Fertilization of Some Range Soils in the Rocky Mountains

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Soil fertilization is a tool that may be used in range management for improvement of quality and quantity of forage. It has potential value in reseeding operations to increase initial survival and subsequent growth and in the recovery of poor and depleted native ranges. Fertilization research on range soils in the Rocky Mountains is relatively new. Only recently has much attention been given to increasing the productiveness of native ranges. One of the major problems is to determine which soils or groups of soils will respond to fertilization since effort would be wasted in treating soils with a favorable fertility status.

The Intermountain Forest and Range Experiment Station conducted fertilizer studies a few years ago in which a response was obtained with nitrogen (N). Otherwise the results were inconclusive. The results were not published. The staff of the Forestry and Range Management Section of the Colorado Agricultural Experiment Station (1952) is currently conducting tests with nitrogen and phosphorus (P) on soils growing native shortgrass and mixed-prairie range types. Nitrogen has given both a quantitative and qualitative response on the herbage whereas P has given only a qualitative response. The soils have medium textures and are neutral or calcareous in reaction. Currently the economy of such applications to native range soils appears questionable.

Work by Brouse (1952–53) on meadow soils in the sandhill region of Nebraska has shown that native plants in moist meadows benefit from commercial fertilizers, but differences in soil, plant species and moisture supply caused much variation in results. Phosphorus favored the establishment and maintenance of legumes in these subirrigated meadows whereas a combination of N and P resulted in the best hay yields. Potassium (K) had a minor effect on hay yields. It is questionable that the increased yields will justify the cost of fertilization.

DeLand (1952) reported that profitable increases in production from mountain and intermountain soils can be obtained by applying 250 to 300 pounds of treble superphosphate on alternate years and 40 to 50 pounds of available N annually. The work was done in Montana on irrigated pastures.

Much work is being done by the Colorado Agricultural Experiment Station and cooperating agencies on irrigated mountain meadow soils in the Rocky Mountains. Reports have been given on this work by Nelson (1952) and others. In general, N consistently increases the yield of grasses and usually depresses legume growth. Phosphorus produces no growth on grasses and is somewhat erratic on legumes, but the quality of the forage is improved. The soils of mountain meadows are commonly neutral or calcareous, and water tables are usually high.

Much of the research on range and pasture soils has dealt with the primary or major elements, namely, N, P and K. However, in recent years attention has been sharply drawn to the need for trace or minor elements on some soils throughout the world. The minor elements are iron (Fe), manganese (Mn), boron (B), zinc (Zn) and copper (Cu). A third group sometimes referred to as secondary elements or soil amendments has resulted in increased yields on some soils. These elements are calcium (Ca), magnesium (Mg) and sulfur (S). The response from additions of any of these elements will depend upon the deficiencies of the particular soil being tested.

The determination of the role of minor elements in herbage growth seems to have been a secondary development, following other attempts to correct certain livestock disorders. In some places large increases of herbage result from applications of minor elements. Much of the literature deals with pasture research in New Zealand, Australia and England; research with minor elements on range soils in western United States is almost negligible. The worldwide work on minor elements has been gathered and excellently discussed in the Bibliography of the Literature on the Minor Elements (Chilean Nitrate Educational Bureau, Inc., 1948–53).

Many native ranges are too steep or too rocky to cultivate or reseed. If the surface application of commercial fertilizers would improve herbage growth, then fertilization could be a management tool for such lands. In 1947 this study was established to determine the results of top dressing range soils in the Rocky Mountains with 14 fertilizers and soil amendments.

Methods and Materials

Fertilizer plots were located on seven important soils. Each plot was 1/800-acre in size. Treatments were placed on 14 plots and 2 check plots were established, making a total of 16 plots for each set.

[1] *Maintained by the Forest Service, U. S. Department of Agriculture, for Arizona, Colorado, Kansas, Nebraska, New Mexico, South Dakota, west Texas and Wyoming, with headquarters at Colorado A & M College, Fort Collins, Colorado.*

Table 1. Application rates of fertilizers used in 1947 test

Treatment Added	Application Rate of Element	
	Pounds per acre	
Primary elements		
Ammonium nitrate	32.5	N
Superphosphate	20	P_2O_5[1]
Potassium sulphate	49	K_2O[2]
Secondary elements		
Calcium acetate	28	Ca
Magnesium acetate	10	Mg
Sulfur	10	S
Trace elements		
Iron citrate	10	Fe
Manganese acetate	10	Mn
Boric acid	2	B
Zinc acetate	10	Zn
Cupric acetate	10	Cu
Other elements		
Cobaltus acetate	10	Co
Molybdic acid	10	Mo
Sodium acetate	10	Na

[1] Equivalent to 8.7 pounds of P.
[2] Equivalent to 40.7 pounds of K.

Replicates were established on each soil. The placement of fertilizer in the plots was by random selection. Because the quantity of fertilizer for each plot was small, it was thoroughly mixed with local soil to obtain sufficient volume to spread evenly by hand over the plot. The 1947 treatments were top-dressed only; the 1949 treatments were worked into the surface soil with a hoe in those spots not covered with plants. The application rates and the 14 fertilizers used in the 1947 treatment are shown in Table 1. The rates and fertilizers used in 1949 are shown in Table 2.

The lime used in the 1949 treatments had a neutralizing value of 110 percent in terms of $CaCO_3$, indicating the presence of some magnesium carbonate. Phosphorus was applied as treble superphosphate (46 percent P_2O_5); potash as potassium sulphate (49 percent K_2O); and nitrogen as ammonium nitrate (32.5 percent N). The complete set of treatments (Table 2) was added to all sites except those soils from Morrison shale, basalt and andesite. To these three soils, only the complete treatment of lime plus NPK was added. The 1949 treatments were placed on old plots of the 1947 treatments which had never shown a response or where the original response had played out (Table 2).

In all tests response was evaluated by increased height of leaves and seed stalks, and by color changes compared to that of the plants in the check plots.

Soil samples for laboratory analysis were taken from untreated portions of each site and combined into a composite sample. Texture analyses were made by the hydrometer method with 30-percent Calgon solution as a dispersing agent. Soil acidity was measured with the glass electrode. Exchangeable bases and exchange capacity were determined by the ammonium-acetate displacement method for calcium and magnesium. Potassium and sodium were determined by the flame photometer. Phosphorus was measured by the sodium bicarbonate method of Olsen *et al.* (1954).

Characteristics of Areas Tested

Characteristics of the seven areas tested are shown in Table 3. The ponderosa pine areas have a range in annual precipitation of 15 to 25 inches while the spruce areas have 30 inches or more. The range condition varied among the soils selected from good to depleted.

The data in Table 4 show that the soils from granitic rocks contain large amounts of gravel and none contain more than 43 percent silt-plus-clay. The other soils contain from 53 to 65 percent silt-plus-clay. In comparison, good farming soils contain from 60 to 90 percent silt-plus-clay.

The degree of soil acidity exerts a strong influence on the availability of the different plant nutrients in soils (Truog, 1946). The most desirable conditions exist between pH 6.0 and 7.5. The soils tested generally fall within this range (Table 4), and no difficulty should be expected from the soils being either too acid or basic. Field

Table 2. Application rates of fertilizers used in 1949 test

Treatments Added	Application Rate of Element				Placement on 1947 Plots
	Ca	P_2O_5	K_2O	N	
	Pounds per acre				
Ca (lime)	500				Ca
Ca + P	500	300[1]			P
Ca + K	500		500[2]		K
Ca + P + K	500	300	500		N
Ca + N + P + K	500	300	500	200	Mo

[1] Equivalent to 131 pounds of P.
[2] Equivalent to 415 pounds of K.

Table 3. Parent material and vegetational characteristics of the seven soils tested

Soils Developed from	Approximate Elevation (feet)	Vegetation zone	Plant Cover			
			Range condition	Plant density		Vigor
				Grass	Total	
Granitic alluvium	7,500	Ponderosa pine	Reseeded	—	30	Fair
Granite-gneiss bedrock	9,500	Ponderosa pine	Poor	5	15	Low
Granite bedrock	8,500	Ponderosa pine	Poor	8	10	Low
Andesite bedrock	10,000	Ponderosa pine—fir	Good	20	25	High
Ancient alluvium	9,000	Spruce	Depleted	8	22	Low
Basalt bedrock	10,500	Spruce	Fair	16	25	Good
Morrison shale	9,000	Spruce—aspen	Fair	90	95	High

examinations showed that the organic-matter content is decidedly higher for soils developed from shales, andesite and basalt than in soils from granites.

The exchange capacity is a measure of the total capacity or ability of the soil to hold readily available nutrients. The data in Table 5 show remarkable differences between groups of soils in this respect. Exchangeable bases are the plant nutrients that are readily available to plants through the soil solution. The data show that the exchangeable-base contents of the soils differ a great deal. The soils from shale are much higher in Ca and K than all other soils; those from granitic parent materials are very low in Ca, Mg, and K; those from basic igneous parent materials are intermediate in fertility status.

The pounds per acre of P_2O_5 as determined by the sodium bicarbonate test are shown in Table 5. By this test a definite response will be obtained from phosphate fertilizer when the test falls below 25 pounds per acre; between 25 and 50 pounds, a probable response is expected; a possible but unlikely response is expected when the values are between 50 and 75 pounds; and no response when the test is above 75 pounds per acre. The results show that all soils are out of the first or deficient class and probably contain adequate phosphorus for the growth of native vegetation. Three of the soils are very high in phosphorus.

Table 4. Mechanical composition and acidity of soils tested

Soils Developed from	Mechanical Composition				Soil acidity
	Gravel	Sand	Silt	Clay	
	More than 2 mm.	2.0 to 0.5 mm.	0.5 to 0.02 mm.	Less than 0.02 mm.	
	Percent				*pH*
Granitic alluvium	21.3	45.0	20.5	13.2	6.2
Granite-gneiss bedrock	13.0	44.2	27.4	15.4	5.7
Granite bedrock	56.0	22.0	15.3	6.8	6.5
Andesite bedrock	15.4	31.5	32.3	20.8	6.4
Ancient alluvium	9.7	24.8	42.8	22.8	6.1
Basalt bedrock	14.4	29.1	27.2	29.3	5.6
Morrison shale	19.8	16.8	45.3	18.1	6.0

Table 5. Readily available nutrients of the soils tested

Soil Parent Material	Exchange Capacity[1]		Available Nutrients Present						
			Ca		Mg		K		P_2O_5
	m.e.	Lbs./A	m.e.	Lbs./A	m.e.	Lbs./A	m.e.	Lbs./A	Lbs./A
Infertile soils									
Granitic alluvium	7.6	3,048	4.9	1,952	1.8	433	0.5	404	44
Granite-gneiss bedrock	11.4	4,552	6.6	2,624	1.5	355	0.3	224	104
Granite bedrock	11.7	4,672	7.6	3,040	1.7	416	0.4	324	53
Fertile soils									
Andesite bedrock	18.0	7,204	12.9	5,152	2.8	693	1.2	914	143
Ancient alluvium	15.5	6,208	11.2	4,500	2.4	586	0.3	264	53
Basalt bedrock	20.6	8,248	11.8	4,704	3.5	846	0.6	482	44
Very fertile soils									
Morrison shale	32.0	12,800	23.0	9,208	2.1	508	2.0	1,544	92

[1] The total amount of available nutrients present expressed as milli-equivalents (m.e.) per 100 gm. of oven-dry soil. All conversions from m.e. to pounds per acre on basis of 2 million pounds of soil in top 7 inches of surface.

Results and Discussion

Fertility is an inherent characteristic of the soil. Plants will respond to fertilizer applications when the fertility status of a soil is low or unbalanced, but they will not respond when the fertility status is high and well balanced. Because of difficulties in locating areas protected from grazing it was not possible in this study to secure a uniform plant condition for all soils tested, but regardless of variations in kinds of plants or in range condition the response of the native vegetation should give an indication of the fertility status of each soil. The treatments that produced a response on the plants are shown in the tabulation below for each of the seven areas tested.

Granite alluvium: Grasses—1, Forbs—0, Shrubs—1
Bromus inermis—K, N, NPK
Artemisia frigida—N, NPK

Granite-gneiss bedrock: Grasses—6, Forbs—4, Shrubs—2
Muhlenbergia filiculmis—N, K, NPK
Artemisia frigida—NPK, K(?), N

Granite bedrock: Grasses—2, Forbs—5, Shrubs—1
Festuca arizonica—N, K, NPK, PK
Muhlenbergia montana—N, K, NPK, PK
Artemisia frigida—N, NPK

Andesite bedrock: Grasses—4, Forbs—5, Shrubs—2

Ancient alluvium: Grasses—5, Forbs—4, Shrubs—0
Bromus pumpellianus (?)—N
Festuca ovina—N

Basalt bedrock: Grasses—5, Forbs—10, Shrubs—0

Morrison shale: Grasses—6, Forbs—8, Shrubs—0
Poa pratensis—N
Poa ampla (?)—N

The numbers of grasses, forbs and shrubs present are shown for each of the seven areas in the above tabulation. Altogether 18 grasses, 25 forbs and 3 shrubs were identified but in no instance did any one species occur on all soils. These tests were designed to determine nutrient deficiencies in soils as shown by the plants present and not to compare responses between species of plants or the same species on all soils. However, it is interesting to know that *Festuca arizonica* responded to the N, K, NPK, and PK treatments on soils developed from granite bedrock but not on soils developed from andesite. *Muhlenbergia montana* responded similarly. *Poa pratensis* responded to N on soils from Morrison shale but not on soils from basalt bedrock. *Artemisia frigida* showed marked response to various treatments containing N on all soils from granitic materials but not from soils on andesite.

Plants on soils from granitic materials responded the best to the fertilizers added. Plants on soils from ancient alluvium and Morrison shale responded only to N and then only by a deeper green color of the foliage. Plants on soils from andesite and basalt responded to no treatment. This behavior was strongly supported by laboratory analyses of the soils (Table 5). From the combined field tests and laboratory data it is possible to establish three classes for the soils of this study, namely, (1) infertile soils—derived from granitic rocks; (2) fertile soils—derived from basic igneous rocks, and (3) very fertile soils—derived from shales. This grouping has been made in Table 5.

An examination of the percent ages of silt and clay (Table 4) shows an increase from the infertile to the fertile and the very fertile soil groups. The increased amounts of silt and clay favor the retention of soil moisture and this, in combination with the fertility levels, has a marked effect on the total productivity of each of the seven soils.

The major elements, N, P and K, produced the only responses in the plants of these tests. Nitrogen resulted in a greening of herbage and increased growth on soils from granites, a greener color on soils from Morrison shale and ancient alluvium, and no response on soils from andesite and basalt. The only marked increase in growth occurred in *Bromus inermis* on soils from granitic alluvium, and here the herbage volume was 75 to 100 percent greater and the seed-stalk heights 2 to 4 inches higher than on adjacent unfertilized plots. *Artemisia frigida*, an undesirable shrub, responded strongly to N on all soils where it was present except those from andesite. In this study, the effects of N did not extend over a period of more than two years.

Phosphorus and K produced no noticeable results on soils from basalt, andesite, ancient alluvium or Morrison shale in either the 1947 or 1949 treatments. This suggests that additions of P and K to these soils would not be necessary.

Inconclusive results were obtained from P and K on soils developed from granitic materials. It has been shown in Wisconsin (1951) that soils from granite rocks may be deficient in K to the extent that small additions of K are ineffective. Large additions gave a marked increase in alfalfa yields. Accordingly, the application rate of K in these tests was greatly increased in 1949 over that in 1947 (Table 2). As a result K alone and as KP produced a response on the granitic soils but the response was not strong. Phosphorus alone never resulted in a noticeable increase in herbage in either the 1947 or 1949 applications. This response checks with the laboratory tests for P_2O_5 shown in Table 5. Likewise, P is rarely effective when applied as a top dressing.

None of the secondary, trace or other elements in Table 1 produced a quantitative response in any of the plants on the seven soils during the 5 years of the study. These elements have wide ranges in solubilities, some being very insoluble, but all were applied on the possibility that shallow roots of the plants might be effective in extraction of nutrients from near the surface of the soil. It seems reasonable to conclude that none of the soils tested are deficient in the minor elements. All are soils whose parent materials are from rocks in their first weathering cycle and hence the diverse minerals in these rocks possibly supply all nutrient requirements of the native plants. Morrison shale, the only sedimentary rock, is high in nutrients of all kinds.

A greater and more prolonged response was obtained from the 1949 treatments over those of 1947. This is attributed to the larger quantities of fertilizers used. The soil needs were not satisfied (materials were absorbed by the clays) by the 1947 treatments and the nutrients were not available to the plants on the infertile granitic soils.

This experiment was designed to test response from top dressings of fertilizers. Top dressing is a satisfactory method of application for nitrogen and readily soluble salts but is less satisfactory for salts of low solubility. Ordinarily fertilizers are worked into the soil but cultivation is impossible in most mountain soils and if fertilizers are used they must be top-dressed.

No attempt was made to compare herbage weights on the different treatments; neither were costs of increased forage computed as a basis for practical ranching operations. These points are the subjects of more extensive experiments now being conducted.

Summary

Under conditions of this study, no important increases in native herbage were obtained by top dressing with 14 fertilizers and minor elements on seven range soils tested in the Rocky Mountains. Nitrogen fertilization produced increased herbage on soils from

granitic materials for one to two years following application. Applications of N resulted in no response on soils from basalt and andesite. Responses to additions of K were not conclusive but were strong enough to suggest that the soils from granitic materials are deficient in K. The response to P fertilizers was indefinite on soils from granite. There was no growth response to additions of minor elements on any soil.

Laboratory analyses of the soils correlated well with field tests in defining relative fertility levels of the different soils and provided reasons to explain differences in the relative productiveness of the soils. Both the field and laboratory tests suggested that the best response to fertilization would be obtained on soils developed from granitic materials.

Acknowledgments

The author is grateful to Professor Robert Gardner of the Colorado Agricultural Experiment Station who assisted in the development of the original study plans. C. V. Cole of the Bureau of Plant Industry, Soils and Agricultural Engineering, U.S.D.A., made the phosphorus tests reported herein. Other soil analyses were made by the author at the Department of Soils, University of Wisconsin. Appreciation is expressed for use of the laboratory facilities. The plants in this study were identified by W. M. Johnson and G. T. Turner of the Rocky Mountain Forest and Range Experiment Station.

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