Once this information is available, the soils of an area can be grouped according to their relative phosphorus-fixing capacities, and recommendations for phosphorus fertilization can be made.

The available potassium content is another important factor in evaluating the fertility level of a soil. The availability of potassium in a given soil for annual crops is related in large part to the amount of exchangeable potassium, which is the form generally measured by a soil test. The ability of a soil to supply potassium over a long time, however, depends upon the amount of nonexchangeable potassium present. Therefore, in evaluating the potassium status of a soil the level of both exchangeable and nonexchangeable potassium must be considered.

The importance of a high level of soil potassium is shown by Table II. The highest average yields of corn for a 3-year period were obtained at the high soil potassium level. The yield response data indicate that at the low soil level 20 pounds of K_2O per acre was sufficient, while at the high soil level none was needed. However, a fertilization program should take into account not only the effect on the yield but also the effect on the soil. The soil-test data show that to increase the potassium level of the soil appreciably at least 80 pounds of K_2O per acre must be applied; to maintain the high level at least 20 pounds of K_2O must be applied (Table III). In making recommendations based on soil tests it is important to consider what is happening to the fertility level of the soil as well as the nutrient requirements of the crop.

The level to which potassium can be built in a soil depends upon the cation exchange capacity and the cations present on the exchange complex. Generally, the higher the cation exchange capacity, the larger is the reservoir in which potassium can be stored. Therefore, it is usually possible to build the available potassium content of soils with a high cation exchange capacity to a higher level than those of a low capacity.

Soil	% of Applied K Retained: Acid	% of Applied K Retained: Limed
Norfolk (low cation exchange capacity)	22	49
Cecil (medium cation exchange capacity)	60	89

The amount of potassium held was greatly increased when the soils were limed, which resulted in the replacement of exchangeable hydrogen and aluminum by calcium and magnesium (*8*). If the potassium level of acid soils is to be increased by fertilization, it is important that the soils first be limed.

Information about the lime status of a soil also is obtained from a soil test. Generally, the pH of the soil is used as the criterion for determining whether or not a response will be obtained to the addition of lime. Soil pH alone, however, is not a good index for determining the lime needs of a soil. Coleman, Kamprath, and Weed (*1*) pointed out that the nature of the ion exchange material is important in determining at what pH level a response to lime will be obtained. The amount and kind of clay and the amount and characteristics of the organic matter determine the ion exchange properties of the soil. Plants differ as to the optimum pH and lime level necessary for good growth. Therefore, it is necessary to consider the kind of plant to be grown as well as the chemical properties of the soil when making lime recommendations for acid soils.

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Commercial Laboratory and Advisory Procedures in Subtropical Agriculture

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Advisory systems based on soil and plant analysis are of great value in subtropical agriculture. Considerable attention must be paid to trace elements because of light soils and extreme leaching. The combination of soil and climate necessitates sampling on a 2-week schedule soils producing vegetables, gladioli, chrysanthemums, and other plants having limited food storage capacity. A much less frequent schedule (three to four times per year) is needed for citrus, cane, pasture, sod, and other perennials.

The importance of advisory procedures based on adequate analysis of soil and plant has increased considerably in the last decade. Today it has come of age, although much remains to be done to increase its accuracy and usefulness.

Procedures and calibrations were established in the Middle Atlantic states, primarily in New Jersey. The methods used are based on Morgan's extracting solution, carefully calibrated with crop response at Seabrook Farms and later at laboratories at Bridgeton, N. J., and Hollywood, Fla. The requirements in terms of soil nutrient levels have been established for a number of crops, but correlations are still going on to define nutrient levels and amounts of fertilizer necessary to change one level to another.

About 10% of our work deals with determination of soluble nutrients and total nutrients in plants. Plant tests check on soil tests and also point out possible deficiencies. Soil tests point out deficiencies or excess of nutrients in time to make corrections without seriously lowering crop production. Often by the time such deficiencies or excesses are noted in plant analysis, serious crop losses have resulted.

Many calibrations for vegetables in New Jersey held well for Florida, but several new problems presented themselves.

Trace Elements

The first major change involved certain trace elements. In New Jersey we had run tests for pH, organic matter, available nitrogen, phosphorus, potassium, calcium, and magnesium, and occasionally boron and manganese. Under Florida conditions it was also necessary to determine copper, iron, and zinc. Now the complete list is run as a matter of routine.

The need for checking trace elements is especially acute under Florida conditions, where light soils originally contained small amounts of these elements and high annual rainfall has leached them from the soil. It is highly advantageous to test for all these elements in New Jersey, Pennsylvania, Delaware, Maryland, Virginia, Georgia, and the Caribbean Islands. Seldom are as many trace elements in short supply as in Florida, but routine testing has helped uncover both shortages and excesses in other areas.

Chemostatic Control

The light soils and high annual rainfall make control of all elements a more serious problem than on soils of high exchange capacity and in a more equitable climate.

While Florida has a number of soils with a relatively good exchange capacity, most of the soils we are dealing with have an exchange capacity of less than 2 meq. per 100 grams. Many are sand with a little organic matter. This influences the frequency of testing for many elements as well as the need for determining trace elements. Soils of low exchange capacity are definitely limited as to amounts of nutrients they will hold under leaching conditions. Nearly everything must be supplied from the fertilizer bag, yet not too much can be applied at one time, lest we "burn" the crop.

This has prompted large use of organic sources of nitrogen. Unfortunately when extra nutrients are needed because of heavy leaching, the organics often fail to do the job. Cold weather following rains, or the lowered oxygen content of the soil, slows down decomposition of the organic nitrogen to a point where it is unsatisfactory. Fortunately, periodic and frequent testing can evaluate such a situation and a grower can usually apply available nitrogen quickly enough to save his crop.

To evaluate the changes brought about by variable weather and on soil of limited holding capacity has required frequent testing. For most annuals which store little plant food, it has been necessary to test areas every 2 weeks, and occasionally extra samples are taken.

The frequency of testing is much less for perennial crops that have much greater storage capacity, and therefore are less dependent on daily or weekly fluctuations in soil nutrients. For pastures and citrus, good results can be obtained by making tests three or four times a year.

Such frequent testing of the soil may be called "chemostatic" control of plant nutrition. Much as a thermostat controls the operation of a furnace to provide a uniform temperature, chemostatic control can provide a chemical climate or a range of nutrients favorable for crop production. Although not automatic, chemostatic control can provide much more favorable growth than any hit-or-miss system.

In practice we try to establish a schedule of fertilization which provides a basis for crop nutrition. Then periodic testing determines whether applications should be reduced, maintained, or increased.

Nitrogen tests are most useful. We determine all three forms of available nitrogen in one test. Nitrate and nitrite forms in the Morgan's soil extract are reduced with titanous chloride solution to the ammonium form. This ammonium nitrogen, plus what was originally available as ammonium, is determined with a modified Graves reagent, and as in other tests, is measured photometrically.

Fertility Levels

Additional problems are presented with new crops, or with familiar crops grown under vastly different conditions. Experience with avocado and mango is still rather meager. Generally, nutrient levels are kept under conditions similar to those for citrus.

In most cases pH is adjusted to 6.0 to 6.5 once a year by use of dolomite.

Citrus. Citrus is marked by rather high requirements for nitrogen and calcium, but low for phosphorus and potassium. An examination of the leaf often shows 5% or more of dry weight as calcium, with less than 1% of potassium. Such trees produce a normal crop. Under certain conditions these potassium levels may be allowed to fall too low, with resultant poor growth (Table I). Nevertheless, frost resistance to a certain degree is inversely related to potassium fertilization and within certain ranges is directly related to nitrogen fertilization. Excellent growing conditions can be maintained by adjusting nutrient levels (pounds per acre) three or four times a year, based on an over-all treatment.

N	75–100	B	2–4
P	15–25	Mn	2.5–10
K	100–150	Cu	1–4
Ca	1000+	Fe	2.5–5
Mg	150+	Zn	2.5–20

A major problem on old groves is accumulation of copper in the soils to toxic levels, which interfere seriously with root development and iron uptake. Generally, this can be corrected by raising the pH to 6.5 to 7.0 with dolomite, increasing the available phosphorus content to 50 to 75 pounds per acre, including as much organic matter as possible through cover crops and weeds, and increasing the iron content. Where

Table I. Analysis[a] of Pineapple Orange Leaves

	Good Tree, %	Poor Tree, %	Dying Tree %
Nitrogen	2.00	2.42	2.40
Phosphorus	0.14	0.14	0.14
Potassium	0.46	0.45	0.36
Calcium	6.0	6.1	6.4
Magnesium	0.17	0.17	0.14
Boron	0.0038	0.0042	0.0040
Manganese	0.0017	0.0015	0.0015
Copper	0.0020	0.0020	0.0030
Iron	0.0070	0.0065	0.0100
Zinc	0.0050	0.0080	0.0034

[a] Dry weight basis.

Table II. Influence of Soil Treatment on Leaf Analysis and Yield of Sugar Cane

Treatment[a]		Leaf Analysis, %[b]			Yield		
P_2O_5, lb.	K_2O, lb.	N	P	K	Cane, tons/acre	%	Sugar, tons/acre
0	150	1.92	0.18	1.08	40.03	10.02	4.01
25	150	2.22	0.23	1.04	42.87	9.84	4.22
50	150	2.32	0.26	1.04	41.62	9.77	4.10
100	150	2.40	0.28	0.96	42.75	9.67	4.13
200	150	2.30	0.33	0.85	43.75	9.21	4.02
0	300	1.92	0.21	1.18	42.50	9.98	4.24
25	300	2.40	0.24	1.18	45.73	9.81	4.45
50	300	2.32	0.28	1.08	43.84	9.63	4.22
100	300	2.60	0.27	1.00	43.45	9.40	4.08
200	300	2.60	0.30	1.00	42.08	9.44	3.97

[a] Pounds per acre applied as 20% superphosphate and 60% KCl.
[b] Dry weight basis.

Table III. Analysis[a] of Good and Poor Cane

Element	Leaf Analysis, P.P.M.[b] Good cane	Poor cane
Aluminum	25–75	25–75
Cobalt	0.1–1.0	0.1–1.0
Copper	25–75	25–75
Iron	4	2.4
Manganese	250	60
Molybdenum	25–75	2–6
Titanium	25–75	25–75
Vanadium	25–75	25–75
Zinc	18	0.6

[a] Mature leaves of 10-month-old cane.
[b] Dry weight basis. Spectrographic analysis except for iron, manganese, and zinc which were done colorimetrically.

injury is severe, recovery is greatly hastened on acid soils by addition of chelated iron at the rate of 4 to 8 ounces per tree.

Sugar Cane. Most of the sugar cane in Florida is grown on the muck soils close to Lake Okeechobee. However, about 14,000 acres are grown in the vicinity of Fellsmere, which may be on muck, sandy muck, or sand. The muck soils require little or no nitrogen; evidently liberation of available nitrogen from the muck is able to keep up with the normal rate of growth. Relatively small amounts of phosphorus have been used, with emphasis on potassium and secondaries of manganese and copper.

The practice has been to supply about 600 pounds of an 0–8–30 with 3% MnO, 1.5% CuO, 0.15% B_2O_3, and 0.45% ZnO, with 8 pounds of chelated iron per ton to newly set cane; the ratoons receive 150 pounds of K_2O per acre with minors as indicated, or K_2O alone. Long cropping of the muck without further additions of phosphate has resulted in a condition giving response to added phosphates. When several levels of phosphorus were applied to the soil with two applications of potassium, there was a response to 25 pounds of phosphorus per acre after a check receiving no phosphorus, but indication that higher phosphorus levels may depress yields (Table II). Some of this depression may be a result of trace element deficiencies (Table III).

Applying about 18 pounds of P_2O_5 per acre to ratoon crops in fields testing less than 25 pounds of available phosphorus has substantially increased yield. Response to sulfur, or the effect of sulfur in lowering pH with resultant increase in availability of trace elements, has given improved yields (Table IV).

We are trying to establish a 15- to 25-pound level of available phosphorus and 250-pound level of available potassium per acre of muck soil at time of planting or shortly after harvesting. Experiments are under way to determine whether higher levels of secondaries may be used, particularly in conjunction with larger amounts of phosphorus and potassium.

On sands and sandy mucks, several tests are under way to determine the feasibility of side dressing with extra fertilizer during the growing season. At present, one application is made to bring available nitrogen in the 15- to 25-pound range and available potassium in the 100- to 150-pound range, and 50 pounds of nitrogen per acre are applied about 6 weeks later. Current tests are made to maintain the levels of nitrogen, phosphorus, and potassium as at first fertilization by applications 6 and 10 weeks after first application.

Pastures

Florida is the largest beef-producing state east of the Mississippi and ranks with a number of western states. In recent years it has built up a large population of dairy cattle. Some horse breeding is also done.

There is a great need for adequate pastures. The poor soils on which most of the pasture is grown require large amounts of fertilizer. In many areas it takes 15 acres to support an animal in poor style. By proper use of improved pasture grasses, and adequate irrigation, drainage, and fertility practices, it is possible to supply good support for three to four animals per acre the year around. Most operators have made some changes, but there is vast room for improvement.

If the grower has improved pastures with desirable grasses such as Pangola, bahia, fescue, St. Augustine, and Carib, and a good drainage and irrigation system, the level (pounds per acre) is adjusted three or four times a year to:

	Sandy Soils	Muck Soils High in Ca and Mg
N	75–150	25–50
P	15–25	15–25
K	100	150–200
Ca	1000+	...
Mg	100+	...
Mn	5–20	...
B	1–2	1–5
Cu	1–2	1–2
Fe	1–5	...
Zn	2.5–20	2.5–20

pH is adjusted to less than 6.0 once a year with sulfur, if necessary to increase availability of trace elements.

We try to maintain different fertility levels for pasture legumes such as white Dutch clover. Nitrogen is kept at a low range of about 25 pounds per acre, phosphorus at 25, potassium at 150 to 250, calcium at 1000+, magnesium at 150+, manganese at 10 to 20, boron at 2 to 4, copper at 1 to 4, and zinc at 10 to 20.

Pangola does better on a high nitrogen level of 75 to 150 pounds. Bahia gives satisfactory growth at levels of about 50 pounds per acre.

Table IV. Influence of Treatment on Yields[a] of Sugar Cane

(Ratoon crops)

Treatment[b]	No. of Fields	Yield, Tons/Acre
Minus phosphorus	24	36.1
Plus phosphorus	18	44.1
Minus sulfur	23	37.9
Plus sulfur	19	43.8
Minus phosphorus and sulfur	13	35.6
Plus phosphorus and sulfur	10	47.5

[a] Weight of commercially harvested cane.
[b] All fields received approximately 250 pounds KCl, 50 pounds $MnSO_4$, 8.5 pounds CuO, 5 pounds $ZnSO_4$, and 2 pounds borax per acre. Phosphate treatments consisted of 18 pounds of P_2O_5 per acre from triple super. Sulfur applied at 200 pounds per acre.

Foliage Plants

Florida has come into its own as a large producer of foliage plants, such as philodendron, diffenbachia, and dracaena. Little is known about satisfactory nutrient levels.

We have been getting good growth by maintaining nitrogen levels at 50 to 150 pounds, and phosphorus levels at 15 to 25 pounds. On soils in Dade County considerable oölitic limestone may be close to the surface, so that calcium levels are already in the 5000- to 8000-pound range. With such high calcium levels, growth is better when potassium is maintained at about 250 rather than 100 to 150 pounds per acre. However, a constant check must be maintained on magnesia, as some limestone may be low in this element, and potassium application may cause magnesium deficiency.

Boron has been maintained at 2 to 4, manganese at 2.5 to 10, copper at 1 to 2, and zinc at 2.5 to 10 pounds per acre. Satisfactory growth has been obtained with such levels, although further calibration may show need for revamping these ranges.

Flower and Vegetable Crops

The flower and vegetable crops have presented somewhat different problems in subtropical agriculture.

Chrysanthemums. A relatively mild climate has permitted growing chrysanthemums in the open or under saran. Schedules of lighting, planting, and spraying have been worked out so that the industry has prospered, with huge increase of acreage.

Cost of installation and culture runs

rather high. Because of close cropping (plants approximately 7 × 5 inches apart) and controlled water conditions, it is desirable to maintain higher nutrient levels than with many other crops. We try to maintain nitrogen at 150 to 250, phosphorus at 50 to 75, potassium at 200 to 300, calcium at 1000, magnesium at 150+, boron at 2 to 4, manganese at 2.5 to 10, copper at 1 to 2, iron at 2.5 to 5, and zinc at 2.5 to 10 pounds per acre. The nutrients are checked at 2-week intervals and adjusted if necessary.

Gladioli. About 10,000 acres of gladioli are grown annually in the open in Florida. Original concepts of feeding with low nitrogen levels to reduce bulb rots have had to be markedly reversed under Florida conditions. Because gladioli are grown mostly on sandy soils, lack of nitrogen is often a problem. Better dipping procedures with new fungicides have greatly lessened the bulb losses to Fusarium, permitting much higher nitrogen levels.

At present we try to maintain an available nitrogen level of 50 to 75, phosphorus of 15 to 25, potassium of 100 to 150, calcium of 1000+, magnesium of 100+, boron of 2 to 4, manganese of 2.5 to 10, iron of 1 to 5, and zinc of 2.5 to 20 pounds per acre until time of spiking. These levels are adjusted on a 2-week interval analysis, if scheduled applications have not maintained desired amounts. At time of spiking the potassium level is raised into the 150- to 250-pound range and maintained until shortly before the spike is cut.

On light soils calcium deficiency often causes bud malformation. Part of the difficulty is brought about because of the high potassium level necessary to produce good quality bulbs and the antagonism between the two elements. To correct this situation, several sprays of calcium chloride or nitrate at the rate of 4 pounds per 100 gallons are applied to plants beginning shortly before spiking has started.

Vegetables. Practically all the vegetables common to other areas, except such perennials as asparagus, rhubarb, and dill, can be grown in Florida. Special varieties adapted to the area have improved yields and quality; skill in proper planting, insect and disease control, and fertilization have made this production feasible.

Generally we maintain nitrogen at 50 to 150, phosphorus at 12 to 25, potassium at 150 to 250, calcium at 1000+, magnesium at 100+, boron at 1 to 2, manganese at 2.5 to 10, copper at 1 to 2, and zinc at 2.5 to 20 pounds per acre.

Nearly all vegetable crops are checked often, key samples usually being taken every 2 weeks.

What Is Required for a Commercial Consulting and Soil-Testing Service

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In conducting a commercial laboratory, factors to be considered are: accuracy of soil analyses, type of extractant and interpretation of results, nutritional elements involved, the specific soil problems of concern, and achievements expected. With these data available and a broad knowledge of soil, plant, and animal mineral nutritional requirements, the laboratory is well on its way toward success.

IN 1934 only a few scientists were interested in soil testing, and many were opposed because of lack of information. The first publication of the author (*1*) in 1934 culminated several years of chemical research aimed to assist the grower in crop production.

Within the next few years scientists in every state and in many parts of the world began to take seriously this approach to a solution of the grower's problems. Publications began to appear in the scientific literature, practically all in favor of soil testing. Different methods were developed, some adapted to specific locations and conditions.

A method of soil testing which is chemically accurate and gives basic information about a soil is desirable, and interpretation of the data accumulated from the use of this system, in the light of the crop concerned, is the most scientific approach to the solution of the problem. Any organization that

Table I. Variations in Soil Conditions on One Farm

(Soil type RBSiL)

			Pounds per Acre													Mo, Parts per 2 Billion
		% Organic Matter	Nitrogen													
Field	pH		NO_3	NH_3	P_2O_5	K_2O	Ca	Mg	Fe	Mn	B	Cu	Zn	Toxic Al		
3	5.8	3.8	0.9	12	32.5	126	2225	106	0.4	0.65	0.34	0.5	0.27	0.60		50
4	6.0	3.6	5	8	50	191	2225	98	0.3	1.30	0.28	1.0	0.19	1.48		50
8	5.4	3.0	7	4	32.5	126	921	98	0.3	1.69	0.36	1.0	Trace	0.60		20
9	5.8	3.1	1	5	50	126	1150	130	0.4	1.56	0.38	0.5	1.5	0.12		10
10A	5.8	3.4	11	7	42	99	1880	126	0.3	1.65	0.25	1.6	2.3	0.18		50
12	4.8	3.4	8	10	35	140	921	50	0.4	4.80	0.42	3.3	2.5	0.72		20
25	5.9	3.5	11	12	31	82	1650	130	0.4	1.69	0.38	1.3	Trace	0.60		20
26	4.7	3.1	3	5	44	112	1185	32	0.3	5.25	0.37	4.3	2.5	0.48		50
Mean	5.53	3.36	5.86	7.88	39.63	125.25	1519.63	96.25	0.35	2.32	0.35	1.69	1.54	0.60		33.75
Mean dev.	0.42	0.22	3.39	2.63	6.88	20.69	475.38	27.63	0.05	1.48	0.04	1.06	0.89	0.25		16.44