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GREENHOUSE ASSAY OF FERTILITY OF CALIFORNIA SOILS

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This issue reports a new pot-culture technique...

..*for studying the supply of available nutrients* in California soils. The method gives a fairly reliable indication of whether pasture, field crops, and truck crops on a given soil will respond to nitrogen, phosphorus, or potassium application.

In this technique, various combinations of nutrients (nitrogen, phosphorus, and potassium) are added to pot cultures; Romaine lettuce is grown for definite periods; and relative yields are calculated for partial treatments (N + P, N + K, and P + K) on the basis of yield with full treatment (all three nutrients).

Calibration of pot tests with field tests indicates...

..*that nitrogen applications* can be expected to increase yields of pasture and field and truck crops if the relative yield of the no-nitrogen treatment in pot tests is 30 per cent or less (provided water, other nutrients, and soil conditions are not limiting).

..*that phosphorus applications* can be expected to increase yields of these crops if the relative yield of the no-phosphorus treatment is 20 per cent or less (with the same proviso).

Among over 450 California soils tested...

..*the percentage found to be low in available nitrogen* ranged from 48 to 71 in different soil groups (Storie's classification).

..*the percentage low in available phosphorus* ranged from about 40 among alluvial soils (groups I and II) to over 70 among claypans and hardpans (groups IV and V). Both highly acidic and strongly basic soils tended to be low in available phosphorus.

..*nearly all appeared to be well supplied with potassium* for the crops and soils included in the study.

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GREENHOUSE ASSAY OF FERTILITY OF CALIFORNIA SOILS[1]

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GREENHOUSE TESTS were begun in Berkeley in 1943 to study the fertility or nutrient supply of California soils, apart from other factors affecting growth of plants. An attempt was made to utilize greenhouse pot tests as a tool of soil analysis with an indicator plant as a yardstick. The present paper briefly discusses the essential features of the technique and the interpretation of the results. Also, it gives an account of the fertility levels of California soils.

A NEW DIAGNOSTIC TECHNIQUE

The new soil test uses Romaine lettuce as an indicator plant and makes use of the concept of relative plant yields. Romaine lettuce was chosen because it grows fast and is relatively free from disease.

Lettuce Pot-Culture Test. Plants are grown in 6-inch flower pots, coated inside and outside with two layers of black asphalt paint plus a coat of aluminum paint outside. For each soil test, 20 pots are filled with 1,600 grams of dry soil, to which various nutrient combinations have been added. Five treatments, replicated four times, are used in each test. One treatment is a check, with no nutrients added. The full treatment (table 1) includes nitrogen, phosphorus, and potassium. In three partial treatments, each nutrient in turn is omitted.

Nutrients are added in units of 80 mg per pot, which corresponds with 100 pounds per acre. The subscript numbers following the nutrient symbols (table 1) indicate the number of units of each nutrient used in a given treatment. The *standard* full treatment is $N_2P_3K_1$ (2 units of nitrogen, 3 of phosphorus, 1 of potassium). But the number of units used in full treatment is

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TABLE 1

COMBINATIONS OF NUTRIENTS ADDED TO 1600 GRAMS OF SOIL

Symbol and description	Nitrogen	Phosphorus	Potassium
$N_0P_0K_0$, check, no treatment	0	0	0
$N_2P_3K_1$, full treatment*	2×80 mg N	3×80 mg P_2O_5	80 mg K_2O
$N_0P_3K_1$, partial treatment (no nitrogen)	0	3×80 mg P_2O_5	80 mg K_2O
$N_2P_0K_1$, partial treatment (no phosphorus)	2×80 mg N	0	80 mg K_2O
$N_2P_3K_0$, partial treatment (no potassium)	2×80 mg N	3×80 mg P_2O_5	0

* Full treatment was sometimes varied to meet special soil characteristics.

changed to suit known soil characteristics: thus on a soil with high fixing power for phosphorus, full treatment might be $N_2P_6K_1$.

Nitrogen is added as ammonium nitrate, phosphorus as monocalcium phosphate, and potassium as potassium sulfate. These materials, added as solutions, are thoroughly mixed with the air-dry soil.

Each pot is planted with a month-old Romaine lettuce seedling, which was germinated in a nursery flat. After a growth period of 6 weeks in summer or 8 weeks in winter, the plants are harvested, dried at 70° C, and weighed. Examples of the lettuce test are shown in figure 1 and in table 2.

TABLE 2

SOIL FERTILITY ANALYSIS OF CAYUCOS ADOBE CLAY (S244)

Nutrient treatment	Individual yields, oven-dry, grams	Average yield, grams	Relative yield, per cent
$N_0P_0K_0$	0.36, 0.32, 0.27, 0.21	0.29	4
$N_2P_3K_1$	7.6, 7.6, 8.2, 7.4	7.7	100
$N_0P_3K_1$	2.2, 2.4, 1.5, 2.9	2.3	30
$N_2P_0K_1$	0.19, 0.25, 0.20, 0.29	0.23	3
$N_2P_3K_0$	6.6, 7.9, 7.2, 6.9	7.2	93

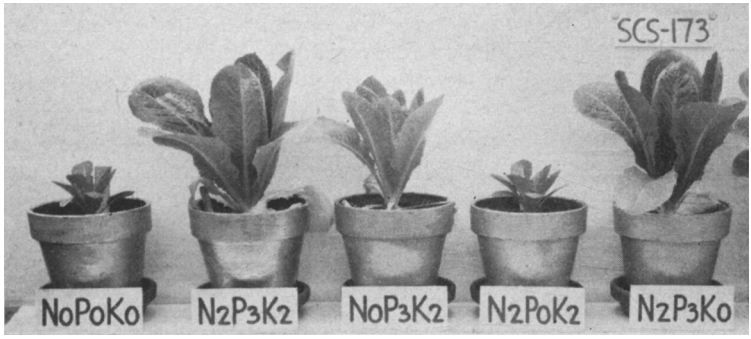

Fig. 1. Lettuce test of a soil showing severe phosphate deficiency and slight nitrogen deficiency.

Concept of Relative Yield. It is convenient to express the dry weights of the lettuce plants as relative yields by dividing the full-treatment yield into the partial-treatment yield, and multiplying by 100. Thus, if the weights of the lettuce plants are 7.7 grams for the full treatment ($N_2P_3K_1$) and 0.23 grams for the "no phosphorus" treatment ($N_2P_0K_1$), the relative P_0 yield is $\frac{0.23}{7.7} \times 100 = 3$ per cent. Although the absolute yields vary considerably with season, the relative yields are much less variable. Carefully controlled soil-temperature experiments indicate that in some soils the relative P_0 yields tend to be especially low in cold soils ($< 15°$ C).

The relative yield is a measure of the soil's power to supply a given nutrient element under the experimental standardized conditions employed. *The higher the relative yield the greater is the nutrient supply of the soil.* The same indicator plant (lettuce) and the same moisture supply are used throughout the study. In a qualitative sense the method is akin to the Mitscherlich (1930)[5] test. A preliminary account has been given by Vandecaveye (1948). The method has been used by Bingham (1949) to calibrate a chemical phosphate test.

[5] See "Literature Cited" for citations, referred to in the text by author and date.

CALIBRATION OF POT TESTS WITH FIELD EXPERIMENTS

In coöperation with the Soil Conservation Service and especially with the Agricultural Extension Service, over 100 soils were subjected to both field experiment and lettuce pot test. The field experiments included mainly small grains, pastures, hay, legumes, covercrops, and a few truck crops. The field-pot correlations are depicted in figure 2. On the horizontal axis are shown relative N_0 and P_0 yields of lettuce plants grown in pots. On the vertical axis are given—expressed as per cent—the number of field trials which respond to nitrogen or phosphorus, singly or in combination.

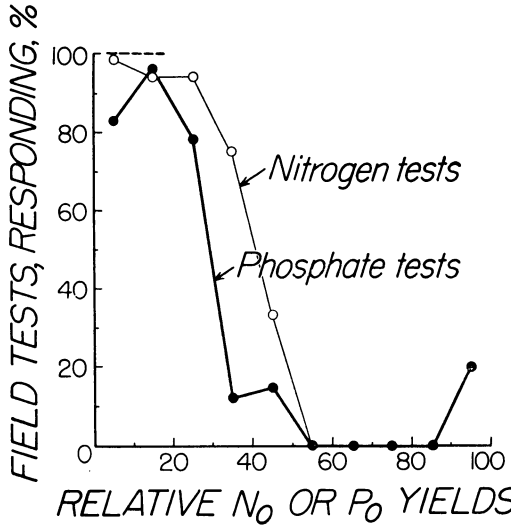

Fig. 2. Calibration of lettuce test by field tests.

The field tests were conducted on a great variety of soils in all parts of the state. For a given experiment the soil samples for the pot tests were collected from the untreated (check) plots of the field trials. The type of field test varied from quantitative, statistically designed plot arrangements to semi-quantitative demonstration plots. In the latter sets only those treatments which gave marked responses were considered positive. Small responses were treated as no responses. Because of variations in rainfall and in irrigation practices, no correlation between field yields and pot yields was attempted. The percentage number of fields giving positive results were merely plotted against lettuce yields in the greenhouse. Thus, from 35 field experiments giving relative P_0 lettuce yields of 10 per cent or less, 29 of the fields, or 83 per cent, responded to phosphate fertilization, either in presence or in absence of nitrogen fertilization.

Clearly, the lower the relative lettuce yield of the pot test, the greater is the chance of securing a field response. It should be emphasized that these studies do not involve tree crops and vines. Phosphate responses in the field are especially noticeable during the cooler season of the year.

SURVEY OF FERTILITY LEVELS OF CALIFORNIA SOILS

Over 450 soils (surface soils to a depth of 8 inches) from various parts of the state (fig. 3) have been tested in the greenhouse. A large number were selected by state and federal soil technicians during soil-survey activities.

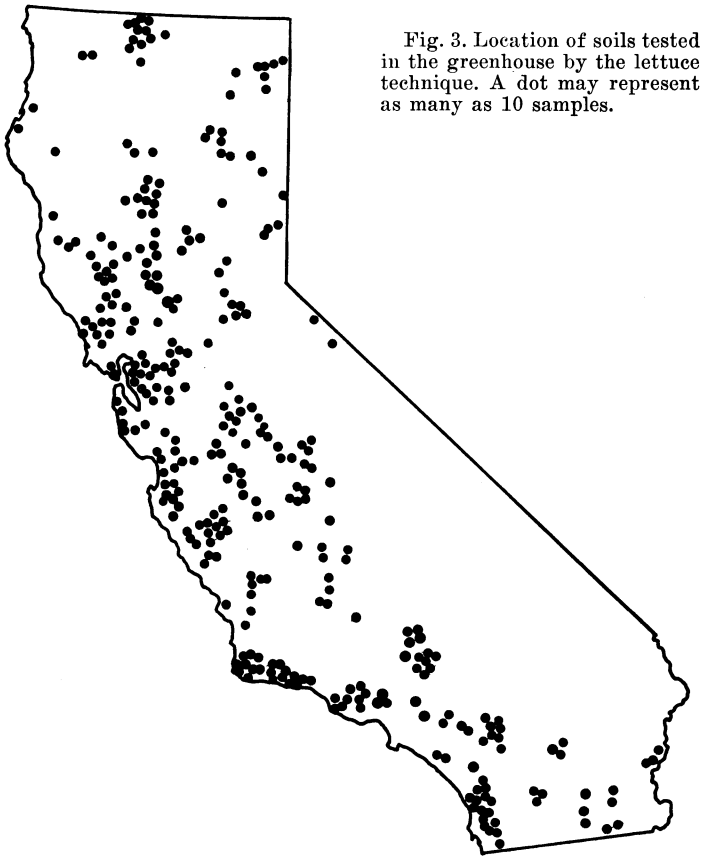

Fig. 3. Location of soils tested in the greenhouse by the lettuce technique. A dot may represent as many as 10 samples.

These samples represent standard soil types and soil series. Another large portion was collected by members of the Agricultural Extension Service in connection with fertility studies. A careful comparison of the properties of all soils with their series and type characteristics indicated no bias in selection. In other words, there was no pronounced tendency to select low-fertility variates of a given soil series.

Fertility Variations within Soil Series and Types. Samples from the Greenfield series in Monterey County displayed the following relative yields (five samples):

Relative N_0 yields: 77, 58, 32, 24, 12.

Relative P_0 yields: 74, 41, 28, 10, 4.

Representatives of the Hanford series in Riverside, San Diego, Los Angeles, and San Bernardino counties produced the following relative yields (nine soils): Relative N_0 yields: 75, 42, 24, 23, 20, 17, 17, 15, 14.

Relative P_0 yields: 80, 71, 36, 28, 19, 19, 15, 9, 8.

In these two soil series, which represent some of the best alluvial soils in the state, the variation in fertility is very great. Both low and high nitrogen and phosphate levels are found within the same soil series.

The Hugo series collected in the sedimentary hills and mountains of Contra Costa, Colusa, Lake, Tehama, and Napa counties showed the following relative P_0 yields (seven soils): 53, 51, 18, 17, 11, 7, 1.

For fifteen reddish Aiken soils found in hills and mountains composed of basic igneous rocks, the relative P_0 yields were 42, 35, 22, 21, 19, 9, 9, 8, 8, 7, 6, 6, 5, 4, 2.

TABLE 3

RELATIVE LETTUCE YIELDS OF FIVE REPRESENTATIVES OF VIRGIN PANOCHE SOIL SERIES, WESTERN FRESNO COUNTY, DECEMBER TO JANUARY

Number	pH	Texture	Yield of $N_2P_2K_1$, grams	Relative yield, per cent	
				Without nitrogen: $\frac{N_0P_2K_1}{N_2P_2K_1} \times 100$	Without phosphorus: $\frac{N_2P_0K_1}{N_2P_2K_1} \times 100$
S-346	8.5	Loam	3.5	26	12
S-347	8.2	Loam	4.2	43	29
S-348	8.2	Loam	5.0	34	8
S-349	8.1	Clay loam	2.9	59	28
S-350	8.1	Loam	3.3	6	6

In these two upland soils not only are the high phosphate levels absent but the low values predominate.

Mr. F. Harradine collected five virgin samples of the Panoche series in western Fresno County. As seen from table 3, even within the same soil type, variations in fertility are quite marked.

In summary it may be stated that variations in fertility within soil series and types are pronounced. In spite of these variabilities, certain soil types and series may be differentiated from each other in regard to their nutrient status. Thus, Greenfield and Hanford series tend to have higher phosphate levels than Hugo and Aiken series. In the field these differences become accentuated because the Greenfield and Hanford series are deep soils, whereas the Hugo and Aiken soils are shallow. The former provide a large storehouse of nutrients which may be explored by deep rooting; the latter permit only restricted root development.

Soil Groupings. It is helpful to arrange levels of soil fertility according to Storie's broad groups of soils (Storie and Weir, 1948). *Recent soils* (I, II) are formed on recent alluvial fans and on flood plains. They are deep and have no unfavorable profile features. Some of the most productive soils in the state belong to this group. *Older alluvial soils* (III) have moderate accumulations of clay in the subsoil. *Claypan soils* (IV, VI) and *hardpan soils*

(V) have developed on older plains or terraces. They have marked accumulations of clay in the subsoil or cementations which tend to impede root development. Soils of *hills and mountains* are found on a great variety of rocks. These soils are usually shallow.

All results reported in this study refer to surface soil, 0–8 inches in depth. As a rule, the subsoils tend to be lower in the nutrients tested.

TABLE 4

NITROGEN LEVELS OF CALIFORNIA SOILS

Soil group	Number of soils tested	Percentage of soils tested which are:	
		Low in available nitrogen	High in available nitrogen
Recent alluvial soils (I, II)	121	55	16
Older alluvial soils (III)	81	56	14
Claypan soils (IV)	59	71	19
Hardpan soils (V)	27	48	22
Soils of hills and mountains (VII, VIII, IX)	96	68	17

TABLE 5

PHOSPHORUS LEVELS OF CALIFORNIA SOILS

Soil group	Number of soils tested	Percentage of soils tested which are:	
		Low in available phosphorus	High in available phosphorus
Recent alluvial soils (I, II)	137	38	52
Older alluvial soils (III)	91	42	52
Claypan soils (IV)	65	71	23
Hardpan soils (V)	27	74	11
Soils of hills and mountains (VII, VIII, IX)	110	67	24

Nitrogen Deficiencies. According to figure 2, a relative lettuce yield of 30 per cent or less in pot tests denotes a soil low in nitrogen which probably will give a field response for many field crops and truck crops. N_0 yields above 50 per cent indicate high nitrogen supplies and little chance of field response. Table 4 shows how many soils in each of the five soil groups are deficient or well supplied with nitrogen. It is surprising to learn that 50 to 70 per cent of all the soils examined are sufficiently low in available nitrogen to promise a field response, provided other elements are not limiting.

Phosphorus Deficiencies. Soils giving a P_0 lettuce yield of 20 per cent or less (figure 2) are so low in available phosphorus that they will, as a rule, produce a field response, for field crops and truck crops, provided water, other nutrient elements, and specific soil conditions such as alkali or acidity are not limiting. Soils above 30 per cent relative lettuce yields probably will not justify phosphate fertilization. The number of soils, expressed as percentage, which in the greenhouse have P_0 lettuce yields below 20 per cent or

above 30 per cent are listed in table 5. The results are very striking. Low phosphate levels appear to be widespread, especially with terrace soils and hill and mountain soils. In contrast the recent alluvial soils are somewhat better supplied with available phosphorus. These soils possess the additional advantage of having great depth and thus providing a large nutrient reservoir.

TABLE 6

PHOSPHORUS LEVEL RELATED TO SOIL REACTION

Soil reaction groups, pH		Number of soils tested	Number of soils, in per cent, which are low in available phosphorus
Below 5.9	acid	105	79
6.0–6.3	acid	91	65
6.4–6.7		89	37
6.8–7.9		116	26
8.0–8.3	basic	27	44
Greater than 8.3	basic	20	80

Relation to Soil Reaction. According to table 6, soils having a pronounced acid reaction tend to be low in available phosphorus. The same is true for soils which are markedly basic or alkaline. Soils having neutral or only slightly acid and slightly basic reactions are, on the average, better supplied with available phosphorus.

Potassium Deficiencies. Nearly all of the soils investigated appear to be well supplied with potash for the crops included in this study.

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