Nutrient Testing of Soils to Determine Fertilizer Needs on Central Sierra Nevada Deer-Cattle Ranges

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Abstract

Soil samples representing six major forest soil series and two meadow unclassified types were collected from 17 locations on critical deer migration routes in the central Sierra Nevada, California. Nutrient tests were conducted in the greenhouse using soft chess *(Bromus mollis)* as an indicator species to determine deficiencies of nitrogen, phosphorus, and sulfur. These tests were carried out to assess fertilizer needs and the probability of field response to increased nutrient levels in the soil for improvement of forage quality and quantity on deer migration routes. All soils were nitrogen deficient; the meadow soils were less so than the forest soils. In 94% of the soils samples, the addition of phosphorus (70%) or phosphorus and sulfur (24%) with nitrogen increased plant yields dramatically (as much as 26 times) compared with adding nitrogen alone. Addition of sulfur with nitrogen produced a yield response equal to that produced by phosphorus or phosphorus plus sulfur with nitrogen in three soils. Nitrogen was the nutrient most limiting for plant growth; phosphorus was next important and was essential for best response in most soils. Sulfur produced variable responses, usually increasing plant yields only after nitrogen and phosphorus deficiencies were corrected. Productivity of forage and browse species growing on these soils is determined by nutrient status; characteristics delineated at the series level, such as depth, texture, and structure; and moisture-temperature relations in specific years.

The migratory mule deer herds on the west slope of the Sierra Nevada, California, have declined since the 1950's. The North Kings Deer Herd, selected for study because it is representative of this area, has declined from an estimated 17,000 animals in the early 1950's (Longhurst et al. 1952) to 3,200 in 1972. The range of this herd occupies 205,000 hectares between 300 and 3,200 m in elevation in the central Sierra Nevada, primarily on the Sierra National Forest. The winter ranges are primarily in the oak-woodland, chaparral and the lower edge of the ponderosa pine belt. Summer ranges are in the mixed-conifer and white fir zones. Deer use the same migration routes each spring and fall between these ranges. The migrations vary from 10 to 50 km in length and average about 1,400 m elevation change. The upward migration in the spring averages about 40 days and the downward migration in the fall averages about 15 days. Both migrations represent a period of nutritional stress on the deer because of low quality and quantity of forage.

The quality of the winter-range annual forbs and grasses begins to decline in April or May, depending upon moisture-temperature relations of specific years, and the deer start their upward migration before the summer range is ready. The deer are forced to delay in holding areas located at favorable sites enroute (Bertram and Rempel 1977), where they must subsist, primarily, on dry, low-quality forage from the previous season's growth. Does are in the last trimester of gestation during the spring migration. The decline in fat reserves and variation in fetal size that occur at this time of year have been interpreted as adversely affecting fetal survival (Salwasser et al. 1978). Reduction of these fetal development problems is likely to produce greater fawn survival. Composition counts indicate that the primary cause of herd decline is the 60% mortality of fawns during their first 90 days of life. Other factors probably interplay with those of nutrition to cause the drastic reduction in herd size that has occurred in recent years.

Research was begun to find ways to improve quality and quantity of forage on critical areas along deer migration routes. Revegetation with early growing and high-quality plants and fertilization to increase early season growth were the two main thrusts of cooperative research by the Forest Service and Agricultural Research Service, U.S. Dep. Agr. Since the entire range is grazed by cattle, increased quality and quantity of forage would benefit livestock also and reduce the possibility of inter-specific competition for forage.

In areas where herbaceous or browse species naturally occur, fertilization seemed to be a promising way to increase the quality and quantity of available forage for deer and cattle (Bayoumi and Smith 1976, Basile 1970). Fertilization has been shown to be valuable in producing early growth (Martin and Berry 1970, Hunt 1973) and in increasing nutrient value of forage, especially protein content (Carpenter and Williams 1973, Hunt 1973, and Gibbens and Pieper 1962).

Two objectives of this study were to determine the nutrient status of the major soils on important holding areas along the deer migration routes and to evaluate forage plant responses to added nitrogen, phosphorus and sulfur. This information can then be used as a basis for a fertilization program to increase quality and quantity of forage and browse plants for both deer and cattle in these areas (Smith 1966, Eckert and Bleak 1960, Wagle and Vlamis 1961, Jenny et al. 1950). A third objective was to examine in relation to soil series and nutrient treatments two factors of forage quality, protein content and calcium:phosphorus ratio, which may be important to the fetal development of deer.

Methods

Surface soil samples (0–20 cm) were collected for nutrient testing from 17 soils representative of holding areas along deer migration routes at elevations from 1340 to 2150 m in the North Kings Deer Herd Range of the Central Sierra Nevada. Mean annual precipita-

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tion of the area ranges from 65–140 cm, most of which occurs in winter and spring. Samples were representative of six extensive and important forest soil series and two unclassified meadow soil types of the area (Table 1). Where soil series were widespread, samples were collected from more than one area.

The six forest soils are a clay loam, a loam, a sandy loam, a coarse sandy loam, a sand, and a cobbly loamy coarse sand. All soils are moderately deep (120 cm) to deep (290 cm) and all are well-drained. They range from limited to excellent producers of commercial timber, but all six can support a shrub, forb, and grass cover as an understory or when areas are logged.

Soils of the Holland and Musick series are fine-loamy, mixed, mesic Ultic Haploxeralfs. Soils of the Shaver series are in the coarse-loamy, mixed, mesic family of Pachic Ultic Haploxerolls. The Ducey series is classified as coarse-loamy, mixed, frigid Typic Xerumbrepts; the Dinkey series as sandy skeletal, mixed, frigid Typic Xerorthents; and the Corbett series as loamy coarse sand, mixed, frigid Typic Xeropsamments (Anon. 1958–1977).

Nutrient testing was conducted in the greenhouse following the method of Jenny et al. (1950) as modified by Evans et al. (1962). Soil samples were thoroughly mixed, air dried, and sieved through a 6-mm mesh screen to remove pebbles and gravel. Waxed paper cups were filled with 1600 gm of soil, and then water solutions of nutrients were added. Nitrogen was applied as ammonium nitrate, phosphorus as phosphoric acid, and sulfur as sodium sulfate. Soft chess cultivar 'Blando brome' *(Bromus mollis)* was used as the indicator plant because it is easy to grow and reflects nutrient responses well. A four-replicate, randomized-block factorial design was used, with three rates of nitrogen (0, 56, and 224 kg/ha), and three rates of phosphorus (0, 56, and 224 kg/ha) alone and in combination. Sulfur (112/kg/ha) was used in combination with high nitrogen and high nitrogen-high phosphorus applications. With some samples of limited soil, only the high rates of nitrogen and phosphorus were used. Nutrient applications were calculated on the basis of soil weight; it was assumed that the surface 15 cm of soil weights 2,240,000 kg/ha.

Soft chess was grown, with 12 plants per pot, for 8 weeks in all soils in the greenhouse with enough water supplied so that the plants were never under moisture stress. All top growth was harvested, oven-dried, and weighed to determine yield responses to nutrients. Comparisons also were made among responses of soft chess, alsike clover *(Trifolium hybridum)* and mountain whitethorn *(Ceanothus cordulatus)* to nutrients in selected soils.

After the pot test growth period was completed and aboveground biomass of soft chess was dried and weighed, proximate analysis to determine protein content and calcium:phosphorus ratio (AOAC 1955) was run on the plant material harvested from five nutrient treatments on four soils. The plant material was ground and the samples from replications I and II and replications III and IV were combined to make two samples for chemical analysis. Plant material from pot tests of soils from four sites representative of the migration routes were selected for chemical analysis: Nutmeg Saddle, a lower elevation Shaver series soil; Bear Wallow, a high elevation Shaver series soil; Sugarpine Hill, a high elevation Ducey series; and Post Corral, a high elevation meadow soil (Table 1). Nutrient treatments included in this analysis were: control, nitrogen at 224 kg/ha, phosphorus at 224 kg/ha, nitrogen plus phosphorus, and nitrogen plus phosphorus plus sulfur at 112 kg/ha.

Analysis of variance and Duncan's multiple range test were used to determine statistical significance of nutrient responses. A nutrient response factor (NRF), derived as the ratio between maximum yield response of soft chess with the optimum nurtient treatment and the yield of the control, was used to determine fertilizer requirements.

Results and Discussion

Nutrient Responses of Soft Chess

Most soils tested were extremely nutrient deficient; soft chess yield at the optimum nutrient level averaged about 14 times that of the control (NRF-Table 2). Yield response to nutrients in individual soils ranged from two to 30 times that of the check. All soils were nitrogen deficient, ranging from minimum to extreme. The meadow soils with their high organic matter were less nitrogen deficient than were the forest soils with one exception—a forest soil from the Blue Sale location. The Blue Sale location was an unlogged, low elevation, ponderosa pine *(Pinus ponderosa)* site with much accumulated litter. Other forest soils were extremely to moderately nitrogen deficient depending on location, but the complexity of site factors makes it almost impossible to ascribe definitive characteristics to the degree of nitrogen deficiency in these soils.

In 94% of the soils, phosphorus, sulfur, or phosphorus and sulfur were necessary in addition to nitrogen to obtain the opti-

Table 1. Location description of soil samples.

Locations	Elevation (m)	Soil series	Site description
Nutmeg Saddle	1,460	Shaver	Ponderosa pine, burn-plantation, annual grass dominated
Bear Wallow	2,000	Shaver	Mixed conifer, patch cut
Grand Bluffs	1,830	Shaver	Mixed conifer, old logged and burned area, manzanita, ceanothus, and ribes cut and piled
Sugarpine Hill-West	2,070	Ducey	Glacial moraine, logged and replanted, snowbrush dominated site
Sugarpine Hill-East (2 sites)	2,050	Ducey	White fir, patch cut, ponderosa pine plantation
Sawmill Flat	2,050	Corbett	White fir, clear cut
Sawmill Flat	2,050	Dinkey (Variant)	White fir, uncut
Sawmill Flat	2,050	Dinkey	White fir, selectively cut
Blue Sale	1,340	Musick	Ponderosa pine, uncut
Weather Station-1	1,160	Holland	Ponderosa pine, logged in 1975
Weather Station-2	1,160	Holland	Ponderosa pine, logged in 1975, landing-compacted soil
Landing Site (2 sites)	1,340	Holland (Variant)	Ponderosa pine, logged in 1975, landing-compacted soil
Post Corral Meadow	2,500	Unclassified meadow	Wet meadow, grazed, lodgepole encroachment
Tule Meadow	2,150	Unclassified meadow	Wet meadow, grazed
Snow Corral	2,070	Corbett	White fir, selectively cut

mum expression of nitrogen deficiency in maximum response to nutrients. Phosphorus with nitrogen gave maximum yields in 70% of the soils, but sulfur was required with nitrogen and phosphorus for highest yield in 24% of the soils. In three soils, sulfur with nitrogen produced a response statistically (P=0.01) equal to that produced by nitrogen and phosphorus or all three nutrients. A timber soil, from Snow Corral, had adequate levels of phosphorus and sulfur so yield of soft chess was increased only by the addition of nitrogen. In contrast, a meadow soil, from Post Corral Meadow, was extremely deficient in phosphorus along with nitrogen. A second meadow soil, from Tule Meadow, was deficient in nitrogen, phosphorus, and sulfur.

Overall results of nutrient testing of the 17 soils indicated that these soils are primarily nitrogen deficient; secondarily, phosphorus deficient; and thirdly, some are sulfur deficient. Nitrogen and phosphorus deficiencies can be expected, generally, in this area. Sulfur deficiencies are confined to specific soils but not related to the soil series classification and generally are not growth controlling until nitrogen and phosphorus deficiencies have been corrected. Martin (1958) reached similar conclusions about the pattern of sulfur deficiency on California soils in his extensive survey of nutrient responses of soils of the state even though high-elevation forest and meadow soils were not included in his study.

Nutrient Responses of Mountain Whitethorn and Alsike Clover

Mountain whitethorn seedlings grown in two high-elevation forest soils (Bear Wallow and Sugarpine Hill-West locations) responded positively, in terms of height, to optimum nutrient treatment compared to the control. Response of soft chess indicated that a Shaver soil at Bear Wallow was extremely nutrient deficient (NRF of 21.8) and that maximum yields could be expected with nitrogen, phosphorus, and sulfur. Next highest yields could be expected with nitrogen plus phosphorus. Heights of established seedlings of mountain whitethorn 7 weeks after nutrient application in Bear Wallow soils were almost double with the optimum nutrient combination ($N_{224}P_{224}S_{112}$) (21 cm) compared with the control (12 cm) and almost as high with nitrogen plus phosphorus (19 cm). In a Dinkey soil at Sugarpine Hill-West, which has an NRF of 14.8 (Table 2), seedling height of mountain whitethorn was increased from 18 cm with the control to 23 cm with nitrogen plus phosphorus. In a Shaver soil collected at Nutmeg Saddle, a site below the usual elevation of mountain whitethorn, nutrient application produced no statistically significant difference in growth.

Alsike cover, a legume adapted to the general area, was grown in a meadow soil from Post Corral with a nutrient response factor of 29.6 and in a Shaver soil from Nutmeg Saddle with an NRF of 18.5. This species reflected small numerical, but not statistical, differences in response to nutrient treatment on a given soil; but yields differed widely between soils (Check=1.4 and $N_{224}P_{224}$=2.2 gm/pot in Shaver soil and check = 4.5 and $N_{224}P_{224}$=5.8 gm/pot in the meadow soil). Yield of clover after 6 weeks of growth in the meadow soil with optimum nutrients was more than 2.5 times greater than comparable yield in the forest soil.

Edaphic characteristics besides nitrogen, phosphorus, and sulfur affected growth of both mountain whitethorn and alsike clover. Some of these differences in soil characteristics that affect productivity of plants are evident in the comparison among the major soil series of the area from their delineation into different soil taxonomic classes (Soil Survey Staff 1975).

Forage Quality Responses

Proximate analysis of the pot-grown plants showed that all soils are capable of producing forage with protein levels meeting the needs of ruminant animals under optimum growing conditions (Table 3). Protein levels of plants grown on the meadow soil were especially high when not fertilized. In timber soils, nitrogen alone tended to increase protein and phosphorus alone tended to reduce it.

Table 2. Yield (gm/pot) of soft chess *(Bromus mollis)* with fertilizer treatments in soils and nutrient response factors (NRF) of soils from different locations.[1]

Locations	Fertilizer treatments[2]											
	Check	$^{P}56$	$^{P}224$	$^{N}56$	$^{N}56^{P}56$	$^{N}56^{P}224$	$^{N}224$	$^{N}224^{P}56$	$^{N}224^{P}224$	$^{N}224\,^{P}224\,^{S}112$	$^{N}224^{S}112$	Nutrient response factor[3]
Nutmeg Saddle	.07^{d}	.07^{d}	.08^{d}	.32^{cd}	.42^{c}	.25^{cd}	.90^{b}	.96^{ab}	1.18^{a}	1.06^{ab}	.18^{cd}	18.5^{a-d}
Bear Wallow	.06^{c}	.09^{c}	.28^{c}	.27^{c}	.24^{c}	.12^{c}	.12^{c}	.22^{c}	.80^{b}	1.33^{a}	.05^{c}	21.8^{a-d}
Grand Bluffs	.34^{b}	.43^{b}	.52^{b}	.41^{b}	.76^{b}	.84^{ab}	.52^{b}	1.46^{a}	1.44^{a}	1.48^{a}	.72^{b}	4.6^{d}
Sugarpine Hill-West	.12^{d}	.10^{d}	.23^{d}	.48^{c}	.63^{bc}	.64^{bc}	.60^{bc}	.82^{b}	1.52^{a}	1.74^{a}	.70^{bc}	14.8^{a-d}
Sugarpine Hill-East (1)	.04^{e}	.24^{c-e}	.32^{b-d}	.07de	.32^{c-e}	.44^{bc}	.08de	.19^{c-e}	.57^{b}	1.14^{a}	.09de	25.7^{a-c}
Sugarpine Hill-East (2)	.06^{c}	—	.24^{bc}	—	—	—	.05^{c}	—	1.12^{a}	1.32^{a}	.09^{c}	30.5^{a}
Sawmill Flat-logged	.41^{c}	—	.39^{c}	—	—	—	.48^{c}	—	1.35^{a}	.90^{b}	1.11^{ab}	3.8^{d}
Sawmill Flat-uncut	.25^{d}	—	.35^{d}	—	—	—	1.46^{c}	—	2.00^{b}	2.42^{a}	2.08^{ab}	10.5^{b-d}
Sawmill Flat-Sel. logged	.68^{c}	—	.74^{bc}	—	—	—	.94^{bc}	—	2.43^{a}	2.64^{a}	1.32^{b}	3.9^{d}
Blue Sale	.28^{e}	.83^{c-e}	1.06^{b-e}	.25^{e}	1.30^{a-c}	1.75^{ab}	.32^{e}	1.26^{a-d}	1.24^{a-d}	1.96^{a}	.43de	7.7^{cd}
Weather Station (1)	.06^{c}	—	.12^{c}	—	—	—	.23^{ac}	—	.41^{a}	.38^{ab}	.17^{ac}	7.3^{cd}
Weather Station (2)	.15^{c}	.10^{c}	.10^{c}	.28^{c}	.59^{bc}	.66^{bc}	.82^{ac}	1.05^{ab}	1.40^{a}	1.38^{a}	1.03^{ab}	9.3^{cd}
Landing Site (1)	.22^{e}	—	.32^{e}	—	—	—	1.74^{c}	—	2.40^{b}	2.97^{a}	1.32^{d}	14.3^{a-d}
Landing Site (2)	.36^{e}	.41de	.50^{c-e}	1.07^{a-d}	1.09^{a-d}	1.13^{a-c}	.78^{ab}	1.33^{ab}	1.61^{a}	1.50^{a}	1.18^{ac}	4.4^{d}
Post Corral Meadow	.05^{f}	.17^{ef}	.60^{cd}	.18^{ef}	.56^{d}	.86^{bc}	.18^{ef}	.44de	1.21^{a}	.94^{b}	.10^{f}	29.6^{ab}
Tule Meadow	.07de	.39^{c-e}	.40^{cd}	.05^{e}	.72^{bc}	.67^{bc}	.09de	.56^{c}	.87^{b}	1.66^{a}	.04^{e}	26.9^{a-c}
Snow Corral	.75^{b}	—	.82^{b}	—	—	—	1.79^{a}	—	1.54^{a}	1.44^{a}	.80^{b}	2.4^{d}

[1]Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. Comparisons of yields are made horizontally or within specific soils. Comparisons of nutrient response factors are made vertically or among specific soils. Maximum yields and those not statistically different, are underlined for reader's convenience.

[2]Nutrient treatments are: $^{N}56$=nitrogen at 56 kg/ha; $^{N}224$=nitrogen at 224 kg/ha; $^{P}56$=phosphorus at 56 kg/ha; $^{P}224$=phosphorus at 224 kg/ha; and $^{S}112$=sulfur at 112 kg/ha. All equivalent rates are calculated on the basis of soil weight with the first 15 cm of soil weighing 2,240,000 kg/ha.

[3]Response factor was derived by dividing check yield into maximum yield resulting from added nutrients.

Table 3. Crude protein (percent) of soft chess grown in pot tests of four soils.

Fertilizer Treatments	Nutmeg Saddle	Bear Wallow	Sugarpine Hill	Post Corral	Means[1]
Control	25.4	30.6	22.2	44.6	30.7[ab]
$^{N}224$	30.8	36.9	32.4	34.2	33.6[a]
$^{P}224$	29.8	21.9	21.0	21.7	23.6[d]
$^{N}224^{P}224$	28.0	30.0	22.6	32.0	28.1[bc]
$^{N}224^{P}224^{S}112$	24.8	22.8	27.6	31.6	26.6[c]
Means	27.7	28.4	25.2	32.8	

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Table 4. Calcium:phosphorus ratios of soft chess grown in pot tests of four soils.

Fertilizer treatments	Nutmeg Saddle	Bear Wallow	Sugarpine Hill	Post Corral	Means[1]
Control	2.0	1.4	1.7	5.4	2.6[ab]
$^{N}224$	3.3	5.4	3.7	2.1	3.6[c]
$^{P}224$	2.0	1.6	1.5	1.5	1.6[a]
$^{N}224^{P}224$	3.3	3.9	3.3	1.8	3.1[bc]
$^{N}224^{P}224^{S}112$	2.0	2.9	2.0	1.4	2.1[ab]
Means	2.5	3.0	2.4	2.4	

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test.

Calcium:phosphorus ratios were all judged to be acceptable with the possible exception of the unfertilized meadow soil and the nitrogen-alone fertilized soil from Bear Wallow (Table 4). Except in the meadow soil, nitrogen tended to increase the calcium:phosphorus ratio by decreasing phosphorus. Phosphorus fertilization tended to decrease the ratio by increasing phosphorus.

Results of this study and previous investigation (Evans et al. 1962) have shown that soft chess grown in nutrient pot tests is extremely sensitive to deficiencies of not only nitrogen but also phosphorus and sulfur. Because of its sensitivity, yields of soft chess in relation to soil treatments of nitrogen, phosphorus, and sulfur indicate maximum fertilizer responses of forage and browse species. In the annual grasslands of California, correlation between responses of soft chess in pot tests and field fertilizer trials have been extremely good (Evans et al. 1962).

However, the potential of other forage or browse species to respond to nutrient levels may not be as great as it is for soft chess. Wagle and Vlamis (1961) found that because bitterbrush *(Purshia tridentata* and *P. glandulosa)* fixes nitrogen it did not respond to applications of this nutrient like their test plant, Romaine lettuce. *Ceanothus* spp. also develop root nodules and fix nitrogen (Russell and Evans 1966, Vlamis et al. 1958), so application of nitrogenous fertilizer probably would not increase growth or would be less important than with a grass. However, phosphorus and sulfur fertilization would be important for increased quantity and quality of browse for deer. Gibbens and Pieper (1962) found healthy unfertilized *Ceanothus cuneatus* plants produced more growth than fertilized plants; however, in decadent stands, the fertilized plants produced significantly more growth than the unfertilized plants and the deer showed a preference for the fertilized plants.

In like manner, a legume, such as alsike clover, does not depend on nitrogen fertilizer for maximum growth, but the phosphorus and sulfur available affect its growth and production. Perennial grasses will respond to nitrogen and if deficiencies exist, to phosphorus and sulfur as well (Eckert and Evans 1963).

Conclusions

On all soils tested, nitrogen must be supplied for maximum growth, or to increase early growth to make more forage available during the spring migration. Phosphorus deficiency is also widespread in this area and should be considered in any range improvement planning. Sulfur may or may not be deficient, depending on the specific soil.

Forage production on specific sites, depends on nutritional status of the soil and other edaphic characteristics, such as depth, texture, and structure, that are delineated on the soil series level.

Responses of soft chess indicated that forage quality, in terms of crude protein content and calcium:phosphorus ratio, was relatively unaffected by nutrient treatments and was similar among soils.

A complex of grass, forb, and browse species occurs or can be planted along the deer migration routes. The nutritional requirements of these species vary widely but with a basic knowledge and understanding of the nutritional deficiencies of the major soils in the area, land managers can make more intelligent choices in an improvement program.

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