Yield and Mineral Composition of Grass Species Grown on Acid Grassland Soils[1]

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Highlight

The objective was to study the use of various grass species, two liming materials, and phosphorus as means of improving very acid, unproductive, grassland soils. Phosphorus applications increased yields of all 10 species at all levels of liming. Liming with a mixture of calcic and magnesium limes increased yield more than either alone. The outstanding performance of veldtgrass was associated with its calcium-foraging ability, which resulted in the highest tissue concentrations of calcium. These guidelines point toward the use of phosphorus and small amounts of limestone, containing both Ca and Mg, with calcium-foraging species for successful forage establishment in acid grassland soils.

A group of dark-colored, strongly-acid, grassland soils that are high in organic matter but are very poor forage producers, occur in California. The soils are situated both in moist mountain meadows and in the well-watered foothills of the north coast. They are often prairie-like, but support a vegetation dominated by worthless forbs or bracken fern. Desirable grasses and legumes are almost completely absent and are difficult to introduce by current techniques.

These unproductive soils occupy positions where abundant forage would be of great value. The mountain meadows are needed for summering livestock and for the rapidly growing number of pack stock used for recreational purposes. The occurrence of these soils along the coast is ironic because the climate is ideally suited to forage production on adjacent better soils.

Two acid soils were selected for greenhouse experiments. The objective was to study the use of various grass species, two liming materials, and phosphorus as means of improving their forage production.

Experimental Soils and Methods

Wilder Variant Series.—The Wilder Variant Series occurs on flat, smooth, high alluvial terraces, and developed from sandstone and graywacke sedimentary rock alluvium. Gravels of sandstone exist throughout the profile. The soil is very strongly acid (pH 4.9), very friable, and high in organic matter. The soil site sampled for the experiments is in the Petrolia area where the annual rainfall is about 60 in. The climate is classified as Mediterranean cool summer with fog—Csbn (Durrenberger, 1960). In its virgin state the soil supports a vegetation dominated by western bracken (*Pteridium aquilinum* var. *lanuginosum*), silver hairgrass (*Aira caryophyllea*), and sheep sorrel (*Rumex acetosella*). On adjacent soil series such as Kneeland, plants of high forage value, including California oatgrass (*Danthonia californica*), soft chess (*Bromus mollis*), and slender oat (*Avena barbata*) are common. Hence, the poor quality of the vegetation on the Wilder contrasts sharply with the vegetation on the adjacent soil series.

Sixmile Series.—The sampling site is a meadow in the Sierra Nevada Mountains near Emigrant Gap, at an elevation of 5,500 ft. Average annual precipitation is about 60 in., most of which falls during November through March as snow. The climate is Mediterranean highland and is warm and dry during the summer, but cold and wet in the winter (Dsb). The parent material of the Sixmile soil is alluvium derived from andesitic breccia, and it is quite similar in chemical characteristics to the Wilder (Table 1). The higher, better-drained portion of the meadow has a very sparse vegetation consisting principally of low forbs, such as pussy paws (*Calyptridium umbellatum*), sheep sorrel, and a few other depauperate annuals. The more poorly drained areas contain meadow genera such as *Carex* and other Cyperaceae. Lodgepole pine (*Pinus murrayana*) is the main woody species surrounding the meadow; it appears to be encroaching on the better-drained areas.

Table 1. A comparison of characteristics of Wilder and Sixmile soils.[1]

	Wilder	Sixmile
Cation exchange cap. me/100 g	30.0	23.1
Organic-matter-free cation exch. cap. me/100 g	11.1	9.4
Exch. Na me/100 g	0.4	0.3
Exch. K me/100 g	0.4	0.2
Exch. Ca me/100 g	0.8	0.5
Exch. Mg me/100 g	0.4	0.3
P (H_2O) ppm soil	0.12	0.25
P (HCO_3) ppm soil	6.0	14.0
Exch. Fe me/100 g	0.2	0.7
Mn (Ex. + sol.) me/100 g	nil	nil
Extract. Al me/100 g	4.8	4.0
N %	0.43	0.33
C %	6.40	4.10
Fe_2O_3 %	2.86	3.06
Organic matter %	10.9	7.0
pH sat. paste, dist. H_2O	4.8	4.7

[1] Supplied by Soils Extension Laboratory and the Department of Soils and Plant Nutrition, University of California, Davis.

Samples of soil from the surface 6 inches of each soil type were sifted through a 0.25-inch screen to remove rock and gravel. Three pH levels were obtained, 4.8, 5.8, and 6.8, by using the untreated soils and two lime

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levels, 1,750 and 5,500 ppm CaO (reagent grade). The amounts required were the same for both soils. The lime and soil were mixed thoroughly and then placed in 5-inch pots lined with polyethylene sleeves which permitted drainage. The pots were arranged in a stratified randomized block design with three replications. Soil moisture was determined gravimetrically, and the pH values were determined on a saturated paste of each soil.

Experiment 1.—The rates of lime were used in combination with phosphorus ($NaH_2PO_4.H_2O$) added at the rate of 0 or 105 ppm P for the Wilder and 0 or 125 ppm P for the Sixmile series. Ten species of grasses were planted on December 10, 1962 and later thinned to 10/pot. All pots received 100 ppm nitrogen as NH_4NO_3, half at 10 days and half at 41 days after planting. The species of grass were:

1. Cereal rye
   Secale cereale
2. Hardinggrass
   Phalaris tuberosa
3. Intermediate wheatgrass
   Agropyron intermedium
4. Kentucky bluegrass
   Poa pratensis
5. Orchardgrass
   Dactylis glomerata
6. Perennial ryegrass
   Lolium perenne
7. Redtop
   Agrostis alba
8. Smooth brome
   Bromus inermis
9. Tall fescue
   Festuca arundinacea
10. Veldtgrass
   Ehrharta calycina

The above-ground portion of the plants was harvested on February 17, 1963 by clipping at the soil surface and dried at 100 C for 3 days.

Experiment 2.—The Wilder soil was limed with CaO, MgO, or a mixture of equal parts CaO and MgO at the same rates as in experiment 1, with the MgO applied on an equivalent neutralizing basis. Two levels of phosphorus, 0 and 100 ppm P, were used, with Na_2HPO_4 as the source. All pots received 100 ppm nitrogen as NH_4NO_3, half at 35 days and half at 50 days after planting. Colonial bentgrass (*Agrostis tenuis*), hardinggrass, orchardgrass, and veldtgrass were seeded July 2 and harvested September 17.

Plants from both experiments were analyzed for phosphorus, aluminum, manganese, calcium, and magnesium.

Table 2. Effect of calcic lime and phosphorus on mean yield and mineral concentrations of 10 grass species grown on acid soils.

Nutrient	Wilder soil			Sixmile soil			LSD
	Lime applied			Lime applied			
Treatment	Nil	Low	High	Nil	Low	High	5%
Yield g/pot							
None	0.24	0.48	0.48	0.39	0.78	0.80	0.18
Phosphorus	1.36	2.04	2.14	1.12	1.95	2.07	0.29
Phosphorus %							
None	0.13	0.10	0.13	0.16	0.13	0.14	N.S.
Phosphorus	0.20	.20	.20	.25	.26	.24	0.03
Aluminum ppm							
None	400	210	180	430	200	310	N.S.
Phosphorus	220	220	160	220	300	260	N.S.
Manganese ppm							
None	490	350	330	290	250	260	58
Phosphorus	470	240	250	250	180	190	40
Calcium %							
None	0.33	1.09	0.90	0.34	0.69	0.88	0.28
Phosphorus	.24	.71	.75	.35	.63	.77	0.16
Magnesium %							
None	0.22	0.32	0.33	0.34	0.36	0.36	N.S.
Phosphorus	.27	.26	.28	.29	.35	.34	N.S.

Results

Lime and Phosphorus (Experiment 1).—The average yield for the ten species was markedly increased by the application of phosphorus on both soils at all levels of liming (Table 2). Lime applied at the low rate (pH 5.8) resulted in a substantial increase in yield on both soils, with or without applied phosphorus. However, the increases were less than those resulting from the phosphorus treatment. The yield from the pots treated with the high rate of lime (pH 6.8) was essentially the same as from the pots treated with the low rate of lime on both soils.

Yields of the individual species from untreated pots ranged from 0.7-1.6 g/pot with cereal rye and veldtgrass to essentially nil with Kentucky bluegrass and hardinggrass (Fig. 1). Cereal rye and veldtgrass responded strongly to applied phosphorus, but they were unresponsive to liming on either soil. Hardinggrass responded strongly to liming in the presence of applied phosphorus. Responses of the other species were intermediate.

The variability of the data on the mineral composition of the individual species makes difficult the interpretation of differences in composition. However, some results of significance are evident from the data averaged for all species. Application of phosphorus increased the average concentration of phosphorus in grasses by 66% on the Wilder soil and by 56% on the Sixmile soil (Table 2). Concentration of aluminum in plant tissue was not affected measurably by the treatments. However, scatter diagrams of yield of individual species—treatment combinations plotted against aluminum concentration in tissue—indicate that high yields on either soil were obtained only at values less

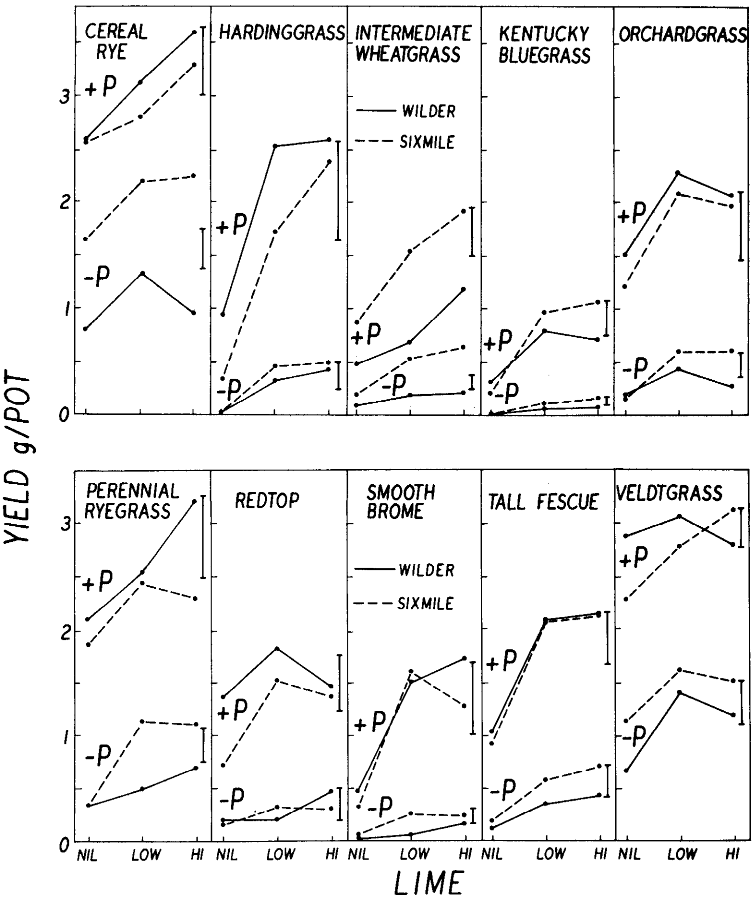

FIG. 1. Yields of 10 grasses as affected by applications of calcic lime and phosphorus on acid soils.

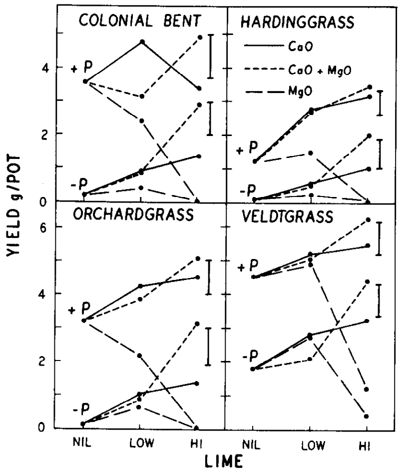

FIG. 3. Yields of four grasses as affected by applications of calcic and magnesian limes and phosphorus on Wilder soil.

than 400 ppm aluminum (Fig. 2).

Manganese in plant tissue was decreased substantially by the low amount of lime applied at either level of phosphorus. The high rate of lime caused no further decrease. Calcium in plant tissue was increased by the low rate of lime; the high rate of lime did not result in a further significant increase. Magnesium in plant tissue was not affected measurably by either the lime or phosphorus treatments. The soil pH, averaged for all species and phosphorus treatments, declined 0.9 units on Wilder soil and 0.6 units on Sixmile soil in the lime treated pots during the course of the experiment (Table 3).

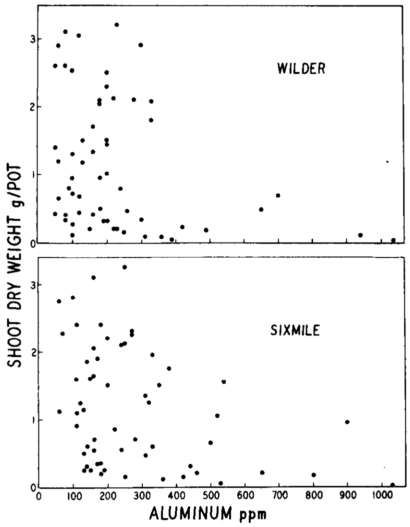

FIG. 2. Relation of yield of 10 grasses to their tissue concentration of aluminum.

Calcic vs Magnesian Lime (Experiment 2). — The grasses increased in yield from calcic lime and phosphorus applications in essentially the same manner as in experiment 1, i.e., generally major responses to phosphorus and minor responses to calcic lime (Fig. 3). The substitution of magnesian lime for half of the calcic lime, on an equivalent neutralizing basis, resulted in major yield responses from all four species in the absence of applied phosphorus. However, magnesian lime alone was deleterious at the low rate, and it was toxic at the high rate both with and without applied phosphorus.

Veldtgrass was the most productive of the four species on the untreated soil. The concentration of calicum was substantially higher in the veldtgrass than in the other species, where grown

Table 3. Effect of rates of calcic lime on soil pH at beginning and end of experiment 1 (averages over all species and phosphorus treatments).

	Lime applied						
	Wilder soil			Sixmile soil			LSD
pH	Nil	Low	High	Nil	Low	High	5%
Initial	4.8	5.8	6.8	4.7	5.8	6.8	.....
At harvest	4.3	4.9	5.9	4.4	5.2	6.2	0.1
Decrease during experiment	.5	.9	.9	.3	.6	.6	.....

Table 4. Effect of amount and kind of lime on concentrations of calcium and magnesium in four species of grass (averaged over two phosphorus treatments).

Lime Amount and Kind	Calcium % Bent-grass	Harding-grass	Orchard-grass	Veldt-grass	Mean	Magnesium % Bent-grass	Harding-grass	Orchard-grass	Veldt-grass	Mean	Mean Ca:Mg ratio
Nil	0.32	0.41	0.28	0.61	0.40	0.24	0.22	0.30	0.18	0.24	1.7
Low Ca	.44	.78	.60	1.24	.76	.23	.18	.34	.12	.22	3.5
High Ca	.70	.96	.88	1.68	1.06	.22	.20	.34	.36	.28	3.8
Low Mg	.21	.49	.41	.45	.39	.52	.46	.56	.70	.56	0.7
High Mg	—	—	—	.65	—	—	—	—	1.87	—	0.3[1]
Low Ca + Mg	.36	.60	.57	.78	.58	.38	.34	.54	.54	.45	1.3
High Ca + Mg	.36	.78	.60	1.20	.74	.44	.54	.58	.64	.55	1.3
Mean	.40	.67	.56	.94		.34	.32	.44	.63		
LSD 5%		0.18			0.22			0.10		0.13	

[1]For veldtgrass, the only surviving species.

on the unlimed soil (Table 4). Veldtgrass tolerated the high magnesian lime treatment better than did the other species, making some growth even though the concentration of magnesium in the tissue was 1.87%. Concentrations of aluminum and manganese did not vary significantly among species or treatments, and levels were of the same order as in Experiment 1.

Discussion

The two range species that were most productive on the untreated soils, veldtgrass and perennial ryegrass, were very responsive to applied phosphorus in the absence of lime, but responded inconsistently to applications of calcic lime. Hardinggrass, tall fescue, and smooth brome responded strongly to the application of low calcic lime in the presence of applied phosphorus, but did very poorly on the untreated soils.

The yield responses obtained on the untreated soils indicate that substantial variation in tolerance to strongly acid soils exists among the forage grasses commonly used in California. Other recent work has shown that there is also a within-species variation, in tolerance to acid soil, in ryegrass (Vose and Randall, 1962) and in wheat and barley (Foy et al., 1965). These researchers demonstrated an association between growth on acid soils and aluminum tolerance among varieties. We found a general association among our species-treatment combinations between yield and concentration of aluminum. As pointed out by Magistad (1925), there is very little aluminum in solution around pH 5; however, at pH 4 it is possible to have sufficient aluminum in solution to cause toxicity in most plants. The post-harvest determinations of soil pH indicate that the pH was sufficiently low in the present studies for aluminum to have existed in a soluble form. Although the plant analyses (shoot only) did not show any correlation between concentration of aluminum and yield, this does not necessarily rule out the possibility that aluminum may have been present in toxic quantities, since excess aluminum may have been retained in the roots (Wright, 1937). The fact that cereal rye and veldtgrass did relatively well in the untreated soil also supports the likelihood of aluminum toxicity, since this may have been due to their aluminum tolerance (established for cereal rye by McLean and Gilbert, 1927). All the other grasses did poorly in the untreated soils.

Unpublished work (W.E.M.) has indicated that the Wilder soil is deficient in magnesium. Evidence from experiment 2 verifies this observation, since all four species selected for this study responded in yield to the substitution of magnesium lime for half of the high rate of calcic lime. Where phosphorus was applied, magnesium response was largely masked. However, the high rate of magnesian lime alone was toxic, being fatal to bentgrass, hardinggrass, and orchardgrass. The veldtgrass survived, but its yield was strongly depressed.

Further evidence of the uniqueness of veldtgrass among the forage grasses tested is indicated by the mineral composition data from experiment 2. As an average of all treatments, calcium in veldtgrass was 74% greater than the mean concentration of the other three species (Table 4). Veldtgrass did not differ markedly from the other species in concentration of the other mineral elements considered, however.

Calcium: magnesium ratios, averaged for the four species, were calculated from tissue concentration data from experiment 2. A ratio of 1.3 resulting from the treatments with the lime-mixtures was associated with best growth of the grasses (Table 4). Ca/Mg ratios of 3.5 and above, resulting from the calcic lime treatments, were less favorable. Ratios of about 0.7 resulting from the magnesian lime applications were associated with even poorer plant growth as calcium-magnesium imbalance in the other direction resulted.

LITERATURE CITED

DURRENBERGER, R. W. 1960. Patterns on land. Geographical, historical, and political maps of California. Roberts Pub. Northridge, Calif.

FOY, C. D., W. A. ARMIGER, L. W. BRIGGLE, AND D. A. REID. 1965. Differential aluminum tolerance of wheat and barley varieties in acid soils. Agron. J. 57:413-417.

MAGISTAD, O. C. 1925. The aluminum content of the soil solution and its relation to soil reaction and plant growth. Soil Sci. 20:181-227.

MCLEAN, F. T., AND B. E. GILBERT. 1927. The relative aluminum tolerance of crop plants. Soil Sci. 24:163-174.

VOSE, P. B., AND P. J. RANDALL. 1962. Resistance to aluminum and manganese toxicities in plants related to variety and cation exchange capacity. Nature 196:85-86.

WRIGHT, K. E. 1943. Internal precipitation of phosphorus in relation to aluminum toxicity. Plant Physiol. 18:708-712.