Current and residual effects of nitrogen fertilizer applied to grass pasture on production of beef cattle in central Saskatchewan

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Cohen, R. D. H., Wright, S. B. M., Thomas, L. R., McCaughey, W. P. and Howard, M. D. 2004. **Current and residual effects of nitrogen fertilizer applied to grass pasture on production of beef cattle in central Saskatchewan**. Can. J. Anim. Sci. **84**: 91–104. Four rates of nitrogen fertilizer (0, 50, 100 and 200 kg N ha^{-1}) were applied for 4 yr to two replications of a 32-yr-old crested wheatgrass (*Agropyron cristatum*) pasture at Lanigan, Saskatchewan, after which no fertilizer was applied for a further 4 yr. The pastures were grazed by pregnant yearling Hereford heifers using a "put-and-take" stocking system. Soil cores (0–60 cm) were taken to monitor soil NO_3-N concentrations either in early spring, before grass growth commenced, or in late fall, after grass growth had ceased. Pasture measurements included available forage at the start of the grazing season, total forage production and the concentrations of crude protein, acid detergent fiber (ADF), ash, Ca, P, Mg, K, Cu, Zn, Fe and Mn. Heifers, fistulated at the esophagus, were used in 1984 and 1985 to obtain samples of the grazed herbage, which were analyzed for organic matter digestibility (OMD), protein and minerals, except P and K. Heifer intakes of digestible organic matter (DOMI), protein and minerals, except P and K, were estimated from their concentrations in fistula extrusa and estimates of intake obtained from extrusa digestibility and fecal output using Cr_2O_3 as a fecal marker. Phosphorus intake was estimated from fecal P concentration. Plasma samples were also collected and analyzed for concentrations of minerals.

Soil NO_3-N concentrations increased during the years of fertilizer application. One year after fertilizer application at 50 kg N ka^{-1} ceased, soil NO_3-N was not significantly different from the control ($P > 0.05$) but soil NO_3-N concentrations remained elevated for 4 yr following cessation of fertilizer applications on the 100 and 200 kg N ha^{-1} treatments ($P < 0.05$). Total forage production was increased by fertilizer application, but the magnitude of the response was determined by the amount of rainfall during the growing season ($P < 0.001$). Following cessation of fertilizer applications, the forage available at the start of three of four grazing seasons remained elevated by previous fertilizer applications ($P < 0.05$). Fertilizer increased the number of animal grazing days (AGD) and total livestock production ($P < 0.05$) in each year of application and in 3 of the 4 yr following withdrawal of fertilizer applications, the degree of the response depended on rainfall, but had no effect on the average daily gain of the heifers in any year ($P > 0.05$).

Fertilizing crested wheatgrass pastures had little affect on the nutrition of the grazing heifers but plant maturation decreased ($P < 0.05$) the concentrations of most nutrients. The total utilization of nutrients was increased with increasing increments of fertilizer because of the increased stocking rates (AGD). It is therefore suggested that if the benefits of fertilizer application are to be captured it is important to increase the stocking rate. There was evidence of a possible early-season sub-clinical hypomagnesemia (grass tetany) and nitrate toxicity at high rates of fertilizer application.

Key words: Nitrogen, fertilizer, soil, pasture, heifers, production, nutrition

Cohen, R. D. H., Wright, S. B. M., Thomas, L. R., McCaughey, W. P. et Howard, M. D. 2004. **Effets courants et résiduels des engrais azotés employés pour bonifier les pâturages sur l'élevage des bovins de boucherie dans le centre de la Saskatchewan.** Can. J. Anim. Sci. **84**: 91–104. À Lanigan (Saskatchewan), les auteurs ont appliqué un engrais azoté à quatre taux (0, 50, 100 et 200 kg N par hectare) sur deux parcelles d'un pâturage d'agropyre à crête (*Agropyron cristatum*) vieux de 32 ans pendant quatre ans puis ont interrompu les amendements les quatre années suivantes. Des génisses Hereford d'un an gravides ont été mises à l'herbe sur ces pâturages selon un régime à charge variable. Ensuite, les auteurs ont prélevé des carottes de sol (profondeur de 0 à 60 cm) et mesuré la concentration de N-NO_3 au début du printemps, avant la repousse, ou à la fin de l'automne, une fois la croissance végétale arrêtée. Ils ont déterminé la quantité de fourrage disponible au début de la période de paissance, la production totale de fourrages et la concentration de protéines brutes, de fibres au détergent acide, de cendres, de Ca, P, Mg, K, Cu, Zn, Fe et Mn. En 1984 et 1985, ils se sont servis de génisses portant une fistule à l'œsophage pour recueillir des échantillons

Abbreviations: **ADF**, acid detergent fiber; **ADG**, average daily gain; **AF**, available forage; **AGD**, animal grazing days; **ANR**, apparent nitrogen recovery; **DM**, dry matter; **DOMI**, digestible organic matter intake; **ECP**, extrusa crude protein; **FCR**, feed conversion ratio; **GTR**, grass tetany ratio; **OMD**, organic matter digestibility; **PCP**, pasture crude protein; **R**, rain; **RSD**, residual standard deviation; **SEM**, standard error of the mean; **TFP**, total forage production; **TLP**, total livestock weight production.

de l'herbe consommée en vue d'une analyse qui a permis d'établir la digestibilité de la matière organique et la concentration de protéines et d'oligo-éléments, à l'exclusion du P et du K. Ils ont estimé la quantité de matière organique digestible, de protéines et d'oligo-éléments (sauf le P et le K) ingérée par les génisses à partir des concentrations notées dans les échantillons prélevés par la fistule et estimé l'absorption d'après la digestibilité de ces prélèvements et les fèces en utilisant du Cr_2O_3 comme marqueur. L'absorption de P a été estimée à partir de la concentration de cet élément dans les fèces. Les auteurs ont aussi prélevé du sang pour en déterminer la concentration d'oligo-éléments. La concentration de N-NO_3 du sol augmente durant les années où on applique de l'engrais. Un an après interruption des amendements, la concentration de N-NO_3 dans le sol était sensiblement la même que dans la parcelle témoin pour le taux de 50 kg de N par hectare, ($P > 0,05$), mais pour ceux de 100 et de 200 kg, elle est demeurée élevée les quatre années suivantes ($P < 0,05$). L'application d'engrais augmente la production totale de fourrage, mais c'est l'importance des précipitations pendant la période végétative qui détermine l'ampleur de la réaction ($P < 0,001$). Après interruption des amendements, l'engrais appliqué antérieurement maintient la quantité de fourrage élevée au début de la période de paissance les trois années sur les quatre qui suivent ($P < 0,05$). L'engrais accroît le nombre de jours de paissance et la production globale des animaux ($P < 0,05$) chaque année où l'on applique de l'engrais et trois années sur quatre après interruption du traitement, l'importance de la réaction variant avec les précipitations sans que le gain quotidien moyen des génisses durant l'année s'en ressente ($P > 0,05$). La bonification des pâturages d'agropyre à crête a peu d'effet sur la nutrition des génisses mises à l'herbe, mais la maturation des plants réduit la concentration de la plupart des éléments nutritifs ($P < 0,05$). Plus le taux d'application de l'engrais augmente, plus il y a assimilation des éléments nutritifs à cause de la meilleure capacité porteuse du pâturage. On en conclut que, pour tirer avantage de l'application d'un engrais, il importe d'augmenter le nombre d'animaux mis à l'herbe. Les auteurs ont relevé des indices d'une éventuelle hypomagnésiémie (tétanie d'herbage) sous-clinique et d'intoxication aux nitrates en début de saison quand la quantité d'engrais appliquée est trop élevée.

Mots clés: Azote, engrais, sol, pâturage, génisses, production, nutrition

Fairway crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] was the first cultivar of crested wheatgrass released for use on the Canadian Prairies in 1932 and since then it has become widely naturalized in its areas of adaptation (Rogler and Lorenz 1983). There have been several reports on the benefits of adding nitrogen fertilizer to crested wheatgrass and other grass pastures (Lawrence et al. 1982; Campbell et al. 1986; Ukrainetz and Campbell 1988; Ukrainetz et al. 1988) in Saskatchewan yet very little fertilizer is applied to the 19.4 million ha of pasture on the Canadian Prairies even though the practice has been reported to be economically beneficial (Holt and Zentner 1985; Zentner et al. 1989). This may be because North American farmers tend to manage animals so that additional forage resulting from fertilization is underutilized (Beaton and Berger 1974). Nitrogen fertilizer has also been shown to be beneficial in rejuvenating old "sod bound" stands of crested wheatgrass (Knowles and Kilcher 1983) and other pastures (Lardner et al. 2000, 2001).

Despite a large number of reports on the effects of fertilizing pasture in Saskatchewan, very few have included the grazing animal (Holt et al. 1991) and we are aware of only one that has studied the residual effects of nitrogen fertilizer. Read and Winkleman (1982) reported residual effects for up to 10 yr after the application of applications of 400 and 800 kg ha^{-1}, but their experiment did not include the grazing animal.

The objective of this experiment was to investigate the current and residual effects of nitrogen fertilizer applied to crested wheatgrass pastures on forage production, nitrogen recovery and the nutrition and production of grazing beef cattle in central Saskatchewan.

MATERIALS AND METHODS

Pastures and Animals

The experiment was conducted at the Termuende Research Station of the University of Saskatchewan, Lanigan (51°49′N, 105°14°W). The topography is gently to moderately hummocky and the soil is a mixed orthic black and carbonated Oxbow, with a loam texture. A 16-ha block of 32-yr-old crested wheatgrass that had never been fertilized was disrupted by a single working with a cultivator to a depth of 5–6 cm and sub-divided into eight 2-ha paddocks. The eight paddocks were randomly divided into two replicates of each of four fertilizer treatments (0, 50, 100 and 200 kg N ha^{-1}) applied as a single application annually for 4 yr (1983–1986) as urea (46-0-0). For the next 4 yr (1987–1990) no fertilizer was applied to any of the pastures. Soil cores (0–15, 15–30 and 30–60 cm) were taken in spring 1983 before fertilizer was applied and again in late October 1983, 1984, spring 1987 and late October each year 1987–1990. Ten cores at each depth were taken on each 2-ha paddock, air dried, crushed and mixed and submitted to the Saskatchewan Soil Testing Laboratory for NO_3-N analysis. The mean total concentrations of NO_3-N mg kg^{-1} through the soil profiles for each rate of fertilizer application are shown in Table 1. Precipitation was measured daily from Apr. 01 to Sep. 30. For the purposes of sample collection, each paddock was visually divided into six strata, each 0.33 ha. Estimates of total forage production (TFP) were made by the paired plot technique (t'Mannetje 1978) using two 1-m^2 exclosure cages per stratum in each paddock. Pastures were clipped to soil level in 1983 and 1984 with portable electric sheep shearing shears every 14 d from two 0.25-m^2 quadrats per stratum in each paddock and the exclosure cages were repositioned at random within each stratum and paddock. Available forage (kg DM ha^{-1}) was measured 1 d before heifers were allocated to the pastures in 1987–1990 by clipping six quadrats per pasture with a modified "Jari" sickle bar mower set at 2.5 cm above the soil surface.

Grazing commenced in spring when it was estimated that the available herbage biomass in the control (0 kg N ha^{-1}) pastures could support a stocking rate of 2.5 pregnant yearling Hereford heifers per hectare and terminated when ani-

Table 1. Mean cumulative soil NO_3-N concentrations (mg kg^{-1}) at depths of 0–60 cm in 1983–1984 and 1987–1990 for crested wheatgrass pastures that received nitrogen fertilizer at rates of 0, 50, 100 and 200 kg N ha^{-1} 1983–1986 at Lanigan, Saskatchewan

	Fertilizer application rate (kg N ha^{-1}) 1983–1986			
	0	50	100	200
Spring 1983 (pre-fertilization)	5	5	5	5
Fall 1983	6	22	28	31
Fall 1984	6	13	17	61
Spring 1987[z]	11	26	33	229
Fall 1987	7	10	68	178
Fall 1988	5	8	33	93
Fall 1989	10	22	17	119
Fall 1990	25	29	46	113

[z] Soil samples were not collected in 1985 and samples collected in spring 1987 represent residual values following 4 yr of application (1983–1986) before new growth occurred in 1987.

mal weight gains could no longer be sustained on individual pastures. A put-and-take stocking system (Mott and Lucas 1952) was used and stocking rates were adjusted every 2 wk in an attempt to maintain similar herbage availability in all paddocks. Liveweights were obtained following an overnight fast without food or water for the tester animals at the start and end of grazing and all animals were weighed every 2 wk, 3–4 h after sunrise to minimize weight fluctuations due to gut fill. Put-and-take animals were similar to tester animals in breed, sex, physiological status and pre-experimental nutrition and weight. The mean liveweight of all heifers at the start of grazing was 349 ± 30 kg, pooled for all years. Determinations of average daily weight gain (ADG kg d^{-1}) were based on the bi-weekly weights of tester animals. Carrying capacity measured as AGD ha^{-1} included both tester and put-and-take animals. Total livestock production (TLP kg liveweight gain ha^{-1}) was determined for each pasture as ADG × AGD and expressed on a per hectare basis (Mott and Lucas 1952).

Nutritional Status

Six heifers in 1984 and 1985 were fistulated at the esophagus, incorporated into the stocking system as put-and-take animals and used to collect samples of grazed herbage following an overnight fast as described by Cohen (1979). Extrusa samples were collected on days 4, 18 and 39 after heifers were allocated to the pastures in 1984 and days 18, 39 and 62 in 1985 from two heifers in each paddock. Extrusa were collected serially from all eight paddocks between 0800 and 1200 on each occasion (Cohen 1979). Fecal output was determined using Cr_2O_3 as a marker for the estimation of fecal output (Corbett et al. 1958). Animals were dosed with 10 g Cr_2O_3 morning and evening for 8 d. Fecal sampling commenced on the morning of day 5 at the time of dosing each morning and afternoon for 4 d to overlap the days on which esophageal extrusa samples were collected. All samples were frozen until preparation for analysis. In vitro organic matter digestibility of extrusa samples and fecal output were used to estimate DOMI. Intakes of other nutrients, except phosphorus, were estimated from their concentration in extrusa samples and dry matter intakes determined at corresponding periods. Phosphorus has been shown to be elevated in esophageal fistula extrusa due to salivary contamination (Lesperance et al. 1960; Langlands 1966; Little 1972) so phosphorus intake was estimated from the relationship between fecal P concentration and P intake (Cohen 1974). Other minerals such as Ca, Mg, Cu and Fe are not elevated in esophageal extrusa (Little 1975) so these were estimated directly from extrusa samples. The mineral status of tester heifers was determined from plasma samples collected every 2 wk during 1984 and 1985. All animals were cared for in accordance with the principles outlined by the Canadian Council on Animal Care (1993).

Analytical and Statistical Techniques

Pasture and extrusa samples were weighed and dried in a forced-draught oven at 60°C for 48 h. Nitrogen concentration was determined by Kjeldahl digestion and ashing by ignition to 600°C for 2 h. Acid detergent fiber was determined using the official methods of the Association of Analytical Chemists (1980), P by the method of Parks and Dunn (1963) and mineral digestions for atomic absorption spectrophotometry by the method of Zasoski and Burau (1977). Extrusa organic matter digestibilities were determined by the method of Tilley and Terry (1963) with modifications (Cohen 1979). Fecal Cr_2O_3 was determined according to the technique of Fenton and Fenton (1979). Plasma P was determined using the Sigma Chemical Co. Kit No. 670. Other plasma minerals were determined on de-proteinized plasma by atomic absorption spectrophotometry.

Data were interpreted using analysis of variance, polynomial and linear/linear regression (SAS Institute, Inc. 1985).

RESULTS AND DISCUSSION

Current Fertilizer Effects

Forage production nitrogen recovery. Rainfall from Apr. 01 to Aug. 31 varied considerably during the 8 yr of the experiment (Table 2) and this had a marked effect on both the current and residual response to fertilizer. Rain (R mm) was a significant covariate with the amount of nitrogen fertilizer applied (N kg ha^{-1}) during the first 4 yr when fertilizer was applied annually so data for rain, fertilizer rate and total forage production (TFP kg DM ha^{-1}) were pooled and a single predictive equation computed:

Table 2. Mean annual rainfall between Apr. 01 and Aug. 31, 1983–1990, average daily gain and animal grazing days for heifers grazing crested wheatgrass pastures fertilized with 0, 50, 100 and 200 kg N ha^{-1} from 1983 to 1986 and left unfertilized from 1987 to 1990.

			Average daily gain (kg)					Animal grazing days (d ha^{-1})				
			Fertilizer (kg N ha^{-1} yr^{-1}) 1983–1986					Fertilizer (kg N ha^{-1} yr^{-1}) 1983–1986				
Year	Rain (mm) Apr.-Aug.	Rain (mm) Apr.-Jun.	0	50	100	200	Mean ± Pooled SEM	0	50	100	200	Mean ± Pooled SEM
1983	349	138	0.75	0.69	0.74	0.68	0.71 ± 0.02	159	210	274	280	226 ± 17
1984	140	88	0.68	0.76	0.59	0.68	0.67 ± 0.03	107	124	138	152	130 ± 7
1985	255	188	0.47	0.36	0.51	0.67	0.50 ± 0.05	175	252	242	266	234 ± 13
1986	263	140	0.34	0.35	0.54	0.49	0.43 ± 0.04	351	409	439	499	424 ± 22
1987	251	125	0.90	1.04	0.90	1.00	0.96 ± 0.03	150	186	227	290	213 ± 20
1988	168	58	1.23	1.05	1.14	1.14	1.14 ± 0.06	92	96	119	126	108 ± 6
1989	209	142	0.78	0.99	0.82	0.89	0.87 ± 0.04	104	104	129	136	118 ± 6
1990	194	118	0.76	0.99	0.84	0.97	0.86 ± 0.03	107	115	114	122	115 ± 4

Long-term average rainfall Apr. 01–Aug. 31 from 1960 to 2000 was 239 mm.

$$\mathrm{TFP} = 285 + 3.17\ \mathrm{N} + 12.9\ \mathrm{R} \quad (\mathrm{RSD} = 808;\ P < 0.001). \tag{1}$$

Apparent nitrogen recovery in harvested herbage (ANR), is the difference in nitrogen recovered from fertilized and unfertilized forage expressed as a percentage of the fertilizer applied and was influenced by rainfall during the growing season ($P < 0.05$). In 1983, ANR was 615, 454 and 350 g kg^{-1} for applications of 50, 100 and 200 kg N ha^{-1} respectively. The corresponding ANR in 1984 were 269, 252 and 205 g kg^{-1}, respectively. Whitehead (1970) suggested that ANR below 450 g kg^{-1} are likely the result of growth-limiting factors not related to nitrogen supply. Growing season precipitation was lower in 1984 than any of the other 7 yr 1983–1990 (Table 2), and in fact was lower than any year, 1974–1992, when Environment Canada recorded weather data at Guernsey, 10 km west of Lanigan. This probably contributed to the low ANR in 1984. ANR for both years were similar to those reported by Cooke et al. (1968) for Saskatchewan pastures during wet and dry years. Reduced ANR in dry years has also been reported elsewhere (Colville et al. 1963; Dawson and Ryden 1985). Under dry soil conditions, NO_3-N has reduced mobility in the soil, restricting the area over which N can be drawn into the plant through the roots. This effectively limits plant uptake of N, thereby reducing ANR (Cooke 1982). Phosphorus is likely to become limiting to plant growth at higher P depletion rates associated with increased forage production following high applications of N fertilizer. The reduction in ANR with increasing levels of N fertilization may therefore reflect a corresponding increased soil-P deficit in both years.

Mineral responses and grass tetany. In 1984 and 1985, nitrogen fertilizer did not affect pasture concentrations of Ca (6.6 ± 0.2 g and 5.4 ± 0.2 g kg^{-1} DM, respectively) or P (1.7 ± 0.03 g and 1.1 ± 0.03 g kg^{-1} DM, respectively). Fertilizer application did increase pasture Cu concentration (mg kg^{-1} DM) in 1983

$$\mathrm{Cu} = 4.5 + 0.9\ \mathrm{N}\ (\mathrm{RSD} = 0.48;\ P < 0.05) \tag{2}$$

but not in 1984 (4.82 + 0.12 mg kg^{-1}DM). Pasture Cu concentrations were below National Research Council (NRC) (1996) recommendations for beef cattle at all levels of fertilizer in 1984, but did exceed the recommended level (8 mg kg^{-1}) at 100 and 200 kg N ha^{-1} in 1983.The mechanism of this response to fertilizer in the wetter year of 1983 is not clear, but may simply reflect the increased ability of a more vigorous plant sward to extract Cu from the soil. This experimental site has been reported to be deficient in Cu (Smart et al. 1981).

Pasture concentrations of Mg, K and Mn were not determined in 1983, but they were in 1984 (2.1 ± 0.04 g kg^{-1} DM; 15.1 ± 0.8 g kg^{-1} DM and 115 ± 1.4 mg kg^{-1} DM, respectively). Of these three minerals, only K was increased by fertilizer rate

$$\mathrm{K} = 12.7 + 0.03\ \mathrm{N}\ (\mathrm{RSD} = 0.4;\ P < 0.01) \tag{3}$$

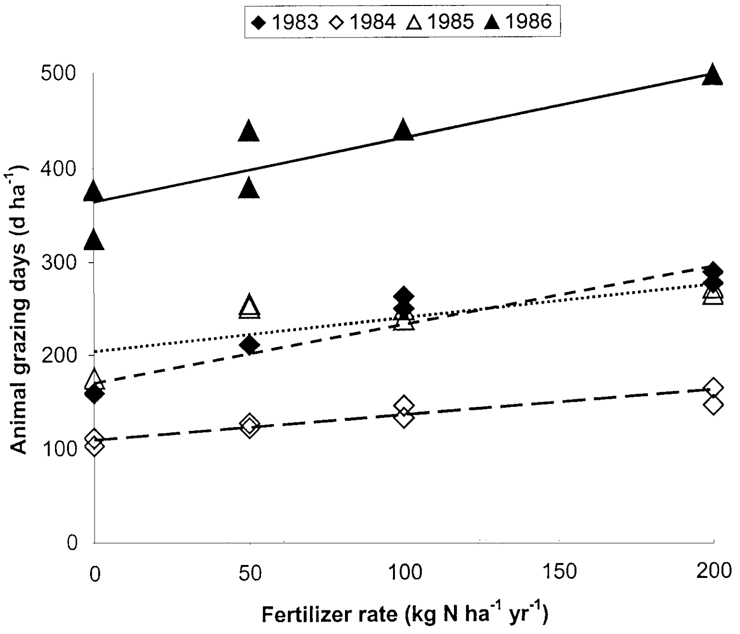
and reduced during maturation

$$\mathrm{K} = 22.0 - 0.3\ D\ (\mathrm{RSD} = 1.3;\ P < 0.01) \tag{4}$$

where D = number of days after grazing commenced. Metson et al. (1966) suggested that Mg levels of at least 2.5 g kg^{-1} DM were required to prevent grass tetany when concentrations of N and K were high. Fertilization with N increased both the N and K concentrations of the forage and high levels of N fertilization have been shown to reduce forage Mg concentration through leaching of exchangeable bases from the plant root zone (Adams et al. 1967). At the same time, plant N and K levels may be increased to a point where they interfere with the absorption of Mg from the intestine (Grunes et al. 1970). Kemp and t'Hart (1957) suggested that a grass tetany ratio (GTR), which is the ratio of K:Ca + Mg in the forage, greater than 2.0 could signal a risk of inducing grass tetany. The GTR in our pastures in 1985 were 1.87, 1.89, 2.12 and 2.21, respectively, for 0, 50, 100 and 200 kg N ha^{-1} fertilizer rates and the regression of GTR on N fertilizer rate was:

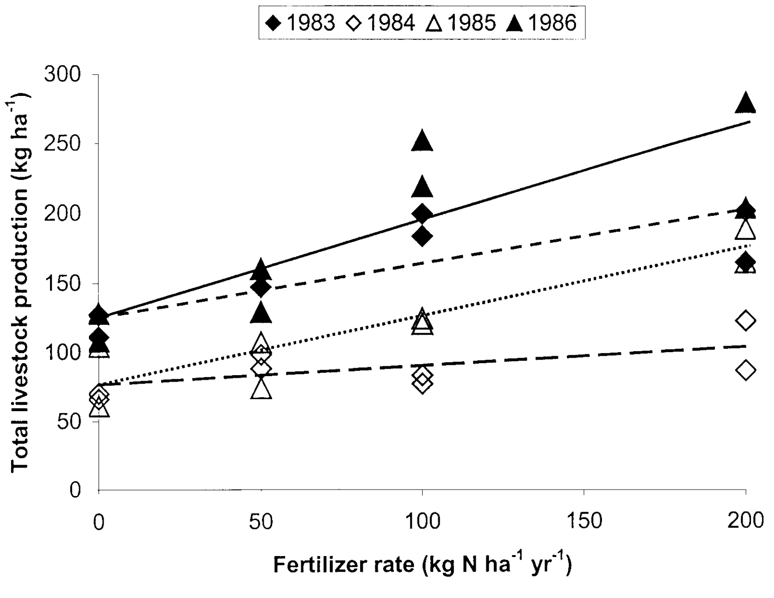
$$\mathrm{GTR} = 1.86 + 0.002\ \mathrm{N}\ (\mathrm{RSD} = 0.14;\ P < 0.05) \tag{5}$$

From this we predict that cattle may be at risk from grass tetany when fertilizer applications exceed 70 kg N ha^{-1}, even in a low rainfall year. There was, however, a signifi-



$AGD_{1983} = 174 + 0.59$ N (RSD = 17.8; $P < 0.001$)
$AGD_{1984} = 111 + 0.22$ N (RSD = 8.0; $P < 0.001$)
$AGD_{1985} = 201 + 0.37$ N (RSD = 25.0; $P < 0.001$)
$AGD_{1986} = 362 + 0.71$ N (RSD = 25.1; $P < 0.001$)

Fig. 1. Effect of applications of nitrogen fertilizer to crested wheatgrass pasture a Lanigan, Saskatchewan, on the number of animal grazing day1983–1986.



$TLP_{1983} = 132 + 0.32$ N (RSD = 22.7; $P < 0.001$)
$TLP_{1984} = 73.2 + 0.15$ N (RSD = 14.2; $P < 0.001$)
$TLP_{1985} = 74.9 + 0.49$ N (RSD = 18.6; $P < 0.001$)
$TLP_{1986} = 127.4 + 0.66$ N (RSD = 38.9; $P < 0.001$)

Fig. 2. Effect of applications of nitrogen fertilizer to crested wheatgrass pasture at Lanigan, Saskatchewan, on total livestock production 1983–1986.

Table 3. The effect of nitrogen fertilizer and season on organic matter digestibility (g kg^{-1}) of esophageal extrusa from heifers grazing crested wheatgrass herbage at three growth stages in central Saskatchewan

Fertilizer rate (kg N ha^{-1})	Growth stage[z]		
	Vegetative	Flowering	Mature
1984			
0	661	546	527
50	635	561	504
100	674	554	545
200	660	574	535
Mean ± SEM	657*a* ± 9.2	558*b* ± 9.5	528*c* ± 14.0
1985			
0	689	646	561
50	709	675	625
100	695	658	628
200	735	717	666
Mean ± SEM	707*a* ± 13.4	674*a* ± 12.9	620*b* ± 14.9

[z] Vegetative stage was day 4 in 1984 and day 18 in 1985. Flowering stage was day 18 in 1984 and day 39 in 1985. Mature stage was day 39 in 1984 and day 62 in 1985.
a–c Means within a row with different letters differ ($P < 0.05$).

Table 4. Regression coefficients (α intercept and β slope), residual standard deviation and *P* value for the effect of fertilizer application rate (N kg ha^{-1}) on pasture crude protein (PCP g kg^{-1} DM) and total crude protein yield (CPY kg ha^{-1}) of crested wheatgrass at Lanigan, Saskatchewan 1983–1984 (CP = α + β N).

Days from start of grazing		α	β	RSD	*P*<
1983					
PCP (g kg^{-1})					
	1	134.8	0.3	9.7	0.01
	42	108.4	0.2	10.9	0.05
	71	87.3	0.1	8.3	0.05
CPY (kg ha^{-1})		350.6	2.3	90.6	0.01
1984					
PCP (g k^{-1})					
	1	106.1	0.3	9.1	0.01
	28	64.8	0.2	4.2	0.01
	42	60.5	0.2	9.3	0.05
CPY (kg ha^{-1})		167.3	1.25	46.4	0.01

cant reduction of GTR with advancing plant maturity (*D*-days from start of grazing):

$$\text{GTR} = 2.62 + 0.02\,D - 0.002\text{D}^2 \quad (\text{RSD} = 0.15;\ P < 0.01) \tag{6}$$

Equation 6 suggests that in 1984 the heifers may have been at risk for the first 28 d of grazing and there was a significant depression in ADG (kg d^{-1}) of the heifers during the first 27 d of grazing as pasture crude protein concentration (PCP g kg^{-1} DM) increased:

$$\text{ADG}_{1\text{-}27} = 2.27 - 0.74\ \text{PCP}\ (\text{RSD} = 0.13;\ P < 0.01) \tag{7}$$

and an increase in ADG with increasing Mg intake (Mg I g d^{-1}) during the first 15 d of grazing:

$$\text{ADG} = 0.10 + 0.07\ \text{Mg I}\ (\text{RSD} = 0.25;\ P < 0.05) \tag{8}$$

Equations 3–8 lead to a suggestion of sub-clinical hypomagnesemia, although we were unable to detect any significant effect of fertilizer on plasma Mg concentrations (Table 7). However, Mg intakes (Table 6) were below NRC (1996) recommendations early in the grazing season of 1985. Therefore it may be prudent to supplement cattle with Mg during the early part of the grazing season if N fertilizer is being applied at rates in excess of 70 kg N ha^{-1}.

Livestock production. Data for ADG are shown in Table 2. The effect of fertilizer rate on ADG was not significant ($P = 0.19$) and there was no significant interaction of year × fertilizer rate ($P = 0.21$), but there was a significant year effect ($P < 0.0001$) related to the amount and month in which the rain occurred. The pastures were grazed for 72, 42, 70 and 64 d during 1983, 1984, 1985 and 1986, respectively, when fertilizer was applied. AGD increased ($P < 0.05$) with N each year (Fig. 1) but R was a significant covariate ($P < 0.001$) and a single pooled equation was computed:

$$\text{AGD} = 48.6 + 0.39\ \text{N} + 0.48\,R \quad (\text{RSD} = 27.0;\ P < 0.001). \tag{9}$$

However, examination of Table 2 indicates that the relationship with rain is more complex than a simple total rainfall. For example, AGD was greatest in 1986, but total rain in April–August was greatest in 1983, most of the rain in 1983 occurring in July (197 mm) when the average temperature was 19.2°C. This may be above the optimum temperature for growth of crested wheatgrass. In contrast, only 138 mm fell in April–June, 1983. In 1986, although rainfall in April–June was only 140 mm, the pastures were in the fourth year of fertilization and there may have been some build-up of residual fertilizer. Further illustration of the complex relationship between fertilizer, rainfall and production can be obtained from a comparison of data in Table 2 for 1985 and 1986. Rainfall in April–June, 1985 was 188 mm, greater than in any other year, yet AGD was only 55% of AGD in 1986, probably because 1984 was an exceptionally dry year. That would have resulted in low soil moisture at the start of the 1985 growing season. However, Table 2 does clearly indicate that low rainfall results in low productivity.

As expected, AGD was significantly related to TFP:

$$\text{AGD} = 72.6 + 0.03\ \text{TFP}\ (\text{RSD} = 34.8;\ P < 0.001). \tag{10}$$

TLP also increased ($P < 0.05$) with N each year, except 1984 (Fig. 2) and once again R was a significant covariate so a single pooled equation was computed:

$$\text{TLP} = 20.2 + 0.32\ \text{N} + 0.13\,R \quad (\text{RSD} = 23.0;\ P < 0.001). \tag{11}$$

There was also a significant relationship between TLP and TFP:

$$\text{TLP} = 44.0 + 0.02\ \text{TFP}\ (\text{RSD} = 25.4;\ P < 0.001). \tag{12}$$

Table 5. Effect of pasture maturation on the nutrient composition of esophageal extrusa collected from heifers grazing crested wheatgrass pastures at Lanigan, Saskatchewan 1984–1985

	Growth stage^{z}			
Nutrient	Vegetative	Flowering	Mature	Pooled SEM
Crude protein (g kg^{-1})				
1984	169*a*	100*b*	72*c*	10.2
1985	167*a*	110*b*	156*a*	4.4
ADF (g kg^{-1})				
1984	358*a*	397*b*	449*c*	9.4
1985	400*a*	437*b*	494*c*	6.9
Ash (g kg^{-1})				
1984	77*a*	66*b*	69*b*	1.2
1985	100*ab*	85*a*	113*b*	2.7
Ca (g kg^{-1})				
1984	5.9*a*	3.3*b*	2.6*b*	0.4
1985	4.3	4.2	4.6	0.1
Mg (g kg^{-1})				
1984	1.7*a*	1.1*b*	0.8*b*	0.1
1985	0.16	1.3	1.6	0.1
Fe (mg kg^{-1})				
1984	233*b*	267*b*	409*a*	19.1
1985	399*b*	407*b*	777*a*	31.5
Cu (mg kg^{-1})				
1984	7.1*a*	5.5*b*	4.0*b*	0.32
1985	11.9*a*	7.4*b*	7.6*b*	0.37
Zn (mg kg^{-1})				
1984	29.4	25.8	25.5	0.44
1985	35.9	31.4	30.4	0.50
Mn (mg kg^{-1})				
1984	34.5*b*	36.7*b*	55.0*a*	2.30
1985	44.0*b*	45.5*b*	76.4*a*	2.90

^{z}Vegetative stage was day 4 in 1984 and day 18 in 1985. Flowering stage was day 18 in 1984 and day 39 in 1985. Mature stage was day 39 in 1984 and day 62 in 1985.

a–c Means within a row with different letters differ ($P < 0.05$).

The finding that ADG did not vary between fertilizer treatments, but TFP, AGD and TLP did, clearly indicates that stocking rates must be increased in order to take advantage of the extra forage produced following fertilizer application. Beaton and Berger (1974) suggested that farmers generally failed to take advantage of additional forage production. The dichotomy between research findings and farmer practice may therefore occur because farmers are expecting an increase in ADG, don't get it and conclude that fertilizing pasture is not worthwhile.

Livestock nutrition. The efficiency of the conversion of available pasture dry matter to liveweight (FCR) was obtained from the ratio of pasture DM yield:liveweight gain. Although N did not significantly affect FCR in either 1983 or 1984, the correlation coefficients were negative (–0.40 and –0.24, respectively), suggesting a trend towards increased efficiency of conversion of pasture to livestock product with increasing N. FCR was significantly lower in 1984 compared with 1983 ($P < 0.05$) and was significantly related to TFP. The pooled regression for both years was:

$$\text{FCR} = 17.01 + 0.003\ \text{TFP}\ (\text{RSD} = 4.95;\ P < 0.01) \tag{13}$$

Organic matter digestibility (OMD g kg^{-1})) of extrusa samples was not affected by fertilizer in 1984, but in 1985, OMD increased linearly with fertilizer application for samples collected on day-31 and day-59 of 1985:

$$\text{OMD}_{39} = 646 + 0.3\ \text{N}\ (\text{RSD} = 27.9;\ P < 0.05) \tag{14}$$

$$\text{OMD}_{62} = 579 + 0.5\ \text{N}\ (\text{RSD} = 21.6;\ P < 0.01) \tag{15}$$

This suggests that a response in herbage digestibility to the application of fertilizer is likely to occur only in a high rainfall year. This is probably associated with a stimulation of re-growth when both soil fertility and moisture are adequate. However, in both years, there was a decline ($P < 0.05$) in OMD as the grazing season progressed (Table 3).

There was a linear increase in pasture protein concentration (PCP g kg^{-1} DM) and this effect was consistent at each sampling period during 1983 and 1984 (Table 4). The reduction in α and β coefficients with time (Table 4) suggests that

Table 6. Effect of pasture maturation on nutrient intakes of heifers grazing crested wheatgrass pastures at Lanigan, Saskatchewan 1984–1985

	Growth stage^z			
Nutrient	Vegetative	Flowering	Mature	Pooled SEM
Crude protein (g d^{-1})				
1984	1340*a*	–	593*b*	132.0
1985	754*b*	1009*a*	788*b*	28.3
P (g d^{-1})				
1984	31*a*	–	14*b*	2.9
1985	32*a*	16*b*	15*b*	1.98
Ca (g d^{-1})				
1984	45*a*	–	19*b*	4.6
1985	20*b*	29*a*	26*ab*	4.9
Mg (g d^{-1})				
1984	13*a*	–	7*b*	1.1
1985	7*b*	11*a*	8*b*	0.51
Fe (mg d^{-1})				
1984	2620	–	2670	9
1985	1980*b*	4339*a*	4230*a*	272
Cu (mg d^{-1})				
1984	48*a*	–	26*b*	4.0
1985	59*a*	74*a*	42*b*	3.3

^{z}Vegetative stage was days 1–8 in 1984 and days 14–22 in 1985. Flowering stage was days 34–42 in 1985. Mature stage was days 34–42 in 1984 and days 62–70 in 1985

a,b Means within a row with different letters differ ($P < 0.05$).

pasture protein concentration was reduced with increasing maturity at all fertilizer levels. In contrast, extrusa crude protein concentration (ECP g kg^{-1} DM) was significantly influenced by fertilizer application rate only early in the grazing season, day 4 in 1984 (ECP_4) and day 18 in 1985 (ECP_{18}):

$$ECP_4 = 157.1 + 0.1\ N\ (RSD = 7.6;\ P < 0.01) \qquad (16)$$

$$ECP_{18} = 142.5 + 0.3\ N\ (RSD = 22.\ 6;\ P < 0.05) \qquad (17)$$

These results suggest considerable selection for protein by the heifers (Popp et al. 1999). Both PCP and the response of PCP to nitrogen fertilizer declined with pasture maturation (Table 4). ECP declined ($P < 0.05$) throughout the grazing season in both 1983 and 1984 and was consistently lower in the dry year of 1984 (Table 5). Similarly, ECP declined during 1984, but in 1985 it declined to day 39 and then increased to day 62 (Table 3) following growth-stimulating rain that occurred on day 50. Crude protein intake (CPI g d^{-1}) had a positive influence on ADG during days 1–15 in the dry year of 1984:

$$ADG_{1\text{-}15} = -2.92 + 0.003\ CPI \quad (RSD = 0.13;\ P < 0.01) \qquad (18)$$

In contrast, early in the wetter season of 1985 (days 1–27) the relationship between ECP and ADG was negative:

$$ADG_{1\text{-}27} = 2.27 - 0.07\ ECP \quad (RSD = 0.13;\ P < 0.01) \qquad (19)$$

but this relationship was positive later in the 1985 season (days 27–55):

$$ADG_{27\text{-}55} = -0.61 + 0.12\ ECP \quad (RSD = 0.23;\ P < 0.05) \qquad (20)$$

The negative influence of ECP on ADG (Eq. 19) may reflect sub-clinical nitrate toxicity. Crude protein concentration of fertilized pastures increased with increasing fertilizer rate (Table 4) and much of the nitrogen may have been as NO_3-N. This may not have occurred in 1984 due to the low rainfall reducing the uptake of nitrogen from the higher levels of fertilization and the corresponding lower yield and quality responses to fertilizer. Available forage (AF kg DM ha^{-1}) was negatively related to ADG in 1985 from days 1 to 27 but positively related from days 55 to 69.

$$ADG_{1\text{-}27} = 1.98 - 0.0004\ AF \quad (RSD = 0.22;\ P < 0.05) \qquad (21)$$

$$ADG_{55\text{-}69} = 0.10 + 0.001\ AF \quad (RSD = 0.36;\ P < 0.05) \qquad (22)$$

Normally, an increase in ADG is expected with increasing available forage, so Eq. 21 is unusual and may also reflect possible NO_3 toxicity early in a season with normal average rainfall.

The ADF, ash, Fe, Mg and Cu concentrations of extrusa in 1984 and 1985 were significantly affected by advancing maturation (Table 5). Advancing maturation did not significantly ($P > 0.05$) affect the Zn concentration of extrusa in either year of the study, while Ca and Mg concentrations of extrusa were influenced ($P < 0.05$) by maturation in 1984 only (Table 5). Fertilizer had no effect on ADF or any of these minerals ($P > 0.05$). The intakes of DOM, protein, Ca, Mg, Cu, Fe and P were significantly influenced by advancing maturation (Table 6), but fertilizer did not influence any of these nutrient intakes. However, because increasing increments of fertilizer resulted in increased AGD (Eq. 9), it follows that the total removal of these nutrients per hectare was also increased by increments of fertilizer application.

When these nutrient intakes were compared with NRC (1996), P intake was below recommended levels from mid- to late season in both years (Table 6). However, plasma P and Ca (Table 7) always indicated an adequate status (NRC 1996), but plasma is not a good estimator of P status (Cohen 1973a,b). Nevertheless, plasma P did decline ($P < 0.05$) with maturation in both 1984 and 1985 (Table 7).

Fe intakes were very high throughout 1984 and 1985 compared with NRC (1996) and may have been antagonistic towards Cu (Humphries et al. 1983), Zn and Mg (Underwood 1977) absorption and metabolism. However this was not apparent from the plasma analyses (Table 7). In both 1984 and 1985, Cu intakes (Table 6) were adequate early in the season, but marginal to low late in the season (NRC 1996). Late in the season (days 28–55), ADG was positively related to pasture Cu concentration (PCu mg kg

Table 7. Effect of pasture maturation on plasma mineral concentrations of heifers grazing crested wheatgrass pastures at Lanigan, Saskatchewan 1984–1985

	Growth stage[z]			
Nutrient	Vegetative	Flowering	Mature	Pooled SEM
P (g d^{-1})				
1984	62.2*a*	52.4*b*	47.9*c*	1.06
1985	79.6*a*	65.2*b*	54.6*c*	1.31
Ca (mg L^{-1})				
1984	107.0*b*	110.1*ab*	115.7*a*	0.64
1985	102.1	100.6	99.2	0.48
Mg (mg L^{-1})				
1984	21.4	21.5	21.8	0.04
1985	21.7*a*	21.1*a*	18.6*b*	0.17
Fe (µmol L^{-1})				
1984	26.9*b*	32.2*a*	28.6*b*	0.40
1985	23.3*b*	30.4*a*	25.1*b*	0.43
Cu (µmol L^{-1})				
1984	9.5*b*	10.2*ab*	11.9*a*	0.18
1985	12.8*b*	14.3*ab*	16.3*b*	0.18
Zn (µmol L^{-1})				
1984	13.5*a*	12.0*b*	12.4*b*	0.11
1985	15.8*a*	16.0*b*	13.7*b*	0.13

[z] Vegetative stage was day 1. Flowering stage was day 28. Mature stage was day 42 in 1984 and day 70 in 1985.

a,b Means within a row with different letters differ ($P < 0.05$).

DM^{-1}), suggesting a growth response by the heifers to increasing pasture copper concentrations:

$$ADG_{28\text{-}55} = -2.29 + 0.84\ PCu \quad (RSD = 0.17;\ P < 0.01) \tag{23}$$

However, despite reduced Cu levels in extrusa (Table 2) and Cu intakes (Table 7) as maturation proceeded, plasma Cu increased ($P < 0.05$; Table 7) suggesting mobilization of Cu stores from the liver. Smart et al. (1986) also reported similar findings with lactating beef cows. When data for extrusa Cu (ECu mg $kgDM^{-1}$) were pooled for both years and regressed on pooled plasma Cu (Pl Cu µmol L^{-1}), a significantly positive relationship existed:

$$Pl\ Cu = 8.00 + 0.96\ ECu - 0.03\ ECu^2 \quad (RSD = 2.11;\ P < 0.01) \tag{24}$$

suggesting that Cu status was significantly influenced by Cu intake.

Residual Fertilizer Effects

The reduced ANR with increasing fertilizer rates and the increase in soil NO_3-N concentrations suggested a build-up of residual nitrogen may have been quite substantial by the end of the 1986 grazing season. Therefore, in spring 1987, we collected more soil samples and they confirmed a large residual level of soil NO_3-N. We therefore ceased applications of fertilizer from 1987 to 1990 to determine the effect of this residual N on production.

Soil NO_3-N

Soil NO_3-N data for 1987–1990 are shown in Fig. 3 and indicate substantial residual soil NO_3-N levels in spring 1987, following 4 yr of fertilizer application and a decline in each subsequent year, when fertilizer was no longer applied. Unfortunately, the experiment had to be terminated in January 1991 with the closure of the Termuende Research Station, but residual soil NO_3-N levels were probably still substantial at the start of the pasture season of 1991. In 1987 and 1988, there was no significant difference ($P > 0.05$) in soil NO_3-N between pastures that had received 0 and 50 kg N ha^{-1} during 1983–1986 (8.98 ± 2.42 and 7.0 ± 2.8 kg ha^{-1}), but the regression of soil NO_3-N on previous fertilizer rate was linear for previous applications of 50, 100 and 200 kg N ha^{-1} in both years:

$$Soil\ NO_3\text{-}N_{1987} = -50.7 + 1.25\ N \quad (RSD = 48.0;\ P < 0.05) \tag{25}$$

$$Soil\ NO_3\text{-}N_{1988} = -25.8 + 0.65\ N \quad (RSD = 21.7;\ P < 0.01) \tag{26}$$

The linear/linear model of the SAS Institute Inc. (1985) indicated that the point of inflection occurred at 45.8 and 46.3 kg N ha^{-1} respectively. The relationship between soil NO_3-N and previous fertilizer rate was quadratic for 1989 and 1990, but the difference between previous applications of 0 and 50 kg N ha^{-1} remained non significant:

$$Soil\ NO_3\text{-}N_{1989} = 16.42 - 0.33\ N + 0.005\ N^2 \quad (RSD = 14.4;\ P < 0.001) \tag{27}$$

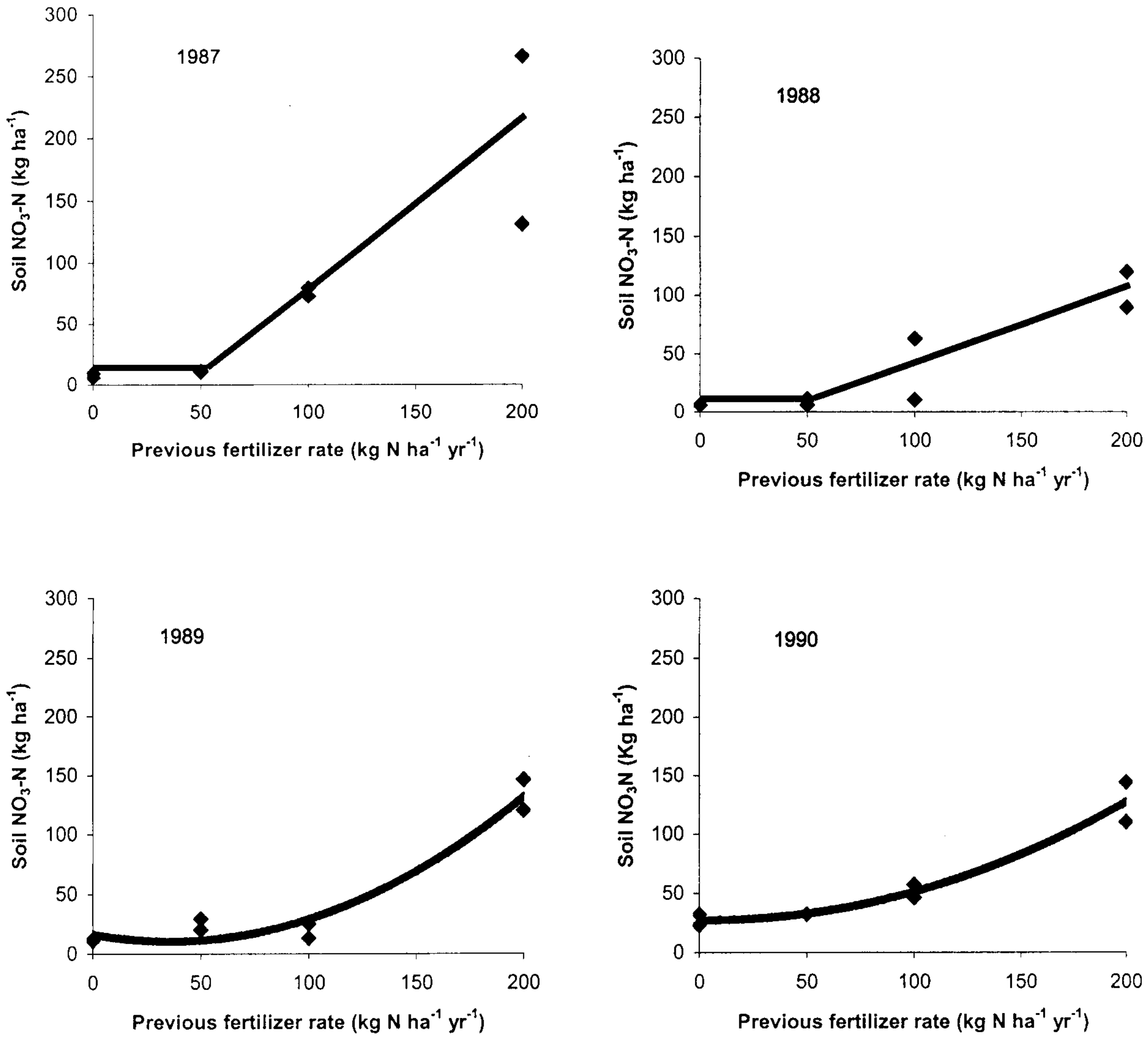


Fig. 3. Effect of previous applications of nitrogen fertilizer to grazed crested wheatgrass pastures during 1983–1986 on residual soil NO_3-N in 1987–1990 at Lanigan, Saskatchewan.

$$\text{Soil } NO_3\text{-}N_{1990} = 27.27 - 0.024\text{ N} + 0.003\text{ N}^2 \text{ (RSD} = 11.7; P < 0.001) \quad (28)$$

Available Forage

The AF (kg DM ha^{-1}) at the start of the 1987 grazing season increased linearly with each increment of previous fertilizer application:

$$AF_{1987} = 448 + 1.72\text{ N (RSD} = 71.1; P < 0.01) \quad (29)$$

In 1988, there was no significant difference between the previous fertilizer treatments (430 ± 159 kg DM ha^{-1}), but in 1989 the relationship was linear/linear with no difference between the previous 0 and 50 kg N ha^{-1} treatments but a linear response for the 50, 100 and 200 kg N ha^{-1} treatments:

$$AF_{1989} = 662 + 3.24\text{ N (RSD} = 212.7; P < 0.05 \quad (30)$$

The linear/linear model of the SAS Institute, Inc. (1985) indicated that the point of inflection occurred exactly at 50 kg N ha^{-1}.

In 1990, the relationship was once again linear across all previous fertilizer rates:

$$AF_{1990} = 1065 + 2.92\text{ N (RSD} = 5.97; P < 0.001 \quad (31)$$

The variation between years in the amount of forage available at the start of the grazing season reflects the variation in rainfall, particularly that in the early growth period (Table 2). This was particularly noticeable in 1988 when both early and total rainfall was low and there was no significant effect of residual soil nitrogen on AF.

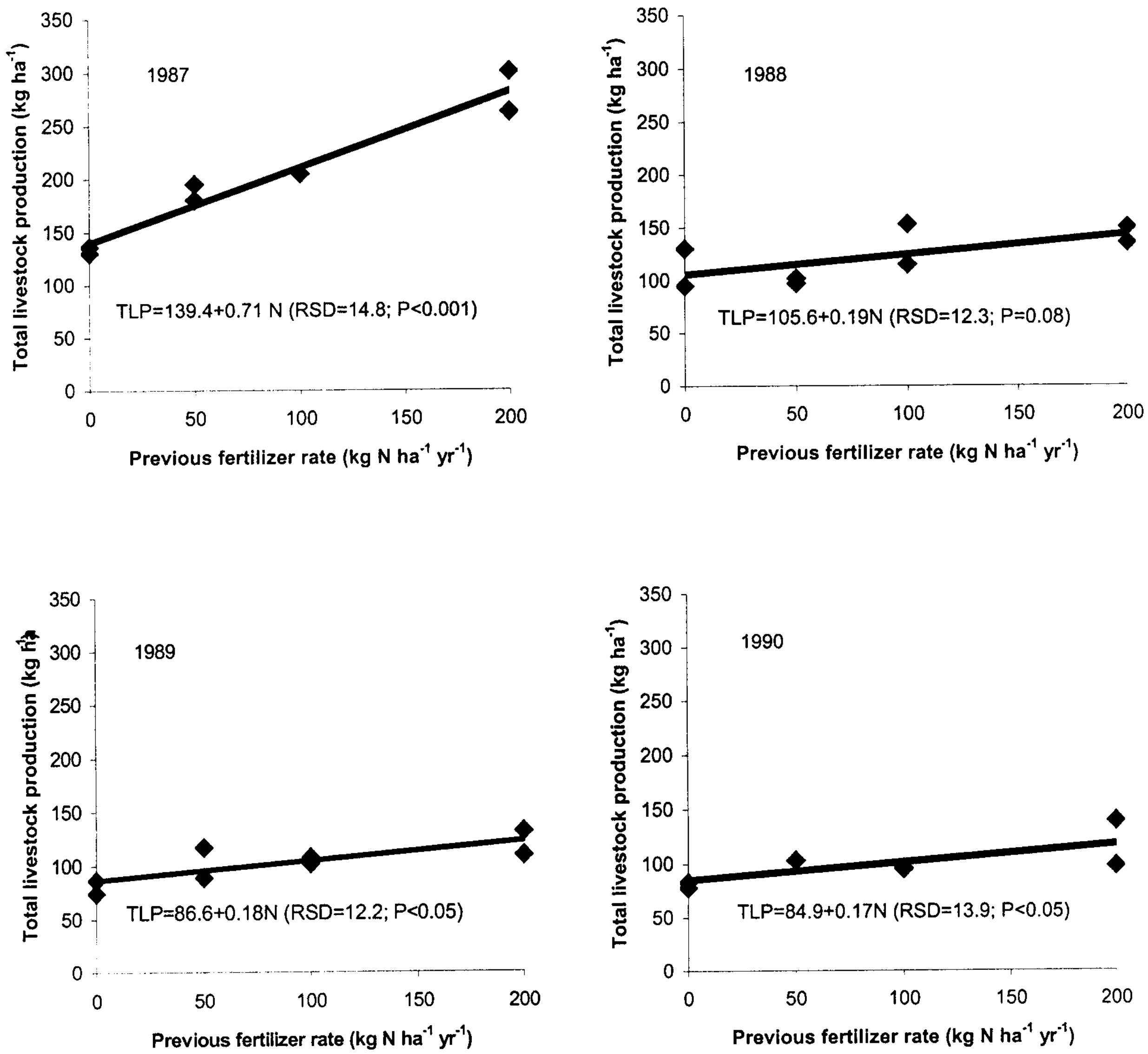


Fig. 4. Effect of previous applications of nitrogen fertilizer to grazed crested wheatgrass pastures during 1983–1986 on total livestock production in 1987–1990 at Lanigan, Saskatchewan.

Heifer Production

The relationship between previous fertilizer application rates and TLP was linear in each of the 4 yr 1987–1990 (Fig. 4) but did not reach significance ($P = 0.08$) in 1988. This reflects the lack of a significant effect of residual soil nitrogen on AF due to low early and total rainfall (Table 2). Animal grazing days (Fig. 5) increased in each year 1987–1990 with each increment of fertilizer applied during 1983–1986 except for 1990 when the effect was not significant ($P = 0.45$). Thus, although the residual benefit to TLP lasted into the fourth year following cessation of fertilizer application, the benefit to stocking rate lasted for only 3 yr. However, although the residual benefits beyond 1988 were significant they were greatly reduced from 1987 as indicated by the coefficients of slope in the equations accompanying Figs. 4 and 5.

CONCLUSIONS

We are not aware of any other reports on long-term effects of fertilizer applications on pasture and beef production and subsequent residual effects on the soil-plant-animal system on the Canadian prairies. Equations 25–31 and Figs. 3–5 suggest that, in this prairie environment, much of the applied fertilizer nitrogen is retained in the soil without significant leaching or denitrification leading to increased productivity for several years after fertilizer application has ceased. Fertilizer is more likely to be applied to pasture when cattle prices are high. Our data suggest that the residual effects of nitrogen fertilizer application may provide benefits to production when low cattle prices preclude the use of fertilizer. The results of this experiment suggest that annual applications of 50 kg N ha^{-1} will provide only mod-

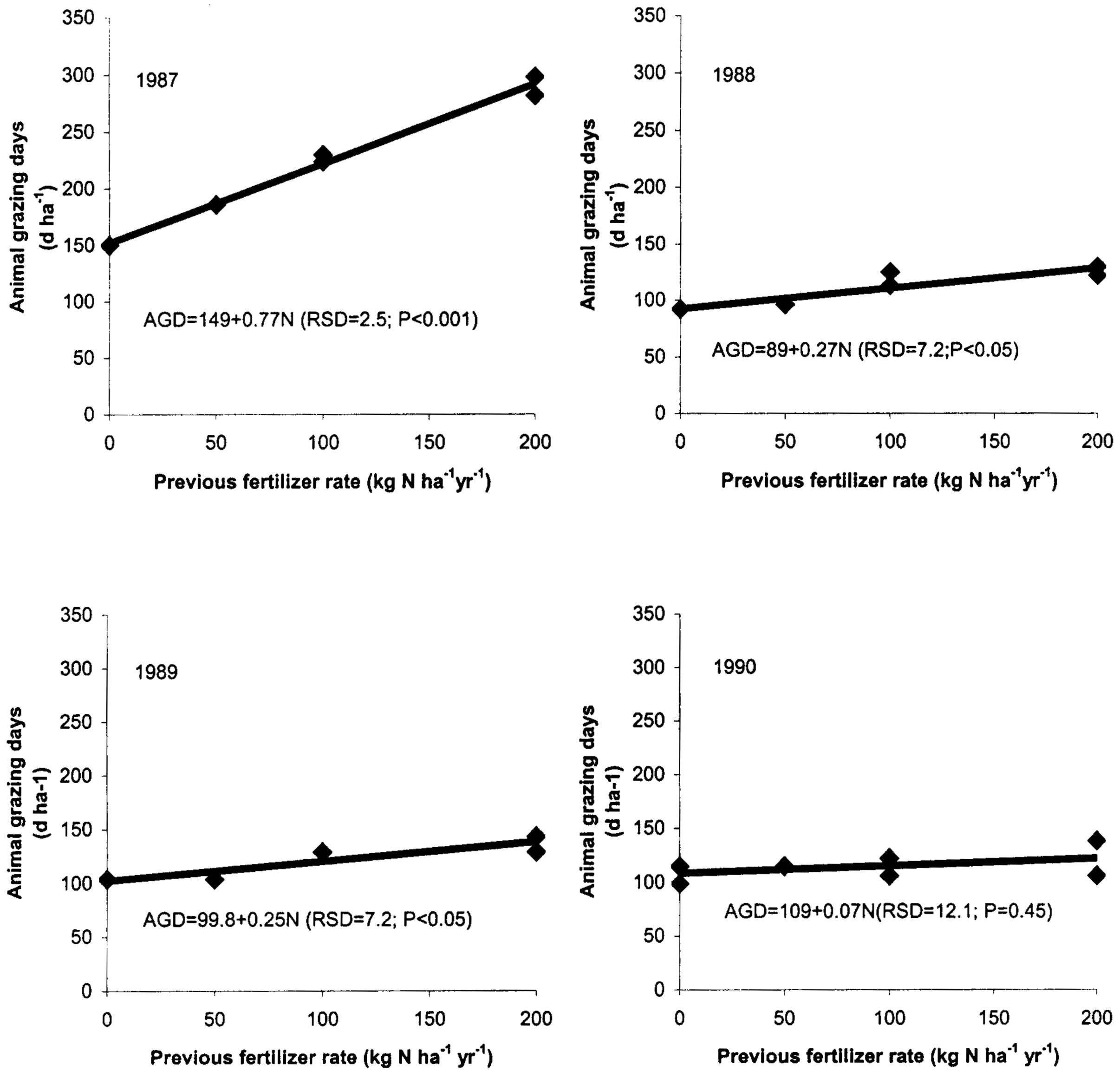


Fig. 5. Effect of previous applications of nitrogen fertilzer to grazed crested wheatgrass pastures during 1983-1986 on animal grazing days in 1987–1990 at Lanigan, Saskatchewan.

erate increases in pasture and animal production and will not provide any worthwhile residual benefits. Large residual levels of soil nitrogen will occur for at least 1 yr after applications of fertilizer cease if these soils are fertilized with annual rates of 100 kg N ha^{-1} or more for at least 4 yr. However, although the residual effects are significant for 3–4 yr this is a diminishing benefit and probably would not continue beyond the fourth year. Nevertheless it would seem likely that reduced rates of fertilizer application in the second and subsequent years following cessation of fertilizer applications could illicit worthwhile increases in production. It is clear, however, that in order to capture the benefits of fertilizer, stocking rates must be increased and that this can be done with no detrimental effect on individual animal performance. It is also clear that the magnitude of any response to fertilizer is dependent on the amount of rain received during the growing season and for an early-growing grass such as crested wheatgrass, the amount of rain received during the spring is very important.

Fertilizing crested wheatgrass pastures had little affect on the nutrition of the grazing heifers. The intakes of digestible organic matter, protein and various minerals by the heifers were rarely affected by fertilizer application. The decline in these traits with increasing plant maturation was, however, significant. Thus, crested wheatgrass is most appropriately grazed as an early season grass. While the nutrient intakes of individual heifers were rarely affected by fertilizer, the total utilization of nutrients was increased with increasing increments of fertilizer because of the increased stocking rates. There was evidence of a possible subclinical hypomagnesemia (grass tetany) in the first 4 weeks of the grazing season and also some concern with respect to subclinical nitrate toxicity at high rates of fertilizer application.

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