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Nitrogen fertilization of dryland grasses in the Northern Great Plains

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Abstract

Dryland grass production is an important agricultural commodity in the Northern Great Plains. Nitrogen (N) fertilizer can increase dry matter production and forage quality, yet there are relatively few rangeland and improved pasture managers who utilize fertilization practices to optimize production. Two trials (1972–1975 and 1978–1981) with 10 common grass species used a single application of 0, 56, or 112 kg N ha^{-1} and 0, 112, or 224 kg N ha^{-1} to evaluate long-term grass performance to N fertilization. Dry matter production in each trial was measured annually for 4 years. Yields increased on average 1,340 kg ha^{-1} with the application of 56 kg N ha^{-1}, and 1,662 kg ha^{-1} with 112 kg N ha^{-1} in Trial 1. In Trial 2, yields increased 3,499 and 5,140 kg ha^{-1} with applications of 112 and 224 kg N ha^{-1}, respectively. Responses to applied N were evident 4 years after application for some species, most likely due to the combination of improved grass vigor and recycling of fertilizer N immobilized in organic forms. Single applications of N were effective in improving dry matter production of some common grasses for multiple years, when water was suitable. The magnitude of response and potential economic return from fertilization were species dependent.

Key Words: seeded grass, forage production, management, fertilizer use efficiency, precipitation use efficiency

Forage grass is produced on approximately 52% of the 141 million hectares in the Northern Great Plains (Kan., Mont., N.D., Neb., S.D., Wyo.; Daugherty 1991). Species composition, plant available nutrients and water, climate, and other agronomic factors influence production and quality characteristics. The application of fertilizer nitrogen (N) to grasses is a key management tool for increased production if soil fertility levels are less than optimum, economics are favorable, and the environment will not be adversely impacted. Many studies have shown a doubling or more of dry matter yields from fertilizer N application (Kilcher 1958, Black 1968, McGinnies 1968, Power and Alessi 1971, Wight and Black 1979, Read and Winkleman 1982, Power 1985).

Fairway crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. intermedium], and Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] responded to annual N fertilization (Kilcher 1958). In the unfertilized checks, intermediate wheatgrass out produced fairway crested wheatgrass and Russian wildrye. However, fairway crested wheatgrass out produced intermediate wheatgrass at higher N levels. Russian wildrye did not yield as much as either of the wheatgrasses following N application, although its proportionate yield increase was greater than that of intermediate wheatgrass. Largest yields were obtained when precipitation, particularly in May, was adequate.

Power (1985) conducted a 9-year study at Mandan, N.D. on 10 seeded perennial grasses which received annual applications of 0, 45, and 225 kg N ha^{-1}. Greatest yields usually occurred in wettest years, and least during dry periods. All grasses responded to increasing N fertilization with several exceptions in the driest year. Similar results were obtained on range vegetation by Johnston et al. (1969). Furthermore, Power (1985) found that compared to the check, average dry matter production for most species at least doubled with the annual addition of 45 kg N ha^{-1}, and increased 3 to 4-fold with 225 kg N ha^{-1} applied annually. Intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. intermedium] produced the most dry matter (9-year cumulative yield), followed by crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.], western wheatgrass [*Pascopyrum smithii* (Rydb.)A. Löve], and green needlegrass [*Stipa viridula* Trin.], with Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] and Garrison creeping foxtail (*Alopecurus arundinaceus* Poir) producing the least.

A 6-year study in North Dakota was conducted on native range (western wheatgrass [*Pascopyrum smithii* (Rydb.)A. Löve], blue grama [*Bouteloua gracilis*, (Kunth) Lag. Ex. Steud], and threadleaf sedge [*Carex filifolia*, Nutt.]). The same total amount of N fertilizer was applied either as a single application at study initiation, in 3 equal applications during the first 3 years, or in 6 equal annual applications (Power and Alessi 1971). Rates included 0, 34, 68, 135, 270, and 540 kg N ha^{-1}. The study found that timing of application did not influence total production, and total production increased with N application. Since a single N fertilizer application increased production for multiple years, the additional time and expense of smaller annual applications may not be warranted.

Mason and Miltimore (1972) applied single applications of ammonium nitrate at 12 rates to a natural cover of beardless

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Table 1. Common dryland grasses in these studies.

Common Name	Scientific Name	Variety
Basin wildrye	*Elymus cinereus* (Scribn. & Merr.) A. Löve	Plant Materials Center
Beardless wheatgrass	*Agropyron inerme* (Scrib. and Smith) Rydb.	Whitman
Crested wheatgrass	*Agropyron desertorum* (Fisch. ex Link) Schult.	Standard
Green needlegrass	*Stipa viridula* Trin.	PM-M-600, Plant Materials Center
Intermediate wheatgrass	*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. intermedium	Greenar
Intermediate wheatgrass	*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. intermedium	Oahe
Pubescent wheatgrass	*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. barbulatum (Schur) Barkw. & D.R. Dewey	Mandan 759
Russian wildrye	*Psathyrostachys juncea* (Fisch.) Nevski	Vinall
Thickspike wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Smith) Gould	Havre
Western wheatgrass	*Pascopyrum smithii* (Rydb.) A. Löve	Unknown

wheatgrass [*Agropyron inerme* (Scrib. and Smith) Rydb.], sandberg bluegrass [*Poa secunda*, Presl.], and big sagebrush [*Artemisia tridentata*, Nutt.], after removing the sagebrush by mowing. They found that considerable increases in yield were obtained over the 10-year study period from a single N application, particularly for the higher fertilization levels, up to 504 kg N ha^{-1}. In another 10-year study, single applications of 0, 50, 100, 400, and 800 kg N ha^{-1} were applied to old stands of fairway crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and production increased with the magnitude of response increasing with applied N (Read and Winkleman 1982). Even at low rates, applied N enhanced growth for several years.

Lutwick and Smith (1979) conducted a 5-year trial on several perennial grasses. Highest unfertilized 5-year cumulative yields were produced by intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey ssp. intermedium], followed in order by western wheatgrass [*Pascopyrum smithii* (Rydb.)A. Löve] and fairway crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] and then Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski]. After a single application of N fertilizer, cumulative 3-year yields responded proportionately greater, with the exception of fairway crested wheatgrass which out produced western wheatgrass.

By applying ^{15}N labeled fertilizer to crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.], Smith and Power (1985) determined the sequential fate and behavior of applied N for 5 years. Most residual N became incorporated in organic form each season, with relatively little left in the ammonium or nitrate forms. However, the newly formed organic N was 3 to 10 times more susceptible to mineralization than the soil N.

Grass production is clearly a significant contributor to livestock enterprises and local and export markets. Recent trends, including potential increases in public land grazing fees, land use restrictions and expiration of Conservation Reserve Program (CRP) contracts may force producers and ranchers to rethink their grass production strategy. Although several grass species are available for seeding, N fertilizer research on the wide range of grass species is limited in the Northern Great Plains. These studies were conducted to help understand the relationship between numerous common grass species, their multi-year responses to a single application of N fertilizer, and their efficiency response to fertilizer N and precipitation.

Materials and Methods

Ten grass species (Table 1) were seeded in randomized complete block designs in the early spring of 1971 and 1977 at the Northern Agricultural Research Center (48° 30' N; 109° 47' 30"W) outside Havre, Mont. The sites were broken out of native sod in 1915, and have been used in a wide range of crop research projects since then. Both trials were planted on fine-loamy, mixed, Aridic Argiborolls. The first trial (Trial 1) site is comprised of Chinook Fine Sandy Loam—2-4% slopes and Telstad-Joplin-Kevin loams—2–4% slopes, whereas the second trial (Trial 2) site was planted on Telstad-Joplin-Kevin loams—2–4% slopes.

Prior to seeding, the site of Trial 1 had been fallowed for 2 years following several years of cereal-fallow rotation. Prior to seeding, the site of Trial 2 had been in introduced grasses for many years, and was plowed and fallowed in preparation for seeding. Species were selected from commonly used grasses in the Northern Great Plains. Grasses were seeded in 1.8 by 3.7 m plots with 0.36 m row spacing with 2 replications. Nitrogen fertilizer (34-0-0) at 0, 56, and 112 kg N ha^{-1} for Trial 1 and 0, 112, and 224 kg N ha^{-1} for Trial 2 was broadcast in late fall of 1971 and 1977 after grass establishment. No additional fertilizer was applied. Full stands were obtained for all grasses.

Grasses were harvested as individual species matured. Trial 1 grasses were hand clipped from 2 subsamples of 1 m^2 at a 2.5 cm cutting height. Trial 2 grasses were mechanically harvested from two 0.6 by 3.1 m areas. Cutting height was 3.8 cm in years 1 to 3, and 5.1 cm in year 4. Samples were dried (40°C) and weighed each year for 4 years. Standard ANOVA and regression analysis were performed. Means were separated using the protected LSD (Snedecor and Cochran 1980).

Results and Discussion

Cumulative Yields of 10 Grasses

The average 4-year cumulative dry matter yield of 10 species over 2 trials showed that a single 112 kg N ha^{-1} application (similar rate for both trials) increased production over the check from 5,143 to 7,723 kg ha^{-1}. Trials 1 and 2 varied considerably in the 4-year cumulative check production, chiefly due to differences in amount and timing of precipitation (Table 2). In Trial 1, with 112

Table 2. Precipitation records for Trials 1 and 2.

Study year	Month: April	May	June	Annual[1]
	(mm)			
Trial 1				
1	21	28	14	293
2	62	22	94	290
3	23	156	8	416
4	73	54	80	488
Trial 2				
1	44	84	28	426
2	41	25	38	274
3	35	44	89	253
4	0	88	38	327
30 yr avg[2]	25	43	56	282

[1] 1 Oct. to 30 Sept..
[2] MAPS (Caprio et al. 1994)

kg N ha^{-1}, average yield increased 1,661 kg ha^{-1} from the check yield of 6,030 kg ha^{-1}, and Trial 2, average yield increased 3,499 kg ha^{-1} from the check yield of 4,256 kg ha^{-1}.

Annual Production

Total precipitation during Trial 2 (1,280 mm) was less than that for Trial 1 (1,487 mm), but cumulative grass production increased, which on the surface would not be expected in semi-arid environments. However, for both trials, average annual precipitation was above normal for the area. The yearly production averages (of 10 species) offer an explanation. In the first year of Trial 1, only a 156 kg ha^{-1} increase over check was produced with 112 kg N ha^{-1}, due to little precipitation (Tables 2 and 3). In contrast, Trial 2 started with a wetter than average first year, and production over the check averaged 2,379 kg ha^{-1} with 112 kg N ha^{-1} (Tables 2 and 4).

Although in the second year of Trial 1 total precipitation was similar to that for the first year, spring precipitation was much greater than the second year, producing a 673 kg ha^{-1} increase over the check. For Trial 2, the second year was drier than the first, and the spring was drier than average. Average production over check fell to 817 kg ha $^{-1}$. In years 3 and 4, Trial 1 received more precipitation than average. During this period, Trial 1 had greater N response than Trial 2, but not enough to make up for the superior performance during year 1 of Trial 2.

Similar to results of Power and Alessi (1971), Mason and Miltimore (1972), and Read and Winkleman (1982), these trials demonstrate how a single N application can boost yields for several years. If growing conditions are poor during the first year (year of application), residual N can remain in the soil/plant system and increase production in subsequent years as observed by Smith and Power (1985). Grass vigor may also be increased which could carry-over into later years.

An essential difference between Trial 1 and Trial 2 was precipitation quantity, especially during the year in which fertilizers

Table 3. Dry matter production in Trial 1 for 10 grass species.

Species	N rate	Year: 1	2	3	4	Cumulative	
		(kg ha^{-1})					
Basin wildrye	0	506 a[1]	1364 a	1795 a	1711 a	5376 a	ABC[2]
	56	592 ab	1498 a	2371 a	2001 a	6462 a	ABC
	112	643 b	1758 a	2369 a	1955 a	6725 a	B
Beardless wheatgrass	0	591 a	1486 a	1287 a	1198 a	4562 a	A
	56	822 a	1386 a	1552 a	1444 a	5204 a	A
	112	791 a	1456 a	1657 a	1436 a	5341 a	A
Crested wheatgrass	0	1370 a	2534 a	1720 a	1355 a	6979 a	CD
	56	1267 a	3058 ab	2469 a	1645 a	8439 b	BCD
	112	1280 a	3573 b	2420 a	1521 a	8793 b	DE
Green needlegrass	0	733 a	2775 a	1851 a	1362 a	6720 a	CD
	56	945 b	2728 a	2084 a	1458 a	7215 a	ABC
	112	982 b	3062 a	2111 a	1557 a	7713 a	C
Intermediate wheatgrass 'Greenar'	0	1099 a	2918 a	1956 a	1496 a	7469 a	D
	56	1120 a	3431 b	2495 b	1799 ab	8844 b	CD
	112	1268 a	3836 c	2597 b	2003 b	9704 c	E
Intermediate wheatgrass 'Oahe'	0	1392 a	2863 a	1574 a	1515 a	7343 a	D
	56	1533 a	3751 b	2729 a	2130 a	10140 a	D
	112	1708 a	4426 b	2787 a	1962 a	10880 a	F
Pubescent wheatgrass	0	1063 a	2565 a	1123 a	1306 a	6057 a	ABCD
	56	1457 a	3696 b	2283 a	1639 a	9074 a	CD
	112	1433 a	3823 b	1834 a	1283 a	8374 a	CD
Russian wildrye	0	676 a	2019 a	1027 a	1064 a	4785 a	AB
	56	694 a	2422 b	1599 a	1265 a	5980 a	AB
	112	642 a	2702 b	1494 a	1267 a	6105 a	AB
Thickspike wheatgrass	0	824 a	2116 a	1706 a	1816 a	6463 a	BCD
	56	818 a	2190 a	1794 a	2019 b	6821 a	ABC
	112	1011 a	2639 b	1949 a	2410 c	8009 b	CD
Western wheatgrass	0	479 a	1515 a	914 a	1632 a	4541 a	A
	56	543 a	1562 a	1203 a	2203 a	5511 a	A
	112	529 a	1611 a	1168 a	1958 a	5266 a	A

[1] Yield values followed by the same letter within a species and column are not different at $p = 0.05$.
[2] Cumulative yield values followed by the same capital letter are not different from other species at the same N rate at $p = 0.05$.

Table 4. Dry matter production in Trial 2 for 10 grass species.

Species	N rate	Year 1	Year 2	Year 3	Year 4	Cumulative	
		(kg ha^{-1})					
Basin wildrye	0	2080 a[1]	624 a	310 a	837 a	3851 a	A[2]
	112	4007 b	950 ab	314 a	1161 a	6432 b	A
	224	4494 b	1219 b	269 a	880 a	6861 b	A
Beardless wheatgrass	0	1673 a	420 a	557 a	1051 a	3701 a	A
	112	3473 b	1312 b	480 a	1058 a	6323 b	A
	224	4296 b	1561 b	803 b	1575 b	8235 c	ABC
Crested wheatgrass	0	2560 a	1008 a	897 a	1777 a	6242 a	C
	112	6418 b	1995 a	951 a	1876 a	11240 b	D
	224	6835 b	4602 b	1255 b	2316 a	15008 c	E
Green needlegrass	0	1500 a	657 a	619 a	959 a	3735 a	A
	112	2828 b	1595 b	827 b	1087 a	6337 b	A
	224	3473 c	2060 c	1033 c	1472 b	8038 c	AB
Intermediate wheatgrass 'Greenar'	0	1840 a	741 a	563 a	1377 a	4521 a	AB
	112	4851 b	1847 b	771 a	1463 a	8932 b	BC
	224	5145 b	2556 c	981 b	1606 a	10288 b	CD
Intermediate wheatgrass 'Oahe'	0	1771 a	862 a	859 a	2129 a	5620 a	BC
	112	5064 b	1826 ab	1017 a	2396 a	10303 b	CD
	224	5511 c	2656 b	1353 b	2165 a	11685 b	D
Pubescent wheatgrass	0	1539 a	690 a	684 a	1165 a	4078 a	A
	112	4544 b	1380 b	695 a	1459 b	8078 b	AB
	224	4985 b	2105 c	1034 b	1537 b	9661 c	BCD
Russian wildrye	0	1248 a	543 a	617 a	794 a	3202 a	A
	112	2591 b	1638 b	755 ab	1107 b	6091 b	A
	224	2932 c	2339 c	892 b	1288 b	7451 c	A
Thickspike wheatgrass	0	1456 a	808 a	712 a	991 a	3967 a	A
	112	3458 b	1430 b	989 b	1165 a	7042 b	AB
	224	4052 b	2049 c	1150c	1205 a	8456 c	ABC
Western wheatgrass	0	1567 a	667 a	498 a	911 a	3642 a	A
	112	3787 b	1218 a	661 a	1107 b	6773 b	A
	224	4364 b	1665 a	872 b	1374 c	8275 c	ABC

[1] Yield values followed by the same letter within a species and column are not different at $p = 0.05$.
[2] Cumulative yield values followed by the same capital letter are not different from other species at the same N rate at $p = 0.05$.

were applied. Although there was a significant fertilizer response in Trial 1, response was much greater in Trial 2. Broadcast N fertilizer is susceptible to positional unavailability, and the drier the conditions, the greater this potential.

Studies by Power (1986) and others have shown that excess N immobilizes in root biomass for future mineralization and plant availability, enters the soil organic fraction through microorganisms, or remains as mineral N and is not prone to leaching. Since less production increase was noted in Trial 1 and little N is lost from the system, there is a likelihood that there is a greater N reserve after Trial 1 compared to Trial 2. This residual N would likely be available in years 5 and 6 producing a N response for some species had the experiment been continued.

Relative N Response by Species

Variation in yield was observed between species. In Trial 1, 56 kg N ha^{-1} significantly increased 4-year cumulative forage yields over check in 2 out of 10 species ($p = 0.05$, Table 3). With 112 kg N ha^{-1}, cumulative forage yields for 3 out of 10 species showed a response over the check. The 112 kg N ha^{-1} application increased forage production over the 56 kg N ha^{-1} application for only 1 out of 10 species. In Trial 2, 112 and 224 kg N ha^{-1} significantly increased 4-year cumulative forage yields over check in all 10 species ($p = 0.05$, Table 4). In comparing the 112 kg N ha^{-1} to the 224 kg N ha^{-1} application, 7 out of 10 species had increased forage production with increased N.

Relative rankings of the 10 species show some consistency from trial to trial, both with and without N fertilization. The grasses producing greatest amounts of dry matter were 'Oahe' and 'Greenar' intermediate wheatgrasses, crested wheatgrass and pubescent wheatgrass (Tables 3 and 4). The other 6 grasses had smaller responses to N, in particular, beardless wheatgrass and green needlegrass, which had consistently small N responses. These responses agree with relative production levels found by Kilcher (1958), and Power (1985), with the exception that Power found relatively smaller yields with crested wheatgrass and green needlegrass, and greater yields with western wheatgrass.

A brief economic analysis was conducted using current values ($230 per metric ton N and $45 per metric ton hay). A cumulative production increase of 622, 1,244 and 2,488 kg ha^{-1} is needed to offset just the fertilizer cost of 56, 112, and 224 kg N ha^{-1}, respectively. In Trial 1, 56 kg N ha^{-1} produced this minimal level in 8 of 10 species, with pubescent wheatgrass returning the most hay per fertilizer dollar, and thickspike wheatgrass the least. At 112 kg N ha^{-1}, 7 of 10 species produced more than the economic break even point, with 'Oahe' intermediate wheatgrass the most economical and western wheatgrass the least. In Trial 2, all 10 species at both fertilization levels produced economic responses, with crested wheatgrass producing the most hay per fertilizer dollar and basin wildrye the least at both N levels.

Table 5. Cumulative fertilizer and precipitation use efficiency for 10 grass species over 4 years.

Species	N Rate	Fertilizer use efficiency Trial 1	Fertilizer use efficiency Trial 2	Precipitation use efficiency Trial 1	Precipitation use efficiency Trial 2
	--- (kg N ha^{-1}) ---	------ (kg grass kg N^{-1}) ------		---- (kg grass mm H_2O^{-1}) -----	
Basin wildrye	0			3.62	3.01
	56	19.4		4.35	
	112	12.0	23.1	4.52	5.03
	224		13.4		5.36
Beardless wheatgrass	0			3.07	2.89
	56	11.5		3.50	
	112	7.0	23.4	3.59	4.94
	224		20.2		6.43
Crested wheatgrass	0			4.69	4.88
	56	26.1		5.68	
	112	16.2	44.6	5.91	8.78
	224		39.1		11.7
Green needlegrass	0			4.52	2.92
	56	8.8		4.85	
	112	8.9	23.2	5.19	4.95
	224		19.2		6.28
Intermediate wheatgrass 'Greenar'	0			5.02	3.53
	56	24.6		5.95	
	112	20.0	39.4	6.53	6.98
	224		25.8		8.04
Intermediate wheatgrass 'Oahe'	0			4.94	4.39
	56	49.9		6.82	
	112	31.6	41.8	7.32	8.05
	224		27.1		9.13
Pubescent wheatgrass	0			4.07	3.19
	56	53.9		6.10	
	112	20.7	35.7	5.63	6.31
	224		24.9		7.55
Russian wildrye	0			3.22	2.50
	56	21.3		4.02	
	112	11.8	25.8	4.11	4.76
	224		19.0		5.82
Thickspike wheatgrass	0			4.35	3.10
	56	6.4		4.59	
	112	13.7	27.5	5.39	5.50
	224		20.0		6.61
Western wheatgrass	0			3.05	2.85
	56	17.3		3.71	
	112	6.5	28.0	3.54	5.29
	224		20.7		6.46
Average	0			4.06	3.33
	56	23.9		4.96	
	112	14.8	31.2	5.17	6.06
	224		22.9		7.34

Fertilizer Use Efficiency

From data on fertilizer rate and grass production greater than check, a fertilizer use efficiency (FUE) was calculated as kg cumulative dry matter per kg applied N (Table 5). In Trial 1, 56 kg N ha^{-1} was more efficient than 112 kg N ha^{-1} for 8 out of 10 species. Pubescent wheatgrass and 'Oahe' intermediate wheatgrass produced the most forage per kg applied N with 56 kg N ha^{-1} (53.9 and 49.9 kg kg N^{-1}), while thickspike wheatgrass and green needlegrass produced the least (6.4 and 8.8 kg kg N^{-1}). At 112 kg N ha^{-1}, 'Oahe' intermediate wheatgrass, pubescent wheatgrass, and 'Greenar' intermediate wheatgrass had the greatest FUE (31.6, 20.7, and 20.0 kg kg N^{-1}, respectively), while western wheatgrass, and beardless wheatgrass had the least FUE (6.5 and 7.0 kg kg N^{-1}).

In Trial 2, 112 kg N ha^{-1} produced a more efficient response than 224 kg N ha^{-1}, for all species. At 112 kg N ha^{-1}, crested wheatgrass and 'Oahe' intermediate wheatgrass had the greatest fertilizer use efficiency (FUE) (44.6 and 41.8 kg kg N^{-1}). Basin wildrye, green needlegrass and beardless wheatgrass had the smallest FUE (23.1, 23.2, and 23.4 kg kg N^{-1}). At the 224 kg N ha^{-1} rate, basin wildrye had the least FUE with 13.4 kg kg N^{-1}, while crested wheatgrass had the greatest at 39.1 kg kg N^{-1}.

In both trials, an increased fertilizer rate resulted in decreased efficiency, consistent with Wight (1976). McGinnies (1968) had similar findings for annual applications of N to old stands of crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.], but when a single N application was made, maximum efficiency was reached at 67 to 112 kg N ha^{-1}, with decreased efficiency at larger and smaller rates. The fertilizer use efficiency decrease with larger N rates is partly explained by limited water. It is more likely for the N to be used at smaller fertilization rates than at greater rates, in a given season. With larger N applications, all the available water will be used before all the N has contributed to growth. Another factor is that greater soil N levels contribute to higher N content in grass tissue. Reductions in efficiencies with smaller N applications were not seen in this study, but McGinnies (1968) tested smaller N rates, and found that over several years, very little fertilizer response was seen. The grasses of Trial 2 converted applied N to dry matter 1.3 to 4.3 times more efficiently than in Trial 1, apparently related to the improved growing conditions, and indicates that different results can occur due to variation in precipitation. Growing conditions during the year of application is particularly critical. In drier years, less fertilizer N is utilized and more is immobilized in grass roots and soil organic matter. This immobilized N is only slowly available over the following years.

Precipitation Use Efficiency

Precipitation use efficiency (PUE) can also be used to evaluate N response of grass species in different environments. A PUE was calculated for each trial from cumulative dry matter production divided by mm of precipitation from 1 October after planting through 30 September of the last sample year.

One reason Trial 1 and Trial 2 had different yields was due to different precipitation patterns during the 2 periods. Because cumulative available water was constant within each trial, PUE within a trial points out the same numerical relationships that are present in dry matter response. Nevertheless, like Power (1980) and Wight and Black (1972), this study showed increasing PUE with increasing fertilizer rates. Grasses with increased production had better PUE levels. A reasonable linear response was found between N rate and PUE for Trial 1 ($r = 0.41$, $p = 0.05$) and Trial 2 ($r = 0.76$, $p = 0.01$). Despite differing climatic responses to applied N, we found a good linear relationship with both trials ($PUE = 0.016$ N-rate $+ 3.79$, $r = 0.71$, $p = 0.01$).

Conclusion

Dryland grass production can be increased by N fertilization. Applied N was used more effectively by grasses when the growing season was more conducive to growth. However, during particularly dry seasons, much of the fertilizer N does not result in increased yield, but according to the literature, and supported by this study, remains unused mainly as organic N in the root system and soil for subsequent years. This one time application of N could have also enhanced the vigor of the grasses by drastically increasing root growth and storage of N in roots, thereby increasing potentially mineralizable N in the soil and increasing production through at least the following 4 years (Smith and Power 1985, Power 1986). Different grasses have differing yield potentials and response potential to N fertilization, as well as other growth and forage quality characteristics. This study found crested wheatgrass, 'Greenar' and 'Oahe' intermediate wheatgrasses and pubescent wheatgrass to consistently rank above 6 other grasses in our trials under different environmental cycles. Economically, these grasses are most likely to give increased hay value for every fertilizer dollar invested.

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