relating to sites, soils, and rejuvenation treatments are described in Chapter 3, Section 3.3.

4.3.2 *Data collection and analysis*

At each site estimates of botanical composition were taken using the point frame quadrat technique (Levy and Madden, 1933). The point frame technique consists of eighteen vertical pins or 'points' spaced 5 cm apart. Each pin is lowered and the species which the pin contacts are counted. Ten lines of 18 'hits' were randomly evaluated three times on each replicate giving a total of 2,160 hits per treatment. Relative percentage cover of primary species was then recorded for each treatment area. Botanical composition was determined each year by a team of two operators (one sampler + one recorder).

Forage samples were harvested from all sites each year for quality analyses. Pathlow plots were harvested on 13 July/94, 17 July/95 and 16 July/96. Prince Albert-DHC plots on 14 July/94, 17 July/95 and 17 July/96. Prince Albert-DNC plots

on 14 July/94, 17 July/95 and 22 July/96. Rama plots on 25 July/94, 18 July/95 and 18 July/96. Finally, Insinger plots were harvested on 25 July/94, 18 July/95 and 18 July/96.

Due to significant interactions between year, site, treatment and fertilizer (Appendix, Table A.9) data were analyzed separately for each site-year combination (Steel et al., 1997). The experimental design at each site was a randomized complete block with a split-plot arrangement of treatments. Treatments were replicated four times at each site. Six rejuvenation treatments comprised whole plots and broadcast fertilizer rates were sub-plots. Legume, grass and forb botanical composition data were subject to logarithmic transformations (log (x+1)) to correct for non-homogenous variances (Bartlett's test) as described by Steel et al. (1997). Transformations were selected which minimized correlations of means and variances. Transformed botanical composition data were subjected to multi-variate analysis (MANOVA) using the General Linear Model procedure of the Statistical Analysis System Institute, Inc. (SAS) (1989). Main effect and split-plot means were tested for differences using Fisher's protected LSD test (P<0.05), and are reported in Tables A.4 to A.8 (Appendix).

4.4 Results and Discussion

Botanical composition at all sites was changed by mechanical treatments (DB, B, M and SP), fertilizer (liquid or granular), and mechanical treatments combined with broadcast fertilizer (Figures 4.1 to 4.15, numeric data are presented in Appendix Tables A.4 to A.8). Multi-variate analysis showed that proportions of botanical components were significantly different in the pastures in each of five sites and differed between years. There was a trend to underestimate the proportion of forbs and overestimate the grasses by the point-quadrat method. Forbs, with few and large

88

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

☐ Alfalfa

■ Other species

☐ Bare ground

NF = No fertilizer
F = Fertilizer
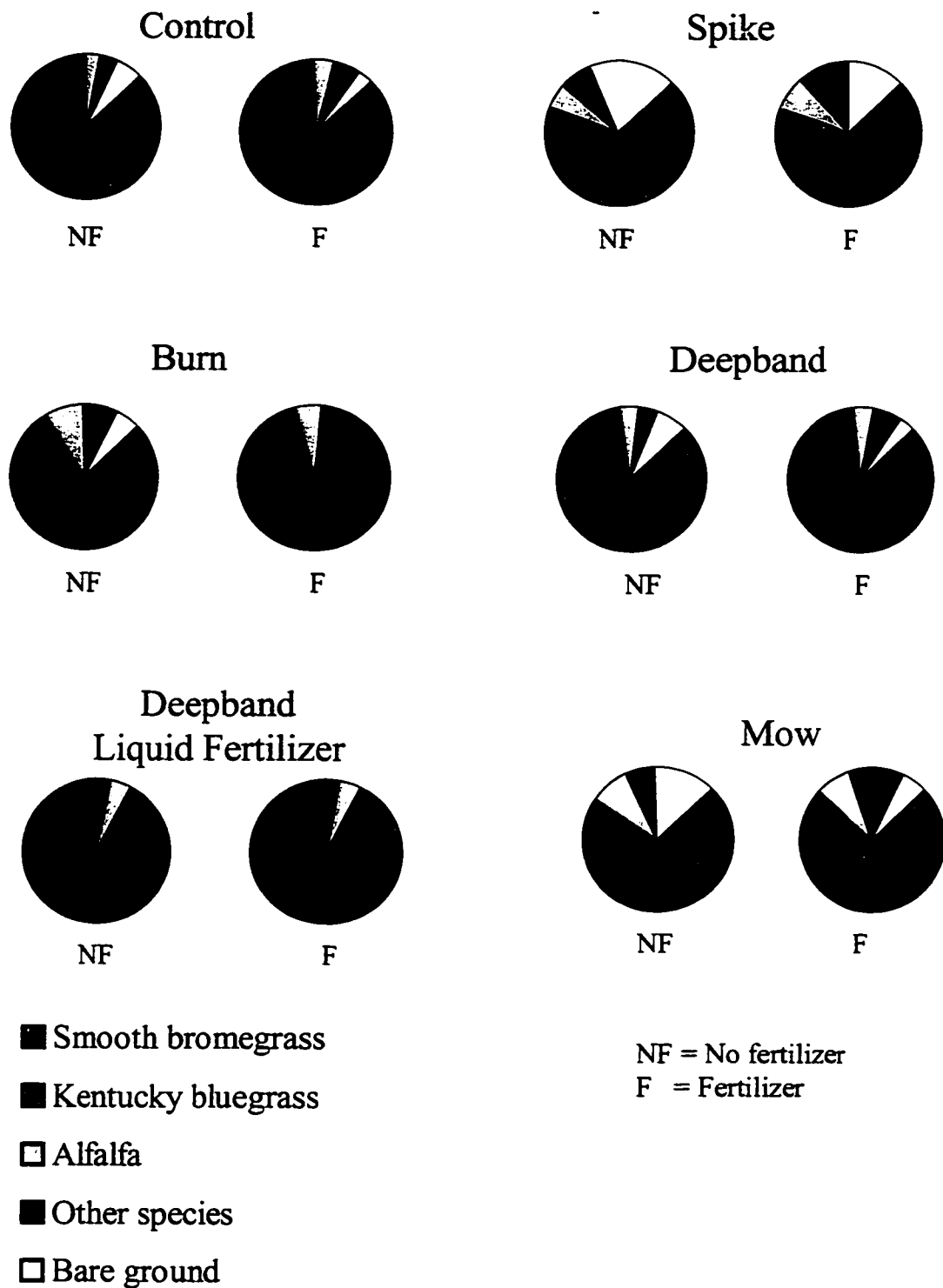
Figure 4.1. Effect of rejuvenation treatments on botanical composition - Pathlow site - 1994 (%).

89

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F   = Fertilizer
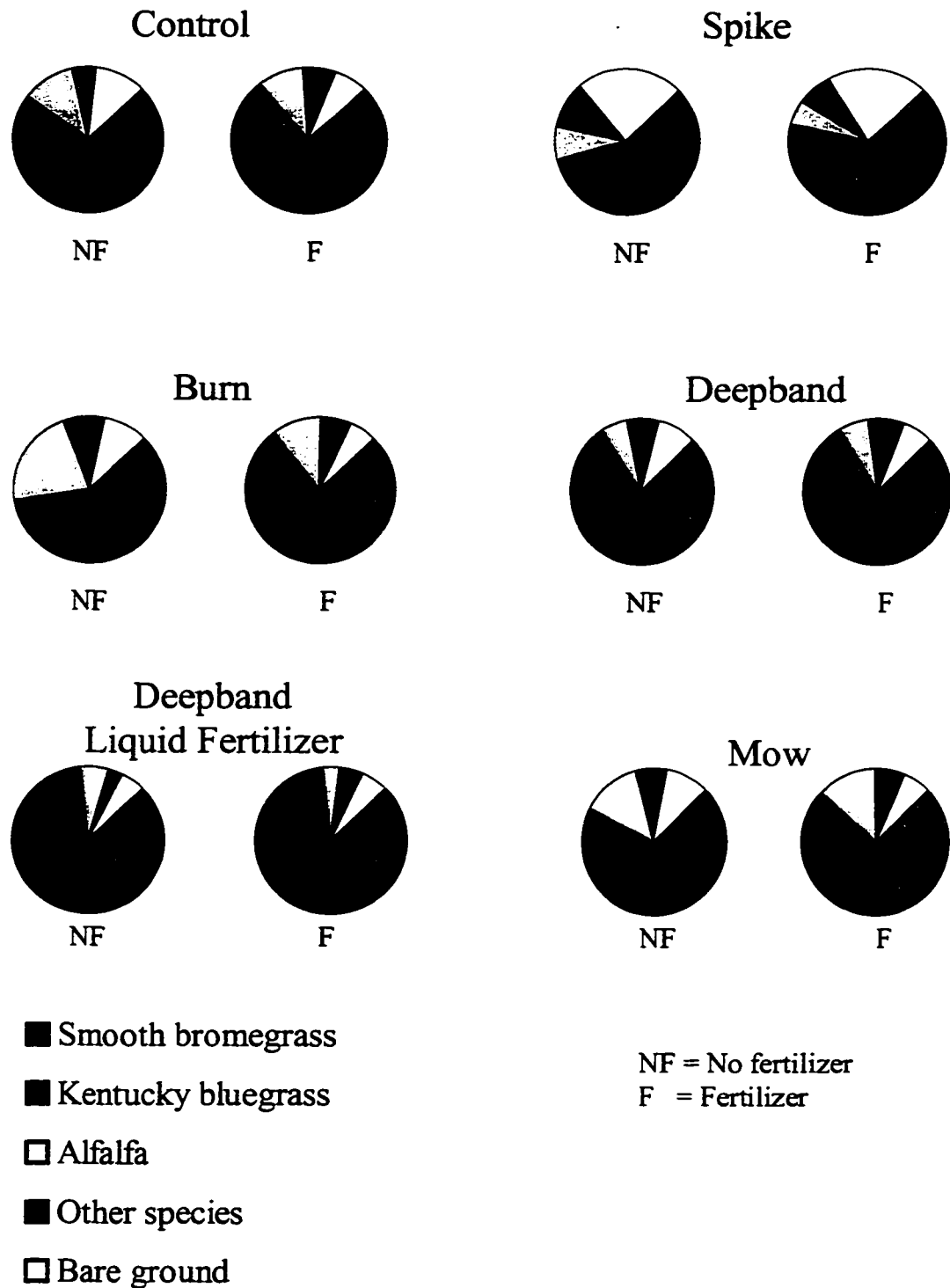
Figure 4.2. Effect of rejuvenation treatments on botanical
composition - Pathlow site - 1995 (%).

90

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
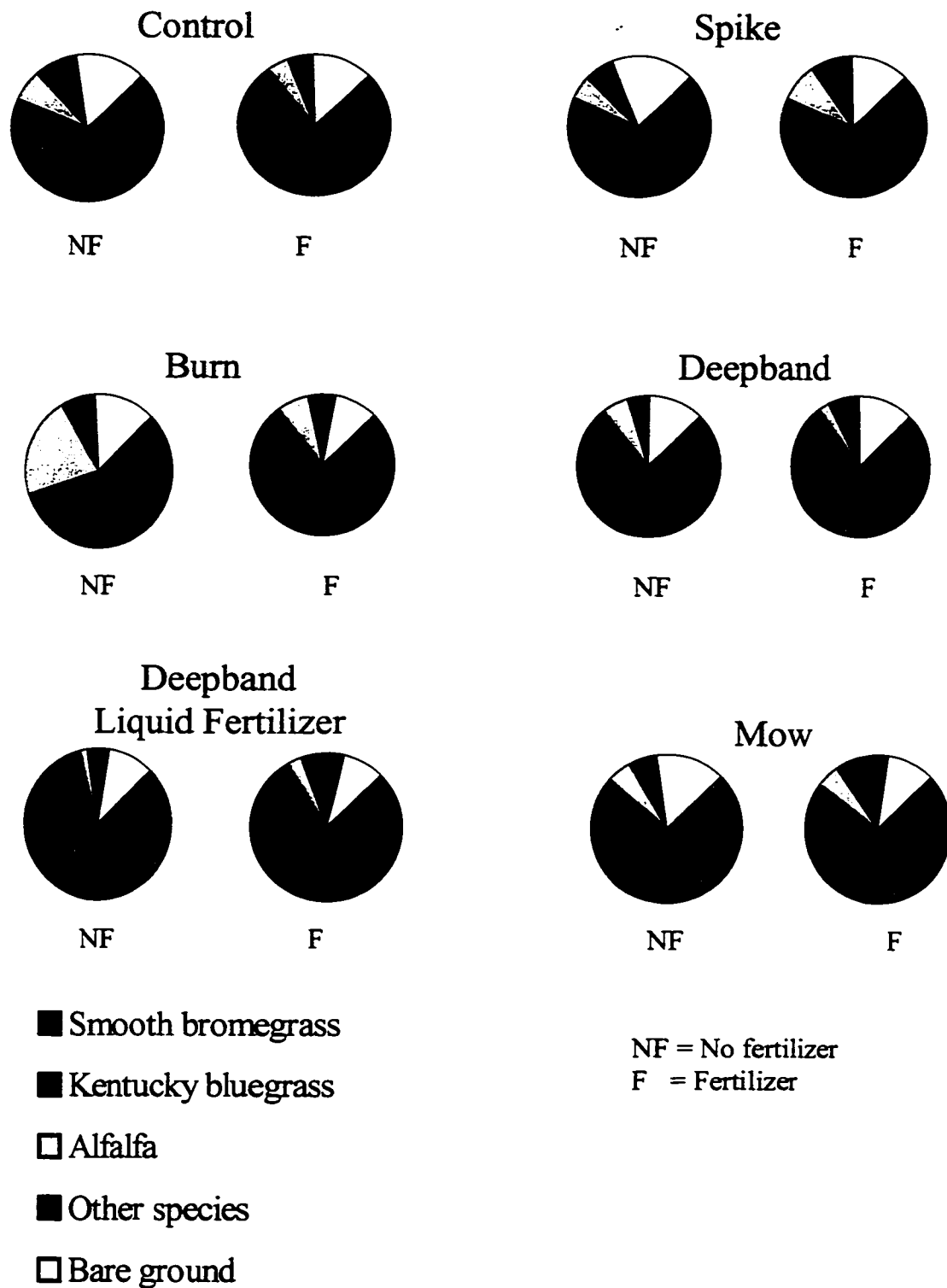
Figure 4.3. Effect of rejuvenation treatments on botanical composition - Pathlow site - 1996 (%).

Control

Spike

Burn

Deepband

Deepband
Liquid Fertilizer

Mow

NF   F   NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

☐ Alfalfa

■ Other species

☐ Bare ground

NF = No fertilizer
F = Fertilizer
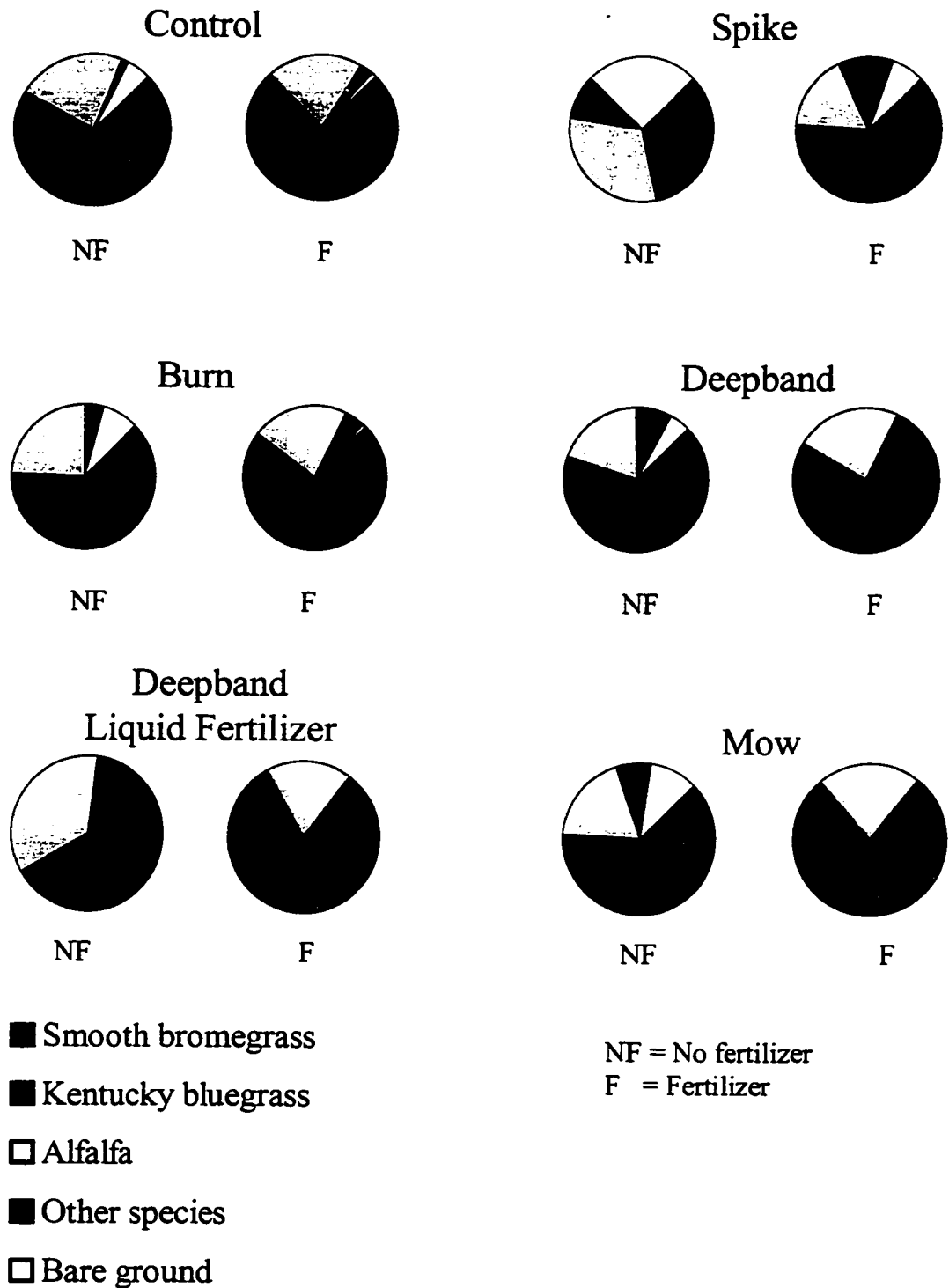
Figure 4.4. Effect of rejuvenation treatments on botanical
           composition - Prince Albert DHC site - 1994 (%).

92

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
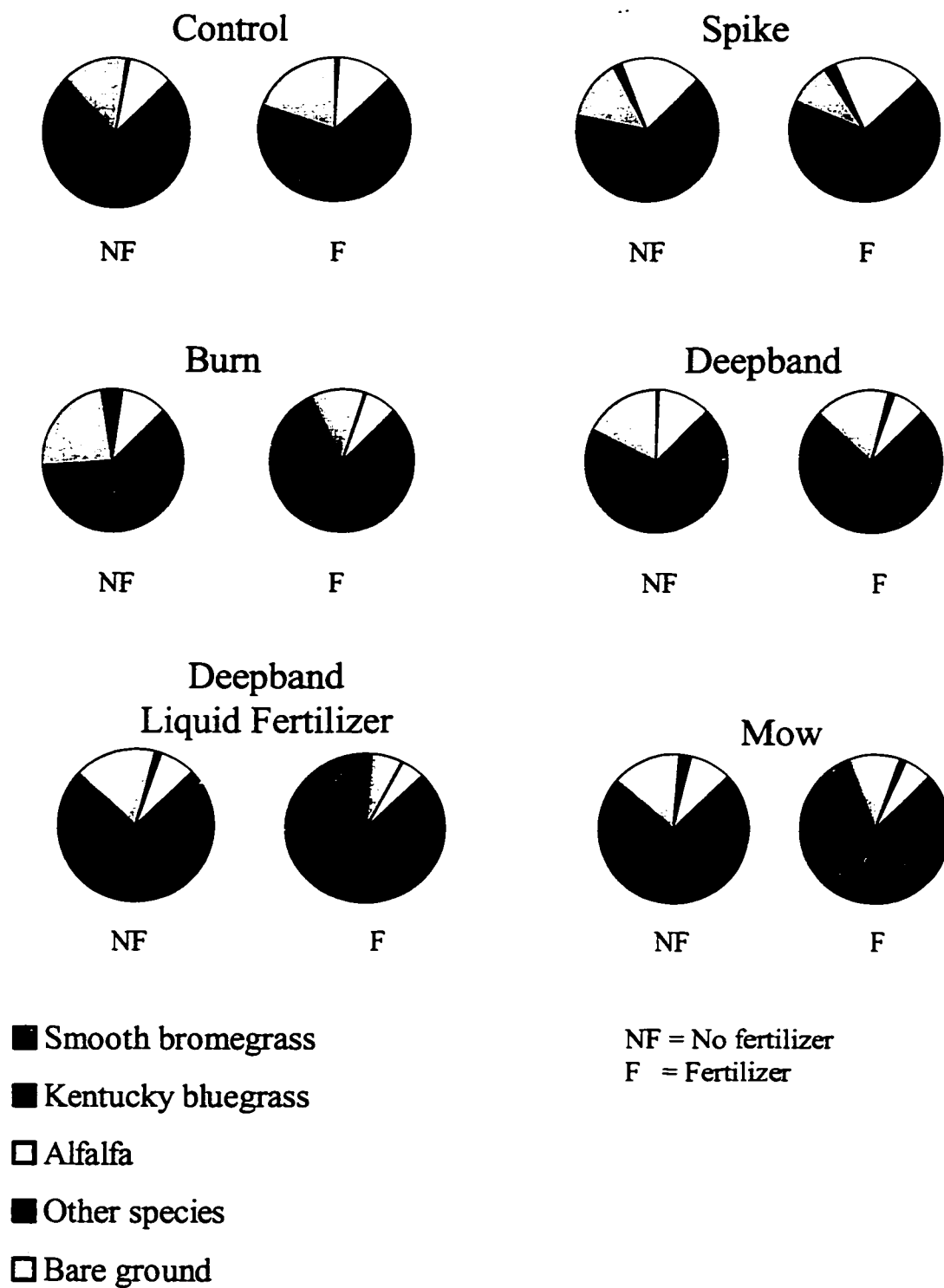
Figure 4.5. Effect of rejuvenation treatments on botanical
composition - Prince Albert DHC site - 1995 (%).

93

Control   Spike

NF   F   NF   F

Burn   Deepband

NF   F   NF   F

Deepband
Liquid Fertilizer   Mow

NF   F   NF   F

■ Smooth bromegrass   NF = No fertilizer
                                 F = Fertilizer
■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground
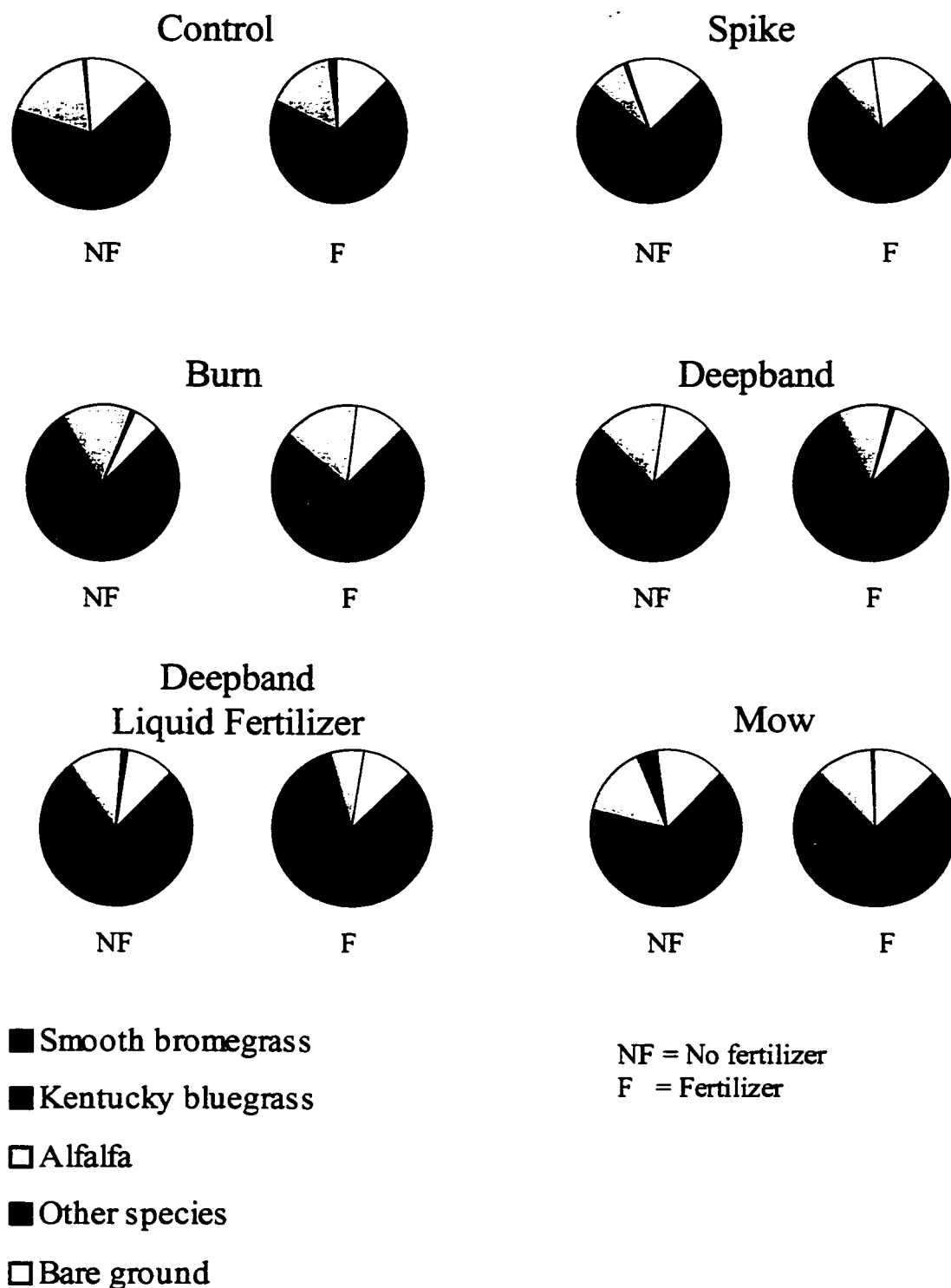
Figure 4.6. Effect of rejuvenation treatments on botanical
              composition - Prince Albert DHC site - 1996 (%).

94

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

☐ Alfalfa

■ Other species

☐ Bare ground

NF = No fertilizer
F = Fertilizer
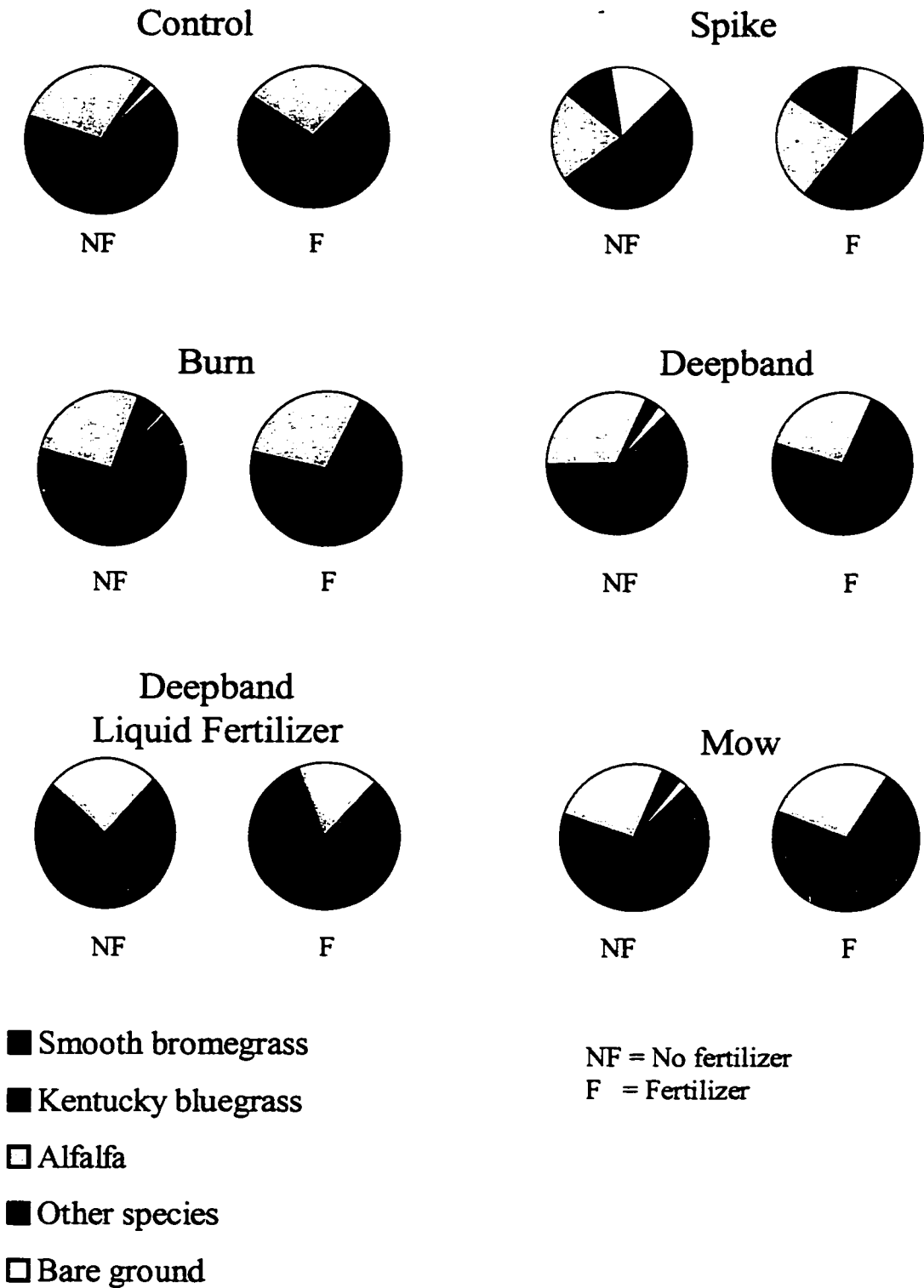
Figure 4.7. Effect of rejuvenation treatments on botanical
composition - Prince Albert DNC site - 1994 (%).

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
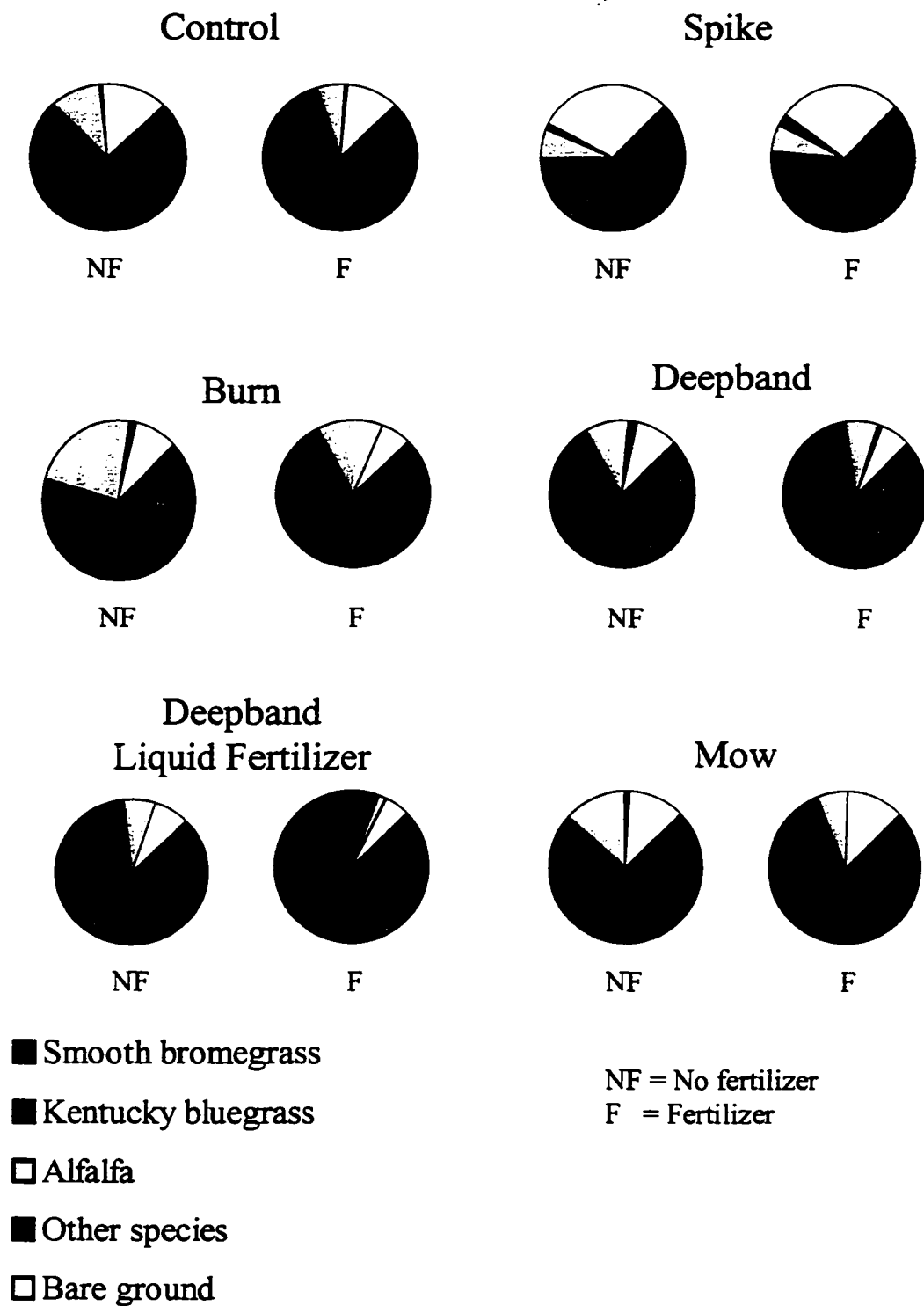
Figure 4.8. Effect of rejuvenation treatments on botanical
composition - Prince Albert DNC site - 1995 (%).

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

☐ Alfalfa

■ Other species

☐ Bare ground

NF = No fertilizer
F = Fertilizer
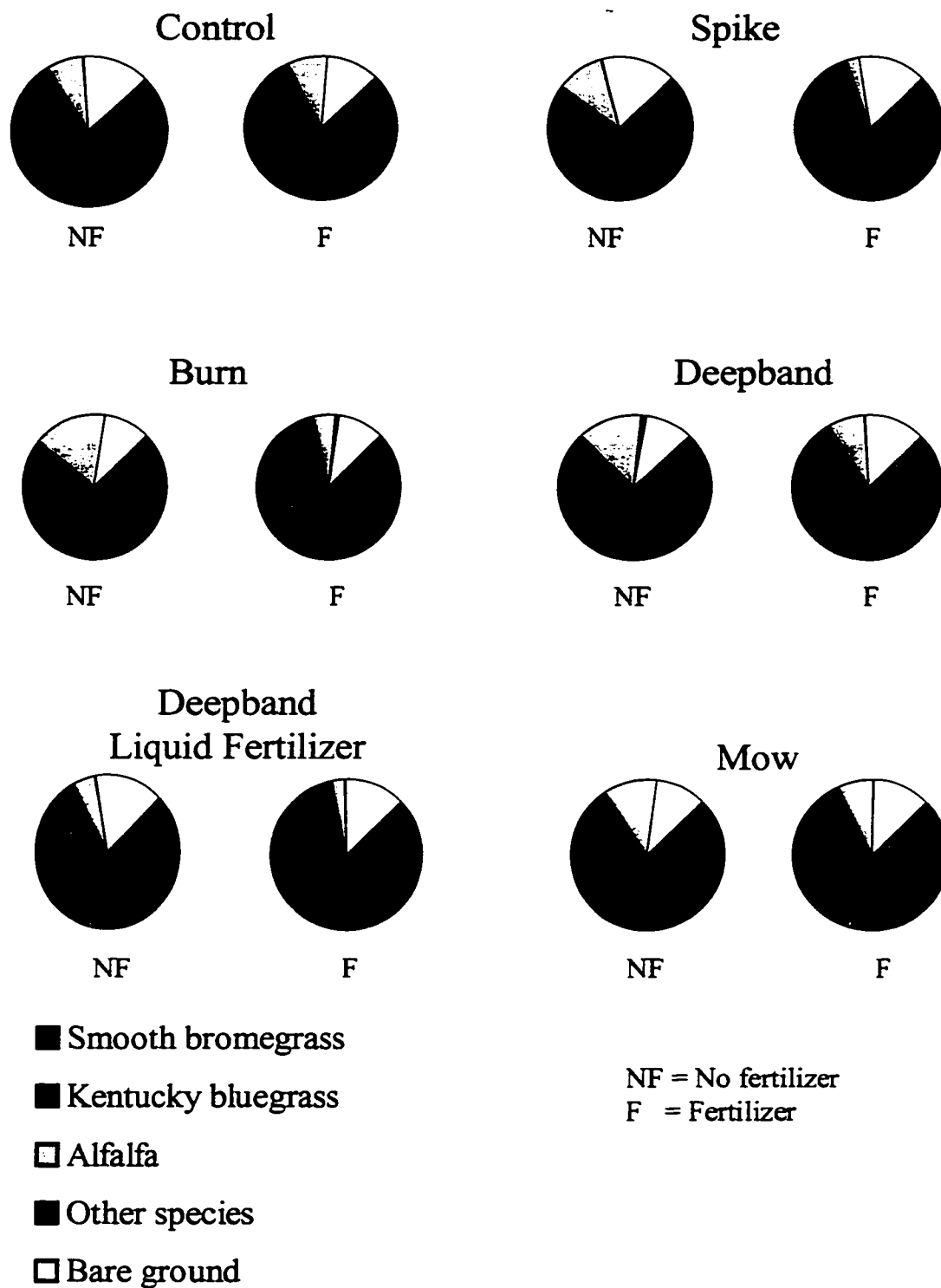
Figure 4.9. Effect of rejuvenation treatments on botanical
    composition - Prince Albert DNC site - 1996 (%).

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband
Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
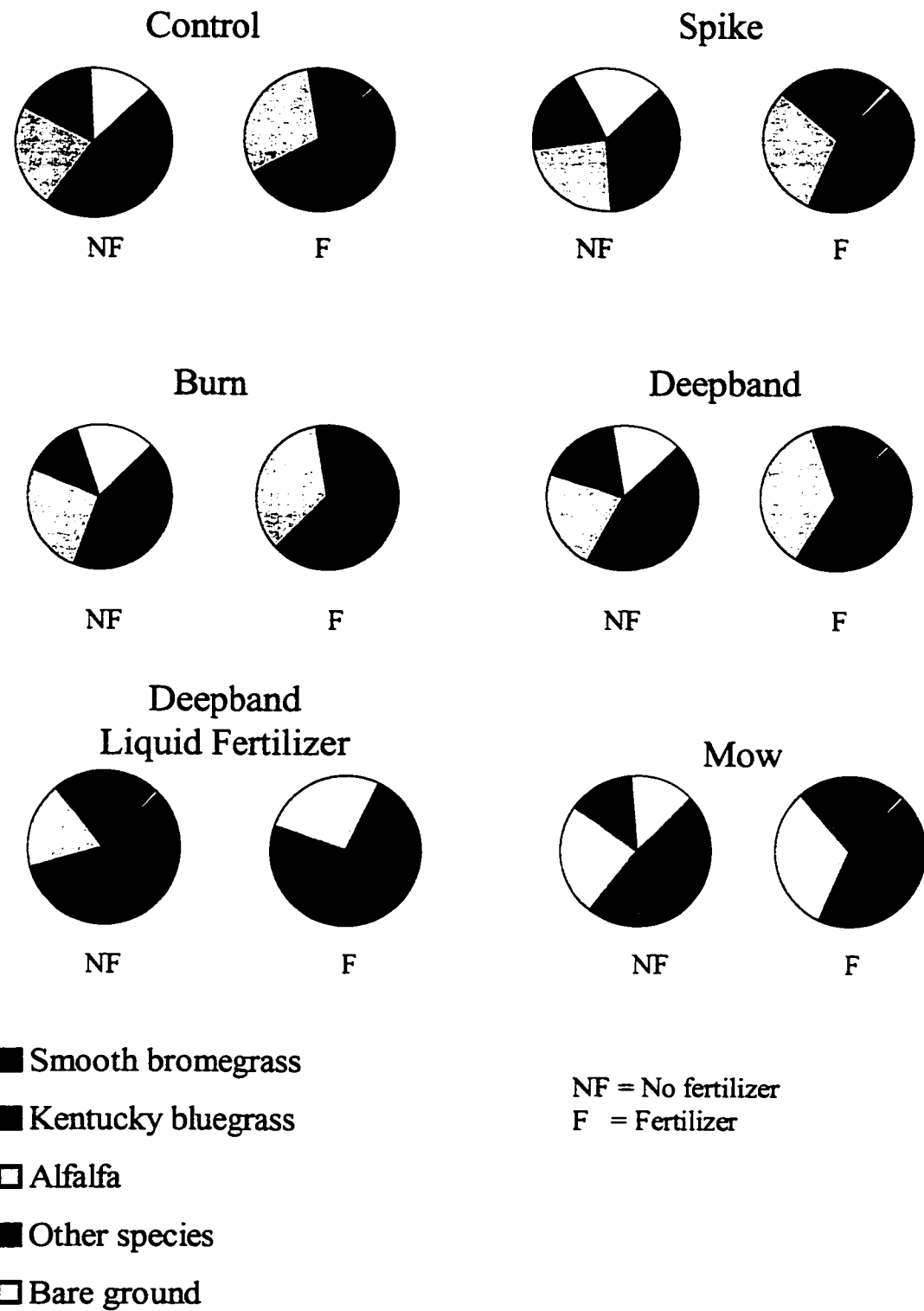
Figure 4.10. Effect of rejuvenation treatments on botanical
composition - Rama site - 1994 (%).

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
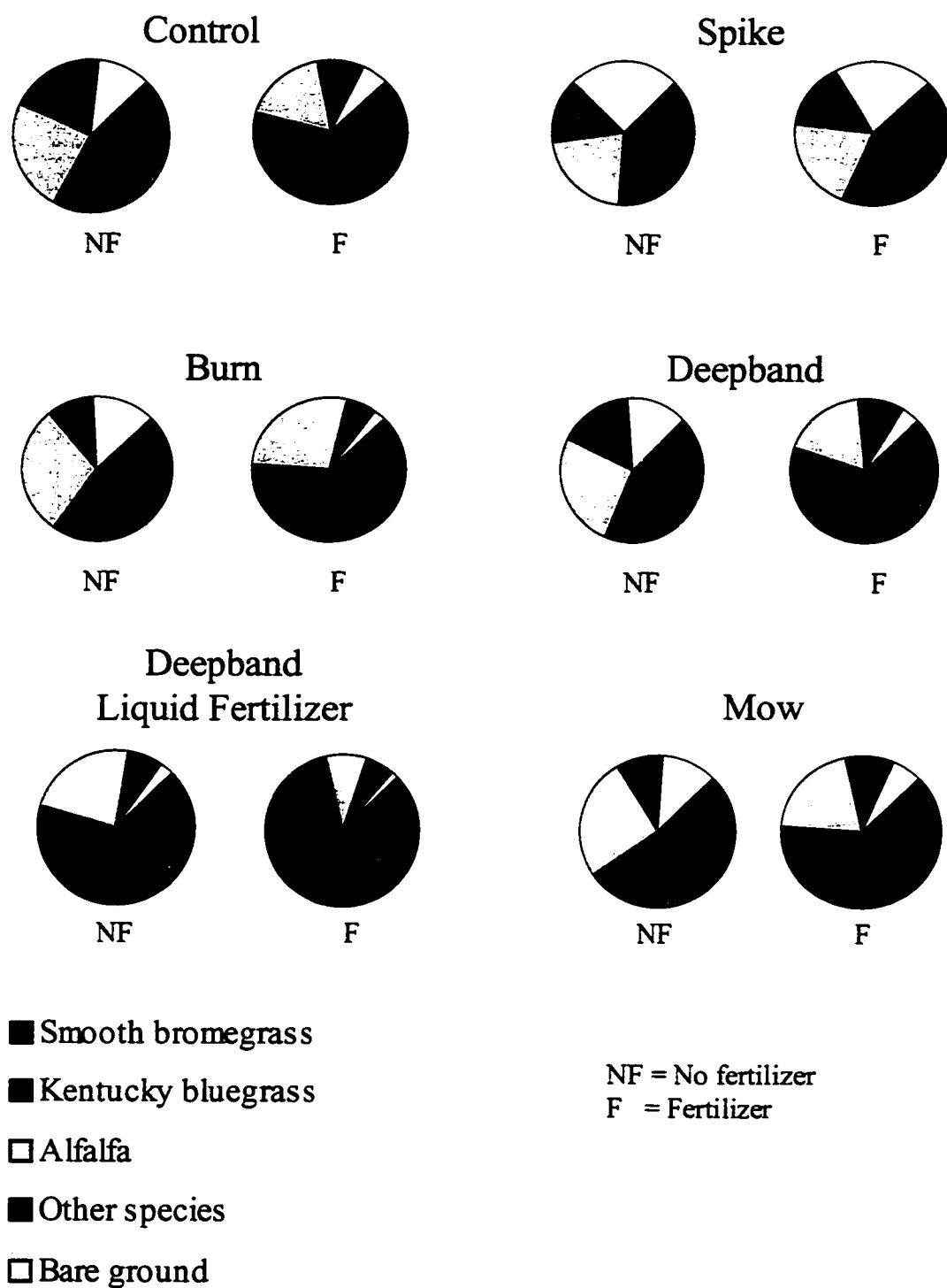
Figure 4.11. Effect of rejuvenation treatments on botanical composition - Rama site - 1995 (%).

Control   Spike

NF   F   NF   F

Burn   Deepband

NF   F   NF   F

Deepband
Liquid Fertilizer   Mow

NF   F   NF   F

■ Smooth bromegrass

■ Kentucky bluegrass   NF = No fertilizer
                                 F = Fertilizer
□ Alfalfa

■ Other species

□ Bare ground
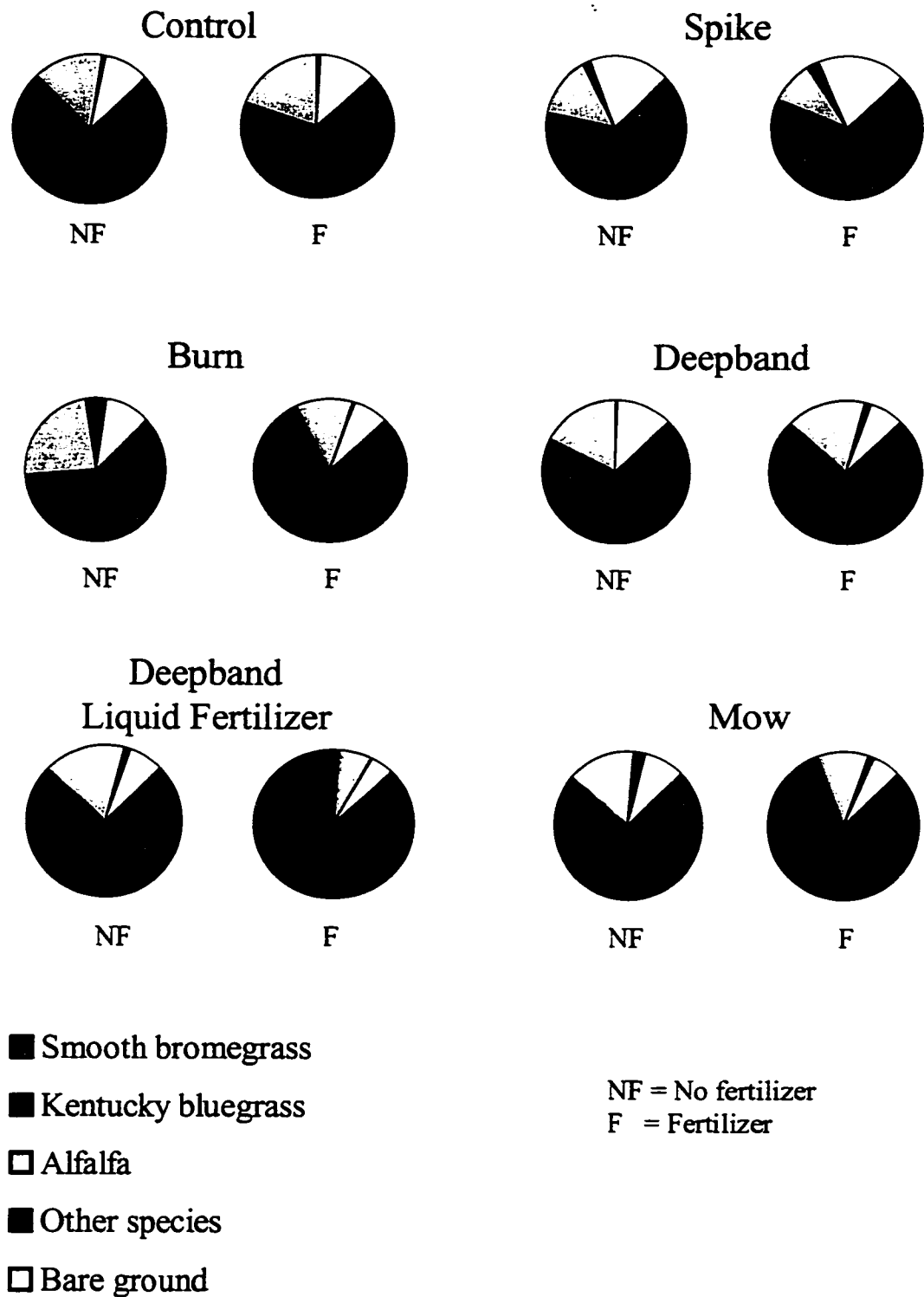
Figure 4.12. Effect of rejuvenation treatments on botanical
              composition - Rama site - 1996 (%).

100

Control   Spike

NF   F   NF   F

Burn   Deepband

NF   F   NF
                                                           F

Deepband
Liquid Fertilizer   Mow

NF   F   NF   F

■ Smooth bromegrass
                                           NF = No fertilizer
■ Kentucky bluegrass   F = Fertilizer

□ Alfalfa

■ Other species

□ Bare ground
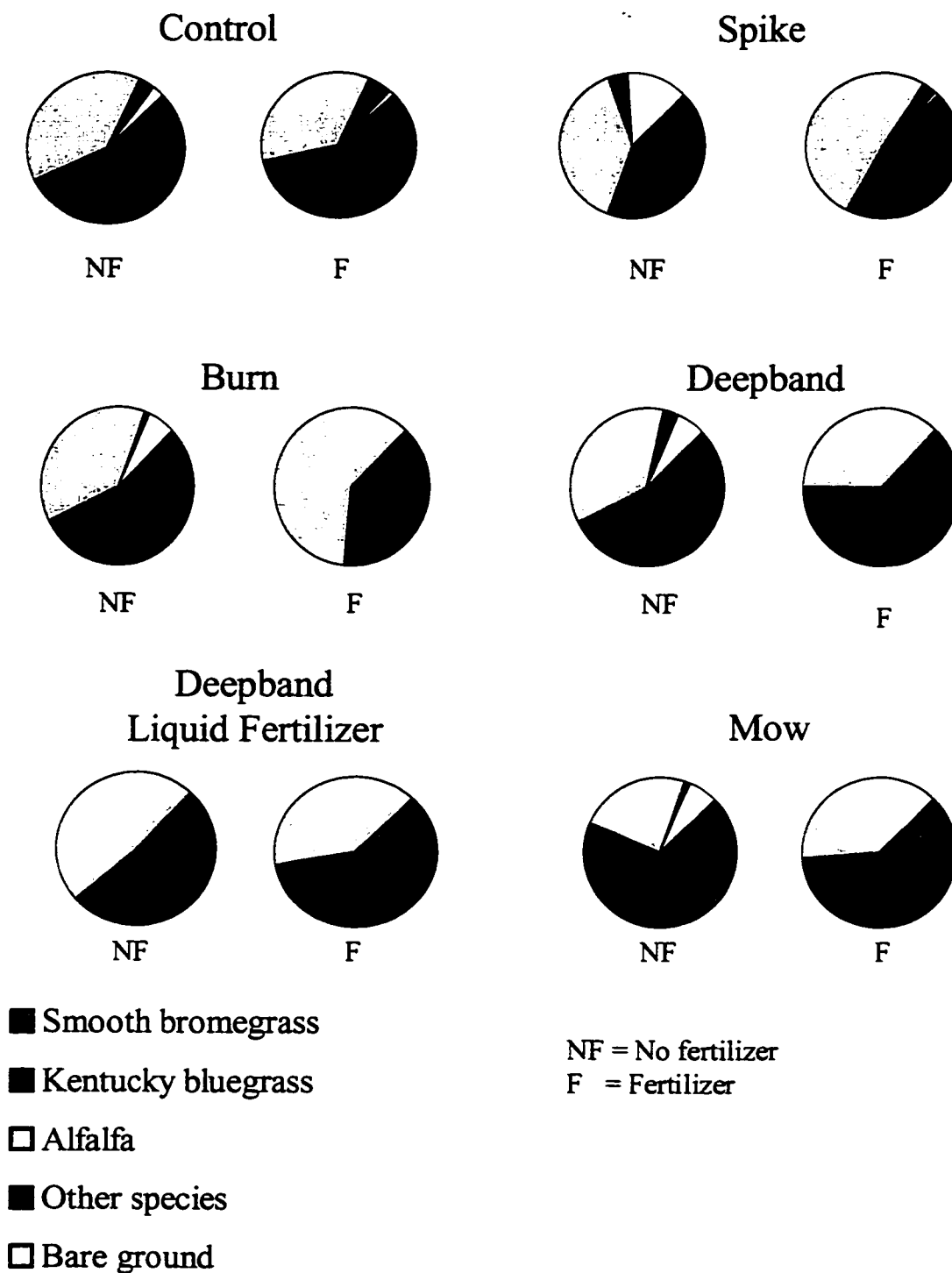
Figure 4.13. Effect of rejuvenation treatments on botanical
              composition - Insinger site - 1994 (%).

101

Control

NF   F

Spike

NF   F

Burn

NF   F

Deepband

NF   F

Deepband Liquid Fertilizer

NF   F

Mow

NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F = Fertilizer
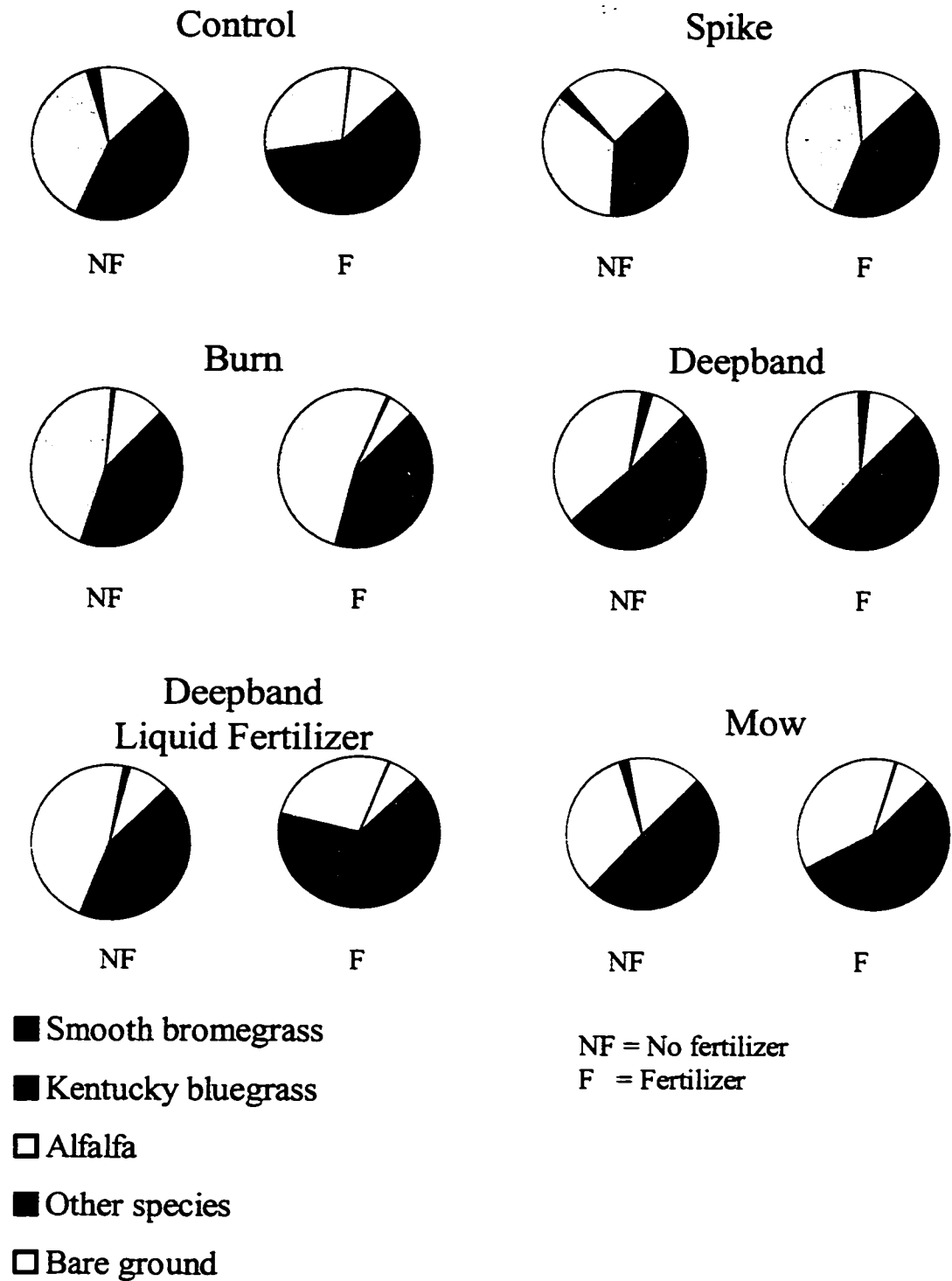
Figure 4.14. Effect of rejuvenation treatments on botanical
composition - Insinger site - 1995 (%).

Control   Spike

NF   F   NF   F

Burn   Deepband

NF   F   NF   F

Deepband
Liquid Fertilizer   Mow

NF   F   NF   F

■ Smooth bromegrass

■ Kentucky bluegrass

□ Alfalfa

■ Other species

□ Bare ground

NF = No fertilizer
F   = Fertilizer
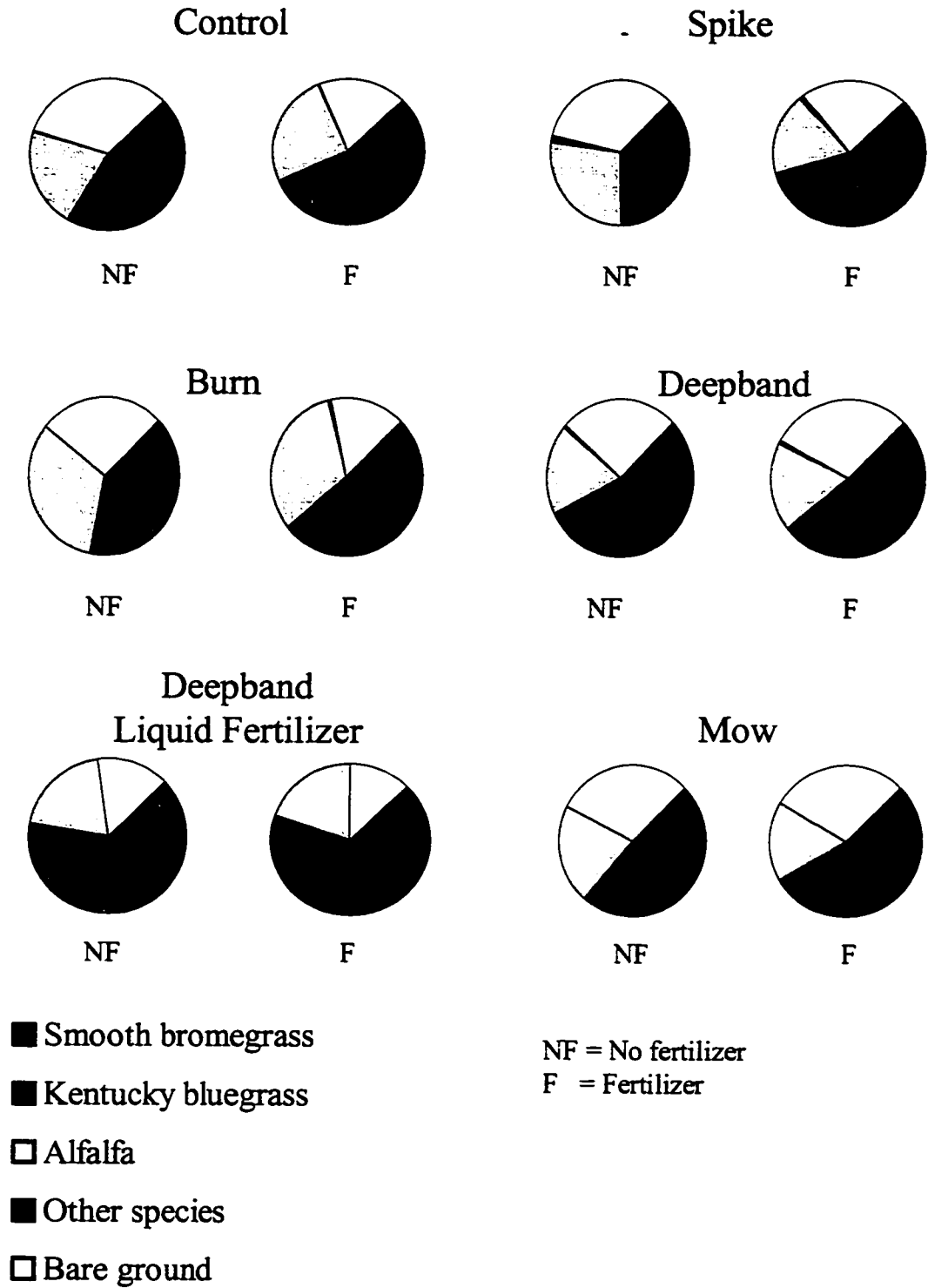
Figure 4.15. Effect of rejuvenation treatments on botanical
composition - Insinger site - 1996 (%).

leaves might intercept less frequently with the pins than would be expected by their proportion on a dry matter basis. Grasses and legumes with numerous small and outstretched leaves increase the chances of pin-contacts (Glatzle et al., 1993). Broad-leaved weeds and other forbs made up 12% or less of the forage in this study.

At Pathlow site, smooth bromegrass proportion increased 23, 40 and 41% in the DBLIQ (100 kg N ha^{-1}) compared to control in 1994, 1995 and 1996, respectively, however this effect was only significant (P<0.05) in 1995 and 1996. Only in the second and third years did the DBLIQ+F (providing 200 kg N ha^{-1}, 90 kg P$_2$O$_5$ ha^{-1}, 46 kg K$_2$O ha^{-1} and 24 kg S ha^{-1}) treatment significantly (P<0.05) increase smooth bromegrass, 61 and 37%, respectively. SP (1996), SP+F (1994, 1996) M+F (1996) and B+F (1995, 1996) also increased smooth bromegrass composition compared to control, however this effect was not significant (P>0.05). In 1996 at Pathlow, a 26, 21 and 12% increase was observed for SP, SP+F and M+F, respectively. Smooth brome increased in the B+F treatment in second and third year by 6 and 19%, respectively, but not significantly (P>0.05).

Application of high rates of nitrogen reduced alfalfa composition at Pathlow site, in DBLIQ+F (200 kg N ha^{-1}) and DBLIQ (100 kg N ha^{-1}) plots in all years compared to control or any other treatment, however this effect was not significant (P>0.05). The reduction in alfalfa composition in these plots over the 3 years is consistent with results of other studies showing that high rates of fertilizer, specifically N, reduces the legume percentage in the sward (Nuttall et al., 1980; Nuttall et al., 1991). Percentage of alfalfa in the B treatment increased steadily from 8% in 1994 to 22% in 1996. Alfalfa component was greater in B plots compared to control in all 3 years, but only significantly (P<0.05) in 1996. Relative to control, alfalfa composition increased 90% (1995) and 226% (1996) at the Pathlow site. Alfalfa composition also increased in B+F (100 kg N ha^{-1}) plots, 68% in yr 1, however there was only a 9% increase over control in 1996. Grass in a grass-legume

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mixture will tend to dominate if moisture conditions are favorable. However, if sub-surface soil moisture conditions are limiting (due to burnoff of spring litter) then the deeper tap roots of alfalfa may utilize available soil moisture at a greater depth than the grass, giving an advantage to the legume (Nuttall *et al.*, 1991).

In the burn plots at Pathlow, Rama and Insinger, bluegrass composition decreased by 22 to 55% over 3 years compared to control plots, however this effect was not significant ($P>0.05$). This is similar to findings reported by Anderson *et al.* (1970) who found that Kentucky bluegrass was all but lost under burning of plots on a little bluestem (*Andropogon scoparius* Michx.) range. Mowing also decreased bluegrass at Pathlow site in the first year by 21%, but not significantly ($P>0.05$). Spike treatment plots had less bluegrass than control plots over all 3 yrs at Pathlow and Rama, and in yr 1 and 3 at the Insinger site. Kentucky bluegrass composition of spiked plots was 28, 25 and 28% less numerically than control levels at Pathlow site in yr 1, 2 and 3, respectively. Bluegrass was 78, 57 and 44% less numerically than control at Rama site in yr 1, 2 and 3, respectively. At Pathlow, spiking and mowing, and at Insinger all mechanical treatments (M and DB) combined with broadcast fertilizer (providing 100 kg N ha^{-1}, 45 kg P_2O_5

ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) decreased Kentucky bluegrass composition in each of 3 years compared to control, but not significantly ($P>0.05$). The greatest decrease in bluegrass component was observed in B+F and SP+F plots, 22 to 44% less than control over the three years. This effect was significant ($P<0.05$) in SP+F plots at Pathlow and Insinger in 1994 and at DNC in 1995 and 1996. Liquid plus broadcast fertilizer (DBLIQ+F) greatly reduced ($P<0.05$) bluegrass composition in yr 1 at Insinger and at DNC in yr 2 and 3. Fertilizer treatments (liquid or granular) had a negative effect on bluegrass composition in the first year but only slightly in the second and third years. When a treatment caused a downward shift in bluegrass

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composition, there tended to be an inverse shift of increased smooth bromegrass composition.

At the Prince Albert sites, in each of three years, smooth bromegrass composition increased 63, 72 and 51% at DNC (P<0.05) and 39, 45 and 43% at DHC (P<0.05) over control levels with the DBLIQ+F (200 kg N ha^{-1}) treatment. Compared to the check, alfalfa composition increased (P<0.05) over control by 120 to 127% in 1995 and 1996, respectively after burning at the dense nesting cover (DNC) site and 64% at DHC in 1995, but not significantly (P>0.05). Alfalfa composition was lower in 1995 and 1996 compared to 1994 in control plots, which may have been due to grass species competition and poor overwintering of the legume. Spiking decreased bluegrass numerically in all three years at DHC and DNC, the greatest was a 31 to 38% drop at DHC in yr 1 and 2. Burning, mowing and deep-band also decreased bluegrass in the first year of the study, but not significantly (P>0.05). Mechanical treatments combined with fertilizer also affected bluegrass composition. There was a reduction (P<0.05) in bluegrass (1 site, 1995-96) and an increase (P<0.05) in smooth bromegrass composition (2 sites, 1996) in the SP+F plots at both the DHC and DNC sites. Bluegrass composition was 21, 23 and 37% less than control in yr 1, 2 and 3, respectively, at the DHC site and 38, 42 and 45% less than control in yr 1, 2 and 3, respectively at the DNC site. The severity of this treatment may have reduced the vigour of bluegrass allowing smooth brome to effectively compete for the fertilizer.

There was more alfalfa and less bluegrass numerically in the control plots at Rama and Insinger sites than at Pathlow or the Prince Albert sites. However, an increased alfalfa component (Tables A.7 and A.8, Appendix A) compared to control, was observed at both Rama (Figures 4.10-4.12) and Insinger (Figures 4.13-4.15) in the B and B+F treatments consistent with other sites, though not significantly (P>0.05). Increases of 13 to 62% in the B plots and 17 to 55% in the B+F plots over

three years were observed. Smooth bromegrass composition increased (P<0.05)

(Appendix, Table A.7) in the DBLIQ (providing 100 kg N ha^{-1}, 45 kg P$_2$O$_5$ ha^{-1}, 23

kg K$_2$O ha^{-1} and 12 kg S ha^{-1}) and DBLIQ+F (providing 200 kg N ha^{-1}, 90 kg P$_2$O$_5$

ha^{-1}, 46 kg K$_2$O ha^{-1} and 24 kg S ha^{-1}) plots at Rama (1995-96) due to the high rate of

nitrogen applied. This observation is consistent with the fertilizer effect on smooth

bromegrass composition at the other four sites. This shift was observed as well in

second and third year after application of the fertilizer, suggesting a residual effect of

fertilizer on botanical composition but not crude protein (Chapter 3, Section 3.4.3.1).

This residual effect was not observed however, in the yield data (Chapter 3, Section

3.4.2) from this site. In the granular fertilizer (C+F) plots, smooth bromegrass

increased (P<0.05) in 1995 and bluegrass decreased in composition compared to

control in all three years, but not always significantly (P>0.05). A one-time high rate

of granular or liquid fertilizer (providing 100 kg N ha^{-1}) could possibly be used to

alter species composition.

In this study, bare ground decreased significantly (P<0.05) with the DBLIQ+F

treatment in yr 1 and 2 at Rama, and in 1995 at Insinger, DNC and Pathlow, as a

result of a very high rate (200 kg N ha^{-1}) of fertilizer in 1994. At all sites, and over

time, a notable increase in bare ground (P<0.05) was also observed (Appendix, Tables

A.4 to A.8) in SP (4 sites, 1994-95; 1 site, 1995) and SP+F (1 site, 1994-95; 3 sites,

1995) treatments due to the severity of soil disturbance with the treatment. Presence

of other species, specifically annual broad-leaved weeds increased (Figures 4.1-4.15)

also in SP and SP+F as many weed seeds which lay dormant in the soil, were

liberated with spiking and germinated rapidly 3 weeks after initiation of the treatment.

The addition of fertilizer on spiked plots may have also increased competitive weed

growth.

Botanical composition of the pastures at all sites was changed by the fertilizer

rejuvenation treatments (DBLIQ, DBLIQ+F) when compared to the control. Lucero

et al. (1995) also reported that botanical composition changed from a tall fescue-bluegrass-weeds mixture to predominantly tall fescue on previously unmanaged pasture when poultry litter was applied at 5.8 (1991) and 4.1 (1992) mt ha⁻¹, supplying 90 kg N ha⁻¹ and 60 kg P ha⁻¹. Poultry litter rates of at least 11.4 mt ha⁻¹ in 1991 and 8.0 mt ha⁻¹ in 1992 were required to obtain an 80 percent tall fescue sward composition, i.e., the composition obtained by application of recommended rates of inorganic N and P.

Smooth bromegrass increased at all sites in all three years, while bluegrass and weeds decreased as percentage of the sward due N, P, K and S placed at the rate of 100 or 200 kg N ha⁻¹. Rauzi (1978) found that a high rate of nitrogen fertilizer (150 kg ha⁻¹) markedly increased the composition of western wheatgrass (*Agropyron smithii* L.), the key productive species in a short grass prairie. In this study, smooth bromegrass composition ranged from 36 to 49% for control. In the DBLIQ+F plots, composition of smooth bromegrass over 3 years was greatest in the second year, 79.3% at DNC, 74.3% at Rama, 66.2% at DHC, 64.7% at Insinger, and 60.9% at Pathlow site.

In this study, fertilizer (liquid or granular) increased smooth bromegrass (90% of the time) and tended to decrease the bluegrass component (77% of the time). The rejuvenation method of choice will depend on the goal of the individual. Whether to increase the percentage of alfalfa in the stand or simply improve the vigour and productivity of the existing stand will require different techniques. For rejuvenation of pasture land, fertilization treatments are very promising as they can increase productive species composition even if only short term. In this study, smooth bromegrass, only 36% composition in control plots, responded positively to fertilizer application. When and how much fertilizer to apply are questions which need to be answered. High rates of nitrogen are not always cost efficient or environmentally sound. The decision to fertilize must be based on the yield potential of the soils in the

area. Spiking reduced forage production in the year of treatment, as well liberation of soil nutrients from spiking allowed weeds to dominate. Mowing and deep-band had only minimal effects on forage composition. Burning increased alfalfa composition more than burning and broadcast fertilizer at all sites over three years. Some methods of rejuvenation are obviously more expensive than others. Therefore a cost/benefit analysis should also be performed to help make the best management decision.

Chapter 5

The Effect of Rejuvenation on Nutritive Value of Grass-Legume Hay:
I. Dry Matter Intake and Total Tract Digestibility

5.1 Abstract

Rejuvenation of forage stands is probably the most economic and practical method to improve production and quality of forage stands. Animal data are ultimately needed to validate the viability of the rejuvenation technique. This study determined animal responses to changes in forage composition following several methods of rejuvenation. Smooth bromegrass (*Bromus inermis* L.) and alfalfa (*Medicago sativa* L.) hay was harvested from rejuvenated plots on Black and Gray-Wooded soils in Saskatchewan and fed to 24 ram lambs, the hay was harvested at two stages of maturity from plots which underwent the following rejuvenation techniques, selected to provide a range of responses; deep-banded liquid plus broadcast granular fertilizer (providing 200 kg N/ha, 90 kg P_2O_5/ha, 46 kg K_2O/ha, 24 kg S/ha), spring burn and control. As maturity advanced, dry matter intake (DMI) and digestible organic matter intake (DOMI) (g d^{-1} $kg^{-0.75}$) decreased (P<0.05) for all hays (except fertilizer) harvested from the Gray-Wooded site and control hay from Black soil site. Dry matter intake and DOMI was always greater (P<0.05) for hay from the rejuvenated plots than from control, except June 15 hay from fertilized plots (Gray-Wooded site). Grass-legume hay harvested early from the Gray-Wooded soil site had the greatest (P<0.01) voluntary intake, 85.4 g d^{-1} $kg^{-0.75}$. Apparent digestibilities of

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DM and OM were greater (P<0.01) for early harvested forage from control plots at the Gray-Wooded soil site than early harvested hay from the fertilized plots. Metabolizable energy content was higher (P<0.05) for early harvested hay from burn and fertilized plots at the Black soil site than hay from control plots. These results suggest existing forage species if harvested early can be responsive to rejuvenation, resulting in improved animal performance.

5.2 Introduction

Smooth bromegrass (*Bromus inermis* Leyss.) and alfalfa (*Medicago sativa* L.) are major pasture species in the parklands of Saskatchewan. Over time grassy swards inevitably become deficient in nitrogen unless some measure is used to replenish the supply. Many fields are steeply sloped or rocky, limiting the use of conventional methods of forage re-establishment. The productivity and quality of these pastures might, therefore, be increased by rejuvenation of the existing sward.

Rejuvenation of long established tame forages is a practical and economical method to increase yield and quality of the stand. Animal data are needed to adequately validate the impact of rejuvenation treatments on animal productivity. There is little information available regarding animal response to various improvements of grass-legume pastures. The information available shows that legume-dominated stands improve summer forage production and increase protein production and dry matter intake (Van Soest, 1965). Manipulation of forage species with herbicides and fertilizer methods have affected forage nutritive value and animal performance (Haferkamp *et al.*, 1993; Berg and Sims (1995). Carryover effects from fertilization on forage quality or burning on legume composition (Chapters 3 and 4) need to be examined further. Therefore, studies were conducted to determine animal

intake and digestibility responses to changes in forage composition as a result of several methods of rejuvenation.

5.3 Materials and Methods

5.3.1 *Field Studies*

Two sites were chosen in two different soil zones, Pathlow (52° 46' N; 104° 54' W), situated in the Grey-wooded soil zone in central Saskatchewan, and Insinger (51° 45' N; 102° 56' W), situated in the Black soil zone in east-central Saskatchewan. The pastures at both sites were established stands of alfalfa (*Medicago sativa* L.) and smooth bromegrass (*Bromus inermis* L.) with a significant amount of Kentucky bluegrass (*Poa pratensis* L.) (Chapter 4). At both sites in the spring of 1994, six rejuvenation treatments were applied to four 0.63 ha (replicate) blocks: (i) an unfertilized check; (ii) spring burn; (iii) flail mow; (iv) spike; (v) deep-band and (vi) deep-banded liquid fertilizer (100 kg N/ha, 45 kg P_2O_5/ha 23 kg K_2O/ha , 12 kg S/ha) applied at a rate of 350 kg ha^{-1} . The field study experimental design was a randomized complete block-split-plot with four replicates. Additionally, each whole plot was split and topdressed with a granular blend of fertilizer applied at 0 and 350 kg ha^{-1} (providing 100 kg N/ha, 45 kg P_2O_5/ha 23 kg K_2O/ha , 12 kg S/ha) using a Valmar air flow fertilizer spreader.

Liquid fertilizer was deep-banded using an 8 nozzle, 2.4 m liquid fertilizer applicator. This same applicator unit was used for deep-banding (slicing) without liquid fertilizer. The applicator was applied across the plot area, slicing the soil, resulting in minimal disturbance of the soil profile. Spring burning was carried out using a controlled burn contained within plot areas with a wet line, followed by drip torches which were used to burn off all above ground senesced plant material. Forage

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material was mowed using a 2.0 m John Deere rotary flail mower to a height of 2 cm. Plots were spiked using a 3.7 m John Deere DT100 deep tillage cultivator attached with 2 cm anhydrous applicator knives.

The year following the application of treatments, plots from three treatments (DBLIQ+F, B and C) at two sites (Pathlow and Insinger) were chosen and forage material was harvested and fed in an animal nutrition trial to compare hay harvested at different maturity dates, from two soil zones, and three rejuvenation treatments.

5.3.2 Hay Collection

In the summer of 1995, first cut forage was collected from both Pathlow and Insinger sites. Forage material from three rejuvenation treatments, deep-banded liquid fertilizer plus broadcast fertilizer (200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1}, 24 kg S ha^{-1}), burn and control was harvested at each site. Half of the material from each treatment was swathed mid-June (alfalfa 10% bloom; grasses 60% heads emerged) and the remaining was swathed mid-July (alfalfa 20% bloom; grasses 80% heads emerged). The stand at Pathlow was cut on 15 June and 19 July 1995 using a Versatile swather (3.66-m swath width). The stand at Insinger was cut on 16 June and 19 July 1995 with the same equipment. Forage was left to wilt in the field for 72 h before baling. Drying conditions were good mid-June with maximum temperatures averaging 24.3 °C however, conditions mid-July included precipitation for the 4 d during forage wilting (Climatological data, Environment Canada, 1997).

Forages were harvested as sun-cured hay and baled (John Deere 125 baler) into small square bales for ease of handling. Bales were labeled with color-coded tags directly from the baler and stored separate in a hay shed until they were fed in an animal intake and digestibility trial. Prior to feeding, bales were ground through a No. 12 screen to 5 cm length using a Sperry New Holland model 190 mix mill (New

Holland, Penn.) to minimize selection by sheep. Feeds were stored indoors in mini-bulk fertilizer bags until the trial commenced.

5.3.3 *Total Tract Digestibility Trial*

Twelve diets were formulated using the chopped hay from 2 soil zones and 3 rejuvenation treatments harvested at 2 stages of maturity and fed to ram lambs. Diets were fed twice daily at 0700 and 1600 h. Water was available at all times. A commercial mineral-vitamin mixture, containing 160 g Ca, 160 g P, 1.5 g Zn, 25 mg I, 640 mg Mn, 100 mg Fe, 3 g F, 14 mg Co, 151,800 IU vitamin A, 15,180 IU vitamin D3 and 500 IU vitamin E kg^{-1}, was added to the daily diet at the rate of 10 g per sheep during the feeding trial. The diets were evaluated in a total tract digestibility trial with two 21 d feeding trials.

Twenty-four growing Suffolk lambs weighing an average of 37.0 ± 2.3 kg were used. After weighing, the animals were randomly allocated to one of the twelve diets (2 animals per treatment). During the 7 d adaptation period, the animals were kept in floor pens (2 animals per pen) and gradually introduced to the diets. Following the adaptation period the animals were transferred to individual metabolism crates and voluntary feed intake was determined over a 7 d period. During this period the animals were fed to leave 10 to 15% orts. The voluntary intake period was followed by 3 d of restricted feeding (85% of *ad libitum* intake) and 5 d of total fecal collection. After the completion of period one, animals were re-weighed, re-randomized and re-assigned to the 12 dietary treatments. A similar protocol as in period one was followed for period two. Thus each diet was consumed by 4 sheep over two periods.

During the collection period, feces and orts were collected twice daily immediately before feeding, sub-sampled (10% aliquot), composited and frozen.

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Feed and fecal samples were dried in a forced air oven at 65°C for 48 h. Feces from each animal were composited and ground through a Christie-Norris mill fitted with a 1 mm screen. Feed samples collected during the same period were dried and ground similarly to the fecal samples.

5.3.4 *Animal Care*

All animal trials were conducted in accordance with guidelines laid down by the Canadian Council on Animal Care (UCACS, 1996).

5.3.5 *Laboratory Analysis*

Feed and fecal samples were ground through a 1-mm screen in a Christie-Norris laboratory mill and moisture and ash content were determined following the procedures of the Association of Official Analytical Chemists (AOAC, 1990). Dry matter (DM) was determined from moisture analysis on all samples by drying approximately 1 g of the ground samples at 110°C in an oven overnight until a constant weight was reached (method No. 930.15). Samples of feed and feces were also analyzed for organic matter (OM) (ashing overnight at 600°C) (method No. 942.05) content according to the procedures of AOAC (1990).

Apparent metabolizable energy (ME) content of the forage diets was calculated using the relationship published by Blaxter (1964):

$$1 \text{ g forage DOM contains } 15.1 \text{ kJ ME.} \tag{5.1}$$

where DOM is digestible organic matter and ME is metabolizable energy.

5.3.6 Statistical Analysis

The experimental design of the digestibility trial was a completely randomized design with 4 animals assigned to one of twelve feeds. Main effects of rejuvenation methods, compared to an unfertilized control, were tested using analysis of variance General Linear Model (GLM), SAS Institute, Inc. (1989) F tests. Treatment effects were tested at $p=0.05$. Means separation was carried out using single degree of freedom contrasts which are presented in Table 5.2. Contrasts of interest included: 1. early vs. late harvest date; 2. control vs. fertilizer; 3. control vs. burn; 4. burn vs. fertilizer; 5. harvest date x (control vs. fertilizer); 6. harvest date x (control vs. burn); 7. soil zone (early harvest-control vs. fertilizer) 8. soil zone (early harvest-control vs. burn).

5.4 Results and Discussion

Metabolizable energy (ME) content (MJ kg^{-1} DM) of the forages, voluntary dry matter intake (DMI), digestible organic matter intake (DOMI) and apparent total tract digestibility of dry matter (DMD) and organic matter (DOMD) are shown in Table 5.1. Contrasts of rejuvenation treatment and harvest date on ME content, DMI, DOMI and apparent digestibility of DM and OM are shown in Table 5.2.

Crude protein content of the hay (control 9.9%, burn 11.0%, fertilized 11.7%) (quality data, Chapter 3) was adequate to meet requirements for growing ram lambs (National Research Council, 1985).

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Table 5.1. Effect of rejuvenation treatments and harvest date on animal intake and apparent digestibility of grass-legume hay from two soil zones[z].

Rejuvenation Treatment	Control				Deepband liquid fertilizer & granular fertilizer[y]				Burn				Pooled SEM[w]
Soil Zone	Black		Gray-Wooded		Black		Gray-Wooded		Black		Gray-Wooded		
Harvest Date	Early[x]	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	
Metabolizable energy (MJ kg^{-1} DM)	5.16	6.35	9.22	7.62	6.85	7.19	7.98	7.65	6.94	6.78	9.78	7.41	0.4
Apparent digestibility (%)													
Dry matter	42.7	43.2	55.1	47.2	43.4	44.8	47.8	45.7	43.6	42.8	54.0	48.9	1.5
Organic matter	44.8	45.0	57.0	49.6	45.2	47.0	49.6	47.7	45.9	44.6	55.3	51.0	1.4
Intake of dry matter													
g d^{-1}	808	995	1126	1071	1057	1073	1142	1141	1070	1065	1256	1009	0.06
g d^{-1} kg$^{-0.75}$	59.6	68.6	76.2	73.7	73.5	69.9	74.9	75.0	69.6	70.9	85.4	65.3	3.2
g DOMI d^{-1} kg$^{-0.75}$[v]	25.2	29.1	41.4	34.7	31.5	31.1	34.7	33.4	29.9	29.8	44.2	31.8	1.3
% body weight	4.0	3.6	3.2	3.3	3.3	3.5	3.3	3.2	3.5	3.4	2.9	3.8	

[z]Statistical contrasts are compared in Table 5.2
[y]Fertilizer applied at 200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1}, 24 kg S ha^{-1}
[x]Early, 15 June, 1995; Late, 19 July.
[w]Pooled standard error of the mean
[v]DOMI, digestible organic matter intake

Table 5.2. Contrasts[z] of rejuvenation treatment and harvest date effects on animal dry matter intake and apparent digestibility of grass-legume hay from two soil zones.

| | | | | | Early[y] Harvest | | Late Harvest | | Early Harvest | | | |
| | | | | | | | | | Black Soil | | Gray-Wooded Soil | |
	Early vs. Late	Control vs. Fertilizer[x]	Control vs. Burn	Burn vs. Fertilizer	Control vs Fertilizer	Control vs. Burn	Control vs Fertilizer	Control vs. Burn	Control vs. Fertilizer	Control vs. Burn	Control vs Fertilizer	Control vs. Burn
Metabolizable energy (MJ kg⁻¹ DM)	NS	NS	NS	NS	NS	*	NS	NS	*	*	NS	NS
Digestibility (%)												
Dry matter	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	**	NS
Organic matter	**	NS	NS	**	*	NS	NS	NS	NS	NS	**	NS
Intake												
g d⁻¹	NS	*	*	NS	*	**	NS	NS	**	**	NS	NS
g d⁻¹ kg⁻⁰·⁷⁵	NS	NS	NS	NS	*	**	NS	NS	**	*	NS	*
g DOMI d⁻¹ kg⁻⁰·⁷⁵w	**	NS	NS	NS	NS	*	NS	NS	**	NS	**	NS

[z]Contrasts denoted NS are not significant; *p<0.05; **p<0.01.
[y]Early, 15 June, 1995; Late, 19 July, 1995.
[x]Fertilizer applied at 200 kg N ha⁻¹, 90 kg P₂O₅ ha⁻¹, 46 kg K₂O ha⁻¹, 24 kg S ha⁻¹
[w]DOMI, digestible organic matter intake

5.4.1 Voluntary Intake

Dry matter intake was similar for maturity of hay (Gray-Wooded soil site) from fertilized plots but intake decreased with advancing maturity of hay from burn plots (Table 5.1). Intake ranged from 59.6 to 85.4 g d^{-1} kg$^{-0.75}$ across all comparisons. Intake of early harvested forage from the Black soil site (Insinger) ($P<0.05$) and late harvested hay from Gray-Wooded soil site (Pathlow) was greatest from the fertilized plots ($P>0.05$). Hay from the burn treatment, early harvest at the Gray-Wooded soil site (Pathlow) ($P<0.05$) and late harvest from the Black soil site (Insinger), however not significant ($P>0.05$) had greater DMI than hay harvested from control or fertilized plots at these sites. Intakes (g d^{-1}, % body weight) in this study were lower than those reported by Christen *et al.* (1990) who fed 100% timothy (*Phleum pratense* L.) or quackgrass (*Agropyron repens* (L.) Beauv.) diets to sheep to compare nutritive values.

Dry matter intake and DOMI was greater ($P<0.05$) for early harvested hay from the rejuvenated plots (fertilizer or burning; Black soil site) than from control plots. Comparing rejuvenated forage diets from fertilized plots at the Black soil site, metabolic intake was greater for early (June 15) (73.5 g d^{-1} kg$^{-0.75}$) than for late (July 19) (69.9 g d^{-1} kg$^{-0.75}$) harvested forage. However, the values for early harvested hay are lower than those published by McCaughey and Cohen (1989) who reported higher intakes (81.6 g

d^{-1} kg$^{-0.75}$) from mefluidide and maleic hydrazide treated crested wheatgrass (*Agropyron pectiniforme* R. & S.) hay harvested in August and September from a Black soil pasture.

Across all diets, dry matter intake (g d^{-1}) differed ($P<0.05$) between both burn and fertilizer rejuvenation treatments and control (Table 5.2). However, metabolic intake (g d^{-1} kg$^{-0.75}$) of hay harvested 15 June, 1995 was not different ($P>0.05$) from

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hay harvested 19 July, 1995. Digestible organic matter intake was different (P<0.01) between early and late harvested forages. Voluntary intake (DMI, DOMI) of late harvested forages was not different (P>0.05) between diets. However, at the early harvest date DMI (g d^{-1} kg$^{-0.75}$) of hay from the fertilizer plots (except Gray-Wooded) differed (P<0.05) from control and DMI of hay from burn plots differed (P<0.01) from control. Intake (g d^{-1}, g d^{-1} kg$^{-0.75}$, g DOMI d^{-1} kg$^{-0.75}$) of early harvested forage from burn plots differed (P<0.01) from hay from control plots. Finally, intake of hay from fertilized and burn plots at the Black soil site (early harvest) differed (P<0.01) from control plot hay for DMI and DOMI.

Metabolizable energy (ME) content of fertilized and burn plot hays harvested early at the Black soil site (Insinger) was greater (P<0.05) than control hay. ME content of rejuvenated hay harvested early or late from the Gray-Wooded site was not different (P>0.05) from control. The calculated ME content values of most diets in this experiment are lower (5.2 to 9.7 MJ kg^{-1} DM) than those reported by Koch et al. (1987). Those authors evaluated renovated forages (N-fertilized control and sod-seeding legumes) in an animal feeding trial and found ME values ranged from 8.2 to 8.9 MJ kg^{-1} DM from field-cured hay harvested the year following treatment. The exception is early harvested hay from control and burn plots at Pathlow site where ME was 9.22 and 9.78 MJ kg^{-1}, respectively.

5.4.2 Total Tract Digestibility

The greatest DMD and OMD was for control forage harvested early at the Gray-Wooded soil site (Pathlow), 55.1 and 57%, respectively. Apparent total tract digestibility of dry matter and organic matter differed (P<0.05) for hay harvested from either burn or fertilized plots. Organic matter digestibility also differed

(P<0.01) for hay harvested on 15 June compared to that harvested on July 19 however, DMD and ME content were not different (P>0.05).

Apparent digestibilities of DM and OM were greater (P<0.05) in all diets from forages harvested early (15 June), than in forages harvested late (19 July) from the Gray-Wooded site (Pathlow). More specifically, DMD and OMD were greater (P<0.05) for hays from the control plots compared to hay from fertilized plots at the early harvest date.

In conclusion, fertilizing with 200 kg N ha^{-1} and burning had a positive effect on intake and digestibility of nutritional components of sun-cured hay harvested June 15 the following year. These effects were observed largely on hay harvested from the Black soil site. This suggests that the residual effects of rejuvenation, especially burning, will affect forage quality longer than dry matter yield (Chapter 3). These results were observed even though hay from both sites did receive several showers while lying in the swath. Hay harvested July 19 from either the Black or Gray-Wooded soil sites provided no effect of rejuvenation treatment on intake or apparent digestibility of constituents.

The most consistent effect of rejuvenation on animal nutrition was increased DOMI intake and apparent digestibility of OM of hay from burn plots, 15 June harvest both sites. This may have been associated with increased alfalfa component of forage from the burn plots (Chapter 4). Other workers have also reported higher DMI of forage diets with increased legume component in the mixture (Hunt *et al.*, 1985).

Rejuvenation did not greatly affect the efficiency of utilization of digested forages as indicated from the calculated metabolizable energy contents. The greatest effect of rejuvenation was the increase in intake of hay from burn plots harvested early from the Gray-Wooded soil site. Results of the present study suggest that increased animal forage intake and apparent digestibility of forage components and

ME content may be realized with early harvest of the hay crop after imposing a spring prescribed burn of the pasture. Finally, the choice of rejuvenation method will depend on relative cost of method, time and labor availability, and field limitations. Further studies are required to determine additional nutritive data of rejuvenated forages.

Chapter 6

The Effect of Rejuvenation on Nutritive Value of Grass-Legume Hay:
II. Prediction of *In Vivo* Digestibility Using *In Vitro* Digestibility Technique and
Metabolizable Energy Using *In Vitro* Gas Production Technique

6.1 Abstract

Nutritive value of hay from rejuvenated pastures was evaluated by comparison of their chemical composition and *in vitro* vs. *in vivo* values for digestibility and metabolizable energy. Samples of hays from three rejuvenation treatments, deep-banded fertilizer (100 kg N/ha, 45 kg P_2O_5/ha 23 kg K_2O/ha , 12 kg S/ha), burning and control, harvested at two stages of maturity from two soil zones were assessed for organic matter (OM), crude protein (CP), ether extract (EE), *in vitro* gas production and *in vitro* digestibility (IVDMD). The *in vitro* gas production (mL/200 mg DM) method was used to predict metabolizable energy (ME) (MJ kg^{-1} DM) of grass-legume hays. Digestibility *in vitro* was used to predict dry matter digestibility (DMD). For all samples DMD and ME *in vivo* was determined with sheep fed at a maintenance level. Forty-eight hour *in vitro* gas production was greater for alfalfa than for the rejuvenated hays. Hays from control and burn plots at the Gray-Wooded site harvested 15 June had the greatest gas production at 48 h, 66.0 and 60.8 mL/200 mg DM, respectively. These same hays also had the greatest *in vitro* DMD, 541 and 591 g^{-1} kg^{-1} DM, respectively. Although predicted ME values using Menke *in vitro* gas production data were different (P<0.03) from calculated *in vivo* ME values, the

coefficient of variation was only 8.1%. A high correlation (r=0.87) was found between *in vitro* and *in vivo* dry matter digestibility. The IVDMD technique accurately predicted digestibility of the hays, having a coefficient of variation of 0.05%. These *in vitro* techniques should allow the estimation of digestibility and metabolizable energy values for large numbers of forage samples quickly, accurately and cheaply from which computer simulation programs can predict animal performance.

6.2 Introduction

The effect of pasture rejuvenation has been shown to affect production, composition, and quality of standing forage (Chapters 3 and 4). All these components can have an impact on the feeding value of the hay. As well, the nutritive value of these hays is subject to considerable variability. Animal digestibility trials can be costly and unsuitable for screening large numbers of samples. The true value of a feed is dependent on utilization of nutrients after digestion, therefore feed evaluation must incorporate some measure of energetic value as well as digestibility (Schneider and Flatt, 1975). Laboratory *in vitro* techniques can be an important step for evaluating ruminant feedstuffs. The energetic feed value (ME) of forages is closely related to organic matter digestibility or DOM content of feeds (Blaxter, 1964; Chapter 5, Equation 5.1). The amount of gas released in 24 h from forage samples incubated *in vitro* with rumen fluid is closely related to digestibility and therefore to the energetic value of roughages for ruminants (Menke *et al.*, 1979). Menke *et al.* (1979) and Menke and Steingass (1988) further demonstrated that gas production of forages during *in vitro* fermentation with rumen micro-organisms, is an indirect measure of their digestibility and metabolizable energy content.

The objectives of the present study were (i) to assess the gas production technique as a predictor of metabolizable energy (ME) of hay from rejuvenated plots, by comparing predicted ME values using gas production data with calculated *in vivo* ME values from total tract digestibility data (Chapter 5), and (ii) to compare *in vitro* dry matter digestibility (DMD), (Tilley and Terry, 1963) as a predictor of *in vivo* digestibility of grass-legume hays.

6.3 Materials and Methods

6.3.1 *Forage samples*

Twelve hays were harvested at two maturity stages (early vs. late) from two soil zones (Black and Gray-Wooded). They consisted primarily of alfalfa (*Medicago sativa* L.), smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.) and other lesser species. Each hay was harvested from plots the year following three rejuvenation treatments, deep-banded liquid plus granular fertilizer (200 kg N/ha, 90 kg P_2O_5/ha 46 kg K_2O/ha , 24 kg S/ha), spring burn and control.

First cut forage was collected from both sites, Pathlow site situated in the Gray-wooded soil zone in central Saskatchewan, and Insinger site in the Black soil zone in east-central Saskatchewan. Forage material from each rejuvenation treatment, was swathed and baled at two maturity stages for each site. Half of the material from each treatment was swathed mid-June and the remaining was swathed mid-July. The stand at Pathlow was cut on 15 June and 19 July 1995 using a Versatile swather (3.66-m swath width). The stand at Insinger was cut on 16 June and 19 July 1995. Forage was left to wilt in the field for 72 h before baling.

Forage was baled as sun-cured hay using a John Deere 125 baler into small square bales for ease of handling. Bales were labeled with color-coded tags directly

from the baler and stored in a hay shed until they were ground and fed in a ruminant digestibility and intake trial. Feed samples were collected during this trial and assessed for various laboratory analyses.

6.3.2 Laboratory analysis

Feed samples from twelve diets were collected during the feeding trial and analyzed for dry matter (DM), ash, crude protein (CP) and ether extract (EE). All feed samples were ground through a 1-mm screen using a Christie-Norris laboratory mill and moisture and ash content determined following the procedures of the Association of Official Analytical Chemists (AOAC, 1990). Dry matter was determined from moisture analysis on all samples by drying approximately 1 g of the ground sample at 110°C in an oven overnight until a constant weight was reached (method No. 930.15). Organic matter was determined by ashing overnight at 600°C (method No. 942.05). Crude protein was analyzed by determining Kjeldahl nitrogen concentration (nitrogen x 6.25) (method No. 984.13) using a Kjeltec 1030 auto analyzer and ether extract was determined on a Goldfisch 35001 extraction apparatus (method No. 920.39) according to the procedures of AOAC (1990).

6.3.3 In vitro dry matter digestibility

Rumen liquor was collected from a ruminally cannulated Holstein-Friesen cow receiving a mid-lactation total mixed ration (TMR) fed twice daily (0800 and 1600 h) containing 24% alfalfa haylage, 39% corn silage, 10% alfalfa hay and 27% concentrate. Collections were made 1 h pre-feeding by dipping into the ventral portion of the rumen and placing the fluid directly into a prewarmed (39°C), CO_2-flushed thermos. The thermos was sealed and transported immediately to the

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laboratory where the rumen inocula was strained through cheesecloth. Carbon dioxide was bubbled through the ruminal fluid and buffer prior to and during charging of incubation tubes with inocula.

A two-stage rumen inoculum-pepsin procedure was used to determine *in vitro* digestibility. *In vitro* DM (IVDMD) disappearance of twelve forage hays was determined in triplicate after incubation with rumen fluid and pepsin using the Tilley and Terry (1963) method. Each tube was inoculated with 30 ml of a ruminal fluid:buffer (1:5) solution. Samples were then incubated in a water bath for 48 h at 39°C with occasional shaking. At the end of 48 h, tubes were centrifuged and filtered twice and 25 ml pepsin:HCl solution added to each tube. Samples were again incubated in a water bath for an additional 48 h at 39°C. At the end of digestion, samples were dried in a forced air oven for 24 h at 65°C and weighed.

6.3.4 In vitro *gas production*

Fermentation was also carried out in 100 mL graduated glass syringes with vaseline lubricated pistons following the method described by Menke *et al.* (1979). About 250 mg of air dry hay sample, standardized for weight, was incubated in triplicate with 30 mL of incubation medium prepared as described by Menke *et al.* (1979). Rumen liquor was collected before feeding, from a rumen cannulated cow fed the diet described in Section 6.3.3. The syringes and their contents were maintained at 38.5-39°C in a thermostatic incubator with a rotor drive unit for 59 syringes. Three other syringes containing the incubation medium only were also placed in the incubator to correct for gas production due to the microbial activity of the rumen fluid alone. *In vitro* gas production was determined at 0.5, 2, 4, 8, 12, 24, 48 and 72 h of incubation. After each reading, the piston of the syringe was reset to

32 ml whenever it had gone beyond the 60 ml mark. An alfalfa standard was also run with each set of syringes to validate gas curve production.

6.3.5 Statistical analysis and calculations

Two experiments were analyzed separately using General Linear Models procedure (SAS Institute, Inc., 1989). A one-way completely randomized ANOVA design was used to analyze the dependent variables, *in vitro* dry matter digestibility (IVDMD) and *in vivo* dry matter digestibility. Means were separated by a Student-Newman-Keul's test (Steel *et al.*, 1997).

Gas production and nutrient data were then used to predict metabolizable energy (ME) using the following regression equation (Menke and Steingass, 1988) for roughage feeds

$$ME = 2.20 + 0.1357 \, (Gp) + 0.0057 \, (XP) + 0.0002859 \, (XL^2) \qquad (6.1)$$

where Gp is cumulative gas production at 24 h (mL^{-1} 200 g^{-1} DM), XP is percentage crude protein, and XL is percentage crude fat content.

Gas production data were also fitted using non-linear regression (SAS, 1989) to the equation

$$p = a + b \, (1 - e^{-c \, (t-Lt)}) \qquad (6.2)$$

(Dhanoa, 1988), where *p* represents the *in vitro* gas production (mL) at time *t*, (*a* + *b*) was the potential gas production, *c* the fractional rate of gas production per hour and *Lt* represents the lag phase before gas production commenced. Data for potential gas production values, *a*, *b*, *c*, and *a* + *b* are presented in Table 6.2.

The relationship between calculated and predicted metabolizable energy and *in vitro* and *in vivo* digestibility data was tested using a paired t-test (Snedecor and Cochran, 1989). Statistical analysis was performed on predicted and *in vivo* ME data and on *in vivo* and *in vitro* digestibility data to define accuracy of the prediction equation and technique, respectively. Hypothesized differences between data were zero. A correlation matrix between data for *in vitro* and *in vivo* DMD and predicted ME and *in vivo* ME was obtained using SAS (1989).

6.4 Results and Discussion

6.4.1 *Chemical constituents*

The mean values of OM, CP, EE, *in vitro* DMD and *in vivo* DMD are presented in Table 6.1. Organic matter (g^{-1} kg^{-1} DM) was highest in hays harvested 19 July from control and burn plots at the Gray-Wooded soil site. Crude protein and ether extract concentrations were generally higher for all 15 June harvested hays (Black and Gray-Wooded) than 19 July harvested hays. Stage of maturity was not reflected in organic matter content, *in vitro* DMD or apparent *in vivo* DMD for hays from the Black soil site (Table 6.1). For instance the *in vitro* DMD of the hays harvested at the early stage from all rejuvenation plots at the Black soil site were not different ($P>0.05$) from those harvested at the late stage (19 July). *In vitro* DMD for hay harvested early from control and burn plots at the Gray-Wooded site was greater ($P<0.05$) than late harvested hay, except hay from fertilized plots. Hay harvested June 15 from burn plots at the Gray-Wooded soil site had the greatest ($P<0.05$) IVDMD of all hays studied in this trial. *In vivo* DMD was quite similar ($P>0.05$) from both early and late harvested hays from the Black soil site, yet early harvested hays at the Gray-Wooded soil site had higher ($P<0.05$) *in vivo* apparent DMD than the

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Table 6.1. Chemical composition[z] (g/kg dry matter (DM)), *in vitro* DM digestibility (IVDMD) and apparent *in vivo* DM digestibility of twelve grass-legume hays harvested at two maturity dates from three rejuvenation treatments, from either Black or Gray-Wooded soil zones.

	Organic matter	Crude protein	Ether extract	*In vitro* DMD	*In vivo* DMD
Control - Black Soil					
Early[y]	937	102	14	378*d*[x]	427*b*
Late	941	86	11	420*cd*	432*b*
Burn - Black Soil					
Early	940	84	13	421*cd*	436*b*
Late	942	78	10	425*cd*	428*b*
Fertilizer[w] - Black Soil					
Early	948	103	18	404*cd*	434*b*
Late	946	91	11	449*c*	448*b*
Control - Gray-Wooded Soil					
Early	945	98	20	541*b*	551*a*
Late	952	87	16	449*c*	472*b*
Burn - Gray-Wooded Soil					
Early	939	103	17	591*a*	540*a*
Late	953	91	15	475*c*	489*b*
Fertilizer - Gray-Wooded Soil					
Early	934	106	20	486*c*	478*b*
Late	939	122	19	527*b*	457*b*
SEM[v]				14	15

[z]Values shown are means of two replicates
[y]Early, 15 June, 1995; Late, 19 July
[x]Means within column with unlike letters differ (p<0.05)
[w]Fertilizer applied at 200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1}, 24 kg S ha^{-1}
[v]Standard error of the mean

late harvested hays, except from the fertilizer treatment. Digestibility differences apparent in the hays harvested from the Gray-Wooded site were due to stage of maturity at harvest. This was not observed for digestibility of hays from the Black soil site although crude protein and fat content were higher in the early harvested forage. The July 15 hay at the Black soil site did receive showers while curing in the swath suggesting an environmental effect on the resulting digestibilites.

6.4.2 *Gas production*

The volume of gas produced (mL/200 mg DM) using rumen inoculum after 12 or 24 or 48 h incubation and the degradation characteristics (a, b, c, and $a + b$) obtained by fitting the data for gas production of the grass-legume hays to the exponential equation are presented in Table 6.2. The mean rate constant (c) for all hays tested was 0.03 which is slightly lower than 0.05, reported by Khazaal *et al.* (1995) for grass hay or 0.07 for legume hays (Khazaal *et al.* 1993). Values for gas production after 12, 24 and 48 h and a, b, $a+b$, and c constants are higher than those reported by Khazaal *et al.* (1995) for graminaceous hays. These differences may have been due to overprocessing of the samples, first as baled hay and again prior to laboratory analysis. Menke and Steingass (1988) also reported that grinding of low digestible roughage leads to an increase in gas production. However, the potential gas production ($a + b$) values in this study are similar to those of Nsahlai and Umunna (1996) who reported 61, 78 and 63 mL/200 mg DM for barley straw, maize stover and wheat straw (ground to 1 mm size), respectively.

Table 6.2. Cumulative gas production (mL/200 mg DM) *in vitro* of 12 grass-legume hays harvested at two maturity dates from three rejuvenation treatments, from either Gray-Wooded (G) or Black (B) soil zones.

Treatment	Harvesting stage[z]	Soil Zone	Gas produced after			a[y]	b	$a + b$	c	R.S.D.[x]
			12 h	24 h	48 h					
Control	Early	G	32.0	47.1	66.0	5.3	74.3	79.7	0.036	3.1
	Late	B	20.5	30.8	43.2	5.1	45.9	51.0	0.035	1.3
Burn	Early	G	33.6	46.0	60.8	4.8	61.0	65.9	0.051	1.0
	Late	B	20.9	31.2	43.6	5.3	44.0	49.4	0.039	0.9
Fertilizer[w]	Early	G	24.0	35.6	50.2	4.7	52.8	57.7	0.037	1.2
	Late	B	20.5	30.9	45.2	3.8	49.2	53.1	0.035	1.1
Control	Early	B	18.4	26.0	40.5	5.4	52.4	57.8	0.022	1.2
	Late	G	19.9	33.2	53.9	2.9	71.8	74.9	0.024	2.6
Burn	Early	B	17.0	26.1	41.5	4.7	53.3	58.1	0.023	0.8
	Late	G	20.6	32.8	50.0	3.4	59.4	62.9	0.029	2.4
Fertilizer	Early	B	17.1	28.4	43.7	3.2	55.7	59.0	0.025	1.3
	Late	G	18.1	29.1	46.5	3.1	57.3	60.5	0.028	2.2
Mean			20.2	30.6	46.9	4.3	52.0	56.1	0.030	
Alfalfa			46.8	57.1	71.5	4.8	72.1	75.4	0.031	

[z]Early, 15 June, 1995; Late, 19 July

[y] a, b and c are constants in the model $p = a + b (1 - e^{-c(t-Lt)})$ (Dhanoa, 1988), $a + b$ is potential gas production (mL/200 mg DM), c is rate constant of gas production (%/h)

[x]R.S.D. are residual standard deviations of fitted curves

[w]Fertilizer applied at 200 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 46 kg K_2O ha^{-1}, 24 kg S ha^{-1}

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6.4.3 In vitro vs. in vivo digestibility

The correlation coefficient r=0.87, between IVDMD and apparent in vivo dry matter digestibility indicated a strong relationship between the laboratory measurement and the in vivo data. This relationship is similar to that obtained by Tilley and Terry (1963) and Wurster et al. (1971) for digestibility of cool season grasses. The coefficient of variation between data sets was 0.05, and the data sets were not different (P>0.05) according to paired t-test.

It appears that the two stage process of in vitro dry matter digestibility is an accurate predictor of dry matter digestibility in the rumen of the rejuvenated grass-legume hays used in this study. Furthermore the rumen inocula-pepsin method appears the simplest in vitro technique from the operative point of view, in evaluating rejuvenation effects on forage quality of large numbers of samples.

6.4.4 Prediction of metabolizable energy from gas production

Menke and Steingass (1988) reported a coefficient of determination (R^2) of .94 and a residual standard deviation of 4.2 for equation 6.1. However, the paired t-value for predicted vs. in vivo metabolizable energy in this study was 2.47 (Table 6.3), indicating a difference (P<0.03) between predicted and in vivo ME values. The correlation coefficient between predicted vs. in vivo ME values was r=0.70.

The variability of predicted ME vs. in vivo ME could be due to various factors. The high gas production values for hays at 24 h may have been due to over processing effects on the samples influencing particle size (Gerson et al., 1988) and subsequently higher rates of gas production. Secondly, rumen fluid used in this study was from a fistulated animal that was not eating a 100% roughage diet, but a 70% roughage 30% concentrate diet perhaps altering the rumen microbial population

Table 6.3. Prediction of metabolizable energy (ME) (MJ kg^{-1} DM) from 24 h gas production *in vitro*, crude protein and crude fat of grass-legume hays from three rejuvenation treatments harvested at two stages of maturity from two soil zones (Black and Gray-Wooded).

	Control				Deep-banded fertilizer[z]				Burn				t-value	p-value
	Black		Gray-Wooded		Black		Gray-Wooded		Black		Gray-Wooded			
	Early[y]	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late		
In vivo ME	5.16	6.35	9.22	7.62	6.85	7.19	7.98	7.65	6.94	6.78	9.78	7.41	2.47	0.03
Predicted ME	5.78	6.42	8.66	6.75	6.10	6.75	8.50	6.21	6.26	6.48	7.09	6.70		

[z]Fertilizer applied at 200 kg N ha^{-1}, 90 kg P$_2$O$_5$ ha^{-1}, 46 kg K$_2$O ha^{-1}, 24 kg S ha^{-1}
[y]Early, 15 June, 1995; Late, 19 July, 1995

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which in turn affected gas production rates. Thirdly, the errors associated with the use of the equation of Blaxter (1964) (Equation 5.1) for these hay samples. Finally, because of variability among animals used in the *in vivo* determinations (Chapter 5), a large number of animals would be necessary to obtain better precision.

It is concluded that *in vitro* digestibility of forages such as used in this study, may be used to predict *in vivo* digestibility and to some extent, prediction of metabolizable energy from *in vitro* gas production and chemical composition. However, the accuracy of prediction of ME is likely to vary, depending on the type of forages used and the incubation substrate.

To further assess the potential of rejuvenation on the nutritive value of grass-legume pastures and subsequent animal production, studies involving predicted animal performance on pasture using computer simulation software need to be undertaken.

Chapter 7

Predicting Beef Cattle Performance on Rejuvenated Grass-Legume Hay Using the National Research Council's 1996 Computer Model Level 1

7.1 Abstract

Prediction of feed biological values and animal performance when grazing forages requires accurate inputs that influence animal requirements and feed utilization. The National Research Council - Nutrient Requirement Series Application Model is a computer model which can be used to predict these parameters using nutritive data of the grazed forage. A backgrounding simulation was used to estimate steer intake and gain on control and rejuvenated (burn + broadcast fertilizer applied at 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) hays harvested from sites in the Black and Gray-Wooded soil zones. The management variable was a 130 d dry-lot system with an estimated animal gain of 0.65 kg d^{-1}. Crude protein content of rejuvenated forage samples was greater than control only in 1994. In all prediction scenarios using control and rejuvenated forages, energy was the most limiting nutrient for average daily gain. Annual predicted animal average daily gain of rejuvenated hay was greatest in yr 3 at the Gray-Wooded soil site and in yr 1 and 2 at the Black soil site. Predicted mean animal average gain d^{-1} was greater for rejuvenated hay harvested from the Black soil site over three years than for control hay. Rejuvenation of tame hay on Gray-Wooded and

Black soil sites by burning and fertilizing, backgrounded 52 and 44% more steers than control hay.

7.2 Introduction

Prediction of energy and protein requirements of cattle consuming forages can be quite variable. Factors affecting animal performance include environment, and variability of nutritive value of the forage. Over time, production and quality of long established tame pasture will decline. Traditional methods of breaking and re-seeding can be expensive and subject the area to erosion and degradation. Therefore, rejuvenation of pasture or hayland can be a real alternative, improving not only productivity of the stand but nutritive value of the forage as well.

Gaylean and Goetsch (1993) noted that forages alone cannot meet the energy requirements of high producing dairy cows or rapidly growing steers. The often low digestibility and high concentration of cell walls in forages limit energy availability to animals fed high-forage diets. There needs to be an investigation of strategies to increase the duration of quality pasture supply or improve the quality of the pasture.

Computer simulation models can be used in various ways in research, teaching and extension. They can be used to interpret research results, as a teaching tool in adjusting for interactions of feed composition, management and animal requirements, to develop tables of nutrient requirements and finally, estimating requirements for which no data are available (Fox *et al.*, 1995). A new system for evaluating cattle diets based on chemical analyses was developed by Sniffen *et al.* (1992) and Fox and Barry (1994). The system improves the prediction of ruminant performance by classifying feedstuffs according to their nutrient content which meets rumen microbial and host animal needs. Equations and validation of this system are published in Russell *et al.* (1992), Sniffen *et al.* (1992), Fox *et al.* (1992), O'Connor *et*

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al. (1993), Fox *et al.* (1995), and Pitt *et al.* (1996). This system characterizes the nutrient profiles of feedstuffs for use in the National Academy of Science-National Research Council nutrient requirements of beef cattle computer program (National Research Council, 1996). Therefore, the objectives of this chapter are (i) to predict daily intake and gain of backgrounded steers eating control and rejuvenated hays and (ii) predict whether the nutritive analysis and/or dry matter yield of rejuvenated forages will potentially increase mean animal average daily gain or numbers of animals backgrounded over a three year period using the 1996 NRC nutrient requirements of beef cattle application program.

7.3 Materials and Methods

7.3.1 *Sample collection*

Two hays, consisting mainly of alfalfa (*Medicago sativa* L.), smooth bromegrass (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.) were grown at two dryland sites in central Saskatchewan. Mid-July forage samples were collected from 1994 through 1996 at both sites, Pathlow site situated in the Gray-wooded soil zone in central Saskatchewan and Insinger site in the Black soil zone in east-central Saskatchewan.

Forage material from two rejuvenation treatments, burn plus broadcast fertilizer (providing 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) and control was harvested mid-July 1994 through 1996 at each site. All samples collected were then evaluated for numerous laboratory chemical analyses.

7.3.2 Laboratory analysis

Forage samples from the two rejuvenation treatments were analyzed for dry matter (DM), ash, ether extract (EE), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), non-protein nitrogen (NPN), acid detergent lignin (ADL), soluble crude protein (SCP), neutral detergent insoluble crude protein (NDICP), acid detergent insoluble crude protein (ADICP), and nonstructural carbohydrates (NSC).

Prior to analyses, all forage samples were ground through a 1-mm screen using a Christie-Norris mill. Samples were then analyzed for moisture (method No. 930.15) and ash content (method No. 942.05) following the procedures of the Association of Official Analytical Chemists (AOAC, 1990). Ether extract was determined on a Goldfisch 35001 extraction apparatus (method No. 920.39). Kjeldahl nitrogen was determined (method No. 984.13) using a Kjeltec 1030 auto analyzer and ADF and ADL (method No. 973.18) according to the procedures of the AOAC (1990). NDF was determined according to the procedure of Van Soest *et al.* (1991). Neutral and acid detergent insoluble CP in forage samples were determined on NDF and ADF residues, respectively, using the Kjeldahl method [AOAC (1990) method No. 984.13]. Non-protein nitrogen was determined using the sodium tungstate procedure of Greenberg and Shipe (1979) and soluble CP as described by Roe et al. (1990). For soluble CP, 0.5 g of sample was incubated with 50 mL of borate phosphate buffer for 1 h at 39°C. The sample was then filtered and insoluble nitrogen determined by the Kjeldahl method [AOAC (1990) method No. 984.13]. Protein solubility and non-protein nitrogen are expressed as percent of total CP. Total starch was determined using the alpha-amylase amyloglucosidase method (Megazyme kit, Megazyme, NSW, Australia). Non structural carbohydrates were calculated using

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the following formula (Sniffen *et al.*, 1992)

$$100 - \{NDF - [NDICP \times (CP/100)] + ASH + EE + CP\} \qquad (7.1)$$

where NDF is neutral detergent fiber, NDICP is neutral detergent insoluble crude protein, CP is crude protein and EE is ether extract.

Total digestible nutrients (TDN) were calculated using the formula for grass forages (70% or more) (Van Soest *et al.*, 1979)

$$TDN = 114.420 - 1.492 \times ADF \qquad (7.2)$$

where ADF is acid detergent fiber.

7.3.3 *Computer simulation*

Nutrient values of hays harvested from sites in two soil zones from 1994 through to 1996 were entered in a feeds file of the Nutrient Requirements of Beef Cattle Model Application Level I (NRC, 1996). Lab values for dietary carbohydrate and protein fractions of all feeds and digestion rates are based on Sniffen *et al.* (1992) and Van Soest (1994). Nutrient data were then used to generate predicted animal intake, average daily gain (ADG) and supplied metabolizable energy and protein.

A simulated dry-lot backgrounding model was entered using 14 month old Angus x Hereford steers with an initial shrunk body weight of 275 kg gaining 0.65 kg d^{-1} ending with a weight of 345 kg. Animals were fed over a 130 d winter feeding period to be sold as 'grassers' the following spring. Body condition score was 5.0 (0-9 scale) and all animals were implanted prior to feeding. Inputs for environment

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included wind speed at 10 kph, previous temperature at -8°C, current temperature at -10°C, night cooling, hair depth at 1.4 cm, thick hide, hair coat clean and dry and no heat stress.

7.4 Results and Discussion

7.4.1 *Chemical composition*

Chemical composition of the clipped forage samples from control and burn + fertilizer plots over 3 yr is presented in Table 7.1. Table 7.1 numeric data is a mean of two laboratory duplicates. 1994 samples from the Black soil site show differences in CP (106 vs. 128 g kg^{-1}), NDF (620 vs. 605 g kg^{-1}), ADL (130 vs. 112 g kg^{-1}), and AD insoluble protein (131 vs. 101 g kg^{-1}) between control and burn + fertilizer, respectively. 1995 samples showed only a difference in non-protein nitrogen (NPN), 634 vs. 749 g kg^{-1} between control and burn + fertilizer, respectively. Differences in ADF (396 vs. 416 g kg^{-1}), ADL (93 vs. 117 g kg^{-1}) and NPN (577 vs. 833 g kg^{-1}), between control and burn + fertilizer, respectively were observed in 1996 samples.

1994 samples from the Gray-Wooded soil site show differences in EE (18 vs. 28 g kg^{-1}), CP (82 vs. 110 g kg^{-1}), NDF (622 vs. 657 g kg^{-1}), ADF (377 vs. 392 g kg^{-1}), and non-structural carbohydrates (238 vs. 194 g kg^{-1}) between control and burn + fertilizer, respectively. 1995 samples showed a difference in non-protein nitrogen (811 vs. 737 g kg^{-1}), ND insoluble protein (405 vs. 375 g kg^{-1}), and AD insoluble protein (103 vs. 128 g kg^{-1}) between control and burn + fertilizer, respectively. Differences in CP (88 vs. 95 g kg^{-1}), NPN (567 vs. 716 g kg^{-1}) and ND insoluble protein (289 vs. 328 g kg^{-1}), between control and burn + fertilizer, respectively, were observed in 1996 samples.

Table 7.1. Chemical composition of grass-legume forage from two rejuvenation treatments, from either Black or Gray-Wooded soil zones (g kg⁻¹ DM basis).

	Control						Burn + fertilizer[z]					
	Black Soil			Gray-Wooded Soil			Black Soil			Gray-Wooded Soil		
	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
Ash	78	79	86	81	72	76	78	70	84	76	74	81
Ether extract	17	20	28	18	27	35	26	27	30	28	36	32
Neutral detergent fiber	620	677	643	622	640	615	605	668	641	657	622	610
Acid detergent fiber	408	458	396	377	368	370	394	458	416	392	388	372
Acid detergent lignin	130	128	93	69	86	75	112	136	117	62	89	80
Crude protein (CP)	106	92	117	82	101	88	128	95	115	110	101	95
Soluble crude protein (% of CP)	315	337	339	294	363	318	354	391	335	311	365	341
Non-protein nitrogen (% of SCP)	859	634	577	903	811	567	884	749	833	882	737	716
ND insoluble protein (g kg⁻¹ of CP)	412	371	401	493	405	289	415	348	410	506	375	328
AD insoluble protein (g kg⁻¹ of CP)	131	178	115	106	103	112	101	179	145	102	128	111
Non structural carbohydrates	223	166	175	238	200	215	222	174	177	194	214	213

[z]Fertilizer applied at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹, 12 kg S ha⁻¹

Samples from the Black soil site were generally higher in NDF, ADF and ADL and generally lower in EE and AD insoluble protein than samples from the Gray-Wooded soil site. Rejuvenation of tame pasture with burn + fertilizer treatment increased crude protein of the 1994 samples, however this was not the case for the 1995 and 1996 samples, indicating the residual effect of fertilizer did not carry over into the second year.

7.4.2 *Prediction of intake and daily weight gain*

Predicted energetic values, intake and metabolizable protein (MP) and energy (ME) allowed ADG and estimated animal average daily gain are shown in Tables 7.2 and 7.3. Predicted diet ME, NEm and NEg values were generally higher for samples from the Gray-Wooded soil site than samples from the Black soil site. Degradable intake protein (DIP) balance was deficient only for the 1994 control forage from the Gray-Wooded soil site. DIP was generally higher for the rejuvenated forages than control from both soil sites in all three years.

Energy was the most limiting nutrient in all feeding simulations. Both MP and ME allowed average daily gains were generally higher for steers eating hay from the Gray-Wooded soil site than from the Black soil site. As well, MP and ME allowed ADG was higher for hay from the control treatment than from the rejuvenated treatments in 1995 at the Gray-Wooded site and in 1996 at the Black soil site. This may have been due to the higher ADF values for the rejuvenated hays (Table 7.1). Total digestible nutrient input values (TDN) were estimated using ADF values for all forages, therefore predicted ME values and subsequently ADG would be lower for the rejuvenated forages.

However, rejuvenated forages had greater production (herbage mass) compared to control in all years which would allow either more animals to be fed or

Table 7.2. The effect of a mixed grass (75%)/legume (25%) diet on estimated intake and daily gain of steers.

| | Gray-Wooded Soil | | | | | | Black Soil | | | | | |
| | Control | | | Burn + Fertilizer[z] | | | Control | | | Burn + Fertilizer | | |
	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
Diet ME (Mcal kg⁻¹)	2.06	2.11	2.10	1.99	2.01	2.09	1.90	1.65	1.97	1.98	1.64	1.86
Diet NEm (Mcal kg⁻¹)	1.22	1.27	1.26	1.15	1.17	1.25	1.07	0.82	1.13	1.14	0.82	1.03
Diet NEg (Mcal kg⁻¹)	0.67	0.71	0.70	0.60	0.62	0.69	0.53	0.29	0.58	0.59	0.29	0.49
DIP Balance (g d⁻¹)	-1.8	128.9	28.7	241.8	166.4	88.6	227.3	192.2	291.5	388.9	220.2	315.3
DMI predicted (kg d⁻¹)	8.34	8.37	8.37	8.27	8.29	8.36	8.13	7.79	8.24	8.25	7.79	8.04
MP allowed ADG (kg d⁻¹)	0.61	0.69	0.65	0.66	0.66	0.72	0.53	0.27	0.60	0.69	0.30	0.55
ME allowed ADG (kg d⁻¹)	0.48	0.54	0.53	0.43	0.46	0.56	0.30	0.10	0.37	0.42	0.11	0.30

[z]Fertilizer applied at 100 kg N ha⁻¹, 45 kg P_2O_5 ha⁻¹, 23 kg K_2O ha⁻¹ and 12 kg S ha⁻¹

Table 7.3. The effect of rejuvenation on a mixed grass (75%)/legume (25%) hay on estimated animal average daily gain. (kg d^{-1})

	1994	1995	1996	MEAN
Gray-Wooded Soil Site				
Control	0.48	0.54	0.53	0.51
Burn + Fertilizer[z]	0.43	0.46	0.56	0.48
Black Soil Site				
Control	0.30	0.10	0.37	0.26
Burn + Fertilizer	0.42	0.11	0.30	0.28

[z]Fertilizer applied at 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}

the same number of animals to be fed for a longer time. Burn + fertilizer treated

pasture produced 4537 and 3876 kg ha^{-1} more total cumulative yield than control

(Chapter 3, Tables 3.1 and 3.5), at Black and Gray-Wooded sites, respectively.

Average predicted DMI was 8.2 kg d^{-1}, therefore each steer would consume 1060 kg

over the 130 d period. Consequently, more steers could be backgrounded on

rejuvenated hay compared to control hay harvested from both soil zones, based on

greater dry matter productivity of the rejuvenated pasture and nutritive data from

laboratory analysis. The results indicate that 52 and 44% more animals could be

backgrounded on rejuvenated hay harvested from Gray-Wooded and Black soil sites,

respectively. Animal ADG of steers eating rejuvenated hay was greater in yr 3 at the

Gray-Wooded soil site, and in yr 1 and 2 at the Black soil site than control hay.

Calculated mean animal ADG was greater for rejuvenated hay harvested from the

Black soil site than for control hay over the three years. Therefore this suggests that

rejuvenation of the forage stand by combined burning + fertilizer can increase not

only annual pasture productivity and quality but will result in a greater numbers of

animals backgrounded over the long term.

8.0 GENERAL CONCLUSIONS

The decision to rejuvenate a long establised forage stand is made to increase not only forage yield and quality but also the composition of more productive grass or legume species. Rejuvenation methods utilizing present forage species and minimal disturbance to the area are attractive alternatives.

Dry matter yield of tame forages was increased greatly in the year of application but only moderately in the second or third year following mechanical, chemical and combined rejuvenation methods. Deep-banding or slicing and flail mowing had only minimal effects on productivity of the forage. Burning increased DMY 40% over control in both first and second year only at the Gray-Wooded soil site. Spiking decreased DMY in the year of application at all sites and only increased production slightly the following two years. Peat and Bowes (1995) used a spiking treatment on a 20-year-old crested wheatgrass stand at Neudorf, Saskatchewan. They reported a surface roughness problem with the severity of the spike treatment, and lowered yields during the treatment year, however increases of 128%, 89%, 50% and 27% were observed over the next four years. Carryover effects from spiking were not observed in this study. In 1994, the high rate of nitrogen (DBLIQ+F), providing 200 kg N ha^{-1}, 90 kg P$_2$O$_5$ ha^{-1}, 46 kg K$_2$O ha^{-1} and 24 kg S ha^{-1} increased DMY at 4 sites, ranging 84 to 185% greater than control. This effect did not carry over into the second or third year of the study. Ukrainetz *et al.* (1988) also reported DMY of perennial forages increased in year of application on Gray Luvisolic soils with rates of 100, 200, 400 and 800 kg N ha^{-1}. However, on Dark Brown soils, annual applications resulted in up to 37% more DM than single applications (Ukrainetz and Campbell, 1988).

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Mechanical treatments (deep-banding, mowing and spiking) and burning combined with broadcast fertilizer (providing 100 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, 23 kg K_2O ha^{-1} and 12 kg S ha^{-1}) increased DMY in the first year, ranging from 20 to 120% more production than control treatments at all sites. Increased DMY of combined mechanical and fertilizer treatments was lower in the second and third year, ranging from 8 to 85% at all sites. Overall, DMY response of combined treatments was highly variable over the three years of the study.

Applying 200 kg N ha^{-1} increased forage crude protein in 1994, 55% more than control at one site. However, crude protein content of the 1995 and 1996 samples was similar to control values for this treatment. In British Columbia, nitrogen fertilization also increased ($P<0.05$) standing crop and pinegrass crude protein (CP) content compared to control (Wikeem *et al.*, 1993). Broadcast fertilizer combined with mechanical treatments decreased calcium content of the pasture. Nitrogen in the fertilizer blend decreased the legume composition, thereby reducing calcium concentration of the grass-legume mixture, an effect also reported by Rodger (1982). Burning tended to increase calcium content of the herbage after 3 years, possibly due to increased alfalfa composition observed in the burn plots. Phosphorous content increased with fertilizer combined with mechanical treatments but not with spiking, burning, deep-banding or mowing as single treatments.

Spiking reduced grass and legume composition, but increased the presence of annual weeds and bare ground. Burning increased alfalfa composition and decreased Kentucky bluegrass composition only in the first year. Broadcast fertilizer, at 100 kg N ha^{-1} increased the smooth bromegrass component each year but decreased the alfalfa component. Fertilizer (granular or liquid) alone or combined with mechanical treatments (deep-band, mow, spike or burn) increased the composition of smooth bromegrass and decreased composition of bluegrass, weeds and bare ground.

Spiking, mowing or deep-banding as single treatments failed to show a lasting significant effect on forage yield or quality at Pathlow, DHC, DNC or Rama. The younger stand at Insinger site showed significant yield increases in the third year for spike, deep-band and mow treatments.

The most consistent effect of rejuvenation on animal performance was increased DOMI intake and apparent digestibility of OM of hay from burn plots, harvested June 15 from Black or Gray-Wooded sites or July 15 from the Gray Wooded soil site. This may have been associated with increased alfalfa component of forage from the burn plots. Higher DMI of forage diets with increased legume component in the mixture were also reported by Hunt *et al.* (1985). Rejuvenation did not greatly affect the metabolizable energy content of the forages. The greatest effect of rejuvenation was the increased metabolic intake (g d^{-1} $kg^{-0.75}$) of June 15 harvested hay from burn plots at the Gray-Wooded soil site. These results suggest that increased animal forage intake and apparent digestibility of forage components and ME content may be realized with early harvest of the hay crop after imposing a spring prescribed burn of the pasture. As well, *in vitro* digestibility of forages such as used in this study, may be used to predict *in vivo* digestibility and to some extent, prediction of metabolizable energy from *in vitro* gas production and chemical composition. However, the accuracy of prediction of ME is likely to vary, depending on the type of forages used.

The use of NRC (1996) computer model Nutrient Requirement Series Application Model Level I to predict ADG using nutritive and DMY data of the forage indicated the advantage of increased numbers of animals backgrounded from hay cut from rejuvenation plots after three years. Not only did rejuvenated hays have greater DMY compared to control over all years and increased nutritive value in the first year, these effects of rejuvenation would allow either more animals to be fed the hay or a longer feeding period. This also resulted in predicted animal average gain

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per day being greater in 1996 on Gray-Wooded soils and in 1994 and 1995 on Black soils for rejuvenated hay compared to control hay. Finally, calculated mean animal gain per day was greater for rejuvenated hay harvested from the Black soil site than control hay over the long term.

A multi-site 3-year study within two soil zones evaluating the effects of rejuvenation of tame forages in the Aspen Parkland of Saskatchewan has never been done until these set of experiments. Rejuvenation should only be considered when there is a sufficient amount of productive species present in the stand and soil testing indicates a low availability of plant nutrients. Forage production, quality and botanical composition and laboratory and animal data were shown to be positively affected by rejuvenation techniques. However, the greatest effect was from fertilizer treatments on total forage yield after 3 years, thus indicating a benefit of increased animal productivity from consumption of the forage either as pasture or hay.

9.0 REFERENCES

Adebowale, E.A. and Nakashima, Y. 1992. Rumen degradation of some *Leguminosae* and *Graminae* roughages: Effect of chemical pre-treatment with or without cellulase preparation on dry matter and cell wall disappearance. Anim. Feed Sci. Technol. 38:219-235.

Aerts, J.V., De Brabander, D.L., Cottyn, B.G. and Buysse, F.X. 1977. Comparison of laboratory methods for predicting the organic matter digestibility of forages. Anim. Feed Sci. Technol. 2:337-349.

Alberta Agriculture. 1981. Alberta forage manual. Alberta Agriculture, Edmonton, AB. Agdex 120, 20-4.

Anderson, J.L. 1994. Exclosures on the Beaver Dam Slope in Arizona and Utah. Rangelands. 16:184-188.

Anderson, K.L., Smith, E.F. and Owensby, C.E. 1970. Burning bluestem range. J. Range Manage. 23:81-92.

Andrighetto, I., Gruber, L., Cozzi, G., Uray, G., Guidetti, G. and Buchgraber, K. 1992. Prediction of digestible organic matter in dry matter *in vivo* from the chemical composition, *in vitro* and *in situ* measurements on native mountain forages. Anim. Feed Sci. Technol. 39:323-333.

Arno, S.F. and Gruell, G.E. 1983. Fire history at the forest-grassland ecotone in southwestern Montana. J. Range Manage. 36:332-336.

Arny, A.C. and Schmid, A.R. 1942. A study of the inclined point quadrat method of botanical analysis of pasture mixtures. J. Am. Soc. Agron. 34:238-247.

Association of Official Analytical Chemists. 1990. Official methods of analysis of the Association of Official Analytical Chemists., 15th Ed. AOAC, Inc., Arlington, VA.

Bae, D.H., Welch, J.G. and Smith, A.M. 1979. Forage intake and rumination of sheep. J. Anim. Sci. 49:1292-1299.

Barnard, J.E., Davis, L.H., LeBaron, A.D. and Bushnell, J.L. 1985. No till renovation of meadows. Utah Agr. Exp. Stn. Bull. Vol. 46. pp 135-139.

Barnes, D.K. and Sheaffer, C.C. 1995. Alfalfa. In: Forages: Volume I, An introduction to grassland agriculture. Barnes, R.F., Miller, D.A. and Nelson, C.J. Eds. Iowa State University Press, Ames, Iowa. pp. 205-216.

Barnhart, S.K. 1995a. Interseeding and no-till pasture renovation. Iowa State Univ. Coop. Ext. Serv. Bull. No. 1097. 4 pp.

Barnhart, S.K. 1995b. Evaluating hay and pasture stands for winter injury. Iowa State Univ. Coop. Ext. Serv. Bull. No. 1362. 4 pp.

Barnhart, S.K. and Wedin, W.F. 1981. Reduced-tillage pasture renovation in the semihumid temperate region of the U.S.A. Proc. XIV Int. Grassld. Congr. pp. 545-547.

Bentley, H.L. 1899. Progress of experiments in forage crops and range improvement at Abilene, Tex. U.S.D.A. Div. Agrostology Cir. 23. 20 pp.

Berg, W.A. and Sims, P.L. 1995. Nitrogen fertilizer use efficiency in steer gain on old world bluestem. J. Range Manage. 48:465-469.

Berg. W.A. 1995. Response of a mixed native warm-season grass planting to nitrogen fertilization. J. Range Manage. 48:64-67.

Bergen, P., Moyer, J.R. and Kozub, G.C. 1990. Dandelion (*Taraxacum officinale*) use by cattle grazing on irrigated pasture. Weed Tech. 4:258-263.

Beuvink, J.M.W. and Kogut, J. 1993. Modeling gas production kinetics of grass silages incubated with buffered ruminal fluid. J. Anim. Sci. 71:1041-1046.

Beuvink, J.M.W. and Spoelstra, S.F. 1994. *In vitro* gas production kinetics of grass silages treated with diffe. ent cell wall-degrading enzymes. Grass and Forage Sci. 49:277-283.

Bittman, S., Waddington, J. and McCartney, D.H. 1991. Performance of alfalfa strains grown in mixture with smooth bromegrass as affected by management. Can. J. Plant Sci. 71:1029-1037.

Blackshaw, R.E., Larney, F.O., Lindwall, C.W. and Kozub, G.C. 1994. Crop rotation and tillage effects on weed populations on the semi-arid Canadian prairies. Weed Technol. 8:231-237.

Blaxter, K.L. 1964. Utilization of the metabolizable energy of grass. Proc. Nut. Soc. 23:62-71.

Blaxter, K.L., Wainman, F.W. and Wilson, R.S. 1961. The regulation of food intake by sheep. Anim. Prod. 3:51-61.

Blummel, M. and Orskov, E.R. 1993. Comparison of *in vitro* gas production and nylon bag degradability of roughages in predicting feed intake in cattle. Anim. Feed Sci. Technol. 40:109-119.

Bowes, G.G. and Friesen, G. 1967. The use of paraquat to improve pastures in Manitoba. Weeds. 15:241-243.

Bozzo, J.A., Beasom, S.L. and Fulbright, T.E. 1992a. Vegetation responses to 2 brush management practices in south Texas. J. Range Manage. 45:170-175.

Bozzo, J.A., Beasom, S.L. and Fulbright, T.E. 1992b. White-tailed deer use of rangeland following browse rejuvenation. J. Range Manage. 45:496-499.

Branson, F.A., Miller, R.F. and McQueen, I.S. 1966. Contour furrowing, pitting and ripping on rangelands of the western United States. J. Range Manage. 19:182-190.

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Brown, B.A., Munsell, R.I. and King, A.V. 1960. Fertilization and renovation of grazed, permanent pastures. Bull. Univ. of Conn. Agric. Exp. Stn. Storrs, CN. Bull 350. 27 pp.

Brown, D. 1954. Methods of surveying and measuring vegetation. Commonw. Bur. Pastures and Field Crops, Hurley, Berks., Bull. 42:1-223.

Burns, J.D. 1978. No-till pasture renovation. Publ. Univ. Ga. Agric. Exp. Stn. Vol. 1 Issue No. 5. pp. 49-52.

Campbell, C.A., Leyshon, A.J., Ukrainetz, H. and Zentner, R. 1986. Time of application and source of nitrogen fertilizer on yield, quality, nitrogen recovery and net returns for dryland forage grasses. Can. J. Plant Sci. 66:915-931.

Campbell, M.H. 1974. Effects of glyphosate on the germination and establishment of surface-sown pasture species. Aust. J. Exp. Agric. Anim. Husb. 14:557-560.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.

Canfield, R.H. 1950. Sampling ranges by the line interception method. S.W. For. and Range Exp. Sta. Res. Rept. 4, 28 pp.

Chamblee, D.S. and Collins, M. 1988. Relationships with other species in a mixture. In: Alfalfa and Alfalfa Improvement. Hanson, A.A., Barnes, D.K. and Hill, Jr., R.R. (Ed.) Amer. Soc. Agron. Inc., Crop Sci. Soc. Amer. Inc., Soil Sci. Soc. Amer. Inc. Madison, WI. pp. 439-462.

Cherney, J.H. and Volenec, J.J. 1992. Forage evaluation as influenced by environmental replication: A review. Crop Sci. 32:841-846.

Chiasson, T.C. 1960. The effects of various increments of N, P and K on the yield and botanical composition of permanent pastures. Can. J. Plant Sci. 40:235-247.

Christen, A.M., Seoane, J.R. and Leroux, G.D. 1990. The nutritive value for sheep of quackgrass and timothy hays harvested at two stages of growth. J. Anim. Sci. 68:3350-3359.

Clarke, S.E., Campbell, J.A. and Campbell, J.B. 1942. An ecological and grazing capacity study of the native grass pastures in southern Alberta, Saskatchewan and Manitoba. Dom. Can. Dept. Agr. Tech. Bull. 44, 31 pp.

Cochran, R.C., Adams, D.C., Wallace, J.D. and Galyean, M.L. 1986. Predicticting digestibility of different diets with internal markers: Evaluation of four potential markers. J. Anim. Sci. 63:1476-1483.

Coelho, M., Hembry, F.G., Barton, F.E. and Saxton, A.M. 1988. A comparison of microbial, enzymatic, chemical and near-infrared reflectance spectroscopy methods in forage evaluation. Anim. Feed Sci. Technol. 20:219-231.

Cohen, R.D.H., Thomas, L.R. and Wright, S.B.M. 1987. Effect of nitrogen fertilizer on the nutrition and production of beef cattle grazing a crested wheatgrass/smooth bromegrass pasture. Proc. West. Sec. Amer. Soc. Anim. Sci. pp. 191-195.

Coleman, S.W., Barton, II, F.E. and Meyer, R.D. 1985. The use of near-infrared reflectance spectroscopy to predict species composition of forage mixtures. Crop Sci. 25:834-837.

Cook, C.W. and Stubbendieck, J. Eds. 1986. Range research: Basic problems and techniques. Society for range management. Denver, CO. 336 pp.

Cooper, C.S., Hyder, D.N., Petersen, R.G. and Sneva, F.A. 1957. The constituent differential method of estimating species composition in mixed hay. Agron. J. 49:190-193.

Cottam, G. and Curtis, J.T. 1956. The use of distance measures in phytosociological sampling. Ecology. 37:451-460.

Cotter, P.F., Dahl, B.E. and Scott, G. 1983. Utilization of a short duration grazing system for renovation and management of weeping lovegrass (*Eragrostis curvula*) in the rolling plains of Texas. Proc. Forage and Grassl. Conf. Eau Claire, WI.

Coupland, R.T. 1950. Ecology of mixed prairie in Canada. Ecological Monog. 20:271-315.

Crocker, R.L. and Tiver, N.S. 1948. Survey methods in grassland ecology. J. Br. Grassl. Soc. 3:1-26.

Davies, A., Adams, W.A. and Wilman, D. 1989. Soil compaction in permanent pastures and its amelioration by slitting. J. Agric. Sci. (Camb.) 113:189-197.

Deinum, B., Steg, A. and Hof, G. 1984. Measurement and prediction of digestibility of forage maize in the Netherlands. Anim. Feed Sci. Technol. 10:301-313.

Derrick, R.W., Moseley, G. and Wilman, D. 1993. Intake, by sheep, and digestibility of chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. J. Agr. Sci. (Camb.). 120:51-61.

Dhanoa, M.S. 1988. On the analysis of dacron bag data for low degradability feeds. Grass and Forage Sci. 43:441-444.

Dill, T.O., Waller, S.S., Vogel, K.P., Gates, R.N. and Stroup, W.W. 1986. Renovation of seeded warm-season pastures with atrazine. J. Range Manage, 39:72-75.

Dix, R.L. 1961. An application of the point-centred quarter method to the sampling of grassland vegetation. J. Range Manage. 14:63-69.

Dodds. D.L. and Van Der Puy, D.L. 1985. Grassland renovation. North Dakota State Univ. Ext. Serv. Publ. R-544. 6 pp.

Douglas, G. 1965. Chemical renewal of lowland pastures. J. Brit. Grassl. Soc. 20:233-240.

Engle, D.M., Stritzke, J.F., Bidwell, T.G. and Claypool, P.L. 1993. Late-summer fire and follow-up herbicide treatments in tallgrass prairie. J. Range Manage. 46:542-547.

Environment Canada. 1994. Canadian monthly climate data and 1961-1990 normals. 1994 release CD-ROM.

Environment Canada. 1997. Canadian monthly climate data 1994-96. Saskatchewan Environmental Services Centre, Saskatoon, SK.

Erickson, L.R. and Currie, P.O. 1985. Rangeland improvement machine for multiple renovation practices on semi-arid rangelands. Tran. Amer. Soc. Agr. Eng. 28:94-96.

Evans, J.K. 1980. Improving pastures through renovation. Proc. Forage Grassl. Conf. pp. 149-163.

Evans, J.K., Lacefield, G.D., Taylor, T.H. and Smith, E.M. 1985. Renovating grass fields. Univ. KY. Coop. Ext. Serv. Vol. 26. 2 pp.

Fairey, N.A. 1991. Effects of nitrogen fertilizer, cutting frequency and companion legume on herbage production and quality of four grasses. Can. J. Plant Sci. 71:717-725.

Feistmann, F.J. 1979. Range renovation equipment for British Columbia interior grassland. Ann. Rep. Veg. Rehabil. Equip. Workshop. U.S.D.A. Forest Serv. Washington, D.C. Vol 4. pp. 44-46.

Fox, D.G. and Barry, M.C. 1994. Predicting cattle net energy and protein requirements and supply under widely varying conditions. Livestock production for the 21st century. Ed. Thacker, P. University of Saskatchewan, Saskatoon, SK. pp. 41-58.

Fox, D.G., Barry, M.C., Pitt, R.E., Roseler, D.K. and Stone, W.C. 1995. Application of the Cornell Net Carbohydrate and Protein Model for cattle consuming forages. J. Anim. Sci. 73:267-277.

Fox, D.G., Sniffen, C.J., O'Connor, J.D., Russell, J.B. and Van Soest, P.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.

France, J., Dhanoa, M.S., Theodorou, M.K., Lister, S.J., Davies, D.R. and Isac, D. 1993. A model to interpret gas accumulation profiles assiciated with *in vitro* degradation of ruminant feeds. J. Theor. Biol. 163:99-111.

Frengley, G.A.G. and Andersen, C.J. 1989. Pragmatism in hill pasture renovation. Proc. N. Z. Grassl. Assoc. 50:151-156.

Gay, C.W. and Dwyer, D.D. 1965. Effects of one year's nitrogen fertilization on native vegetation under clipping and burning. J. Range Manage. 18:273-277.

Gaylean, M.L. and Goetsch, A.L. 1993. Utilization of forage fiber by ruminants. In: Cell Wall Structure and Digestibility. Jung, H.G., Buxton, D.R., Hatfield, R.D. and Ralph. J. (Ed.) pp. 33-40. Amer. Soc. Agron. Inc., Crop Sci. Soc. Amer. Inc.. Soil Sci. Soc. Amer. Inc. Madison, WI.

Gerson, T., King, A.S.D., Kelly, K.E. and Kelly, W.J. 1988. Influence of particle size and surface area on *in vitro* rates of gas production, lipolysis of triacylglycerol and hydrogenation of linoleic acid by sheep rumen digesta or *Ruminococcus flavefaciens*. J. Agric. Sci. (Camb.). 110:31-37.

Gill, K.S. and Arshad, M.A. 1995. Weed flora in the early growth period of spring crops under conventional, reduced and zero tillage systems on a clay soil in northern Alberta, Canada. Soil Tillage Res. 33:65-79.

Gillen, R.L., Rollins, D. and Stritzke, J.F. 1987. Atrazine, spring burning and nitrogen for improvement of tallgrass prairie. J. Range Manage. 40:444-447.

Glatzle, A., Mechel, A. and Vaz Lourenco, M.E. 1993. Technical notes: Botanical components of annual Mediterranean grassland as determined by point-intercept and clipped methods. J. Range Manage. 46:271-274.

Goering, H.K. and Van Soest, P.J. 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). Agr. Handbook No. 379. U.S.D.A. U.S. Govt. Print Office. Wash., D.C. 20 pp.

Graber, L.F. 1927. Improvement of permanent bluegrass pastures with sweet clover. J. Amer. Soc. Agron. 19:944-1006.

Greenberg, N.A. and Shipe, W.P. 1979. Comparison of the abilities of trichloacetic, Picric, sulfosalicylic and tungstic acids to precipitate protein hydrolysates and proteins. J. Food Sci. 44:735-737.

Griffith, L.W., Schuman, G.E., Rauzi, F. and Baumgartner, R.E. 1984. Mechanical renovation of shortgrass prairie for increased herbage production. J. Range Manage. 38:7-10.

Haferkamp, M.R., Volesky, J.D., Borman, M.M., Heitschmidt, R.K. and Currie, P.O. 1993. Effects of mechanical treatments and climate factors on the productivity of Northern Great Plains rangelands. J. Range Manage. 46:346-350.

Hambleton, L. 1976. Semi-automated method for the simultaneous determination of phosphorous, calcium and crude protein in animal feeds. Adv. Auto. Anal. 2:147-154.

Harrington, J.D. and Washko, J.B. 1962. Sod subjugation with herbicides for pasture renovation. Bull. Penn. State Univ. Agr. Exp. Sta. Bull. 694. 19 pp.

Hart, R.H., Haise, H.R., Walker, D.D. and Lewis, R.D. 1980. Mountain meadow management: 12 years of variety, fertilization, irrigation and renovation research. U.S.D.A. Res. Report Bull. Cheyenne, WY. No. 16. 29 pp.

Hart, R.H., Shoop, M.C. and Ashby, M.M. 1995. Nitrogen and atrazine on shortgrass: Vegetation, cattle and economic responses. J. Range Manage. 48:165-171.

Haydock, K.P. and Shaw, N.H. 1975. The comparitive yield method for estimating dry matter yield of pasture. Aust. J. Exp. Agric. Anim. Husb. 15:663-670.

Hazell, D.B. 1965. Vegetative composition, forage production and plant vigor as influenced by date of mowing. J. Range Manage. 18:261-264.

Heaney, D.P., Pigden, W.J. and Minson, D.J. 1969. Indoor feeding trials for estimating digestibility and intake. In: Experimental methods for evaluating herbage. Campbell, J.B. Ed. Canada Department of Agriculture. Pub. 1315. Queen's Printer. Ottawa, ON. pp. 185-199.

Heitschmidt, R.K., Volesky, J.D., Haferkamp, M.R. and Currie, P.O. 1993. Steer performance on native and modified Northern Great Plains rangeland. J. Range Manage. 46:529-533.

Heslehurst, M.R. 1971. The point quadrat method of vegetation analysis: A review. Univ. of Reading Dept. of Agr. No. 10. 18 pp.

Heyting, A. 1968. Discussion and development of the point-centred quarter method of sampling grassland vegetation. J. Range Manage. 21:370-380.

Hidayat, K., Hillman, K., Newbold, C.J. and Stewart, C.S. 1993. The contributions of bacteria and protozoa to ruminal forage fermentation *in vitro*, as determined by microbial gas production. Anim. Feed Sci. Technol. 42:193-208.

Hilmon, J.B. and Hughes, R.H. 1965. Fire and forage in the wiregrass type. J. Range Manage. 18:251-254.

Hodel, D.R. and Pittenger, D.R. 1994. Responses of eight groundcover species to renovation by mowing. J. Environ. Hort. 12:4-7.

Hoffman, P.C., Sievert, S.J., Shaver, R.D., Welch, D.A. and Combs, D.K. 1993. *In situ* dry matter, protein and fibre degradation of perennial forages. J. Dairy Sci. 76:2632-2643.

Holechek, J.L., Wofford, H., Arthun, D., Galyean, M.L. and Wallace, J.D. 1986. Evaluation of total fecal collection for measuring cattle forage intake. J. Range Manage. 39:2-4.

Holloway, J.W., Estell, II., R.E. and Butts, Jr., W.T. 1981. Relationship between fecal components and forage consumption and digestibility. J. Anim. Sci. 52: 836-848.

Horton, G.M.J. and McElroy, L.W. 1977. Nutritive value of sedge and Kentucky bluegrass hays grown in Alberta. Can. J. Plant Sci. 57:187-193.

Houston, W.R. 1977. Species susceptibility to atrazine herbicide on shortgrass range. J. Range Manage. 30:50-52.

Houston, W.R. and Van der Sluijs, D.H. 1973. Increasing crude protein content of forage with atrazine on shortgrass prairie. USDA-ARS Prod. Res. Rep. 153.

Howard, M.D., Muntifering, R.B., Howard, M.M. and Hayek, M.G. 1992. Effects of time and level of energy supplementation on intake and digestibility of low-quality tall fescue hay by sheep. J. Anim. Sci. 72:51-60.

Hultgreen, G. and Leduc, P. 1993. A demonstration of pasture renovation techniques for increased forage production in Saskatchewan. Agriculture Development Fund Final Report.

Hume, L. and Shirriff, S. 1995. The effect of quadrat shape and placement on the accuracy of yield and density estimates for crops seeded in narrow rows. Can. J. Plant Sci. 75:889-892.

Hungate, R.E. 1966. The rumen and its microbes. Academic Press, New York, N.Y.

Hunt, C.W., Paterson, J.A. and Williams, J.E. 1985. Intake and digestibility of alfalfa-tall fescue combination diets fed to lambs. J. Anim. Sci. 60:301-306.

Hurto, K.A. and Turgeon, A.J. 1979. Effect of thatch on residual activity of nonselective herbicides used in turfgrass renovation. Agron. J. 71:66-71.

Hutchinson, I., Colosi, J. and Lewin, R.A. 1984. The biology of Canadian weeds. 63. *Sonchus asper* (L.) Hill and *S. oleraceus* L. Can. J. Plant Sci. 64:731-744.

Hyder, D.N., Houston, W.R. and Burwell, J.B. 1976. Drought resistance of blue grama as affected by atrazine and N fertilizer. J. Range Manage. 29:214-216.

Johnson, B.J. 1988. Timing of multiple glyphosate and SC-0224 treatments for bermudagrass renovation in turf. Res. Rep. Univ. Georgia Agric. Exp. Stn. No. 561. 12 pp.

Johnson, K.D., Lechtenberg, V.L., Vorst, J.J. and Hendrix, K.S. 1982. Indirect estimation of grass-legume ratios in mixed swards. Agron. J. 74:1089-1091.

Jones, L. 1962. Herbicides to aid pasture renovation. J. Br. Grassld. Soc. 17:85-86.

Jorgenson, T. and Bjorge, H. 1993. Prescribed pasture burn for improved grazing. Agriculture Development Fund Project Final Report No. D-91-CR-0979.

Kartchner, R.J., Wight, J.R., Bishop, J.L. and Bellows, R.A. 1983. Beef and forage production on contour furrowed rangeland interseeded with alfalfa. J. Range Manage. 36:479-482.

Khazaal, K., Dentinho, M.T., Ribeiro, J.M. and Orskov, E.R. 1993. A comparison of gas production during incubation with rumen contents *in vitro* and nylon bag degradability as predictors of the apparent digestibility *in vivo* and the voluntary intake of hays. Anim. Prod. 57:105-112.

Khazaal, K., Dentinho, M.T., Ribeiro, J.M. and Orskov, E.R. 1995. Prediction of apparent digestibility and voluntary intake of hays fed to sheep: Comparison between using fiber components, *in vitro* digestibility or characteristics of gas production or nylon bag degradation. Anim. Sci. 61:527-538.

Koch, D.W., Holter, J.B., Coates, D.M. and Mitchell, J.R. 1987. Animal evaluation of forages following several methods of field renovation. Agron. J. 79:1044-1048.

Krishnamoorthy, U., Soller, H., Steingass, H. and Menke, K.H. 1991. A comparititive study on rumen fermentation of energy supplements *in vitro*. J. Anim. Physiol. Anim. Nutr. 65:28-35.

Kunelius, H.T. 1981. Renovation of pastures and haylands in Atlantic provinces of Canada. Prog. Rep. Clovers Spec. Purpose Legumes Res. Vol 14. pp. 77.

Lavin, F. 1967. Fall fertilization of intermediate wheatgrass in the southwestern Ponderosa pine zone. J. Range Manage. 20:16-21.

Lawrence, B.K., Waller, S.S., Moser, L.E., Anderson, B.E. and Larson, L.L. 1995. Weed suppression with grazing or atrazine during big bluestem establishment. J. Range Manage. 48:376-379.

Leasure, J.K. 1949. Determining the species composition of swards. Agron. J. 41:204-206.

Lemna, W.K. and Messersmith, C.G. 1990. The biology of Canadian weeds. 94. *Sonchus arvensis* L. Can. J. Plant Sci. 70:509-532.

Leonard, W.F, Bruce, S.J., Russell, A.J. and Cook, M.R. 1989. Proc. N. Z. Grassl. Assoc. 46:77-82.

Levy, B.E. and Madden, A.E. 1933. The point method of pasture analysis. N. Z. J. Agric. 46:267-279.

López, S., Hovell, F.D.DeB., Manyuchi, B. and Smart, R.I. 1995. Comparison of sample preparation methods for the determination of the rumen degradation characteristics of fresh and ensiled forages by the nylon bag technique. Anim. Sci. 60:439-450.

Lucero, D.W., Martens, D.C., McKenna, J.R. and Starner, D.E. 1995. Poultry litter effects on unmanaged pasture yield, nitrogen and phosphorous uptakes and botanical composition. Commun. Soil Sci. Plant Anal. 26:861-881.

Malhi, S.S., Heier, K., Nielsen, K. and Davies, W.E. 1995. Pasture rejuvenation through mechanical aeration. Alberta Soils Workshop.

Malhi, S.S., Laverty, D.H., Harapiak, J.T., Kryzanowski, L.M. and Penney, D.C. 1993. Fertilizer management for forage crops in central Alberta. Agriculture Canada, Ottawa, ON. Technical Bulletin 1993-3E. 39 pp.

Malik. N. and Waddington, J. 1990. No-till pasture renovation after sward suppresion by herbicides. Can. J. Plant Sci. 70:261-267.

Marten, G.C. 1964. Visual estimation of botanical composition in simple legume-grass mixtures. Agron. J. 56:549-552.

Marten, N.P., Sheaffer, C.C., Wyse, D.L. and Schriever, D.A. 1983. Herbicide and planting date influence establishment of sod-seeded alfalfa. Agron. J. 75:951-955.

Martin, N.P., Hasbargen, P.R., Arthaud, R.L. and Sullivan, G.J. 1983. Pasture demonstration for beef: Agronomic considerations. Proc. XIV Int. Grassld. Congr. Lexington, KY. pp. 795-798.

Martin, G.C., Sheaffer, C.C. and Wyse, D.L. 1987. Forage nutritive value and palatability of perennial weeds. Agron. J. 79:980-986.

Masters, R.A., Mitchell, R.B., Vogel, K.P. and Waller, S.S. 1993. Influence of improvement practices on big bluestem and indiangrass seed production in tallgrass prairies. J. Range Manage. 46:183-188.

Masters, R.A., Vogel, K.P. and Mitchell, R.B. 1992. Response of central great plains tallgrass prairie to fire, fertilizer and atrazine. J. Range Manage. 45:291-295.

Mbwile, R.P. and Udén, P. 1991. Comparison of laboratory methods on precision and accuracy of predicting forage organic matter digestibility. Anim. Feed Sci. Technol. 32:243-251.

McCaughey, W.P. 1989. Management of crested wheatgrass pastures using plant growth regulators and nitrogen. Ph.D. thesis. University of Saskatchewan. Saskatoon, SK.

McCaughey, W.P. and Cohen, R.D.H. 1989. Effect of plant growth regulators and harvest date on yield, botanical composition, chemical constitution, intake and digestibility of crested wheatgrass-alfalfa herbage by sheep. Can. J. Anim. Sci. 69:745-756.

McCaughey, W.P. and Simons, R.G. 1996. Harvest management and N-fertilization effects on yield and regrowth of smooth bromegrass, crested wheatgrass and meadow bromegrass in the eastern prairies. Can. J. Plant Sci. 76:773-782.

McDonald, I. 1981. A revised model for the estimation of protein degradability in the rumen. J. Agric. Sci. (Camb.) 96:251-252.

McMurphy, W.E. and Anderson, K.L. 1965. Burning Flint hills range. J. Range Manage. 18:265-269.

Mehrez, A.Z. and Orskov, E.R. 1977. A study of the artificial fibre bag technique for determining the digestibility of feeds in the rumen. J. Agric. Sci. (Camb.) 88:645-650.

Menke, K.H. and Steingass, H. 1988. Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production. Anim. Res. Dev. 28:7-55.

Menke, K.H., Raab, L., Salewski, A., Steingass, H., Fritz, D. and Schneider, W. 1979. The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor *in vitro*. J. Agric. Sci. (Camb.) 93:217-222.

Michalk, D.L. and Herbert, P.K. 1977. Assessment of four techniques for estimating yield on dryland pastures. Agron. J. 69:864-868.

Michalk, D.L., Nan-Ping, F. and Chin-Ming, Z. 1993a. Improvement of dry tropical rangelands in Hainan Island, China: 1. Evaluation of pasture legumes. J. Range Manage. 46:331-339.

Michalk, D.L., Nan-Ping, F. and Chin-Ming, Z. 1993b. Improvement of dry tropical rangelands in Hainan Island, China: 2. Evaluation of pasture grasses. J. Range Manage. 46:339-345.

Minson, D.J. 1990. Forage in ruminant nutrition. New York, N.Y. Academic Press Inc. pp. 483.

Mir, Z., Acharya, S.N., Mir, P.S., Taylor, W.G., Zaman, M.S., Mears, G.J. and Goonewardene, L.A. 1997. Nutrient composition, *in vitro* gas production and digestibility of fenugreek (*Trigonella foenum-graecum*) and alfalfa forages. Can. J. Anim. Sci. 77:119-124.

Misselbrook, T. H., Laws, J.A. and Pain, B.F. 1996. Surface application and shallow injection of cattle slurry on grassland: nitrogen losses, herbage yields and nitrogen recoveries. Grass and Forage Sci. 51:270-277.

Moore, K.J., Roberts, C.A. and Fritz, J.O. 1990. Indirect estimation of botanical composition of alfalfa-smooth bromegrass mixtures. Agron. J. 82:287-290.

Mountier, N.S. and Radcliffe, J.E. 1964. Problems in measuring pasture composition in the field. Part III. An evaluation of point analysis, dry-weight analysis and tiller analysis. N.Z.J. Bot. 2:131-142.

Moyer, J.R. and Smoliak, S. 1987. Shrubby cinquefoil control changes range forage production. Can. J. Plant Sci. 67:727-734.

Naeth, M.A., Bailey, A.W., Chanasyk, D.S. and Pluth, D.J. 1991. Water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. J. Range Manage. 44:13-17.

Naga, M.A. and Harmeyer, J.H. 1975. Gas and volatile fatty acid production at different rates of rumen microbial protein synthesis *in vitro*. J. Anim. Sci. 40:374-379.

Najda, H.G., Darwent, A.L. and Hamilton, G. 1982. The biology of weeds. 54. *Crepis tectorum* L. Can. J. Plant Sci. 62:473-481.

National Academy of Sciences-National Research Council (NRC). 1985. Nutrient requirements of sheep. 5th Rev. Ed. National Academy Press, Washington, D.C.

National Academy of Sciences-National Research Council (NRC). 1996. Nutrient requirements of beef cattle. 7th Rev. Ed. National Academy Press, Washington, D.C.

Neathery, M.W. 1972. Conventional digestion trials *vs.* nylon bag technique for determining seasonal difference in quality of midland bermudagrass forage. J. Anim. Sci. 34:1075-1084.

Nelson, B.D., Montgomery, C.R., Schilling, P.E. and Mason, L. 1975. Effects of fermentation time on *in vivo/in vitro* relationships. J. Dairy Sci. 59:270-277.

Nozière, P. and Michalet-Doreau, B.M. 1996. Validation of in sacco method: Influence of sampling site, nylon bag or rumen contents, on fibrolytic activity of solid-associated microorganisms. Anim. Feed Sci. Technol. 57:203-210.

Nsahlai, I.V. and Umunna, N.N. 1996. Comparison between reconstituted sheep faeces and rumen fluid inocula and between *in vitro* and *in sacco* digestibility methods as predictors of intake and *in vivo* digestibility. J. Agr. Sci. (Camb.). 126:235-248.

Nuttall, W.F., Cooke, D.A., Waddington, J. and Robertson, J.A. 1980. Effect of nitrogen and phosphorous fertilizers on a bromegrass and alfalfa mixture grown under two systems of pasture management. I. Yield, percentage legume in sward and soil test. Agron. J. 72:289-294.

Nuttall, W.F., McCartney, D.H., Bittman, S., Horton, P.R. and Waddington, J. 1991. The effect of N, P, S fertilizer, temperature and precipitation on the yield of bromegrass and alfalfa pasture established on a Luvisolic soil. Can. J. Plant Sci. 71:1047-1055.

O'Connor, J.D., Sniffen, C.J., Fox, D.G. and Chalupa, W. 1993. A net carbohydrate and protein system for evaluating cattle diets. IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298-1311

Olsen, F.J. and Tiharuhondi, E.R. 1972. The productivity and botanical composition of some selected grass/legume pasture mixtures at different seeding rates. E. Afr. Agric. For. J. 38:16-22.

Olsen, F.J., Jones, J.H. and Patterson, J.J. 1981. Sod-seeding forage legumes in a tall fescue sward. Agron. J. 73:1032-1036.

Orskov, E.R. and McDonald, I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. (Camb.). 92:499-503.

Orskov, E.R. and Ryle, M. 1990. Energy nutrition in ruminants. Elsevier Sci. Publ. Co. Inc. New York, N.Y.

Orskov, E.R., Reid, G.W. and Kay, M. 1988. Prediction of intake by cattle from degradation characteristics of roughages. Anim. Prod. 46:29-34.

Owensby, C.E. and Anderson, K.L. 1967. Yield responses to time of burning in the Kansas Flint hills. J. Range Manage. 20:12-16.

Owensby, C.E. and Smith, E.F. 1979. Fertilizing and burning Flint Hills range. J. Range Manage. 32:254-258.

Parish, R., Turkington, R. and Klein, E. 1990. The influence of mowing, fertilization and plant removal on the botanical composition of an artificial sward. Can. J. Bot. 68:1080-1085.

Pearen, J.R. and Baron, V.S. 1996. Productivity and composition of smooth and meadow bromegrass mixtures with alfalfa under frequent cutting management. Can. J. Plant Sci. 76:763-771.

Pearen, J.R. and Koeghan, J.M. 1982. A review of factors influencing successful pasture renovation. Trop. Agric. (Trinidad) 59:179-182.

Pearen, J.R., Baron, V.S. and Cowan, I.W. 1995. Productivity and composition of bromegrass alfalfa mixtures for hay in the Aspen Parklands of western Canada. Can. J. Plant Sci. 75:429-436.

Peat, H. and Bowes, G.G. 1995. Spiking to rejuvenate crested wheatgrass. In: Direct seeding into crested wheatgrass. Agriculture Development Fund Final Report. No. D-90-CR-0822.

Pell, A.N. and Schofield, P. 1993. Computerized monitoring of gas production to measure forage digestion *in vitro*. J. Dairy Sci. 76:1063-1073.

Petersen, R.G., and Chamblee, D.S. 1955. Optimum size of sample for hand separation of forage crops into their component species in small plot experiments. Agron. J. 47:20-23.

Petit, H.V., Seone, J.R. and Flipot, P.M. 1985. Digestibility and voluntary intake of forages fed as hay or wilted silage to beef steers. Can. J. Anim. Sci. 65:879-889.

Pitt, R.E., Van Kessel, J.S., Fox, D.G., Barry, M.C. and Van Soest, P.J. 1996. Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. J. Anim. Sci. 74:226-230.

Poissonet, P.S., Poissonet, J.A., Godron, M.P. and Long, G.A. 1973. A comparison of sampling methods in dense herbaceaous pasture. J. Range Manage. 26:65-67.

Popolizio, C.A., Goetz, H. and Chapman, P.L. 1994. Short-term response of riparian vegetation to 4 grazing treatments. J. Range Manage. 47:48-53.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1998. Grazing system and stocking rate effects on the productivity, botanical composition and soil surface characteristics of alfalfa-grass pastures. Can. J. Anim. Sci. 77:669-676.

Poppi, D.P. and McLennan, S.R. 1995. Protein and energy utilization by ruminants at pasture. J. Anim. Sci. 73:278-290.

Prigge, E.C., Baker, M.J. and Varga, G.A. 1984. Comparative digestion, rumen fermentation and kinetics of forage diets by steers and wethers. J. Anim. Sci. 59:237-245.

Radcliffe, J.E. and Mountier, N.S. 1964a. Problems in measuring pasture composition in the field. Part I. Discussion of general problems and some considerations of the point method. N. Z. J. Bot. 2:90-97.

Radcliffe, J.E. and Mountier, N.S. 1964b. Problems in measuring pasture composition in the field. Part II. The effect of vegetation height using the point method. N. Z. J. Bot. 2:98-105.

Rasmussen, G.A., Scifres, C.J. and Drawe, D.L. 1983. Huisache growth, browse quality and use following burning. J. Range Manage. 36:337-342.

Rauzi, F. 1974. Mechanical and chemical range renovation in southeastern Wyoming. J. Range Manage. 27:48-52.

Rauzi, F. 1975. Severe mechanical and chemical range renovation in northeastern Wyoming. J. Range Manage. 28:319-326.

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Rauzi, F. 1978. High rates of nitrogen change composition of shortgrass rangeland in southeastern Wyoming. J. Range Manage. 31:366-370.

Rauzi, F. and Fairbourn, M.L. 1983. Effects of annual applications of low N fertilizer rates on a mixed grass prairie. J. Range Manage. 36:359-362.

Reynolds, J.P., Fulbright, T.E. and Beasom, S.L. 1992. Mechanical rejuvention to dampen seasonal variation in chemical composition of browse. J. Range Manage. 45:589-592.

Robinson, S.E. and Winch, J.E. 1985. Pasture renovation. Fact Sheet Ont. Minist. Agr. Food. Vol. 85:112 5 pp.

Rodger, J.B.A. 1982. The effect of fertilizer nitrogen, phosphorous and potassium on the calcium, magnesium and phosphorous status of pasture cut for silage. J. Agric. Sci. (Camb.). 99:199-205.

Roe, M.B., Sniffen, C.J. and Chase, L.E. 1990. Techniques for measuring protein fractions in feedstuffs. Proc. Cornell Nutr. Conf. Feed Manuf. Cornell University, Ithaca, NY. pp. 81.

Rook, A.J. and Gill, M. 1990. Prediction of the voluntary intake of grass silages by beef cattle. I. Linear regression analyses. Anim. Prod. 50:425-438.

Rook, A.J., Dhanoa, M.S. and Gill, M. 1990a. Prediction of the voluntary intake of grass silages by beef cattle. II. Principal component and ridge regression analyses. Anim. Prod. 50:439-454.

Rook, A.J., Dhanoa, M.S. and Gill, M. 1990b. Prediction of the voluntary intake of grass silages by beef cattle. III. Precision of alternative predicition models. Anim. Prod. 50:455-466.

Rubio, H.O., Wood, M.K., Gomez, A. and Reyes, G. 1996. Native forage quality, quantity and profitability as affected by fertilization in northern Mexico. J. Range Manage. 49:315-319.

Russell, J.B., O'Connor, J.D., Fox, D.G., Van Soest, P.J. and Sniffen, C.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.

Russell, J.S. 1985. Soil treatment, plant species and management effects on improved pastures on a solodic soil in the semi-arid subtopics. Aust. J. Exp. Agric. 25:367-379.

Ryerson, D.E., Taylor, J.E., Baker, L.O., Harold, L., Houlton, A.R. and Stroud, D.W. 1970. Clubmoss on Montana rangelands. Montana Agr. Exp. Sta. Bull. 645. 116 pp.

Samson, J.R. and Moser, L.E. 1982. Sod-seeding perennial grasses into eastern Nebraska pastures. Agron. J. 74:1055-1060.

Saskatchewan Soil Survey. 1992. Saskatoon Institute of Pedology. University of Saskatchewan, Saskatoon, SK.

Scales, G.H., Streeter, C.L., Denham, A.H. and Ward, G.M. 1974. A comparison of indirect methods of predicting in vivo digestibility of grazed forages. J. Anim. Sci. 38:192-199.

Schneider, B.H. and Flatt, W.P. 1975. The evaluation of feeds through digestibility experiments. The University of Georgia Press. Athens, GA. pp. 423.

Schofield, P. and Pell, A.N. 1995a. Validity of using accumulated gas pressure readings to measure forage digestion in vitro: A comparison involving three forages. J. Dairy Sci. 78:2230-2238.

Schofield, P. and Pell, A.N. 1995b. Measurement and kinetic analysis of the neutral detergent-soluble carbohydrate fraction of legumes and grasses. J. Anim. Sci. 73:3455-3463.

Schofield, P., Pitt, R.E. and Pell, A.N. 1994. Kinetics of fiber digestion from in vitro gas production. J. Anim. Sci. 72:2980-2991.

Schreiber, M.M. 1967. Effect of density and control of Canada thistle on production and utilization of alfalfa pasture. Weeds. 15:138-146.

Schuman, G.E. and Rauzi, F. 1985. Mechanical renovation of rangelands for increased forage production and carrying capacity. Rangelands. 7:156-158.

Sedivec, K.K. and Manske, L.L. 1990. Renovation of rangeland and grassland pastures. N.D.S.U. Ext. Serv. Publ. Fargo, N.D. Vol. 14. 6 pp.

Sheaffer, C.C., Miller, D.W. and Marten, G.C. 1990. Grass dominance and mixture yield and quality in perennial grass-alfalfa mixtures. J. Prod. Agric. 3:480-485.

Shenk, J.E. Westerhaus, M.O. and Hoover, M.R. 1979. Analysis of forages by infrared reflectance. J. Dairy Sci. 62:807-812.

Shenk, J.E., Landa, I., Hoover, M.R. and Westerhaus, M.O. 1981. Description and evaluation of a near infrared reflectance spectro-computer for forage and grain anlaysis. Crop Sci. 21:355-358.

Siaw, D.E.K.A., Osuji, P.O. and Nsahlai, I.V. 1993. Evaluation of multipurpose tree germplasm: The use of gas production and rumen degradation characteristics. J. Agr. Sci. (Camb.). 120:319-330.

Sileshi, Z., Owen, E., Dhanoa, M.S. and Theodorou, M.K. 1996. Prediction of *in situ* rumen dry matter disappearance of Ethiopian forages from an *in vitro* gas production technique using a pressure transducer, chemical analyses or *in vitro* digestibility. Anim. Feed Sci. Technol. 61:73-87.

Simons, R.G., Grant, C.A. and Bailey, L.D. 1995. Effect of fertilizer placement on yield of established alfalfa stands. Can. J. Plant Sci. 75:883-887.

Smith, A.E. 1992. Use of herbicides in tall fescue pasture renovation. Res. Rep. Univ. Ga. Agr. Exp. Stn. Athens, GA. No. 602. 8 pp.

Smith, D. 1981. Forage management in the north. D. Smith Ed. 4th Edition. Kendall Hunt Pub. Co., Toronto, ON.

Snedecor, G.W. and Cochran, W.G. 1989. Statistical methods. 8th Ed. Iowa State College Press, Ames, IW.

Sniffen, C.J., O'Connor, J.D., Van Soest, P.J., Fox, D.G. and Russell, J.B. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562-3577.

Soiseth, R.J., Wight, J.R. and Aase, J.K. 1974. Improvement of panspot (Solonetzic) range sites by contour furrowing. J. Range Manage. 27:107-110.

Sprague, M.A. 1952. The substitution of chemicals for tillage in pasture renovation. Agron. J. 44:405-409.

Sprague, V.G. and Myers, W.M. 1945. A comparitive study of methods for determining yields of Kentucky bluegrass and white clover when grown in association. J. Am. Soc. Agron. 37:370-377.

Springer, B. 1992. Alfalfa stand renovation. Agriculture Development Fund Project Final Report.

Standaert, J.E. 1986. The benefits of fescue pasture renewal. Proc. South Pasture Forage Crop Imp. Conf. New Orleans, MI. pp. 41-46.

Statistical Analysis System Institute, Inc. 1989. User's guide, Version 6, 4th Ed., Vol 2. Cary, North Carolina.

Steel, R.G.D., Torrie, J.H. and Dickey, D.A. 1997. Principles and procedures of statistics. A biometrical approach. McGraw-Hill Co., Inc. 3rd Ed. New York, NY.

Stone, W.C. and Fryer, J.R. 1935. A botanical study of pasture mixtures. Sci. Agr. 15:777-805.

t' Mannetje, L. and Haydock, K.P. 1963. The dry-weight-rank method for the botanical analysis of pasture. J. Br. Grassl. Soc. 18:268-275.

t' Mannetje, L. Ed. 1978. Measurement of grassland vegetation and animal production. Hurley, Berks. : Commonwealth Bureau of Pastures and Field Crops. Bull. 52.

Tanner, J.W., Gamble, E.E. and Tossel, W.E. 1966. Determination of botanical composition of two-component forage mixtures. Can. J. Plant Sci. 40:225-234.

Taylor, T.H., Smith, E.M. and Templeton, Jr., W.C. 1969. Use of minimum tillage and herbicide for establishing legumes in Kentucky bluegrass (*Poa pratensis* L.) swards. Agron J. 61:761-766.

Taylor, T.H., Wedin, W.F. and Templeton, Jr., W.C. 1979. Stand establishment and renovation of old sods for forage. In: Tall Fescue. Buckner, R.C. and Bush, L.P. Eds. Agronomy. 20:155-170.

Theodorou, M.K., Williams, B.A., Dhanoa, M.S., McAllan, A.B. and France, J. 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. Anim. Feed Sci. Technol. 48:185-197.

Thom, E.R., Sheath, G.W., Bryant, A.M and Cox, N.R. 1986a. Renovation of pastures containing *Paspalum spp.* 1. Persistance of overdrilled ryegrass and prairie grass and effect on seasonal pasture production. N. Z. J. Agr. Res. 29:575-585.

Thom, E.R., Sheath, G.W., Bryant, A.M and Cox, N.R. 1986b. Renovation of pastures containing *Paspalum spp.* 2. Effects of nitrogen fertiliser on the growth and persistence of overdrilled ryegrass. N. Z. J. Agr. Res. 29:587-598.

Thom, E.R., Sheath, G.W., Bryant, A.M and Cox, N.R. 1986c. Renovation of pastures containing *Paspalum spp.* 3. Effect of defoliation management and irrigation on ryegrass growth and persistance. N. Z. J. Agr. Res. 29:599-611.

Tidmarsh, C.E.M and Havenga, C.M. 1955. The wheel-point method of survey and measurement of semi-open grasslands and Karoo vegetation in South Africa. Mem. Bot. Surv. S. Afr. 29:1-10.

Tilley, J.M.A. and Terry, R.A. 1963. A two-stage technique for the *in vitro* digestion of forage crops. J. Br. Grassl. Soc. 18:104-111.

Tinney, F.W., Aamodt, O.S. and Ahlgren, H.L. 1937. Preliminary report of a study on methods used in botanical analyses of pasture swards. J. Am. Soc. Agron. 29:835-840.

Tiwari, D.K., Jackobs, J.A. and Carmer, S.G. 1963. Statistical technique for correcting botanical or floristic estimates in pasture research. Agron. J. 55:226-228.

Ukrainetz, H. and Campbell, C.A. 1988. N and P fertilization of bromegrass in the Dark Brown soil zone of Saskatchewan. Can. J. Plant Sci. 68:457-470.

Ukrainetz, H., Campbell, C.A., Zentner, R.P. and Monreal, M. 1988. Response of bromegrass to N, P and S fertilizer on a gray Luvisolic soil in northwestern Saskatchewan. Can. J. Plant Sci. 68:687-703.

University Committee on Animal Care and Supply (UCACS). 1996. Guidelines of the Canadian Council on Animal Care.

Van Keuren, R.W. 1980. Managing established pastures. Proc. Forage Grassl. Conf. pp. 165-175.

Van Keuren, R.W. and Ahlgren, H.L. 1957a. A statistical study of several methods used in determining the botanical composition of a sward: I. A study of established pastures. Agron. J. 49:532-536.

Van Keuren, R.W. and Ahlgren, H.L. 1957b. A statistical study of several methods used in determining the botanical composition of a sward: II. A study of several forage mixtures. Agron. J. 49:581-586.

Van Keuren, R.W. and Matches, A.G. 1988. Pasture production and utilization. In: Alfalfa and alfalfa improvement. (Eds.) Hanson, A.A., Barnes, D.K. and Hill, R.R. American Society of Agronomy, Crop Science of America, Soil Science of America, Madison, WI. pp. 515-538.

Van Keuren, R.W., Watson, V.H. and Triplett, Jr., G.B. 1985. Pasture and meadow renovation. In: Monograph series of Weed Science Society of America. Vol 2:140-174.

Van Soest, P.J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834-843.

Van Soest, P.J., Wine, R.H. and Moore, L.A. 1966. Estimation of the true digestibility of forages by the *in vitro* digestion of cell walls. Proc. 10th Int. Grassl. Congr. p. 438.

Van Soest, P.J. 1994. Ed. Nutritional ecology of the ruminant. Cornell University Press. Ithaca, N.Y. 476 pp.

Van Soest, P.J. and Wine, R.H. 1967. Use of detergent in the analysis of fibrous feeds. IV. Determination of plant cell wall constituents. J. Assoc. Off. Anal. Chem. 50:50-55.

Van Soest, P.J., Fadel, J. G. and Sniffen, C.J. 1979. Discount factors for energy and protein in ruminant feeds. Proc. Cornell Nutr. Conf. Ithaca, N.Y. pp. 63-75.

Van Soest, P.J., Mertens, D.R. and Deinum, B. 1978. Preharvest factors influencing quality of conserved forages. J. Anim. Sci. 47:712-720.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Vogl, R.J. 1965. Effects of spring burning on yields of brush prairie savanna. J. Range Manage. 18:202-205.

Volesky, J.D., Mowrey, D.P. and Smith, G.R. 1996. Performance of rose clover and hairy vetch interseeded into Old World bluestem. J. Range Manage. 49:448-451.

von Keyserlingk, M.A.G. and Mathison, G.W. 1989. Use of the *in situ* technique and passage rate constants in predicting voluntary intake and apparent digestibility of forages by steers. Can. J. Anim. Sci. 69:973-987.

von Keyserlingk, M.A.G., Swift, M.L., Puchala, R. and Shelford, J.A. 1996. Degradability characteristics of dry matter and crude protein of forages in ruminants. Anim. Feed Sci. Technol. 57:291-311.

Waddington, J. and Bowren, K.E. 1976. Pasture renovation by direct drilling after weed control and sward suppression by herbicides. Can. J. Plant Sci. 56:985-988.

Walker, B.H. 1970. An evaluation of eight methods of botanical analysis on grasslands in Rhodesia. J. Appl. Ecol. 7:403-416.

Weaver, J.E. and Rowland, N.W. 1952. Effects of excessive natural mulch on development, yield and structure of native grassland. Bot. Gaz. 114:1-19.

Webb, W.M. and Guthery, F.S. 1983. Response of wildlife food plants to spring discing of mesquite rangeland in northwest Texas. J. Range Manage. 36:351-353.

Welty, L.E., Anderson, R.L., Delaney, R.H. and Hensleigh, P.F. 1981. Glyphosate timing effects on establishment of sod-seeded legumes and grasses. Agron. J. 73:813-8817.

Welty, L.E., Ditterline, R.L., Hall, J.A. and Prestbye, L.S. 1988. Effect of tillage for renovation of established alfalfa. App. Agr. Res. No. 3. 3:123-127.

Welty, L.E., Hensleigh, P.F. and Stewart, V.R. 1983. Methods for sod-seeding of small-seeded legumes and grasses. Mont. Agr. Exp. Sta. Bull. No. 752. 15 pp.

Wheaton, H.N. and Meinke, L. 1975. Renovation and legume selection. Spec. Rep. Univ. Mo. Columbia Agric. Exp. Stn. Vol. 178. pp. 6-9.

Whitman, W.C. and Siggeirsson, E.I. 1954. Comparison of line interception and point contact methods in the analysis of mixed grass range vegetation. Ecology 35:431-436.

Wight, J.R. and White, L.M. 1974. Interseeding and pitting on a sandy range site in eastern Montana. J. Range Manage. 27:206-210.

Wight, J.R., Neff, E.L. and Soiseth, R.J. 1978. Vegetation response to contour furrowing. J. Range Manage. 31:97-101.

Wikeem, B.M., Newman, R.F. and Van Ryswyk, A.L. 1993. Forage response to N, P and S fertilization on clearcut lodgepole pine sites. J. Range Manage. 46:262-270.

Wikeem, B.M., Newman, R.F. and van Ryswyk, A.L. 1989. Effect of fertilization date and litter removal on grassland forage production. J. Range Manage. 42:412-415.

Willms, W.D., Adams, B.W. and Dormaar, J.F. 1996. Seasonal changes of herbage biomass on the fescue prairie. J. Range Manage. 49:100-104.

Willms, W.D., McGinn, S.M. and Dormaar, J.F. 1993. Influence of litter on herbage production in the mixed prairie. J. Range Manage. 46:320-324.

Wilman, D. and Derrick, R.W. 1994. Concentration and availability to sheep of N, P, K, Ca, Mg and Na in chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. J. Agric. Sci. (Camb.) 122:217-223.

Wilman, D. and Mzamane, N. 1982. The content and yield of six elements in four grasses as affected by nitrogen application and interval between harvests. Fert. Res. 3:97-109.

Wolf, D.D. and Allen, V.G. 1990. Yield and regrowth characteristics of alfalfa grazed by steers during spring and summer. Agron. J. 82:1079-1082.

Wurster, M.J., Kamstra, L.D. and Ross, J.G. 1971. Evaluation of cool season grass species and varieties using *in vivo* and *in vitro* techniques. Agron. J. 63:241-245.

APPENDIX

Table A.1. Site locations and soil types

Location	Section	Elevation (m)	Growing-degree days	Precipitation (mm)	Soil type[Z]	pH	Texture[Y]
Pathlow	SE1/4, 13-43-22 W2nd	534 m	1502	409	Gray Podzolic (Waitville-Northern Light)	7.9	L-ClL
DHC - PA	NW1/4, 14-47-26 W2nd	450 m	1412	398	Black Chernozem (Orthic Hamlin-Blaine Lake)	7.2	SaL-Si
DNC - PA	NE1/4, 14-47-26 W2nd	450 m	1412	398	Black Chernozem (Orthic Hamlin-Blaine Lake)	7.2	SaL-Si
Rama	NW1/4, 25-31-8 W2nd	518 m	1558	416	Black Chernozem (Orthic Meadow-Crooked Lake)	8.2	L-ClL-GrL
Insinger	NW1/4, 33-29-8 W2nd	518 m	1560	420	Black Chernozem (Orthic Meota-Whitesand)	8.0	L-SaL-GrSaL

[Z] Saskatchewan Soil Survey, Saskatoon Institute of Pedology (1992)
[Y] Cl, L, ClL, GrL, SaL, GrSaL and Si indicate clay, loam, clay loam, gravelly loam, sandy loam, gravely sandy loam and silt, respectively

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Table A.2. Mean monthly temperature (°C) at Pathlow, DHC, DNC, Rama and Insinger sites.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pathlow												
1994	-23.4	-21.1	-5.2	7.4	10.8	15.7	16.9	15.9	13.5	5.2	-6.6	-13.0
1995	-16.1	-14.3	-8.5	-2.3	10.3	18.1	16.7	16.0	12.1	4.2	-11.4	-16.4
1996	-24.7	-14.2	-12.4	5.8	12.6	17.0	18.5	17.5	9.9	1.7	-13.1	-19.3
30-yr average	-19.1	-15.5	-9.0	2.2	10.6	15.5	17.6	16.3	10.4	4.0	-7.1	-16.2
DHC/DNC												
1994	-23.2	-21.6	-2.0	3.8	10.3	15.0	17.1	15.6	12.9	4.6	-8.0	-15.6
1995	-16.1	-14.1	-8.4	-1.1	9.3	16.9	16.9	15.7	11.4	4.3	-11.3	-17.1
1996	-25.0	-14.0	-11.6	1.4	7.9	16.2	17.6	17.9	10.0	2.6	-12.5	-20.1
30-yr average	-19.8	-15.9	-8.8	2.6	10.4	15.2	17.5	16.1	9.9	3.7	-7.5	-16.9
Rama												
1994	-23.1	-20.1	-2.0	3.6	11.5	15.5	16.9	15.5	13.2	6.2	-3.3	-12.6
1995	-15.8	-13.7	-7.8	-2.3	9.8	17.8	17.6	16.5	12.1	4.4	-10.6	-15.6
1996	-23.1	-13.3	-11.0	0.0	7.8	16.5	17.3	18.0	10.9	3.6	-12.2	-19.0
30-yr average	-18.6	-14.7	-8.0	2.2	10.6	15.2	17.7	16.4	10.5	4.2	-6.4	-15.4
Insinger												
1994	-22.9	-20.4	-2.4	3.2	11.4	15.5	16.9	15.4	13.3	6.2	-3.5	-12.0
1995	-15.9	-13.9	-8.0	-2.2	9.9	17.6	17.6	16.3	11.5	4.3	-10.7	-15.6
1996	-24.1	-14.0	-11.3	0.2	8.0	16.5	17.4	18.1	10.9	3.2	-12.6	-19.3
30-yr average	-18.4	-14.9	-8.1	2.8	10.6	15.8	18.2	17.0	10.8	4.6	-6.0	-15.3

Table A.3. Annual and monthly precipitation (mm) at Pathlow, DHC, DNC, Rama and Insinger sites.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Pathlow													
1994	11.3	10.0	4.8	8.2	54.7	60.1	81.2	45.3	21.6	15.9	19.7	19.8	352.6
1995	17.1	21.0	42.4	24.9	5.4	55.7	30.3	134.8	2.0	35.5	25.7	20.8	415.6
1996	4.5	6.2	14.2	28.2	68.4	23.2	146.7	10.2	36.4	27.5	19.3	20.4	405.2
30-yr average	17.7	13.9	18.5	20.7	41.4	61.9	66.7	53.1	41.3	26.6	18.2	22.5	402.5
DHC/DNC													
1994	20.9	11.4	6.3	17.4	106.3	88.0	94.6	46.2	19.6	40.3	20.4	24.2	495.6
1995	18.2	23.0	28.9	53.0	16.0	30.4	39.1	102.5	5.0	41.2	27.4	29.7	414.4
1996	4.6	5.0	7.6	59.6	56.1	42.6	69.3	36.0	79.2	31.4	16.4	15.4	423.2
30-yr average	15.4	13.6	18.2	22.2	41.6	66.9	72.1	58.6	39.8	21.6	16.5	19.1	405.5
Rama													
1994	18.8	14.4	10.0	5.0	74.6	82.6	61.0	62.0	30.2	20.2	6.4	27.6	412.8
1995	12.8	21.2	23.0	33.4	40.8	53.4	48.4	154.4	16.0	57.6	39.0	22.2	522.2
1996	14.0	4.4	10.2	40.4	27.0	26.6	94.8	43.8	27.8	31.0	29.8	43.6	393.4
30-yr average	15.8	13.5	21.2	17.5	41.0	66.9	57.5	55.5	44.1	23.3	14.8	16.9	387.9
Insinger													
1994	25.4	13.8	5.8	3.9	67.0	144.0	45.0	95.4	24.0	28.0	18.4	22.6	493.3
1995	25.6	36.8	62.2	53.2	15.7	61.2	36.6	170.6	1.5	53.0	38.4	28.6	583.4
1996	20.8	7.2	5.4	44.7	20.2	27.4	149.3	35.1	36.8	18.6	28.0	45.0	438.5
30-yr average	21.2	16.2	25.6	20.3	50.7	68.8	64.2	57.5	48.0	24.5	17.8	21.0	435.8

Table A.4. Effect of rejuvenation treatments on botanical composition - Pathlow site (%).

1994

Species	Control NF[z]	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM[y]
Smooth bromegrass	40.5abc	40.7abc	35.3c	42.1abc	42.5abc	37.6bc	41.7abc	37.0bc	50.0a	47.1ab	35.3c	35.1c	3.0
Kentucky bluegrass	46.4ab	46.1ab	33.2bc	25.9c	36.1abc	45.8ab	43.5ab	48.9a	40.5ab	43.2ab	36.7abc	39.2abc	3.2
Alfalfa	3.4a	4.4a	5.6a	7.9a	8.3a	5.7a	4.0a	4.5a	4.4a	4.4a	8.7a	7.8a	1.3
Other species	4.0c	5.8c	7.1bc	11.7a	7.7bc	10.5ab	4.3c	6.3c	5.0c	5.3c	6.2c	12.3a	0.8
Bare ground	5.7bc	3.0bc	18.9a	12.4ab	5.4bc	0.4c	6.6bc	3.3bc	0.1c	0c	13.2ab	5.6bc	1.2

1995

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	37.8bc	32.3bc	32.1bc	36.4bc	28.3c	40.1b	35.9bc	38.4bc	53.1a	60.9a	28.5c	31.5bc	3.1
Kentucky bluegrass	34.7abc	44.3a	26.1c	30.1bc	31.8abc	36.9abc	42.3ab	40.4ab	32.7abc	25.0c	41.5ab	42.6ab	3.3
Alfalfa	11.4ab	9.9b	7.6b	5.5b	21.7a	10.9ab	6.3b	6.4b	6.0b	3.2b	13.4ab	13.1ab	1.7
Other species	5.4ab	6.5ab	10.5a	7.3ab	8.7ab	6.4ab	6.9ab	8.2ab	3.3b	5.2ab	6.8ab	6.6ab	0.9
Bare ground	10.7b	7.0bcde	23.7a	20.7a	9.5bcd	5.7de	8.6bcde	6.6cde	4.9e	5.7de	9.8bc	6.2cde	0.5

1996

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	36.6bc	46.0ab	46.2ab	44.3abc	32.4c	43.4abc	40.1abc	37.3bc	51.6a	50.1a	33.2c	41.0abc	2.9
Kentucky bluegrass	32.4abc	31.0abc	23.2c	25.0bc	25.0bc	33.6abc	36.9abc	40.2ab	31.9abc	28.9abc	41.1a	31.9abc	3.0
Alfalfa	6.6b	4.6b	5.2b	8.7b	21.5a	7.2b	6.2b	2.5b	1.8b	2.9b	5.2b	4.9b	1.3
Other species	9.5ab	5.3b	7.0ab	9.2ab	7.8ab	6.0b	4.7b	7.1ab	4.8b	9.2ab	5.8b	11.9a	0.8
Bare ground	14.9ab	13.1ab	18.5a	12.8ab	13.3ab	9.8b	12.2b	12.9ab	9.9b	8.9b	14.7ab	10.3b	1.3

[z]NF = no broadcast fertilizer, F = broadcast fertilizer (350 kg ha⁻¹)

[y]SEM = standard error of the mean

a-e Means within rows with unlike letters differ (p<0.05)

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Table A.5. Effect of rejuvenation treatments on botanical composition - Prince Albert DHC site (%).

1994

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM[y]
	NF[z]	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	43.2bc	47.7bc	38.5c	42.1bc	40.8bc	44.7bc	41.8bc	45.8bc	51.5ab	60.1a	39.0c	49.2abc	3.2
Kentucky bluegrass	27.6a	27.9a	19.0a	21.6a	22.2a	28.0a	25.7a	25.1a	23.9a	19.2a	24.4a	26.6a	2.0
Alfalfa	22.5a	20.6a	19.9a	17.0a	24.5a	22.1a	19.6a	23.3a	18.7a	18.4a	19.1a	21.6a	1.7
Other species	1.6b	2.6b	6.4ab	12.1a	4.2b	4.5b	8.3ab	5.4ab	5.7ab	2.2b	7.1ab	1.8b	0.9
Bare ground	5.1bcd	1.2d	16.2a	7.2bc	8.3bc	0.7d	4.6cd	0.4d	0.2d	0.1d	10.4b	0.8d	1.0

1995

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM
	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	45.7bcd	42.8cde	47.3bcd	46.4abcd	33.4e	52.8b	39.3de	41.0cde	41.0cde	66.2a	40.2cde	49.7bc	3.1
Kentucky bluegrass	29.7a	25.2a	18.4a	22.7a	28.1a	27.4a	30.7a	33.4a	33.5a	22.3a	33.4a	31.9a	1.9
Alfalfa	14.3ab	19.4ab	14.0ab	9.7ab	23.5a	12.1ab	17.4ab	17.0ab	16.9ab	6.5b	14.9ab	11.1ab	1.5
Other species	0.9b	0.8b	2.0ab	2.5ab	4.8a	0.4b	0.7b	1.3ab	1.3ab	0.3b	2.9ab	1.4ab	0.7
Bare ground	9.4b	11.8ab	18.3a	18.8a	10.2b	7.3b	11.9ab	7.3b	7.3b	4.7b	8.6b	5.9b	0.8

1996

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM
	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	40.8d	44.5cd	56.1abc	59.0a	45.5cd	48.2abcd	45.9cd	48.1abcd	49.1abcd	58.5ab	43.8d	47.2bcd	3.3
Kentucky bluegrass	26.9a	24.9a	17.5a	16.9a	29.6a	24.9a	28.7a	32.2a	27.9a	24.2a	22.7a	28.1a	2.0
Alfalfa	18.0a	15.8a	8.1a	9.0a	14.3a	16.0a	14.7a	11.2a	11.5a	7.0a	14.5a	11.3a	1.0
Other species	0.7b	1.7b	0.9b	0.3b	0.7b	0.4b	0.4b	0.8b	1.3b	0.3b	4.4a	0.7b	0.9
Bare ground	13.6ab	13.1ab	17.4a	14.8ab	9.9bc	10.5bc	10.3bc	7.7c	10.1bc	10.0bc	14.6ab	12.7abc	0.8

[z]NF = no broadcast fertilizer, F = broadcast fertilizer (350 kg ha⁻¹)
[y]SEM = standard error of the mean
a-e Means within rows with unlike letters differ (p<0.05)

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Table A.6. Effect of rejuvenation treatments on botanical composition - Prince Albert DNC site (%).

1994

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM[y]
	NF[z]	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	39.1de	51.4bc	28.2f	30.0ef	43.5cd	46.8bcd	40.1de	46.0bcd	56.4ab	63.9a	42.4cd	45.8bcd	2.9
Kentucky bluegrass	28.6a	20.9a	24.4a	17.7a	23.1a	19.4a	20.5a	20.2a	17.5a	17.8a	25.4a	22.6a	2.0
Alfalfa	29.1ab	27.0ab	20.6ab	24.1ab	26.8ab	28.8ab	32.2a	26.8ab	25.8ab	17.6b	26.0ab	28.3ab	2.9
Other species	1.7c	0.5c	11.8ab	16.6a	5.8bc	4.8bc	3.0bc	5.3bc	0.1c	0.6c	4.3bc	2.7c	0.6
Bare ground	1.5b	0.2b	15.0a	11.2a	0.8b	0.2b	2.5b	0.6b	0.2b	0.1b	1.9b	0.6b	0.3

1995

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM
	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	46.2d	62.4bc	40.7d	46.9d	41.8d	59.4bc	46.1d	62.6bc	68.4b	79.3a	37.9d	58.6c	3.4
Kentucky bluegrass	29.1abc	20.2def	21.7cdef	17.0ef	25.1bcd	20.3def	33.0ab	22.4cde	17.3def	14.1f	36.1a	22.6cde	2.3
Alfalfa	10.4bc	5.8cd	6.5brd	6.0cd	22.9a	13.9b	9.9bc	7.2bcd	6.9bcd	1.5d	13.3bc	6.5bcd	1.2
Other species	0.7ab	0.4ab	1.4ab	2.7a	1.3ab	0b	1.8ab	1.2ab	0b	0.3ab	1.0ab	0.1b	0.5
Bare ground	13.6b	11.2bc	29.7a	27.4a	8.9bc	6.4bc	9.2bc	6.6bc	7.4bc	4.9c	11.7bc	12.2bc	0.6

1996

Species	Control		Spike		Burn		Deep band		Deep band liquid fertilizer		Mow		SEM
	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	
Smooth bromegrass	48.8ef	59.4bcd	49.6def	65.8ab	45.5f	60.6b	50.3cdef	60.0bc	56.8bcde	73.9a	40.9f	57.9bcde	2.9
Kentucky bluegrass	29.9ab	20.7bcd	23.0bcd	16.4de	27.7bc	23.3bcd	24.7bcd	18.7cde	22.9bcd	10.2e	37.5a	22.5bcd	1.3
Alfalfa	7.3cde	8.6bcde	10.7abcd	2.7e	16.6a	5.1cde	14.0ab	7.8cde	5.0de	2.8e	11.2abc	7.2cde	0.7
Other species	0.4ab	0b	0.4ab	0b	0b	0.6ab	1.1a	0.1b	0.2ab	0.2ab	0b	0.3ab	0.1
Bare ground	13.6a	11.5a	16.3a	15.1a	10.2a	10.4a	9.9a	13.4a	15.1a	12.9a	10.5a	12.1a	0.8

[z]NF = no broadcast fertilizer, F = broadcast fertilizer (350 kg ha^{-1})
[y]SEM = standard error of the mean
a-f Means within rows with unlike letters differ ($p<0.05$)

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Table A.7. Effect of rejuvenation treatments on botanical composition - Rama site (%).

1994

Species	Control NF[z]	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM[y]
Smooth bromegrass	36.1bc	42.8bc	33.7c	33.9c	38.4abc	44.7bc	35.2bc	37.7bc	51.5ab	62.3ab	37.5bc	39.9bc	3.0
Kentucky bluegrass	11.6a	12.0a	2.6a	10.1a	4.9a	5.6a	10.0a	8.7a	6.9a	5.6a	10.5a	4.2a	1.2
Alfalfa	22.5cd	30.2abc	24.0bcd	29.9abc	25.6abcd	34.8ab	22.7cd	36.1a	18.4d	26.7abcd	24.6bcd	31.9abc	2.2
Other species	16.6ab	14.3ab	19.7ab	24.6a	13.4ab	14.4ab	17.1ab	16.7ab	22.3ab	5.3b	13.5ab	23.3a	0.8
Bare ground	13.2a	0.7b	20.0a	1.5b	17.7a	0.5b	15.1a	0.8b	0.9b	0.1b	13.9a	0.7b	0.7

1995

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	35.8ef	51.1b	34.3ef	36.2ef	39.3def	50.6bc	32.0f	51.0b	56.2b	74.3a	41.5cde	48.2bcd	3.2
Kentucky bluegrass	9.8ab	15.7a	4.2b	7.8ab	7.9ab	13.1ab	11.5ab	16.9a	10.8ab	9.5ab	11.4ab	15.4a	1.2
Alfalfa	23.5ab	17.9bc	21.9ab	20.4ab	29.2a	27.5ab	26.2ab	18.0bc	23.0ab	8.6c	25.9ab	20.6ab	2.1
Other species	20.1a	9.8bcd	14.5abc	15.1ab	10.3bcd	6.4d	16.8ab	10.1bcd	7.3de	6.3d	9.7bcd	9.6bcd	0.7
Bare ground	10.8bcd	5.5cde	25.1a	20.5a	13.3b	2.4e	13.5b	4.0de	2.7e	1.3e	11.5bc	6.2cde	0.5

1996

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	42.9bc	45.2b	46.0b	44.9b	37.9bc	45.4b	43.4bc	44.6b	46.0b	62.1a	34.2c	41.6bc	2.8
Kentucky bluegrass	12.5ab	15.9ab	7.0b	15.6ab	7.6b	13.2ab	11.9ab	17.0ab	10.6ab	11.4ab	10.6ab	20.3a	1.7
Alfalfa	17.9bc	18.7bc	19.7b	16.3bc	29.0a	23.6ab	22.3ab	18.1bc	22.8ab	10.6c	30.2a	16.8bc	1.9
Other species	21.6a	15.2cd	17.9abc	16.2bcd	18.9abc	13.9cd	18.8abc	14.9cd	17.2abcd	12.4d	21.0ab	16.3bcd	1.4
Bare ground	14.1ab	14.2ab	18.6a	16.1ab	15.6ab	12.9b	12.6b	14.3ab	12.4b	12.5b	13.0b	14.0ab	0.9

[z]NF = no broadcast fertilizer, F = broadcast fertilizer (350 kg ha⁻¹)

[y]SEM = standard error of the mean

a-f Means within rows with unlike letters differ (p<0.05)

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Table A.8. Effect of rejuvenation treatments on botanical composition - Insinger site (%).

1994

Species	Control NF[z]	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM[y]
Smooth bromegrass	37.9abc	49.3ab	32.5c	39.6abc	44.9abc	33.8bc	39.8abc	53.0a	43.1abc	52.5a	43.3abc	50.6a	2.8
Kentucky bluegrass	17.7ab	9.7bcd	10.5bcd	5.6cd	10.5bcd	5.0d	15.4abc	9.9bcd	8.1bcd	7.2cd	25.5a	10.8bcd	1.6
Alfalfa	38.5bc	35.0bc	38.9bc	51.0ab	37.7bc	61.0a	35.5bc	36.5bc	48.3ab	40.1bc	24.1c	38.3bc	2.4
Other species	3.4ab	5.0a	4.4ab	3.0ab	1.2ab	0.1b	3.4ab	0.5b	0.3b	0b	1.1ab	0.3b	1.1
Bare ground	2.5cd	1.0d	13.7a	0.8d	5.7bc	0.1d	5.9b	0.1d	0.2d	0.2d	6.0b	0d	0.9

1995

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	40.9cd	58.0ab	34.7d	41.9cd	38.4cd	40.9cd	44.6bcd	47.8bcd	41.5cd	64.7a	43.7bcd	52.2abc	3.0
Kentucky bluegrass	3.5ab	1.9ab	3.7ab	1.7ab	4.3ab	0.8b	6.9a	1.6ab	2.0a	1.8ab	5.7ab	2.7ab	1.1
Alfalfa	38.3abc	28.9bc	35.3abc	41.9abc	45.9abc	52.4a	38.4abc	37.6abc	46.8ab	26.7e	33.1ab	37.0abc	2.7
Other species	2.5a	0.5a	2.5a	1.2a	0.8a	0.5a	2.2a	2.2a	1.3a	0.3a	1.9a	0.6a	0.4
Bare ground	14.8b	10.7bcd	23.8a	13.3bc	10.6bcd	5.4d	7.9cd	10.8bcd	8.4cd	6.5d	15.6b	7.5d	1.2

1996

Species	Control NF	Control F	Spike NF	Spike F	Burn NF	Burn F	Deep band NF	Deep band F	Deep band liquid fertilizer NF	Deep band liquid fertilizer F	Mow NF	Mow F	SEM
Smooth bromegrass	42.6bc	54.3ab	35.3c	55.6ab	37.4bc	49.5abc	47.0abc	49.3abc	62.7a	64.0a	43.1bc	50.8abc	2.9
Kentucky bluegrass	3.4ab	1.4b	2.0b	2.4b	3.1ab	2.0b	7.9a	2.4b	2.5b	3.9ab	5.9ab	3.4ab	0.8
Alfalfa	21.2abc	25.5abc	27.5abc	18.5c	32.9a	32.2ab	18.6c	18.2c	20.1bc	19.6c	21.1abc	16.8c	1.7
Other species	0.3ab	0.3ab	1.2a	0.6ab	0b	0.4ab	0.8ab	0.7ab	0b	0.1b	0b	0.2b	0.3
Bare ground	32.5ab	18.5ab	34.0a	22.9ab	26.6ab	15.9ab	25.7ab	29.4ab	14.7ab	12.4b	29.9ab	28.8ab	1.3

[z]NF = no broadcast fertilizer, F = broadcast fertilizer (350 kg ha^{-1})
[y]SEM = standard error of the mean
a-d Means within rows with unlike letters differ (p<0.05)

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Table A.9. Summary of analyses of variance of year (Y), site (S), treatment (T), and fertilizer (F) and interaction effects for dry matter yield, quality components, and botanical composition.

Y	S	T	F	YxS	YxT	YxF	SxT	SxF	TxF	YxSxT	YxSxF	YxTxF	SxTxF	YxSxTxF
Dry matter yield (kg ha⁻¹)														
***	***	***	***	***	***	***	***	***	***	***	***	*	***	**
Quality components														
Crude protein (%)														
***	***	***	***	***	***	***	*	NS	NS	NS	***	NS	NS	NS
Calcium (%)														
NS	***	***	***	***	*	NS	*	*	NS	NS	NS	NS	NS	NS
Phosphorous (%)														
***	***	***	***	***	***	***	***	***	NS	NS	*	NS	NS	NS
Botanical composition														
Smooth bromegrass (%)														
***	***	***	***	***	***	***	***	***	NS	NS	NS	NS	NS	NS
Alfalfa (%)														
***	***	***	***	***	NS	***	**	NS	NS	NS	NS	NS	NS	NS
Kentucky bluegrass (%)														
*	***	***	**	***	NS	NS	*	***	NS	NS	NS	NS	NS	NS
Other species (%)														
***	***	***	NS	***	***	NS	NS	***	NS	NS	NS	NS	NS	NS
Bare ground (%)														
***	***	***	***	***	***	***	NS	***	***	NS	**	NS	NS	NS

***, **, * Denote significant effects at $P < 0.001$, $P < 0.01$ and $P < 0.05$, respectively.

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Table A.10 PLANT SPECIES IDENTIFIED IN PLOTS

Scientific name	Common name	Scientific name	Common name
Achillea millefolium	Yarrow	*Medicago sativa*	Alfalfa
Antennaria aprica	Pussytoes/Everlasting	*Melilotus alba*	Yellow sweet clover
Artemesia spp.	Prairie sage	*Populus tremuloides*	Trembling aspen
Agropyron cristatum	Crested wheatgrass	*Polygonum convolvulus*	Wild buckwheat
Astragalus drummondii	Drummond's milk-vetch	*Potentilla spp.*	Prairie cinquefoil
Astragalus striatus	Ascending purple milk-vetch	*Polygonum persicaria*	Ladies' thumb
Bromus inermus	Smooth bromegrass	*Poa pratense*	Kentucky bluegrass
Bromus beibersteinii	Meadow bromegrass	*Poa compressa*	Canada bluegrass
Brassica kaber	Wild mustard	*Potentilla norvegia*	Rough cinquefoil
Cirsium arvense	Canada thistle	*Potentilla pensylvanica*	Prairie cinquefoil
Carex filifolia	Thread-leaved sedge	*Phalaris arundinacea*	Reed canarygrass
Cerastium arvense	Field chickweed	*Phleum pratense*	Timothy
Crepis tectorum	Narrow-leaved hawk's-beard	*Pascopyrum smithii*	Western wheatgrass
Chrysopsis villosa	Hairy golden aster	*Potentilla arguta*	White cinquefoil
Chenopodium album	Lamb's quarters	*Rosa arkansas*	Prairie rose
Equisetum arvense	Horsetail	*Sonchus arvensis*	Sow thistle
Erigon spp.	Smooth/tufted fleabane	*Sisyrinchium montanum*	Blue-eyed grass
Elytrigia repens	Quackgrass	*Setaria viridis*	Green foxtail
Elymus trachycaulus	Slender wheatgrass	*Salix spp.*	Willow
Galium boreale	Northern bedstraw	*Senecio canus*	Silvery groundsel
Geum triflorum	Three-flowered avens	*Smilacina stellata*	Star-flowered Solomon's seal
Galeopsis tetrahit	Hemp-nettle	*Symphoricarpos occidentalis*	Western snowberry
Geranium richardsonii	Wild white geranium	*Solidago spp.*	Goldenrod
Gutierrezia sarothrae	Broom-weed	*Sporobolus cryptandrus*	Sand dropseed
Hymenoxys richardsonii	Colorado rubberweed	*Tragopogon dubium*	Goats-beard
Juncus balticus	Baltic rush	*Thinopyrum intermedium*	Intermediate wheatgrass
Koeleria gracilis	June grass	*Thlapsi arvense*	Stinkweed/Pennycress
Linum pratense	Wild blue flax	*Taraxacum officinale*	Dandelion
Lathyrus ochroleucus	Cream-colored vetchling	*Thinopyrum ponticum*	Tall wheatgrass
Lathyrus venosus	Wild peavine	*Thermopsis rhombifolia*	Golden bean
Lappula echinata	Bluebur	*Trifolium repens*	White clover
Lygodesmia juncea	Skeleton-weed	*Vicia americana*	Wild/American vetch