

dioxide production of the component parts. It is also evident that the shelled beans had a much greater respiration rate than those in the comparison in Table I, although the rates for the pod samples were almost identical. The method of handling the shelled beans may account for the difference in respiratory behavior, since the lot represented in Table I were podded in a commercial viner and washed before being placed in the respiration chambers, while the sample in Table III was shelled by hand and placed in the chamber without delay.

The effect of preparation of the material upon rate of respiration was studied further with snap beans and sweet corn. A comparison of whole snap bean pods with pods with the tip ends removed and with pods cut into 1-inch lengths showed carbon dioxide production over a 7-day storage period at 38° F. for the respective lots to be 37.0, 41.7, and 41.2 mg. per kilogram-hour. It would seem that wounding entailed in the preparation had little effect on the rate of respiration. A comparison of the carbon dioxide output from kernels of sweet corn cut from the cob with a sharp knife with that of husked ears over an 8-day storage period at 32° F. showed

**Table III. Effect of Husking Sweet Corn and Shelling Lima Beans on Carbon Dioxide Production<sup>a</sup>**

Material Tested	Weight of Material, G.	Total CO <sub>2</sub> in 5 Days <sup>a</sup> , G.	Respiratory Rate, Mg. CO <sub>2</sub> /Kg./Hr.
Sweet corn in husk	1000	8.34	69.5
Husked ears from 1000 grams of corn	715	7.48	87.2
Husks from 1000 grams of corn	285	1.74	90.9
Husked ears plus removed husked (2 + 3)	1000	9.22	...
Lima beans, whole pods	1000	3.67	30.6
Seeds from 1000 grams of pods	318	3.49	98.4
Shells from 1000 grams of pods	682	4.32	52.6
Separated seeds plus shells (6 + 7)	1000	7.81	...

<sup>a</sup> Stored at 38° F.

that the separated kernels had a lower carbon dioxide production rate than did the husked ears. The average values were 35.9 and 40.7 mg. per kilogram-hour, respectively.

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## Serpentine-Fused Phosphate Shows High Liming Value; Mechanism of Chelate Action

# SERPENTINE-FUSED PHOSPHATE

## Equivalent Basicity, Solubility, and Liming Value

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Fertilizers prepared by fusing phosphate rock with serpentine and quenching the melt to a glass are manufactured in several countries, notably Japan and Taiwan. The equivalent basicity of such products and their solubility in ammonium citrate and citric acid solutions, as determined by standard laboratory procedures, are shown to be positively correlated with both the glass content and the fineness of the material. As indicated by laboratory tests with several types of soils, serpentine-fused phosphate has value as a soil-liming material.

THE BASIC NATURE of serpentine-fused phosphate is well known. However, of all the properties of such phosphate material so far reported (6-10, 12, 13, 16), the equivalent basicity appears to be the least understood.

Moulton states that 1 ton of olivine-fused phosphate containing 14% magnesium oxide is equivalent to 1200 pounds of limestone for soil sweetening (14, 20). It is believed that serpentine-

fused phosphates which usually contain more than 14% magnesium oxide might have a higher equivalent basicity (7).

A further study of this property would result in a more thorough understanding of the soil-sweetening capability of serpentine-fused phosphate, a quantitative knowledge of which is essential to the use of this material in the formulation of non-acid-forming fertilizer mixtures.

#### Materials

Six samples of fused phosphate were used. Their sources and partial chemical analyses are given in Table I.

Sample TP was from a 2-ton lot of imported Thermo-Phos granular formerly manufactured by the Permanente Metals Corp., Permanente, Calif. This sample does not represent the average production, and the chemical properties

**Table I. Description of Fused Phosphates**

Sample No. <sup>a</sup>	Source	Composition <sup>b</sup> , %				Glass content	Color and Appearance
		P <sub>2</sub> O <sub>5</sub>	CaO	MgO	SiO <sub>2</sub>		
TP	U. S.	19.54	31.99	14.85	23.00	64.5 <sup>c</sup>	Dark gray granular material spotted with white grains
J-1	Japan	18.15	28.01	16.94	29.58	82.8	Dark gray powder
J-2	Japan	20.25	32.13	19.41	22.72	79.0	Light gray powder
I-21	China	21.08	31.57	17.81	23.50	80.0	Bluish black grains with metallic luster
PS	China	19.61	29.93	17.38	25.80	83.8	Dirty green grains
2488	U. S.	22.83	33.84	11.69	22.82	87.5	Dark gray powder

<sup>a</sup> All serpentine-fused phosphates except No. 2488.

<sup>b</sup> Oven-dry basis, except No. 2488 (as received basis).

<sup>c</sup> Figure for a similar sample from same source is 88.0% (8).

**Table II. Screen Analyses of Serpentine- and Olivine-Fused Phosphates<sup>a</sup>**

Mesh	Screen Fraction, %					
	TP	J-1	J-2	I-21	PS	2488
+5	...	...	...	0.5	3.3	...
-5, +10	4.2	...	...	8.2	7.5	...
-10, +20	8.2	0.1	...	32.6	32.7	...
-20, +42	30.9	0.3	0.9	-43.7	41.5	...
-42, +60	20.0	21.0	3.7	8.9	8.7	...
-60, +80	8.6	15.1	7.1	2.7	3.1	...
-80, +100	7.7	18.7	21.5	1.6	1.6	...
-100, +150	6.6	12.8	39.1	0.9	1.0	4.4
-150, +200	6.6	14.7	17.8	0.6	0.4	20.6
-200	7.2	17.3	9.9	0.3	0.2	75.0
	100.0	100.0	100.0	100.0	100.0	100.0

<sup>a</sup> As received.

are somewhat different from those of a similar sample used in previous studies (8). Samples J-1 and J-2 were obtained in 1951 from the Special Phosphatic Fertilizers Association, Tokyo, Japan, through C. H. Hsia and H. F. Chu of the Joint Commission on Rural Reconstruction of China. Samples I-21 and PS are, respectively, products of pilot scale (70) and recent plant scale operations (8), conducted by the Lotung Subsidiary of the Taiwan Fertilizer Co., Taiwan, China. Except as indicated, these five samples are regular commercial phosphate rock-serpentine fusion products. Sample 2488 was obtained from K. D. Jacob, U. S. Department of Agriculture, Beltsville, Md.; this is an experimental olivine-fused phosphate. The composition of this sample shown in Table I is slightly different from that reported by Hill *et al.* (6).

For use in tests on the effect of crystallization on the equivalent basicity and solubility, small portions of sample PS were heat-treated in essentially the same manner as previously described (8) to obtain partly and completely crystallized materials.

Screen analyses of the six samples as received are shown in Table II. Sample TP has been marketed as a minus 6-mesh granular material for direct application (6, 76). In Japan it is required that the fineness of such fusion products be such that 90 and 70% will pass 70- and 100-mesh sieves, respectively (5). Sample J-1 is barely able to meet these specifica-

tions. Samples I-21 and PS have approximately the same screen analysis and are typical of the quenched products before being pulverized. Sample 2488 was marked minus 80-mesh.

### Analytical Methods

**Chemical Analysis** The samples were ground to pass a 100-mesh sieve, with the exception of sample 2488, which was analyzed as received. Small portions of samples TP and PS were ground to various degrees of fineness for use in tests of the effect of

**Table III. Equivalent Basicity of Serpentine- and Olivine-Fused Phosphates by Hydrochloric Acid Extraction**

Sample No.	Equivalent Basicity <sup>a</sup> , G. CaCO <sub>3</sub> /100 G. Phosphate			
	Method A		Method B	
	I	II	I	II
TP	73.0	62.8	73.6	63.4
J-1	69.3	62.0	73.4	66.1
J-2	73.6	67.4	72.0	65.8
I-21	69.6	55.8	67.8	54.0
PS	72.7	62.7	72.8	62.8
2488	60.6	55.2	59.2	53.8
II-16 <sup>b</sup>	61.4	54.6	65.8	59.0

<sup>a</sup> I uncorrected and II corrected for citrate-insoluble P<sub>2</sub>O<sub>5</sub> determined with continuous agitation.

<sup>b</sup> Pilot scale product (70). Citrate solubility of P<sub>2</sub>O<sub>5</sub> 75.7%; citric solubility of P<sub>2</sub>O<sub>5</sub> 95.1%; glass content 96.4%.

particle size on the equivalent basicity and on citrate solubility of the phosphorus pentoxide.

The 1-gram samples for analysis were digested with 30 ml. of nitric acid and 5 ml. of hydrochloric acid, the insoluble residue was reported as silica, and the filtrate was diluted to 250 ml. Phosphorus was determined by the volumetric method, calcium by permanganate titration, and magnesium by weighing as the pyrophosphate without correction for manganese, according to the AOAC procedures for fertilizer materials (2).

Citrate-soluble phosphorus pentoxide was determined by difference between the total phosphorus pentoxide and the citrate-insoluble phosphorus pentoxide (2), while hydrochloric acid-soluble and citric acid-soluble phosphorus pentoxide were determined directly on the extracts. Hydrochloric acid extracts were prepared by Method B (indicated in a following paragraph); citric acid extracts, by the former AOAC test for basic slag (7). All soluble calcium and magnesium were determined directly on the extracts.

**Screen Analysis** Tyler standard screens were used.

The analysis was made by hand-shaking 30- to 50-gram portions on covered screens and weighing the separates. Re-grinding, where necessary, was done with a porcelain mortar.

**Determination of Glass Content** The glass content was determined with a Leitz polarizing microscope in the manner previously reported (8).

**Determination of Equivalent Basicity** Unless otherwise indicated, all the oven-dry samples were ground to pass a 100-mesh sieve. Two methods were used for the equivalent basicity measurements.

**Method A.** The AOAC procedure (2) was followed closely, except that 40 ml. of 1N hydrochloric acid plus 30 ml. of water were used instead of 30 ml. of 1N hydrochloric acid plus 50 ml. of water.

**Method B.** The same procedure (2) was followed, except that the sodium carbonate-sucrose digestion and heating at 575° to 600° C. were omitted, and 20 ml. of 1N hydrochloric acid plus 50 ml. of water were used.

The AOAC procedure for determining equivalent basicity (2), based on the work of Pierre *et al.* (17-19), was developed primarily for mixed fertilizers and is seldom, if ever, used for straight phosphate materials (11). Preliminary calculations based on reported analyses of serpentine- and olivine-fused phosphates (4, 6-10, 13-16, 20, 21) showed that, in the presence of 10 ml. of 2N sodium carbonate-sucrose solution, 30 ml. of 1N hydrochloric acid (2) would be insufficient to neutralize the total basicity of 1 gram of the fused phosphate. So, in the first modification, Method A, the

quantity of 1*N* hydrochloric acid added was raised to 40 ml. Next, from the chemical nature of the fused materials, it appeared that addition of the sodium carbonate-sucrose solution and the subsequent roasting might not be necessary. Thus, in the second modification, Method B, these steps were omitted and the quantity of 1*N* hydrochloric acid was reduced to 20 ml.

Equivalent basicity values for the samples described in Table I and a pilot plant material are shown in Table III. Essentially the same results were obtained by Methods A and B.

**Measurement of Soil pH Values** Soil pH values, before and after additions of serpentine- or olivine-fused phosphate, were determined by Kuehn's method in an aqueous suspension in the presence of pure barium sulfate (22).

### Results and Discussion

**Solubility and Equivalent Basicity Related to Sample Fineness** The solubility of fused phosphates is known to vary with the fineness of the sample. It was suspected that the equivalent basicity behaves in a similar way. Determinations of the citrate solubility and equivalent basicity were, therefore, made on reground portions of samples TP and PS, each prepared from the original grinds of the respective products (Table II). The results are given in

Table IV. The correlation between equivalent basicity without correction for insoluble phosphorus pentoxide and citrate solubility was found to be highly significant for both samples. The linear regression equations representing the average relationship between the two variables for samples TP and PS are, respectively,  $Y = 22.06 + 0.850X$  and  $Y = 35.35 + 0.669X$ .

### Solubility and Basicity Related to Glass Content

The equivalent basicity, solubility, and glass content of annealed samples were determined. The results are given in Table V.

These data show that solubility both in citrate and in citric acid solutions decreases markedly as the glass content diminishes, whereas solubility in hydrochloric acid changes scarcely at all until the glass content becomes less than 40%. The equivalent basicity, when corrected for citrate-insoluble phosphorus pentoxide, also changes markedly with the glass content. However, hydrochloric acid extraction according to Method B does not dissolve all the citrate-insoluble phosphorus pentoxide nor all the citrate-insoluble calcium oxide.

### Solubilities of Essential Constituents

The essential constituents which have much to do with the equivalent basicity of the fused phosphates are phosphorus, calcium, and magnesium. Walthall and Bridger report that the magnesium of an

olivine-fused phosphate was 90% citrate-soluble (27). Moulton states that some olivine-fused phosphate contains 8.2% of soluble magnesium oxide (15), while with other samples, the total and acid-soluble magnesium are practically equal (14). Regarding the solubility of magnesium of serpentine-fused phosphate and the solubility of the calcium of fused phosphates in general, no quantitative information has been published.

The six samples (Table I), ground to pass a 100-mesh sieve, were analyzed for citrate-, hydrochloric acid-, and citric acid-soluble phosphorus pentoxide, calcium oxide, and magnesium oxide. Method B was used for the determination of hydrochloric acid solubility. The results (Table VI) show that: the citric acid solubility of the magnesium oxide for five of the six samples exceeds 97%; the hydrochloric acid solubility, according to Method B, lies between those of citric acid and neutral ammonium citrate; and calcium oxide and phosphorus pentoxide have essentially the same solubility in either of the three solvents. Both citrate and citric tests have been used for measuring the phosphorus pentoxide solubility of serpentine-fused phosphates, although it is considered that the latter may tend to overrate the actual plant food value (6). It can be inferred, therefore, that the hydrochloric acid method may prove to be a rather conservative test for the phosphorus pentoxide, calcium oxide, and magnesium oxide solubility, probably also for the equivalent basicity of high-grade products.

The molal ratios of calcium oxide to phosphorus pentoxide for the samples (Table I) and extracts (Table VI) are shown in Table VII. In these materials, which have a high glass content, the ratios for the samples are very close to those for the extracts. In the case of crystallized samples, however, the ratios (not shown in tables) for the extracts are usually higher and those for the insoluble residues lower than those for the samples. Furthermore, the ratios for the insoluble residues are higher than is required by the apatite formula.

**Table IV. Equivalent Basicity and Phosphorus Pentoxide Solubility of Reground Samples of Serpentine-Fused Phosphates**

Mesh	Sample TP		Sample PS	
	Equivalent basicity <sup>a</sup> , g. CaCO <sub>3</sub> /100 g. phosphate	Citrate solubility of P <sub>2</sub> O <sub>5</sub> <sup>b</sup> , %	Equivalent basicity <sup>a</sup> , g. CaCO <sub>3</sub> /100 g. phosphate	Citrate solubility of P <sub>2</sub> O <sub>5</sub> <sup>b</sup> , %
-10	53.1	36.3	47.5	19.4
-20	52.9	38.1	51.1	26.0
-42	53.9	36.6	56.8	30.8
-60	59.1	43.4	59.1	39.7
-80	65.5	57.2	69.6	44.1
-100	73.6	56.9	72.8	52.1
-150	73.3	56.5	78.9	63.7
-200	80.0	68.8	76.8	67.7

<sup>a</sup> By Method B, not corrected for citrate-insoluble P<sub>2</sub>O<sub>5</sub>.

<sup>b</sup> With intermittent shaking.

**Table V. Effect of Crystallization on Equivalent Basicity and Solubility of Serpentine-Fused Phosphates**

Partially Crystallized Sample	Glass Content, %	Equivalent Basicity <sup>a</sup> , G. CaCO <sub>3</sub> /100 G. Phosphate		P <sub>2</sub> O <sub>5</sub> , %		CaO, %		MgO, %				
		I	II	Citrate-soluble <sup>b</sup>	Hydrochloric acid-soluble	Citric acid-soluble	Citrate-soluble <sup>b</sup>	Hydrochloric acid-soluble	Citric acid-soluble	Citrate-soluble <sup>b</sup>	Hydrochloric acid-soluble	Citric acid-soluble
PS	83.8	72.8	62.8	12.55	14.27	17.52	19.84	22.53	27.23	12.24	13.61	17.24
PS-7-2	62.5	72.1	57.8	9.46	14.38	13.09	15.32	22.35	20.48	10.17	14.64 <sup>c</sup>	13.32
PS-7-6	57.5	69.7	47.9	4.16	14.55	8.14	6.75	22.83	12.46	4.28	14.64 <sup>c</sup>	10.07
PS-7-12	40.5	70.2	47.2	3.31	14.14	6.26	5.36	22.26	11.85	3.52	14.70 <sup>c</sup>	8.25
PS-8-2	1.2	65.4	39.5	1.26	11.85	1.31	1.53	18.28	2.12	0.40	12.75 <sup>c</sup>	1.27
PS-9-2	0	58.4	33.1	1.66	11.44	1.32	1.67	17.28	2.19	0.22	12.32 <sup>c</sup>	0.94

<sup>a</sup> By Method B, using 1*N* HCl; I uncorrected and II corrected for citrate-insoluble P<sub>2</sub>O<sub>5</sub>.

<sup>b</sup> Determined with continuous agitation.

<sup>c</sup> 1.1*N* HCl used.

**Table VI. Solubilities of Phosphorus Pentoxide, Calcium Oxide, and Magnesium Oxide in Three Solvents**

Sample No.	Citrate Solubility <sup>a</sup> , %			Hydrochloric Acid Solubility <sup>b</sup> , %			Citric Acid Solubility, %		
	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	P <sub>2</sub> O <sub>5</sub>	CaO	MgO
TP	63.0	61.4	68.3	71.6	73.9	75.1	86.6	88.1	94.1
J-1	71.5	69.6	74.4	76.5	76.8	80.3	93.8	94.5	98.7
J-2	78.4	78.8	83.2	82.4	82.5	85.1	94.7	96.5	97.4
I-21	53.7	54.7	58.5	71.9	74.2	76.9	93.3	95.3	97.8
PS	64.0	66.3	70.4	72.8	75.3	78.3	89.3	91.0	99.2
2488	83.1	82.1	94.2	94.8 <sup>c</sup>	96.8 <sup>c</sup>	99.0 <sup>c</sup>	85.7	87.2	99.0

<sup>a</sup> With continuous agitation.  
<sup>b</sup> By Method B.  
<sup>c</sup> Did not cake when treated with reagent.

**Table VII. Molal Ratios of Calcium Oxide to Phosphorus Pentoxide for Samples and Extracts**

Sample No.	Sample	Ratio <sup>a</sup> in		
		Citrate extract <sup>a</sup>	Hydrochloric acid extract	Citric acid extract
TP	4.15	4.04	4.28	4.22
J-1	3.91	3.80	3.92	3.93
J-2	4.02	4.04	4.03	4.08
I-21	3.79	3.86	3.91	3.87
PS	3.87	4.00	4.00	3.93
2488	3.75	3.71	3.83	3.82

<sup>a</sup> Calculated from results in Tables I and VI.

**Effect of Serpentine-Fused Phosphate Addition on Soil Acidity**

Tests were conducted to compare the effect of addition of calcium carbonate and fused phosphate samples on the acidity of three acid soils. The air-dry soils and the calculated quantities of calcium carbonate and fused phosphates were thoroughly mixed and placed in 250-ml. borosilicate glass beakers covered with watch glasses. The mixtures were flooded with water to simulate rice paddy conditions and to speed up soil-sweetening action. The pH values were measured each week. The room temperature during the testing period ranged from 28° to 34° C. The results of a 5-week experiment are summarized in Table VIII. Under the conditions of this test the effect of the fused phosphates was of the same order as their determined equivalent basicities.

**Conclusions**

When the AOAC procedure is used for measuring the equivalent basicity of serpentine-fused phosphate, the preliminary sodium carbonate-sucrose treatment and the subsequent roasting can be omitted.

Both equivalent basicity and phosphorus pentoxide citrate solubility of serpentine-fused phosphate vary as the fineness. For coarse and fine materials of the same composition, a highly significant correlation exists between

the equivalent basicity (not corrected for citrate-insoluble phosphorus pentoxide) and the citrate solubility of the phosphorus pentoxide. For practical purposes, all samples should be ground to minus 100-mesh before undergoing equivalent basicity determinations.

The essential constituents phosphorus pentoxide, calcium oxide, and magnesium oxide are most soluble in citric acid, less so in hydrochloric acid, according to the simplified AOAC test, and least soluble in citrate solution. Magnesium oxide is the most soluble constituent in all of the solvents; phosphorus pentoxide and calcium oxide have approximately the same solubility.

The citrate and citric solubilities are very sensitive to the glass content of crystallized material, whereas solubility in hydrochloric acid is not.

In the case of amorphous samples, the molal ratio of calcium oxide to phosphorus pentoxide for the extract is very close to that for the sample.

Soil tests showed that serpentine-fused phosphates have a high liming value.

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**Table VIII. Influence of Applications of Fused Phosphates on pH of Soil<sup>a</sup>**

Soil Treatment	pH of Soil		
	Tungshan silt clay	Taichung loam	Taoyuan loam clay
Untreated	5.9	5.0	5.3
Treated, 5 weeks after addition of			
Pure CaCO <sub>3</sub> <sup>b</sup>	7.1	6.9	6.8
Sample PS (-20-mesh) <sup>c</sup>	7.2	7.2	6.9
Sample PS (-100-mesh) <sup>d</sup>	7.3	7.3	6.8
Sample TP (-100-mesh) <sup>d</sup>	7.3	7.2	6.8
Sample 2488 (as received) <sup>d</sup>	7.3	7.1	6.8

<sup>a</sup> Soils from Taiwan (Formosa), China, kindly supplied by S. C. Chang and H. S. Puh, Agricultural Research Institute of Taiwan.

<sup>b</sup> Applications were 3200, 4200, and 4400 lb. per acre (2,000,000 lb. of soil), respectively, for three soils, these being amounts required to raise soil pH to 6.5 (3, p. 250).

<sup>c</sup> Applications were 6140, 8060, and 8450 lb. per acre, respectively, for three soils. Amounts calculated on basis of average equivalent basicity (52 g. CaCO<sub>3</sub>/100 g. fused phosphate) obtained from results in Table IV.

<sup>d</sup> Applications were 4380, 5750, and 6030 lb. per acre, respectively, for three soils. Amounts calculated on basis of equivalent basicity of 73 g. CaCO<sub>3</sub> per 100 g. of fused phosphate, an average of many determinations on -100-mesh material.

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## CHELATES

# Absorption and Translocation of Ethylenediaminetetraacetic Acid by Sunflower Plants

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Chelating agents are coming into widespread use in agriculture for the prevention and cure of iron-deficiency chlorosis in plants. Little, however, is known about absorption, translocation, and metabolism of these materials by plants. This investigation was carried out in order to gain some information on absorption and translocation of ethylenediaminetetraacetic acid, the most widely used of the chelates. Solution culture experiments with sunflower, employing the split-root technique, indicate that iron is absorbed by one portion of the split root growing in nutrient solutions adjusted to pH 7.0, but is not utilized, resulting in iron-deficiency chlorosis. When ethylenediaminetetraacetic acid was supplied through the other portion of the split root, excellent plant growth was obtained, indicating that the chelate made iron available to all portions of the plant. It would be of considerable help for agricultural use to know whether the chelate transports iron to the root surface where only the iron is absorbed, or whether the whole chelated molecule is absorbed by the roots of plants.

ETHYLENEDIAMINETETRAACETIC ACID (EDTA) and its metal salts are in widespread use both commercially and experimentally in plant nutrition and in plant and animal biochemistry. Since Jacobson (4) first reported the use of ferric dipotassium ethylenediamine tetraacetate (Fe-EDTA) as a satisfactory source of iron for plants growing in solution cultures, there has been considerable impetus behind the use of ethylenediaminetetraacetic acid and similar materials by other workers. Weinstein (12) found that ferric disodium ethylenediamine tetraacetate was a good nutrient source of iron for sunflower plants grown in culture solutions adjusted to pH 7.0. Although iron supplied as ferrous sulfate was absorbed by the plants, it was not utilized at this pH. High nutrient levels of manganese did not induce symptoms of iron deficiency in sunflower plants supplied with iron as ferric disodium ethylenediamine tetraacetate, whereas plants supplied with iron as ferrous sulfate exhibited advanced symptoms of iron-deficiency chlorosis. This suggests that plants absorb the chelated iron molecule and transport it

to the site of enzyme synthesis, where the iron is released through enzymatic decomposition of the chelate and is replaced by hydrogen or other cations.

Ethylenediaminetetraacetic acid and other chelating materials are now being extensively applied to soils for control of iron-deficiency chlorosis in many field and ornamental crops (1, 5-8, 11, 13).

Wallace and North (10) have presented data indicating that ethylenediaminetetraacetic acid is absorbed and metabolized by plants. By supplying corn seedlings with ferric disodium ethylenediamine tetraacetate containing an isotopically labeled nitrogen atom, they found radioactivity in a number of nitrogen fractions. Further evidence that ethylenediaminetetraacetic acid is absorbed by plants is presented in this paper.

### Materials and Methods

An experiment designed to provide evidence relative to absorption and translocation of ethylenediaminetetraacetic acid by sunflower plants was carried out in solution culture. The seeds (*Hel-*

*ianthus annuus* L.) were planted in flats of washed quartz sand on August 11, 1953. On September 1 a series of eight sunflower plants was set up in a split-root technique in solution cultures. Each culture consisted of two 2-liter borosilicate glass beakers with a wooden cover assembly so constructed as to support one plant and to allow aeration of solutions (Figure 1). Plants were supported in an upright position by wooden dowels attached to the cover assembly, which was coated with Tygon varnish. Root systems of the sunflower seedlings were separated into two equal portions, one portion being placed in each of two containers. An additional series of plants was grown in eight conventional solution cultures. Each culture consisted of a 1-gallon wide-mouthed glass jar accommodating two seedlings. Although these plants were subjected to the same nutrient treatments, the root systems were not separated, the cultures being used as controls for each of the split-root treatments.

Complete nutrient solutions, with the exception of additions of iron and ethylenediaminetetraacetic acid, were