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Yield and Quality Response of Subirrigated Meadow Vegetation to Nitrogen, Phosphorus and Sulfur Fertilizer

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ABSTRACT

Production practices that increase hay yields are important for beef cattle producers in the Nebraska Sandhills. This study evaluated the responses of subirrigated meadow vegetation to fertilization with N, P, and S over a 4-yr period. A factorial array of four levels of N (0, 45, 90 and 135 kg ha^{-1}), two levels of P (0 and 20 kg ha^{-1}) and two levels of S (0 and 22 kg ha^{-1}) were applied each year to the same plots, arranged in a randomized complete block design. Average dry matter yields were increased by N, P, and S. There were no fertilizer interaction effects. Yields increased quadratically as N levels increased. For each 45 kg increment of N applied from 0 to 135 kg ha^{-1}, dry matter yield (pooled over P and S) increased 1002, 703, and 402 kg ha^{-1}, respectively. Main effects of P and S increased dry matter yields by 4662 and 577 kg ha^{-1}, respectively. Nitrogen uptake was increased linearly by fertilization with N, P, and S. Forage N use efficiency decreased as N fertilizer rates increased. Crude protein (CP) declined quadratically as N rates increased, but the maximum change was less than 10 g kg^{-1}. In vitro dry matter digestibility (IVDMD) declined linearly as N rates increased. Sulfur and P did not affect either CP or IVDMD. Yield responses were sufficient to justify the use of N, P, and S to increase subirrigated meadow production. Loss of forage quality (CP and IVDMD) was not sufficient to nullify this conclusion.

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HAY from subirrigated meadows is an essential forage resource that supports livestock wintering programs within the 4.8-million ha region of the Nebraska Sandhills. Hay yield and quality are often below site potential. Because of subirrigation, soil water is seldom a factor limiting production. This enhances the potential for increased hay production through improved management practices. A major constraint to high hay yields is low soil fertility. Several studies in subirrigated meadow environments have shown a positive yield response to fertilization (Brouse and Burzlaff, 1968; Daigger and Moline, 1977; Ehlers et al., 1952; McConnell and Waller, 1986; Rehm et al., 1973). It is well accepted that the application of fertilizer can alleviate soil nutrient deficiencies and increase forage yields. However, the magnitude of this response merits further evaluation as a management practice on subirrigated meadows. In addition, the effect of fertilization on forage CP content and IVDMD has not been adequately documented for subirrigated sites and should be considered along with yield response. This study was conducted to quantify the yield, N uptake, N use efficiency and quality responses of subirrigated meadow vegetation to fertilization with N, P, and S.

MATERIALS AND METHODS

The study site was located on a subirrigated meadow at the University of Nebraska, Gudmundsen Sandhills Labo-

Table 1. Initial soil characteristics of the study site. Gudmundsen Sandhills Lab., Whitman, NE.

Depth	pH	Organic matter	P (Bray-1)	K	NO_3-N	SO_4-S
cm		g kg^{-1}	mg kg^{-1}			
0–15	7.6	111	5	120	2.1	16
15–30	7.7	41	3	102	1.3	4
30–45	7.8	34	4	107	1.0	3

ratory near Whitman, Neb. Soils at the study site were classified as Gannett-Loup fine sandy loams (coarse-loamy, mixed, mesic Typic Haplaquolls) which were derived from eolian sand parent material. Selected soil properties at the study site are presented in Table 1. Even though the pH was high, this site was not calcareous, thus the Bray P test was considered a valid indicator of P availability.

The dominant vegetation consisted of smooth bromegrass (*Bromus inermis* Leyss.), redtop (*Agrostis stolonifera* L.), timothy (*Phleum pratense* L.), slender wheatgrass [*Agropyron trachycaulum* (Link) Malte], quackgrass [*A. repens* (L.) Beauv.], Kentucky bluegrass (*Poa pratensis* L.), prairie cordgrass (*Spartina pectinata* Link) and several species of sedges (*Carex* spp. L.), rushes (*Juncus* spp. L.) and spikerushes (*Eleocharis* spp. R.). Less abundant grass species were big bluestem (*Andropogon gerardii* Vitman), Indiangrass [*Sorghastrum nutans* (L.) Nash], and switchgrass (*Panicum virgatum* L.). Legumes and other forbs were minor components of the vegetation. Nomenclature of plants follows Great Plains Flora Association (1986).

Soil water was not a limiting factor during the study because of natural subirrigation. Soils were water saturated at the surface when growth was initiated in the spring and remained wet within the rooting depth of the vegetation throughout the growing season.

Four levels of N (0, 45, 90, and 135 kg ha^{-1}), two levels of P (0 and 20 kg ha^{-1}) and two levels of S (0 and 22 kg ha^{-1}) were broadcast on the same plots (3 by 12 m) each year in April prior to the initiation of new growth. Fertilizer sources were ammonium nitrate (34-0-O), triple super phosphate (0-45-0) and gypsum ($CaSO_4 \cdot 2H_2O$). Field plot design was a factorial arrangement of treatments replicated four times in a randomized complete block. Blocking criteria were based on degree of soil wetness due to subirrigation. Standing crop weight estimates from each treatment were obtained by harvesting an area (0.9 by 10 m) at a 5-cm cutting height on 21 July, 26 July, 18 July, and 25 June for the four consecutive years (1982–1985). These cutting dates corresponded to the time of normal haying operations which were determined primarily by degree of wetness at the soil surface. The dominant species were at anthesis at time of harvest. Representative subsamples were obtained from the harvested material, oven dried at 60 °C to a constant weight, and used to convert yield values to a dry-matter basis. These subsamples were analyzed for N content by the Kjeldahl method (Association of Official Analytical Chemists, 1975) and IVDMD by procedures outlined by Martin and Barnes (1980). Crude protein was estimated from Kjeldahl-N (6.25 × N). Nitrogen uptake values were calculated as a product of yield and forage-N content.

Forage N use efficiency is often expressed as the increased kilogram of forage produced per kilogram of N fertilizer added; it may also be called marginal N use efficiency (Gomm, 1979; Ludwick, 1979; Taylor et al., 1985). Similarly, in this study, forage N use efficiency was calculated by dividing the difference in forage yield between fertilized and nonfertilized treatments by the amount of applied N.

Normality of data was confirmed within each year by testing normality of residuals using PROC UNIVARIATE (SAS Institute, Inc., 1985). This was followed by analysis of variance as a split plot in time over all years for dry matter yield, N uptake, CP, and IVDMD (Table 2). The level of significance selected for treatment effects was $P \leq 0.05$. The YR × N effects were small, but statistically significant. A Bartlett's test of homogeneity of variance was performed on all parameters among years (Snedecor and Cochran, 1968). This test showed homogeneity for all parameters, so years were pooled. Single degree of freedom contrasts were used to separate N main effects. Dry matter yield, N uptake, CP, and IVDMD models were examined to determine the most appropriate fit for response patterns.

Table 2. Probability ($P > F$) for block (B), year (YR), N, P, and S effects on dry matter yield, N uptake, CP concentration and IVDMD on a fertilized subirrigated meadow at the Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

Source	*df*	Dry matter	N uptake	CP	IVDMD
		$P > F$			
B	3	0.001	0.019	0.001	0.333
YR	3	0.001	0.001	0.110	0.001
YR × N	9	0.001	0.001	0.001	0.061
YR × P	3	0.151	0.119	0.254	0.826
YR × N × P	9	0.217	0.277	0.872	0.145
YR × S	3	0.625	0.683	0.611	0.853
YR × N × S	9	0.685	0.846	0.875	0.468
YR × P × S	3	0.122	0.483	0.741	0.535
YR × N × P × S	9	0.958	0.716	0.591	0.374
N	3	0.001	0.001	0.001	0.003
N linear	1	0.001	0.001	0.001	0.001
N quadratic	1	0.001	0.629	0.001	0.131
N cubic	1	0.211	0.709	0.368	0.977
P	1	0.001	0.001	0.385	0.674
N × P	3	0.285	0.411	0.781	0.512
S	1	0.001	0.001	0.748	0.059
N × S	3	0.327	0.588	0.369	0.203
P × S	1	0.541	0.876	0.063	0.353
N × P × S	3	0.166	0.161	0.334	0.289
Error mean square		516869	146	0.59	6.58
CV		10.5%	13.2%	9.2%	4.8%

A polynomial model was used to describe N response and was of the form

$$\hat{Y} = b + c_1\text{N} + c_2\text{N}^2$$

Where $\hat{Y}$ = dependent variables,
b = Y intercept,
c_1 = coefficient of the N linear term, and
c_2 = coefficient of the N quadratic term.

Because main effects of P and S were additive, regression models for N, N + P, N + S, and N + P + S were calculated.

RESULTS AND DISCUSSION

Dry Matter Yields

Mean dry matter yields showed a significant response when fertilized with individual or combined applications of N, P, or S each year (Table 2). Dry matter yield responses to N, P, and S were additive. There were no significant nutrient interaction effects on yield for any of the fertilizer combinations (Table 2).

The yield response to increased levels of N (pooled over P and S) was quadratic (Fig. 1). The regression equation showed forage yields increased 1002, 703, and 402 kg ha^{-1}, respectively, for each 45 kg of N applied from 0 to 135 kg ha^{-1}. The main effect of P was significant and showed an increase of 662 kg ha^{-1} (Table 3). The main effect response to 22 kg ha^{-1} S was 577 kg ha^{-1}. The highest production resulted from the combined application of N, P, and S at 135, 20,

Table 3. Average annual dry matter yield, N uptake, CP concentration and IVDMD from a subirrigated meadow fertilized with N, P, and S at the Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

Fertilizer			Dry matter			
N	P	S	yield	N uptake	CP	IVDMD
kg ha^{-1}			kg ha^{-1}		g kg^{-1}	
0	0	0	4962a*	72a	90.6a	561a
45	0	0	6012b	78a	81.7b	535b
90	0	0	6794c	89b	81.7b	534b
135	0	0	7072c	92b	81.4b	532b
0	20	0	5544d	79c	88.2c	560c
45	20	0	7330e	94d	80.8d	549cd
90	20	0	6978e	90d	80.5d	538ed
135	20	0	7987f	106e	82.6d	525e
0	0	22	5977g	83f	86.5e	527f
45	0	22	6690h	86fg	80.6gf	559g
90	0	22	7318i	92g	78.5g	534f
135	0	22	7472i	101h	84.6ef	522f
0	20	22	6061j	85i	88.5h	544h
45	20	22	6931 k	92i	83.4h	533h
90	20	22	8088l	108j	83.8h	532h
135	20	22	8678m	117k	83.9h	503i

* Values with the same letters were not significantly different at the 0.05 level of confidence.

and 22 kg ha^{-1}, respectively (Table 3). This combination increased the 4-yr average yield by 3716 kg ha^{-1} compared to no fertilizer.

The additive effects of P and S alone or in combination regressed over increasing N rates are shown in Fig. 2. These results indicate that the greatest response can be expected from N and that P and S should be considered in addition to N as part of a fertilization program for increasing forage yields from subirrigated meadows. The initial soil P level showed a need for P although the SO_4–S level seemed adequate.

Increased dry matter yield due to N and P fertilizer is in general agreement with other studies on subirrigated meadows, although the magnitude of response and shape of response surfaces may differ (Daigger and Moline, 1977; McConnell and Waller, 1986; Rehm et al., 1973; Rehm et al., 1976). Positive yield responses to P have been reported at all N rates under conditions of low soil P (Rehm et al., 1973; Rehm et al., 1976). Russell et al. (1965) reported that N alone had little effect on dry matter production except when combined with P. The lack of yield response to S, reported by Rehm et al. (1973) was attributed to the high soil organic matter content (60 g kg^{-1}). Yield response to S was significant in our study even though the organic matter content was 111 g kg^{-1} in the top 15 cm of the soil (Table 1).

Nitrogen Uptake

Nitrogen uptake increased linearly as N rates increased from 0 N to 135 kg ha^{-1} (Table 3, Fig. 3). For each kilogram of N applied, 175 g kg^{-1} of N was accounted for in the forage. The application of P and S also significantly influenced N uptake, but there were no interaction effects among fertilizer elements (Table 2). Nitrogen uptake values increased as N rates were increased from 0 to 135 kg ha^{-1} and were highest when N was applied in combination with P and S (Table 3). The additive effect of N, P, and S on N uptake was apparent. Nitrogen uptake averaged over all N rates was increased by 9, 8, and 18 kg ha^{-1} when P, S, or P + S were applied, respectively (Table 3).

Forage Nitrogen Use Efficiency

The efficiency of N use decreased as N rates were increased. Forage N use efficiencies (averaged over P and S) were 40, 26, and 21 kg kg^{-1} N for N rates of 45, 90, and 135 kg ha^{-1}, respectively (Table 4). The highest yield returns in relation to N applied were at the lowest N rates. At a given N rate, N use efficiency

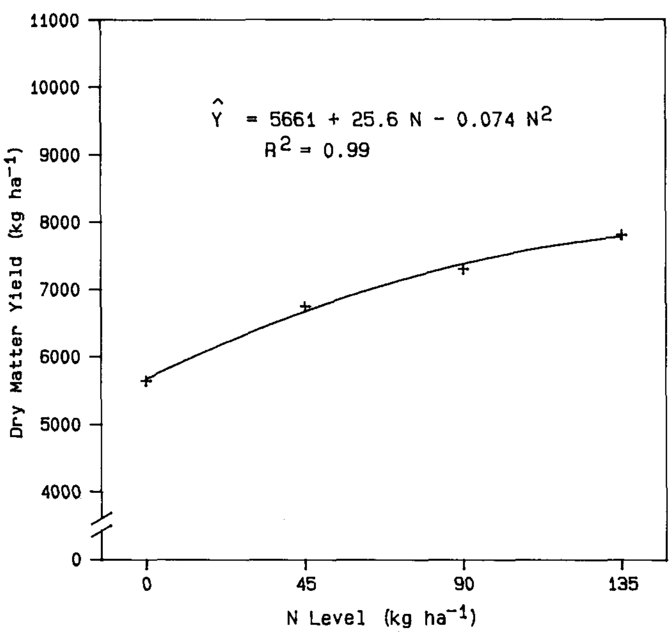

Fig. 1. Average dry matter yields of a subirrigated meadow in response to N fertilizer (pooled over all N, P, and S combinations). Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

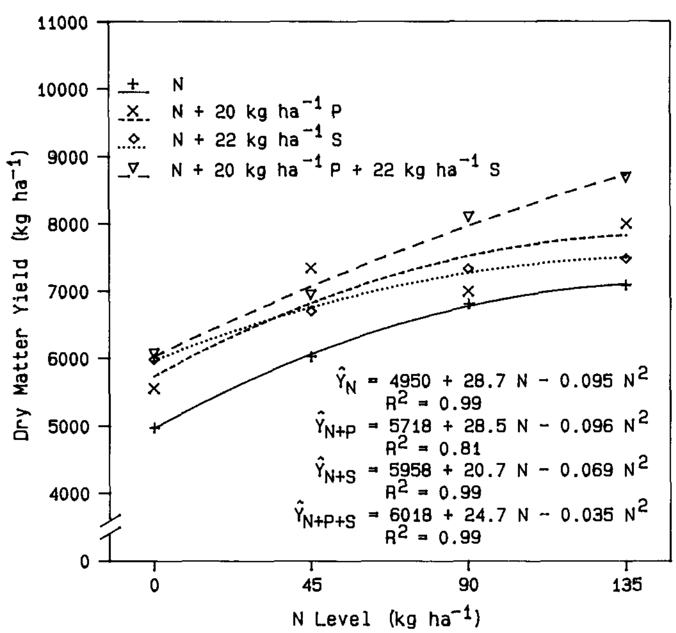

Fig. 2. Average dry matter yields of a subirrigated meadow in response to N fertilizer alone and with P, S, and P + S. Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

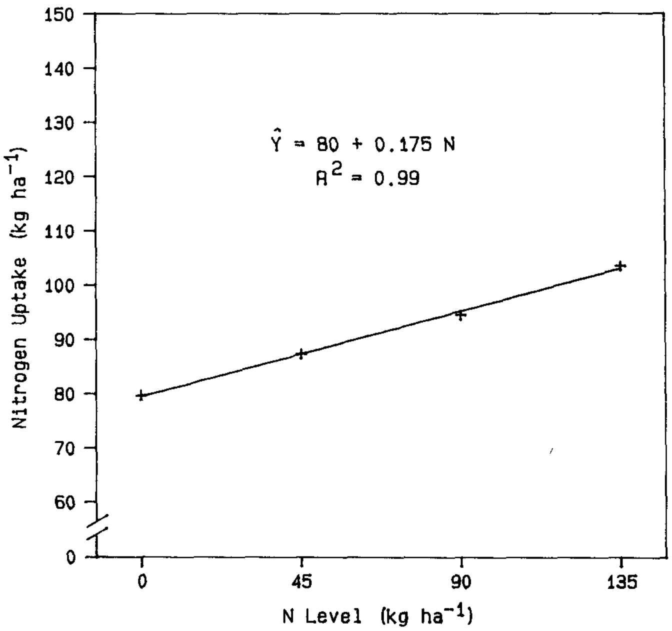

Fig. 3. Average N uptake from a subirrigated meadow in response to N fertilizer rates (pooled over all N, P, and S combinations). Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

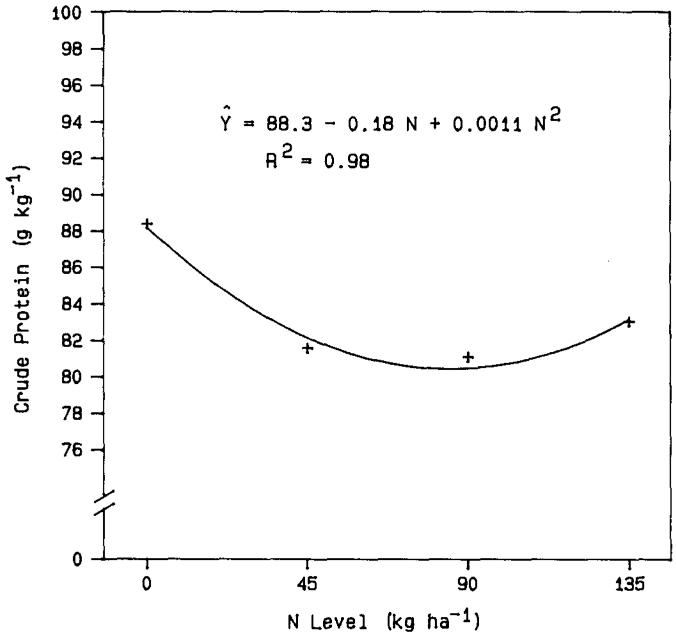

Fig. 4. Average CP of a subirrigated meadow in response to N fertilizer (pooled over all N, P, and S combinations). Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

increased when P and S were applied alone or in combination compared to the check treatment (Table 4). The effect averaged across N rates was also significant. The effects of N fertilization on the N-use efficiency values were similar to studies in other locations, but the magnitude of the response varied. Gomm (1979) working with native meadows in Oregon reported N efficiency values from 9 to 11 kg kg^{-1} N with fertilizer N rates of 90 kg ha^{-1}. At the same N rate, Ludwick (1979) working on native meadows at three different locations in the northern Rocky Mountains, reported N efficiencies of 5.8, 6.1, and 8.2 kg of hay kg^{-1} N. These values were all lower than those obtained in the present study at the same N rate. Taylor et al. (1985) reported forage N use efficiencies of 13 and 21 kg kg^{-1} N for N fertilizer rates of 90 and 135 kg ha^{-1}, respectively. These values are more comparable to the values of this study (Table 4).

Forage Quality

Protein

Crude protein concentration of the forage was reduced by the application of N fertilizer, but was not significantly affected by the application of P or S (Table 2 and 3). There were no significant interactions among any of the applied elements (Table 2). Reductions in CP concentrations were consistently associated with the first increment of N applied (0 vs. 45 kg ha^{-1}), with little change related to increasing N rates (Table 3, Fig. 4).

Table 4. Average forage N use efficiency for subirrigated meadow hay as influenced by fertilization with N, P, and S at the Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

P	S	N (kg ha^{-1}) 45	90	135	
kg ha^{-1}		N efficiency (kg forage kg^{-1} N)			Avg.
0	0	23a*	20a	16a	20a
0	22	38ab	26a	19a	33bc
20	0	53b	22a	22ab	28b
20	22	44b	35b	28b	35c
Average		40a	26b	21c	

* Values within columns with the same letters were not significantly different at the 0.05 level of confidence (Ryan-Einot-Gabriel-Welsch multiple *F* test, SAS Institute, Inc., 1985). Note: statistical designation for average values are independent from columns.

The maximum reduction in CP was less than 10 g kg^{-1} for any mean comparison, and ranged from 1.9 to 9.2 g kg^{-1} (Table 4). Although the reduction in protein content was small, it is a negative response that must be considered in conjunction with the positive yield response. Brouse and Burzlaff (1968) reported a similar response to fertilization with N alone. In their study, each incremental increase in N rates from 0 to 45 and 90 kg ha^{-1} decreased CP content by 10 g kg^{-1}. When rates were increased from 90 to 180 kg ha^{-1}, the CP content increased by 70 g kg^{-1}. The 180 kg rate was higher than the rates in our study. Similarly, Wilhite et al. (1955) showed a tendency for decreased protein content with N fertilizer rates below 180 kg ha^{-1} and an increase in protein content at higher N rates.

The protein content of two introduced species, intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv.] and creeping foxtail (*Alopecurus arundinaceus* Poir.), on subirrigated mountain meadows in Wyoming increased as N fertilization rates increased (Hart et al., 1980). Other studies summarized by Hart et al. (1980) involving native species on subirrigated sites, indicated that N fertilization reduced CP content, or caused no change, depending on location. Brouse and Burzlaff (1968) found that fertilization of mixed grass-legume meadows in Nebraska with N and P resulted in hay CP contents that were associated with fertilizer induced changes in botanical composition. Nitrogen stimulated grass growth and suppressed legume production, whereas P increased the legume component. Since legumes were higher in CP than grasses, these shifts in composition were reflected in CP content. In

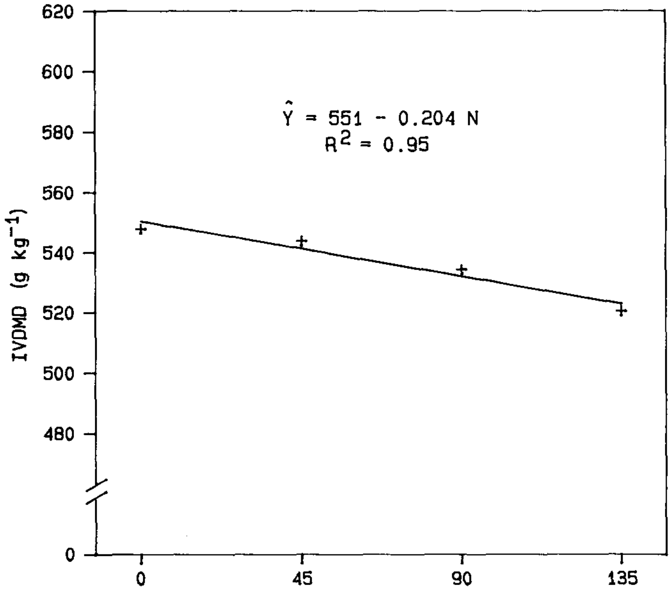

Fig. 5. Average IVDMD of a subirrigated meadow in response to N fertilizer (pooled over all N, P, and S combinations). Gudmundsen Sandhills Lab., Whitman, NE, 1982 to 1985.

our study, legumes were only a minor component of the vegetation and did not show a response to P.

Digestibility

In vitro dry matter digestibility decreased as N rates were increased, but there were no significant differences in IVDMD as a result of P and S applications (Table 2). There were no interactions among any fertilizer combinations (Table 2). The highest IVDMD percentages were those associated with O-N rates (Table 3). Digestibility was reduced by 26 g kg^{-1} when 45 kg ha^{-1} of N (O-P, O-S) was applied compared to O-N. Additional increases in N rates (O-P, O-S) did not cause a significant change in IVDMD (Table 3). The regression of IVDMD means over N rates (pooled over P and S rates) showed a negative, linear response (Fig. 5). These analyses indicate that a reduction of approximately 9 g kg^{-1} IVDMD could be expected for each 45 kg ha^{-1} of N applied when N fertilization rates ranged from 0 to 135 kg ha^{-1}. In contrast, Daigger and Burzlaff (1972) indicated that fertilization of subirrigated meadows with N, P, and K at four different locations did not influence IVDMD of forage from subirrigated meadows in Nebraska. In Wyoming, Waggoner et al. (1979) analyzed 30 hays from five locations and indicated that fertilization appeared to increase digestibility of protein hemicellulose, cellulose, and crude fiber from all hays examined, but the differences were not statistically different. It is apparent that the effect of fertilization on forage digestibility is highly variable and that other factors such as the stage of plant maturity may have more influence.

The reduction in IVDMD caused by N fertilization in our study must be evaluated in conjunction with positive yield responses discussed previously. For example, the average yield increase for the first 45 kg ha^{-1} of N (with no P or S) was 1050 kg ha^{-1} (Table 3). The corresponding reduction in IVDMD was 26 g kg^{-1} at the same N rate, which was minimal compared to the yield increase. This relationship of increased yield and decreased digestibility for the first increment of N was consistent over all P and S fertilizer combinations (Table 3).

The two forage quality parameters measured in this study, CP and IVDMD, were both impacted negatively by fertilizer N. Although the magnitude of the responses were relatively small, forage quality is a factor that must be considered when making fertilizer recommendation for subirrigated meadows.

Although we lack supporting data, it is hypothesized that N fertilization lowered CP and IVDMD values by stimulating culm elongation, thus reducing the leaf to stem ratio. Since it is commonly accepted that protein content and digestibility are higher for leaves than stems, values obtained from total plant analysis for CP content and IVDMD would be altered by any change in this ratio. Unpublished data from a study now in progress supports this explanation.

SUMMARY

Nitrogen, P, and S fertilizer increased dry matter yields of hay from a subirrigated meadow in the Nebraska Sandhills. There were no interaction effects among fertilizers on yield. Since yield responses to N, P, and S were additive, the highest yields were obtained when nutrients were applied in combination. Yield responses to fertilization by year were similar with no change in trends in fertilizer response over time. These data support the practice of fertilizing subirrigated meadows in the Nebraska Sandhills with N, P, and S. The yield responses were adequate to warrant its consideration as an economically feasible practice.

Nitrogen uptake increased as the rate of N fertilizer increased, but only 17.5% of the applied N was accounted for in the forage. The efficiency of N use decreased as N fertilization rates increased. Protein content and IVDMD of the forage were reduced by the application of N fertilizer, but they were not affected by P and S. The magnitude of these forage quality responses were small. Crude protein was reduced by less than 1% for any P, S, or P + S fertilizer combination for all N rates and IVDMD by about 0.9% for each increment (45 kg ha^{-1}) of N applied.

Decreases in forage quality caused by N fertilization should be considered in relation to the increased dry matter yields when evaluating the feasibility of fertilizing subirrigated meadows. The pronounced yield increases from fertilization more than compensate for the minor reductions in forage quality. For example, a yield increase of 63% resulted from the application of 90, 20, and 22 kg ha^{-1} of N, P, and S, respectively compared to a reduction in CP and IVDMD of 0.68 and 2.9%, respectively. However, the importance of maximizing forage quality for the livestock producer should not be overlooked. Harvesting at a less mature stage of plant development should be investigated as a means of improving quality while maintaining yield on subirrigated meadows.

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