Grazing and Fertilization Affect Root Development of Range Grasses

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Highlight

Grazing intensity of native range had little effect on total root weight, but under heavy grazing the percentage of total roots in the upper foot was greater than under moderate grazing. Thirty lb of N significantly increased root weight in the 4-ft profile. Ninety lb of N did not further increase root weight although top growth was significantly increased.

The root system of perennial grasses becomes doubly important when fertilizer or other intensive management practices are used to increase top production. Any reduction in root volume reduces the effective moisture and nutrient reservoir. Efficient soil moisture extraction is vital to optimum production under semiarid conditions. A decrease in root volume or in root: top ratio increases the demands on each unit of root material, and under adverse conditions may jeopardize survival.

The effects of grazing intensity and fertility level on root development of native grassland are often referred to, but controlled studies usually involve forage removal by mechanical means. Very few root data are available from grazing intensity studies (Lorenz and Rogler, 1966).

Materials and Methods

Two pastures at the Northern Great Plains Research Center near Mandan, North Dakota were sampled to compare root development and distribution. One pasture had been heavily grazed and the other moderately grazed since 1916.

The soil of the pasture area is classified as Temvik (formerly Eakin) silt loam. Prior to initiation of the fertilizer study, total N in the 6 inches of surface soil was .257 and .250% for the heavily and moderately grazed pastures, respectively. Changes in chemical properties of the soil and soil moisture extraction pattern for the fertilized plot study were discussed by Smika et al. (1961). Soil moisture was also measured gravimetrically in the grazed areas of the pastures in May and October of each year.

Vegetation of the area is mixed prairie. Dominant species are western wheatgrass *(Agropyron smithii* Rydb.); needleandthread *(Stipa comata* Trin. & Rupr.); blue grama *(Bouteloua gracilis* [HBK.] Lag. ex Steud.); and upland sedges *(Carex* spp.). Continuous heavy use has reduced the western wheatgrass and needleandthread, until blue grama and upland sedges are now the dominant species in the heavily grazed pasture. The vegetation in the moderately grazed pasture has remained relatively unchanged since 1916. Fringed sagewort *(Artemisia frigida* Willd.) and other forbs are present in varying amounts in both pastures.

Ammonium nitrate was applied in October of each year (1951-1961) at rates of 0, 30, and 90 lb N/acre to three replications of plots isolated from grazing in each pasture. Rogler and Lorenz (1957) reported an increase in hay yield from application of N to these plots. Study of the effects of N on the vegetation was continued through 1962.

Another set of plots which received no fertilizer was isolated from grazing in the heavily grazed pasture. A new plot was added to this isolation each year from 1952 through 1962. Forage was harvested from each isolated plot about August 1 of each year.

A tractor-mounted hydraulic soil probe was used to obtain cores from which the roots were separated by washing over a No. 18 soil sieve (16-mesh equivalent) as described by Lorenz and Rogler (1964). Twelve cores (0.875 inch in diameter) per plot resulted in sampling accuracy within one standard deviation about the sample mean 90% of the time for sample weights of 6 g or greater, and 85% of the time for sample weights of less than 6 g. Samples consisted of 12 cores bulked by 6-inch increments for the top foot and by 1-ft increments for the second, third, and fourth feet.

Roots were sampled in late fall of 1961, a season of below-normal precipitation and again in late fall of 1962, a season of above-normal precipitation (Table 1). Precipitation for the 4-year period prior to 1961 is shown as a guide to soil moisture conditions which may have influenced the roots as sampled in 1961 and 1962. Precipitation was near the 48-year average in 1957, but in 1958 and 1959 both annual and seasonal precipitation were far below average. In 1960, above-average seasonal precipitation included over 5 inches which fell during three heavy showers that resulted in extensive runoff. Thus the effective 1960 precipitation was nearer 8 inches than the 13.75 inches recorded for the season.

Results and Discussion

F values obtained by analysis of the root-weight data from the fertilized plots are shown in Table 2. Differences between N-level means were highly significant, but N x Years, N x Pastures and their second order interaction were not significant, indicating similar N response each year in each pasture. The N-level means, averaged for years and pastures, are included in Table 3. Although total root weight was significantly increased when 30-N was applied, no further in-

Table 1. Average precipitation (in inches) for 6 years (1957-1962) and the 1915-62 average at the Northern Great Plains Research Center, Mandan.

Year	Precipitation April-Aug.	Precipitation Annual
1957	10.99	15.38
1958	8.77	12.64
1959	7.06	11.97
1960	13.75	14.98
1961	7.19	12.12
1962	12.34	14.95
1915-1962 ave.	10.97	15.71

Table 2. F values from statistical analysis of root weights from plots of fertilized native range sampled in 2 consecutive years.

Source of variation	F values
Replication	0.76
Pastures	0.12
Nitrogen level	6.62**
Depth of sample	719.68**
Year	17.04**
N x P	0.18
N x D	2.96**
N x Y	0.11
P x D	2.53*
P x Y	4.26*
Y x D	1.58
N x P x D	0.78
N x D x Y	0.37

* Significant at 5% level.
** Significant at 1% level.

Table 3. Ovendry root weight in the 4-foot profile and percent of the weight at each depth for N-levels, pastures, and years.

Average root weight	Depth (In.)	N-levels 0-N	30N	90N	Pastures Heavily grazed	Pastures Moderately grazed	Years 1961	1962
Grams/sample	0-48[1]	13.93	16.36	16.08	15.35	15.56	16.99	13.92
Percent of total	0-6	60.8	62.8	57.6	63.1	57.8	55.6	66.3
	6-12	15.9	15.1	15.9	14.9	16.4	16.4	14.7
	0-12	76.6	77.9	73.5	78.0	74.2	72.0	81.0
	12-24	13.9	13.5	16.1	13.6	15.3	16.8	11.6
	24-36	6.3	5.5	7.3	5.5	7.3	7.7	4.8
	36-48	3.1	3.1	3.1	2.9	3.2	3.5	2.6

[1] Means under the same main heading and underscored by the same line do not differ significantly at the 5% level (Duncan 1955).

Table 4. Comparison of ovendry root weights and percent of the weight at each depth in grazed areas with those from nonfertilized plots isolated from grazing in 1951 and mowed about August 1 each year thereafter.

Root weight	Depth (Inches)	Heavily grazed: Grazed	Heavily grazed: Mowed	Moderately grazed: Grazed	Moderately grazed: Mowed
Grams/sample	0-48	14.14	13.92	14.64	13.95
Percent of total	0-6	66.6	65.8	57.3	57.2
	6-12	12.8	14.6	15.9	17.2
	0-12	79.4	80.4	73.2	74.4
	12-24	14.8	12.0	15.8	14.8
	24-36	3.8	5.0	7.9	7.4
	36-48	2.0	2.6	3.1	3.4

crease resulted from the second increment of N. In comparison, forage production was doubled by 30-N and tripled by 90-N (Rogler and Lorenz, 1957). Similarly, Hylton et al. (1965) found that Italian ryegrass (*Lolium multiflorum* Lam.) produced the most roots when low rates of N were applied, and with increasing N, root weight decreased even though top weight was still increasing.

Lack of significant difference between mean root weights from plots in the two pastures (Table 3) suggests that any effect of grazing intensity on root development was eliminated by the treatments imposed after isolation from grazing. Comparison of root-weight data from grazed areas in each pasture with data from non-fertilized plots mowed annually (Table 4) verifies the small difference in root weight between the two pastures. However, comparison of percentages of roots at each depth shows that the moderately grazed pasture had a greater percentage of its roots at each depth below 6 inches than did the heavily grazed pasture. This was true for the area isolated from grazing as well as for the continuously grazed area. Thus the effects of previous grazing intensity were still evident when depth of rooting was considered. Distribution in the profile as well as total root weight is important in evaluating the effects of treatments on the root system.

Difference between the mean root weights at various depths sampled and the N x Depth interaction was highly significant. However, the percentage of the total root weight at each depth often changed very little, even though N increased total root weight. Within each year, the root distribution by depths was more consistent for the plots in the moderately grazed pasture than for those in the heavily grazed pasture. The percentage of the root weight below the first foot increased with increasing N-level for the plots in the heavily grazed pasture, but it changed very little or decreased for the plots in the moderately grazed pasture.

The average root weight in the 4-foot profile was 16.99 and 13.92 g dry matter per sample for 1961 and 1962, respectively. The difference between these means was highly significant. The total root weight and the weight at each depth were greatest in 1961, the drier of the 2 years. However, a higher percentage of the roots was found in the upper foot, with a lower percentage at each of the lower depths in 1962. The difference in root weight between years (Table 5), and the increase in percentage roots below 1 ft from use of N, were greater for the plots in the heavily grazed pasture than for those in the moderately grazed. During the relatively dry season of 1961, root development below 1 ft was increased in the heavily grazed pasture, especially when N was applied. Perhaps these extra roots exhausted the subsoil moisture during 1961 and died prior to the 1962 sampling. During the moist season of 1962, root concentration increased in the upper foot. This was evident for the plots in the moderately grazed pasture and for the 0-N plots in the heavily grazed pasture. However, the percentage of roots in the second foot increased for the N plots in the heavily grazed pasture.

The plots isolated from grazing for various lengths of time in the heavily grazed pasture were not replicated, and although root data were consistent with the variation that was due to year of sampling, no pattern of response to length of isolation was established (Table 6). Following a slight increase during the first 2 or three years, root weight tended to decrease with time in isolation. Distribution by depth did not vary much within each sampling year and was similar to the averages for the fertilized plots and grazed areas of the heavily grazed pasture. Years and N appeared to have had greater influence on root development and distribution than did isolation from grazing.

There is no way of knowing root weight and distribution prior to application of N, because the pastures were not sampled at that time. If we assume that the relative root development in the grazed areas was the same then as when root samples were taken from the plots, we can make other assumptions. Soil moisture in the 6-ft profile of the heavily grazed pasture averaged 17.90 and 17.15 inches in May and October, respectively, for the 7-year period, 1952 through 1958. Comparable averages for the moderately grazed pasture was 13.87 and 12.08 inches. In both May and October, the heavily grazed pasture had an average of 4.05 inches more water in the 6-ft profile than did the moderately grazed pasture. Of this additional water, less than 0.40 inch was in the upper 2 ft and over 3.65 inches were in the rest of the 6-ft profile. Soil moisture used from the upper 2 ft was very similar for the two pastures; but much less of the subsoil moisture was used in the heavily grazed pasture. This suggests a more active root system at greater depths under moderate grazing, a possibility which would agree with the actual percentage root distribution found when these pastures were sampled.

Soil moisture samples were not taken in the fertilized plots during the first 3 years after fertilizer application began. However, soil moisture was measured in the grazed area and in the fertilized plots of the heavily grazed pasture from 1954 through 1958. Average water content of the 6-ft profile in October was 16.04, 11.58 and 10.33 inches for the grazed area, the 30-N and 90-N plots, respectively. Again differences in the upper 2 ft were small, ranging from 3.78 for the grazed area to 3.06 for the 90-N plot. Averages for the lower 4 ft sampled were 12.26, 8.11 and 7.27 for the grazed, 30-N and 90-N treatments, respectively. Evidently N stimulated root development and extraction of soil moisture from the subsoil. May and October soil moisture was almost identical in the lower 4 ft, but in May the upper 2 ft contained more water than in October. Winter precipitation generally brings the soil moisture of the upper 2 ft to about the same level for all treatments. Cool-season grasses start to use moisture very early in the spring; thus the N plots, which are dominated by western wheatgrass, had extracted from 0.5 to 1 inch of water from the upper 2 ft before the May sampling. Apparently, if subsoil moisture has accumulated, N will stimulate root development in the moist soil. The stored subsoil moisture under heavily grazed range may account for the burst of production reported during the early years of fertilization of this study (Rogler and Lorenz, 1957). After extraction of subsoil moisture from the N plots, the vegetation used seasonal precipitation as it accumulated which prevented recharging of the subsoil. Consequently, root growth below the 2-ft depth was limited by lack of subsoil moisture in the N plots.

The nutrient removal pattern also suggests that N increased the root activity substantially at the greater depths at some time prior to sampling. Smika et al. (1961) reported a significant increase in total soil N for the 0- to 6 and 6- to 12-inch depths, as N rates increased on the plots in the heavily grazed pasture. However, when N was applied total soil N decreased in the third foot and remained the same at greater depths. As N rates increased, available P decreased at all except the top foot of the 6-ft profile.

Summary and Conclusions

In 1961-62 we compared roots developed under heavily and also moderately grazed pastures which had been grazed for 40 years. Root weight in the 4-ft profile was about the same for both pastures. This was true for the continuously grazed areas as well as for plots isolated from

Table 5. Ovendry root weight in the 4-foot profile and the percent of the total weight found at each depth from fertilized plots in the heavily grazed and moderately grazed pastures.

Average root weight	Depth (Inches)	Heavily grazed						Moderately grazed					
		1961			1962			1961			1962		
		0-N	30N	90N	0-N	30N	90N	0-N	30N	90N	0-N	30N	90N
Grams/sample	0-48	15.89	19.00	18.05	11.92	13.83	13.40	15.51	16.56	16.90	12.35	16.04	15.96
Percent of total	0-6	62.4	64.5	56.2	69.1	67.5	61.2	49.6	52.6	46.7	64.8	67.3	67.7
	6-12	14.7	14.4	16.7	14.5	12.7	15.9	17.8	18.1	16.9	16.6	14.8	13.9
	0-12	77.1	78.9	72.9	83.6	80.2	77.1	67.4	70.7	63.6	81.4	82.1	81.6
	12-24	15.5	12.4	16.9	8.5	11.9	15.0	18.1	17.8	20.7	11.7	11.7	11.2
	24-36	4.7	5.3	7.0	5.4	5.1	5.1	10.3	7.6	11.8	4.4	4.0	4.7
	36-48	2.7	3.4	3.2	2.5	2.8	2.8	4.2	3.9	3.9	2.5	2.2	2.5

Table 6. Ovendry root weights and percent of total weight at each depth sampled in 2 consecutive years from plots isolated from grazing for various lengths of time in the heavily grazed pasture.

Root weight	Depth (Inches)	1961 sampling						1962 sampling						
		Years after isolation						Years after isolation						
		10	8	6	4	2	0	11	9	7	5	3	1	0
Grams/sample	0-48	12.52	14.66	17.58	15.33	18.45	18.15	11.48	11.15	11.74	12.37	13.23	8.54	10.08
Percent of total	0-6	58.0	57.2	63.0	65.2	72.0	60.3	68.3	68.3	78.8	73.6	78.5	72.7	73.0
	6-12	14.5	18.1	12.9	15.3	11.2	15.2	14.5	13.0	10.0	12.5	10.1	15.2	10.4
	0-12	72.5	75.3	75.9	80.5	83.2	75.5	82.8	81.3	88.8	86.1	88.6	87.9	83.4
	12-24	18.2	18.3	20.0	10.8	9.9	16.0	11.5	12.6	7.4	10.1	7.9	8.4	13.5
	24-36	5.9	4.1	3.1	6.7	4.2	5.5	3.6	4.0	2.5	2.3	2.1	1.8	2.1
	36-48	3.4	2.3	1.0	2.0	2.7	3.0	2.1	2.1	1.3	1.5	1.4	1.9	1.0

grazing, but the percentage of the total root weight found at each depth was not the same for both pastures. A larger percentage of the root material was found at each depth below the upper foot in the moderately grazed than in the heavily grazed pasture. Application of N to plots isolated from grazing greatly reduced this difference.

N significantly (1% level) increased root weight. Although the second increment of N significantly (1% level) increased top growth, it did not produce any additional root weight. Thus the root:top ratio was much lower for the 90-N than for the 30-N treatment.

Differences between years of sampling were significant (5% level). The total root weight was greatest in the drier of the 2 years. We found a higher percentage of the roots in the upper foot in the wetter year.

An attempt was made to relate the root data to previously published soil moisture and soil chemical data obtained from the same plots. The pattern of soil moisture and nutrient extraction suggests that, sometime after fertilization began (but prior to sampling) the root system must have been larger at the greater depths. Precipitation was too low during this period to recharge the subsoil; thus, after the subsoil moisture which had accumulated under the heavily grazed pasture was depleted, the root system was restricted to the area of the profile recharged by annual precipitation. Soil moisture data explain the unusually large forage production during the first few years of fertilization in the heavily grazed pasture.

LITERATURE CITED

DUNCAN, DAVID B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

HYLTON, L. O., JR., A. ULRICH, AND D. R. CORNELIUS. 1965. Comparison of nitrogen constituents as indicators of the nitrogen status of Italian ryegrass, and relation of top to root growth. Crop Sci. 5: 21-22.

LORENZ, RUSSELL J., AND GEORGE A. ROGLER. 1964. Effect of row spacing and nitrogen fertilizer on production of irrigated Russian wildrye (*Elymus junceus* Fisch.). II. Relative crown and root development. Agron. J. 56: 7-10.

LORENZ, RUSSELL J., AND GEORGE A. ROGLER, 1966. Root growth of northern plains grasses under various fertilizer and management treatments. Amer. Forage and Grassl. Council Proc. Feb. 1966: 1-10.

ROGLER, GEORGE A., AND RUSSELL J. LORENZ. 1957. Nitrogen fertilization of northern Great Plains rangelands. J. Range Manage. 10: 156-160.

SMIKA, D. E., H. J. HAAS, G. A. ROGLER, AND R. J. LORENZ. 1961. Chemical properties and moisture extraction in rangeland soils as influenced by nitrogen fertilization. J. Range Manage. 14: 213-216.