Annual-Range Fertilization in Relation to Soil Moisture Depletion

Cyrus M. McKe11, Jack Major, and Eugene R. Perrier

Plant Physiologist, Crops Research Division, A.R.S., U.S. Department of Agriculture; Assistant Professor, Botany Department, University of California; and Laboratory Technician IV, Irrigation Department, University of California, Davis, California.

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. 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.O.) per acre, 150 pounds of nitrogen plus 200 pounds of phosphorus per acre, and none (check). Ammonium nitrate and triple 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 moisture and suction in bars. The calibration curve for Bouyoucos resin impregnated gypsum blocks is shown in Figure 1.

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

**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 receiving nitrogen-phosphorus was recorded as follows:

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

<table>
<thead>
<tr>
<th>Treatment-Species</th>
<th>March 19</th>
<th>April 10</th>
<th>May 4</th>
<th>May 17</th>
<th>June 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Bromus mollis</td>
<td>7&quot; tall</td>
<td>8&quot; tall, early head</td>
<td>Plants green, seed mature</td>
<td>Leaves brown, seeds dispersed</td>
<td>Leaves and stems brown</td>
</tr>
<tr>
<td>Avena barbata</td>
<td>8&quot; tall</td>
<td>Poor vigor, few heads</td>
<td>10&quot; tall, dry seeds</td>
<td>Seeds dispersed</td>
<td>Leaves and stems brown</td>
</tr>
<tr>
<td>Elymus caput-medusae</td>
<td>4-5&quot; tall, vegetative</td>
<td>5&quot; tall, flowering</td>
<td>8&quot; boot stage</td>
<td>10&quot; tall, full head, plants green</td>
<td>Seeds mature, some plants green</td>
</tr>
<tr>
<td>Erodium botrys</td>
<td>4-5&quot; tall, early flowers</td>
<td>4-5&quot; tall, flowering</td>
<td>Seeds mature</td>
<td>Few flowers remaining</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>Medicago hispida</td>
<td>4&quot; tall, early flowers</td>
<td>Late flowering</td>
<td>Dry burs</td>
<td>Stems dry</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>Phos. 200 Bromus mollis</td>
<td>7&quot; tall</td>
<td>8&quot; tall, early head</td>
<td>Stems, leaves green, seeds</td>
<td>Seed dispersed, leaves brown</td>
<td>Leaves and stems brown</td>
</tr>
<tr>
<td>Avena barbata</td>
<td>8&quot; tall</td>
<td>Few heading, late boot</td>
<td>10&quot; tall, dry seeds</td>
<td>Seeds dispersed</td>
<td>Leaves and stems brown</td>
</tr>
<tr>
<td>Elymus caput-medusae</td>
<td>8&quot; tall</td>
<td>6&quot; tall, vegetative</td>
<td>Boot stage</td>
<td>10&quot; tall, full head, plants green</td>
<td>Seeds mature, some plants green</td>
</tr>
<tr>
<td>Erodium botrys</td>
<td>4-5&quot; tall, early flowers</td>
<td>4-5&quot; tall, flowering</td>
<td>Seeds mature</td>
<td>Seeds dispersed</td>
<td>Leaves hot completely dry</td>
</tr>
<tr>
<td>Medicago hispida</td>
<td>3-5&quot; tall, early flowers</td>
<td>Some mature seeds</td>
<td>Dry burs</td>
<td>Stems dry</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>Nitrogen 150 Bromus mollis</td>
<td>10&quot; tall</td>
<td>12&quot; tall, late-boot to full-head stage</td>
<td>12&quot; tall, dry leaves, green stems</td>
<td>Plants dry, brown</td>
<td>Plants dry, brown</td>
</tr>
<tr>
<td>Avena barbata</td>
<td>10&quot; tall</td>
<td>14-16&quot; tall, boot emerging</td>
<td>16&quot; tall, dry seeds</td>
<td>Seeds dispersed</td>
<td>Plants dry, brown</td>
</tr>
<tr>
<td>Elymus caput-medusae</td>
<td>8&quot; tall</td>
<td>10&quot; tall, vegetative</td>
<td>Boot stage</td>
<td>12&quot; tall, full head, green</td>
<td>Seeds mature, plants dry green</td>
</tr>
<tr>
<td>Erodium botrys</td>
<td>10&quot; tall, early flowers</td>
<td>12-14&quot; tall, flowering</td>
<td>Later than nitrogen-phosphorus</td>
<td>Seeds dispersed</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>Medicago hispida</td>
<td>Few plants early flower</td>
<td>Few plants</td>
<td>Dry burs</td>
<td>Stems dry</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>N$<em>{150}$P$</em>{200}$ Bromus mollis</td>
<td>12&quot; tall</td>
<td>14-16&quot; tall, full head</td>
<td>14-16&quot; tall stems dry, seeds dry</td>
<td>Plants dry, brown</td>
<td>Plants dry, brown</td>
</tr>
<tr>
<td>Avena barbata</td>
<td>12&quot; tall</td>
<td>20&quot; tall, boot to full head</td>
<td>22&quot; tall, early seed</td>
<td>Seeds dispersed</td>
<td>Plants dry, brown</td>
</tr>
<tr>
<td>Elymus caput-medusae</td>
<td>10&quot; tall</td>
<td>10&quot; tall, vegetative</td>
<td>12&quot; tall, late-boot stage</td>
<td>Seeds dispersed, dry plants</td>
<td>Seeds mature, plants dry</td>
</tr>
<tr>
<td>Erodium botrys</td>
<td>10-14&quot; tall, early flowers</td>
<td>10-14&quot; tall, late flowering</td>
<td>Seeds dispersed, dry plants</td>
<td>Seeds dispersed</td>
<td>Leaves shattered</td>
</tr>
<tr>
<td>Medicago hispida</td>
<td>10&quot; tall early flower</td>
<td>Few plants</td>
<td>Dry burs</td>
<td>Stems dry</td>
<td>Leaves shattered</td>
</tr>
</tbody>
</table>
Table 2. Yield and moisture use efficiency of annual range following various fertilizer treatments, 1957.

<table>
<thead>
<tr>
<th>Item</th>
<th>No fertilizer</th>
<th>P&lt;sub&gt;200&lt;/sub&gt;</th>
<th>N&lt;sub&gt;150&lt;/sub&gt;</th>
<th>N&lt;sub&gt;150P&lt;sub&gt;200&lt;/sub&gt;&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches of rainfall</td>
<td>17.01</td>
<td>17.01</td>
<td>17.01</td>
<td>17.01</td>
</tr>
<tr>
<td>(October-June)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage yield in lbs./acre</td>
<td>1,440</td>
<td>1,704</td>
<td>3,160</td>
<td>5,929</td>
</tr>
<tr>
<td>Lbs. forage/inch of rainfall</td>
<td>84.7</td>
<td>100.2</td>
<td>186.3</td>
<td>348.6</td>
</tr>
<tr>
<td>Differences</td>
<td>15.5</td>
<td>86.1**</td>
<td>162.3*</td>
<td>**</td>
</tr>
</tbody>
</table>

** Indicates significance at the 1% level.

Receiving 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](image-url)  
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*), spike-weed (*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,
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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 deter-
mination) was not reached by
the end of the experiment.

The rainfall of 1.85 inches that
occurred during the May 20 pe-
period resulted in (a) reduced suc-
tion at all depths on the nitro-
gen-phosphorus plot; (b) re-
duced suction only at the 6-inch
development 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
development 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 be-
cause they were completely ma-
tured and dry. The slight in-
crease in suction at the 6-inch
development 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 oc-
cur 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 sum-
mer growing annual weeds.

Summary and Conclusions

This study reports the pattern
of moisture depletion under
moderately high rates of nitro-
gen and phosphorus fertilization.

A completely randomized block
experiment with four treatments
replicated four times was estab-
lished on a fine sandy loam soil
with plots 10 x 11 feet centrally
equipped with Bouyoucos blocks
for measuring soil moisture de-
pletion and read approximately
every two weeks during the
growing season. Fall applied fer-
tilizer 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 nitro-
gen. Combination of nitrogen
and phosphorus resulted in a
significant interaction that gave
increased yield of forage.

Abundant plant growth and
more uniform early plant ma-
turity due to the application of
nitrogen remove more soil mois-
ture than is removed from the
soil where plants do not receive
nitrogen. Depletion of soil mois-
ture 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 consid-
erably retarded by depletion of
soil moisture at all depths where
nitrogen is applied.

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Reprints of Forage Evaluation Symposium Available

A combined reprint of the eight articles on forage evaluation given at
the Intersociety Symposium at Purdue University, August 1958, and ap-
ppearing on pages 312-347 of the Agronomy Journal, Vol. 51, April, 1959, are
available. These reprints may be ordered from the American Society of
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