Annual-Range Fertilization in Relation to Soil Moisture Depletion[1]

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The annual range type represents an area of approximately 18 million acres of grassland, oak-grassland and open brush in California. Seed germination and early growth of most annual forage species take place soon after the first fall rains, but the greatest growth of annual forage occurs in late winter and spring when temperatures and soil moisture supplies are favorable.

Fertilization of annual rangelands is a newly recommended practice, not yet widely adopted. However, fertilization has been shown to be an important range improvement technique. Conrad (1951) suggested using exploratory plots on range to indicate fertilizer needs for optimum nutrition of forage plants. Love (1950) stated that the level of soil fertility was an important factor that could no longer be ignored. Fertilizer tests at that time indicated that in spite of the high cost of fertilizers, a proper program of fertilizers should pay dividends on many of the range areas. Martin and Berry (1955, 1956) mention that among the direct benefits of fertilizer application are a greater production of forage, earlier green feed, forage of better nutritive quality and a reduction in the number of summer growing annual weeds.

Fertilization increases plant growth and could be expected to increase moisture use. Interest and concern for moisture relations following range fertilization are indicated by statements of several researchers. Jones, and Love (1945) and Love *et al.* (1955) warn that after the peak of the growing season, while there is still enough moisture left to produce seed, grazing pressures should be eliminated. Williams *et al.* (1956) mention a need to graze fertilized annual ranges to reduce competition from undesirable annual weeds and encourage more desirable species. Martin and Berry (1956) have observed that unpalatable summer weeds grow where annual grasses and legumes lack the vigor to fully extract available soil moisture. They suggest fertilization to stimulate vigorous growth of desirable species and greatly reduce the growth of summer weeds.

Amount of moisture available and its distribution throughout the growing season are critical factors in plant growth on annual rangelands and may be significantly altered by fertilizer application. This study reports the pattern of soil moisture depletion under moderately high rates of nitrogen and phosphorus fertilization in 1957.

Methods and Procedure

A completely randomized block experiment with four treatments replicated four times was established on the R. N. Shellhammer ranch, Solano County, California. Fertilizer treatments applied before the first fall rain consisted of 150 pounds of nitrogen (N) per acre, 200 pounds of phosphorus (P_2O_5) per acre, 150 pounds of nitrogen plus 200 pounds of phosphorus per acre and none (check). Ammonium nitrate and treble super phosphate were used as fertilizer materials. The area is on the west slope of the Sacramento Valley near the Coast Range and has an average annual rainfall of 18 to 20 inches, from September through May. The topography is slightly undulating and soils are derived from alluvium and old valley terraces. Soil of the study site is mapped as Olcott fine sandy loam but was noted to be a mosaic of Olcott fine sandy loam and Clear Lake clay adobe. Vegetation consisted of resident annual grasses and forbs.

The experimental area was fenced and plots 10 x 11 feet were centrally equipped with Bouyoucos resin impregnated gypsum blocks (Bouyoucos, 1954) so that the moisture depletion at the 6-, 12-, 20-, and 36-inch depths could be measured. These blocks were previously field calibrated in clay loam to develop the relation according to the method described by Perrier and Marsh (1958) between soil

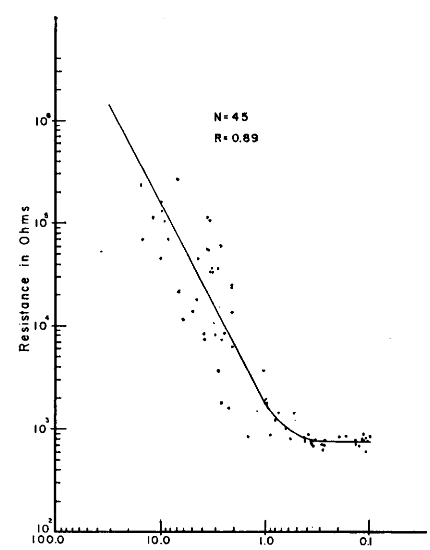

FIGURE 1. Calibration curve for Bouyoucos resin impregnated gypsum blocks.

[1] *Cooperative investigations of the Crops Research Division, A.R.S., U. S. Dept. of Agriculture and the University of California.*

moisture suction and resistance readings (Figure 1). The blocks were read approximately every two weeks throughout the growing season with a Bouyoucos Resistance Bridge, Model C. The readings were taken in terms of resistance in ohms and converted to suction in bars (1 bar = 1 x 10^6 dynes per cm^2 = 0.987 atm.) by use of the calibration curve.

Phenological observations were recorded approximately every three weeks (Table 1). On April 15, 1957, 20-inch deep columns, 6 x 12 inches, were excavated from nitrogen-phosphorus and check plots, and roots were removed by washing.

Forage yield was measured at the peak of growth by clipping at the 1-inch height one square foot of area from each plot.

Results and Discussion

Within two weeks after the first rain (2.5 inches) a plant growth response was noted on plots receiving nitrogen. The forage growth on the plots re-

Table 1. Observations on growth and development of annual range species, 1957

Treatment-Species	March 19	April 10	May 4	May 17	June 16
Check					
Bromus mollis	7″ tall	8″ tall, early head	Plants green, seed mature	Leaves brown, seeds dispersed	Leaves and stems brown
Avena barbata	8″ tall	Poor vigor, few heads	10″ tall, dry seeds	Seeds dispersed	Leaves and stems brown
Elymus caput-medusae	4-5″ tall	5″ tall, vegetative	8″ boot stage	10″ tall, full head, plants green	Seeds mature, some plants green
Erodium botrys	4-5″ tall, early flowers	4-5″ tall, flowering	Seeds mature	Few flowers remaining	Leaves shattered
Medicago hispida	4″ tall, early flowers	Late flowering	Dry burs	Stems dry	Leaves shattered
Phos. 200					
Bromus mollis	7″ tall	8″ tall, early head	Stems, leaves green, seeds	Seed dispersed, leaves brown	Leaves and stems brown
Avena barbata	8″ tall	Few heading, late boot	10″ tall, dry seeds	Seeds dispersed	Leaves and stems brown
Elymus caput-medusae	6″ tall	6″ tall, vegetative	Boot stage	10″ tall, full head, plants green	Seeds mature, some plants hot completely dry
Erodium botrys	4-5″ tall, early flowers	4-5″ tall, flowering	Seeds mature	Seeds dispersed	Leaves shattered
Medicago hispida	3-5″ tall, early flowers	Some mature seeds	Dry burs	Stems dry	Leaves shattered
Nitrogen 150					
Bromus mollis	10″ tall	12″ tall, late-boot to full-head stage	12″ tall, dry leaves, green stems	Stems dry, seeds dispersed	Plants dry, brown
Avena barbata	10″ tall	14-16″ tall, boot emerging	16″ tall, dry seeds	Stems dry, seeds dispersed	Plants dry, brown
Elymus caput-medusae	8″ tall	10″ tall, vegetative	Boot stage	12″ tall, full head, green	Seeds mature, plants dry green
Erodium botrys	10″ tall, early flower	12-14″ tall, flowering	Later than nitrogen-phos.	Seeds dispersed	Leaves shattered
Medicago hispida	Few plants early flower	Few plants	Dry burs	Stems dry	Leaves shattered
$N_{150}P_{200}$					
Bromus mollis	12″ tall	14-16″ tall, full head	14-16″ tall stems dry, seeds dry	Stems dry, seeds dispersed	Plants dry, brown
Avena barbata	12″ tall	20″ tall, boot to full head	22″ tall, early seed	Stems dry, seeds dispersed	Plants dry, brown
Elymus caput-medusae	10″ tall	10″ tall, vegetative	12″ tall, late-boot stage	16″ tall, full head, plants dry	Seeds mature, plants dry
Erodium botrys	10-14″ tall, early flowers	10-14″ tall, late flowering	Seeds dispersed, dry plants	Seeds dispersed	Leaves shattered
Medicago hispida	10″ tall early flower	Few plants	Dry burs	Stems dry	Leaves shattered

Table 2. Yield and moisture use efficiency of annual range following various fertilizer treatments, 1957.

Item	No fertilizer	P_{200}	N_{150}	$N_{150}P_{200}$
Inches of rainfall (October-June)	17.01	17.01	17.01	17.01
Forage yield in lbs./acre	1,440	1,704	3,169	5,929
Lbs. forage/inch of rainfall	84.7	100.2	186.3	348.6
Differences		15.5	86.1**[1]	162.3**

[1]** Indicates significance at the 1% level.

ceiving nitrogen continued during the cool winter months at a greater rate than that on non-fertilized or phosphorus fertilized plots.

Forage yield on plots fertilized with nitrogen was significantly greater than that on non-fertilized plots or on plots receiving only phosphorus (Table 2). The combination of nitrogen and phosphorus produced a greater forage yield than any other treatment. The nitrogen treatment produced more than twice the yield that no treatment did, and on the nitrogen-phosphorus treated plots the yield was about four times as much as on the non-fertilized ones.

A comparison of forage yield in relation to moisture used for each of the treatments indicates that fertilization permits more efficient use of rainfall (Table 2). In range areas, where rainfall is usually the only source of water for plant growth, fertilization appears to be a means of producing more forage with a given amount of moisture.

Root excavations on April 15 indicated that a majority of the plant roots in the non-fertilized plots were located within the upper 12 inches of soil. Excavation for a soil profile pit to the six-foot depth at the end of the summer in a non-fertilized area revealed that roots were present in abundance at the surface and gradually diminished towards the bottom of the pit. In the nitrogen-phosphorus plots roots were uniformly abundant to the 20-inch depth. Many roots in this plot were severed when the soil columns 20-inches deep were removed. No deeper excavations were made in the fertilized plots. The overall reactions of the vegetation to fertilization are illustrated by the course of soil moisture depletion during the growing season.

All plots were at field capacity on March 12 even though the nitrogen and nitrogen-phosphorus plots were supporting luxuriant stands of annual grasses and forbs. Therefore, the increased plant growth in winter did not appreciably drain the moisture reserve in the soil, and moisture

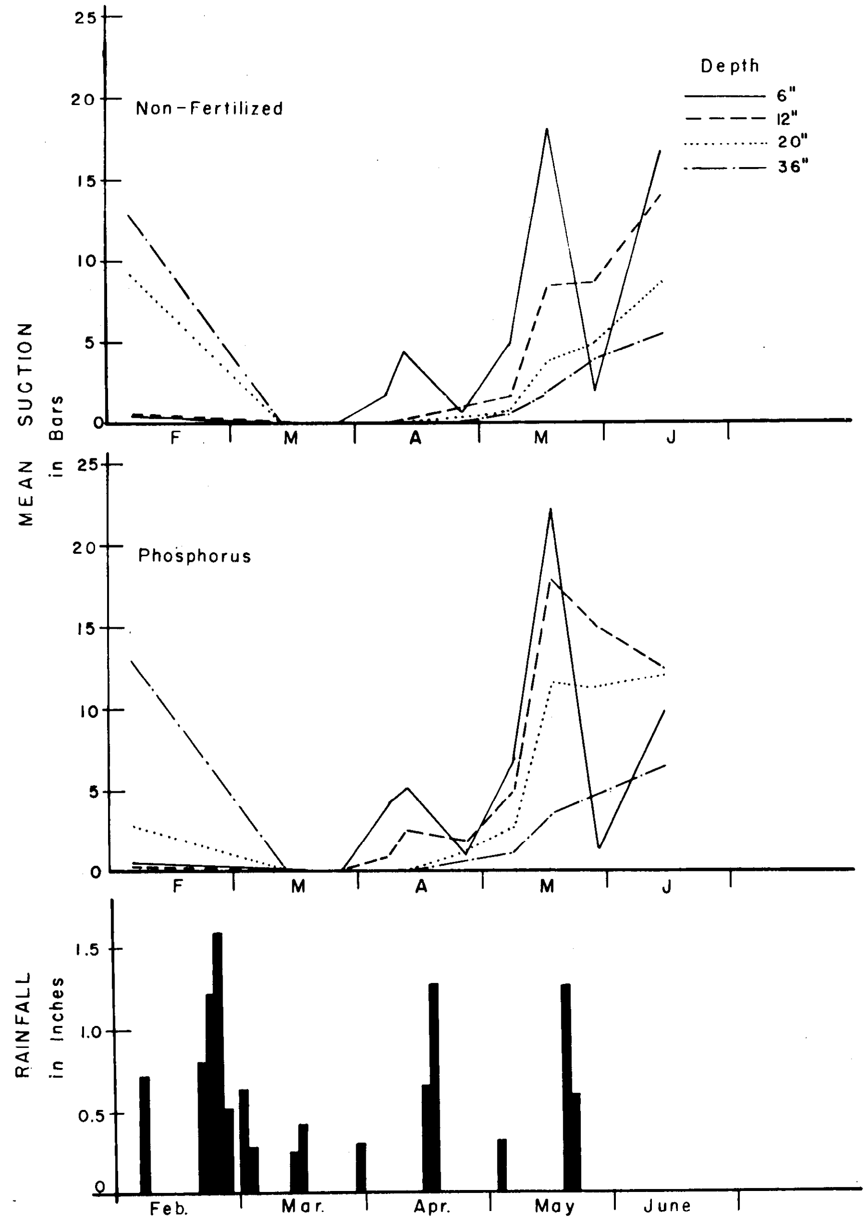

FIGURE 2A. Rainfall and moisture extraction patterns for fertilizer treatments as a function of time: Non-fertilized and phosphorus-fertilized plots.

was equally available on all plots for the rapid growth that occurred as soon as spring temperatures were favorable.

No summer growing annual weeds such as turkey mullein *(Eremocarpus setigerus)*, spikeweed *(Centromadia fitchii)*, and tarweed *(Hemizonia congesta)* were noted on the nitrogen or on the nitrogen-phosphorus plots. Phenological observations indicated that a greater number of plants matured earlier on the nitrogen and nitrogen-phosphorus plots (Table 1) than on the unfertilized plots.

Figure 2 gives the moisture extraction pattern for each of the treatments and the rainfall in inches as a function of time. The extraction patterns are expressed in terms of suction in bars, and as the suction force increases the availability of water to the plants is reduced. Plants on the nitrogen and nitrogen-phosphorus plots were subjected to higher suction forces in general than those on the phosphorus or the nonfertilized plots. These suction forces range from 15 to 25 bars and were associated with extent of time of maturity.

Plants that received the application of nitrogen reduced the soil moisture below the field capacity (0.3 bar) earlier in the season (near the first of April) than the phosphorus or non-fertilized plots. Also, the rate of soil moisture use was higher in these plots, particularly at the lower depths. It appears that in the nitrogen-phosphorus plots root development was greater to the 36-inch depth than in plots with the other treatments as indicated by the rate and time of moisture extraction. Removal of available soil moisture from the 36-inch depth began in the following time sequence: nitrogen-phosphorus plots on March 28; nitrogen on April 8; phosphorus on April 12; and non-fertilized on April 26.

The 1.90 inches of rainfall and an accompanying low transpiration period during the last half of April were the major causes of a reduced rate of moisture depletion. Towards the end of April the moisture use at the shallow depth in all plots increased because of warmer weather, but on the nitrogen-phosphorus and the nitrogen plots moisture use began increasing at *all depths*. The data show that at the beginning of the warm season transpirational requirements of the plants receiving a nitrogen or a nitrogen-phosphorus application increased.

At the 6-, 12- and 20-inch depths the nitrogen-phosphorus and nitrogen plots had reached the wilting point (15 bar determination) by May 10. However, on the nitrogen plots the plants continued to use moisture at all depths but, in general, were later in maturity than those on the nitrogen-phosphorus plots. On the phosphorus plots the pattern of water use was similar to that on the nitrogen plots but water use rates were slightly lower,

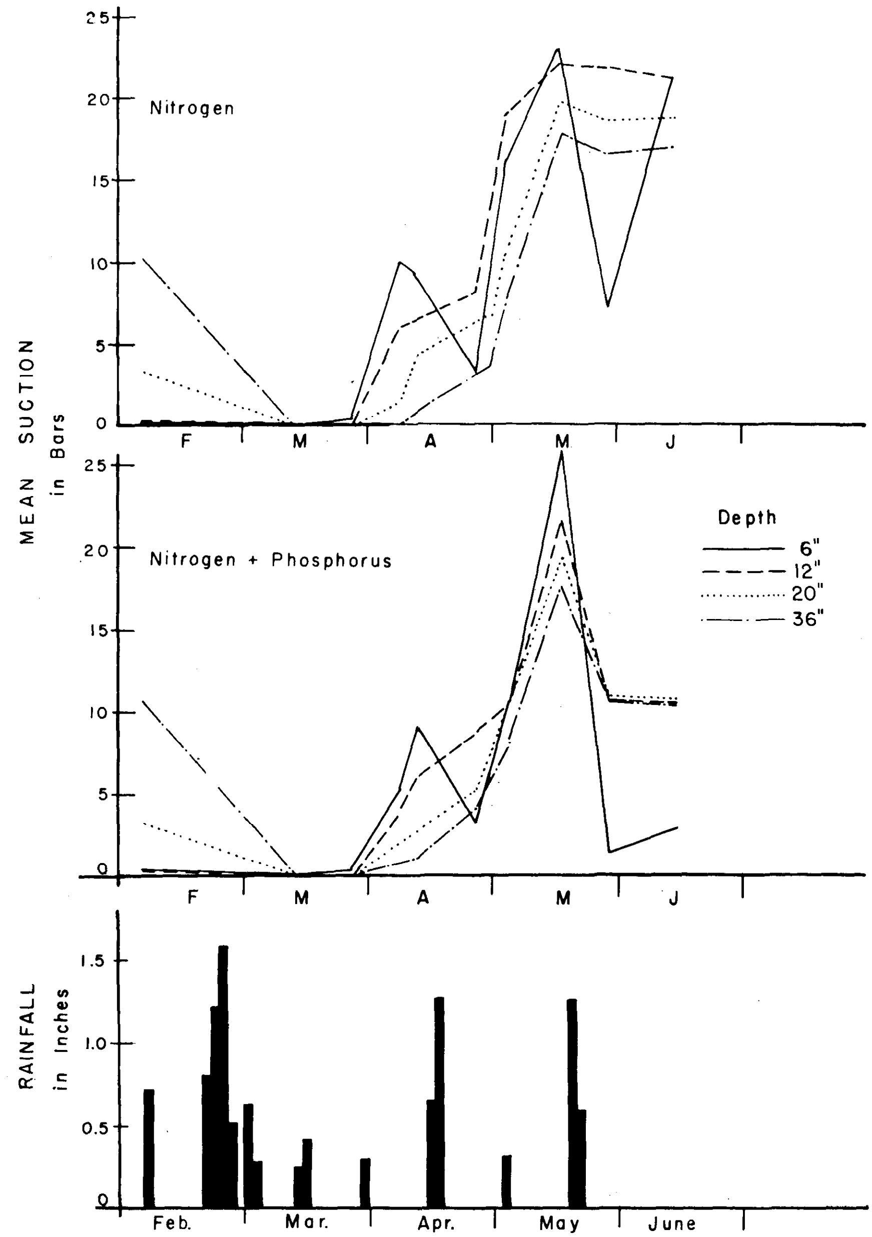

FIGURE 2B. Rainfall and moisture extraction patterns for fertilizer treatments as a function of time: Nitrogen and nitrogen plus phosphorus plots.

particularly at the 36-inch depth. The rate of water use at the 6-inch depth, on the non-fertilized plot was similar to that on plots given the other treatments, but rate of water use at the 12-, 20-, and 36-inch depth was less and the wilting point (15 bar determination) was not reached by the end of the experiment.

The rainfall of 1.85 inches that occurred during the May 20 period resulted in (a) reduced suction at all depths on the nitrogen-phosphorus plot; (b) reduced suction only at the 6-inch depth on the nitrogen plot; (c) reduced suction at the 6- and 12-inch depth on the phosphorus plot, but only a slowing of the rate of moisture removal at the 20- and 36-inch depths; and (d) reduced suction at the 6-inch depth on the non-fertilized plot but only a slight retardation of the rate of moisture extraction at the other depths.

The late rain, on May 20, was not used by the plants on the nitrogen-phosphorus plots because they were completely matured and dry. The slight increase in suction at the 6-inch depth near the first of June is probably a result of evaporation at the soil surface. When this particular soil dries fissures are opened and evaporation can occur within the soil profile. On the nitrogen plots this late rain was used by the plants in the final stages of maturity, and only slight amount of depletion could be related to evaporation. The plants on the phosphorus and non-fertilized plots were not as mature as those on the nitrogen plots and continued to deplete the soil moisture until matured. The continuing rate of depletion of soil moisture on these plots appeared to be caused by late maturing medusa head and summer growing annual weeds.

Summary and Conclusions

This study reports the pattern of moisture depletion under moderately high rates of nitrogen and phosphorus fertilization. A completely randomized block experiment with four treatments replicated four times was established on a fine sandy loam soil with plots 10 x 11 feet centrally equipped with Bouyoucos blocks for measuring soil moisture depletion and read approximately every two weeks during the growing season. Fall applied fertilizer consisted of 150 pounds of nitrogen per acre, 200 pounds of phosphorus per acre, 150 pounds of nitrogen plus 200 pounds of phosphorus per acre, and none (check).

Fertilization of annual range plants with nitrogen resulted in a greater forage production and earlier maturity than no nitrogen. Combination of nitrogen and phosphorus resulted in a significant interaction that gave increased yield of forage.

Abundant plant growth and more uniform early plant maturity due to the application of nitrogen remove more soil moisture than is removed from the soil where plants do not receive nitrogen. Depletion of soil moisture early in the spring and a high rate of moisture use occur as a result of the application of nitrogen. Growth of summer growing annual weeds is considerably retarded by depletion of soil moisture at all depths where nitrogen is applied.

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