S 88. *Study of Fertiliser Uptake using Radio-phosphorus.*

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Field experiments are described in which the uptake of phosphorus by plants was followed by means of ^{32}P. The relative values of various phosphate fertilisers are assessed.

RADIOACTIVE isotopes have long been used as tracers, and one of the earliest applications of the tracer method was in plant physiology. As early as 1923, Hevesy (*Biochem. J.*, **17**, 439) used a radioactive lead isotope, Th-*B*, to measure quantitatively the uptake of lead by bean plants.

Some years later ^{32}P was used in qualitative soil and plant studies (Hevesy, Linderstrom-Lang, and Olsen, *Nature*, 1936, **137**, 66; Brewer and Bramley, *Science*, 1940, **91**, 269; Ballard and Dean, *Soil Sci.*, 1941, **52**, 173), and still later ^{32}P was used for quantitative studies of phosphate-fertiliser uptake by wheat plants (Spinks and Barber, *Sci. Agr.*, 1947, **27**, 145; 1948, **28**, 79; Spinks, Dion, Reade, and Dehm, *ibid.*, p. 309; Proc. Auburn Conference, Dec. 1947, Edwards Brothers, Ann Arbor, 1948). By combining the radioactive measurement of fertiliser uptake with the measurement (by ordinary chemical methods) of total phosphorus uptake, the uptake of soil phosphorus could be determined by difference. In the past, the recovery of phosphate fertiliser by any crop has been determined by a comparison of the uptake of phosphorus by crops grown with and without fertilisers. The extra phosphorus in the fertilised crop was taken as the quantity coming from the fertiliser. The method assumes that fertilised and unfertilised crops take up the same amount of soil phosphorus, and some tracer experiments indicate that this may not always be the case (Spinks and Barber, *locc. cit.*; Spinks, Dion, Reade, and Dehm, *loc. cit.*).

The general procedure is to convert the radioactive phosphorus, diluted with a large amount of inactive phosphorus, into the desired form of phosphate fertiliser. Care is taken that the ^{31}P and ^{32}P are in the same chemical form and intimately mixed, *e.g.*, radioactive ammonium phosphate fertiliser is made by adding phosphoric acid of high specific activity to a solution of inactive ammonium phosphate and subsequently evaporating this solution to dryness with stirring.

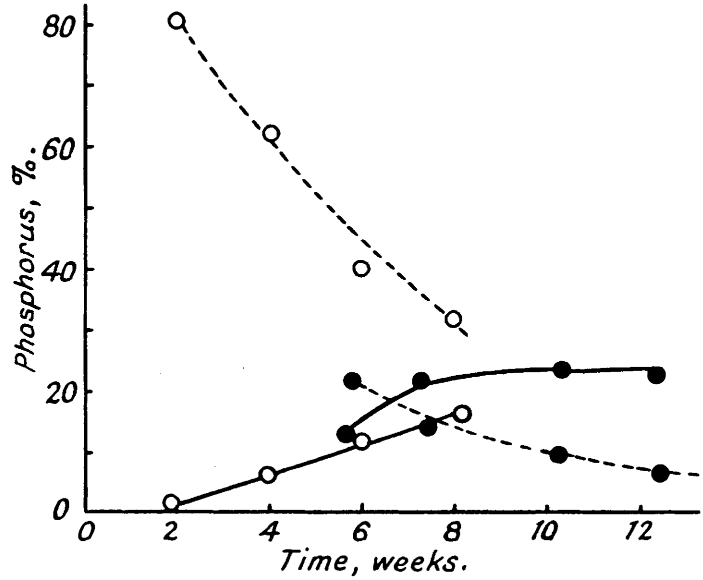
In the work reported here, the radioactive fertiliser was applied to the soil at the time of seeding, and the plants harvested at roughly four-week intervals. The plants were dried and weighed and then wet-ashed with nitric, sulphuric, and perchloric acids (Brenner and Harris, *Chem. Analyst*, 1939, **28**, 56). The resulting solution was made up to a known volume and aliquots of a suitable size were used for total phosphorus and radio-phosphorus determinations. The total phosphorus content was determined colorimetrically by the method of Shelton and Harper (*Iowa State Coll. J. Sci.*, 1941, **15**, 403). The radio-phosphorus was determined, after precipitation as magnesium ammonium phosphate and ignition to pyrophosphate, by measuring with a Geiger–Müller β-chamber. The decay of ^{32}P and counter fluctuations were allowed for by counting the unknown material against a standard consisting of a known amount of the original radioactive fertiliser. Standard geometry was used and corrections for self absorption were made (Spinks and Barber, *locc. cit.*).

Experimental.

In the Canadian prairies the most successful phosphate fertiliser is " 11—48—0 " (ammonium phosphate) and it is commonly applied at very low rates (20 lb. per acre). It is applied with the seed, and when applied at about 40 lbs. per acre, gives average increases in yield of 40% or more. The soils in general are neutral to alkaline in reaction, with plentiful supplies of calcium in the surface and calcium carbonate in subsoil layers.

Various problems have been of interest—such as the effect of type of soil, type of fertiliser, and rate of application of fertiliser. In addition, the question of the nutritive value of the nitrogen in the ammonium phosphate is of interest since it has been suggested as the cause of the superiority of " 11—48—0 " over other phosphate fertilisers in this region.

Fig. 1.



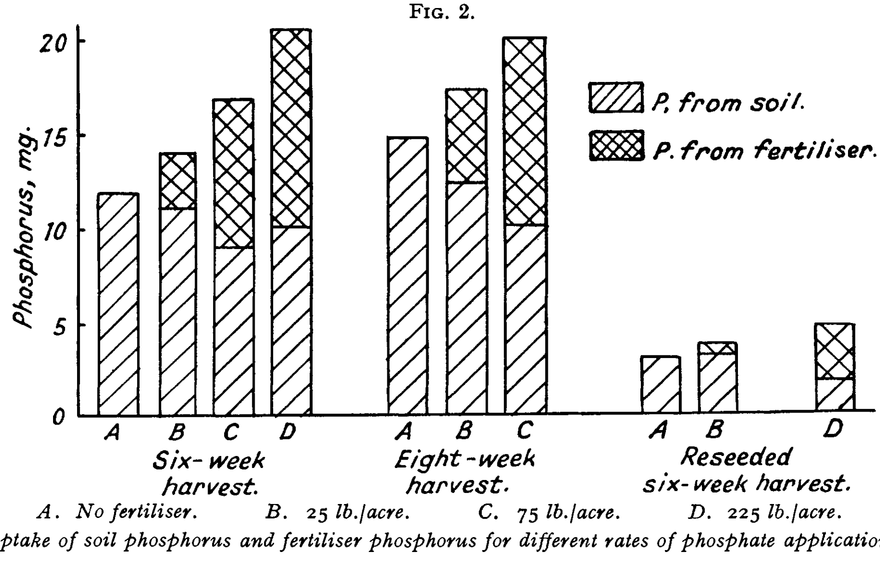
- - - - - *Phosphorus uptake, %, that came from the fertiliser.*
——— *Fertiliser phosphorus, utilised, %.*

Combined results for fertiliser uptake in field and greenhouse.

Field, ●; greenhouse, ○.

[Reproduced, with permisssion, from *Proceedings of the Conference of Nuclear Chemistry,* McMaster University, Hamilton, Canada, 1947, Part II, p. 148.]

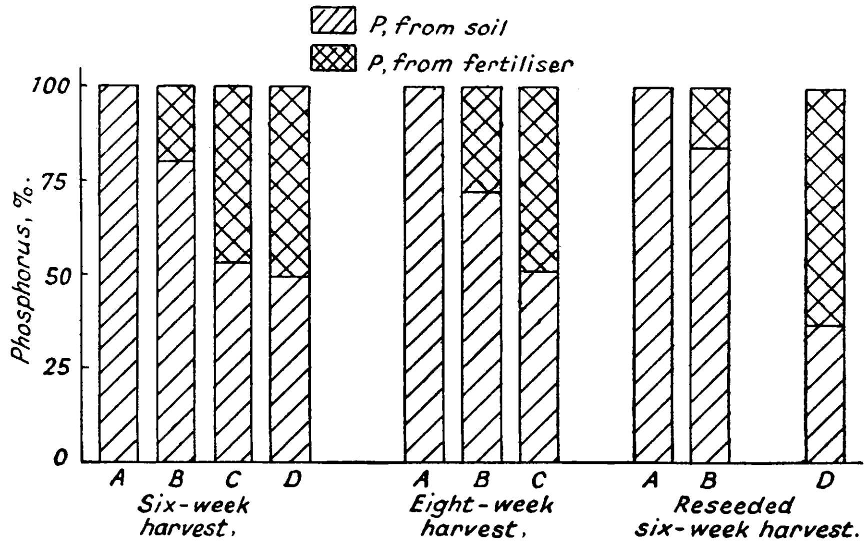
Fig. 2.



A. No fertiliser. *B.* 25 *lb./acre.* *C.* 75 *lb./acre.* *D.* 225 *lb./acre.*

Uptake of soil phosphorus and fertiliser phosphorus for different rates of phosphate application.

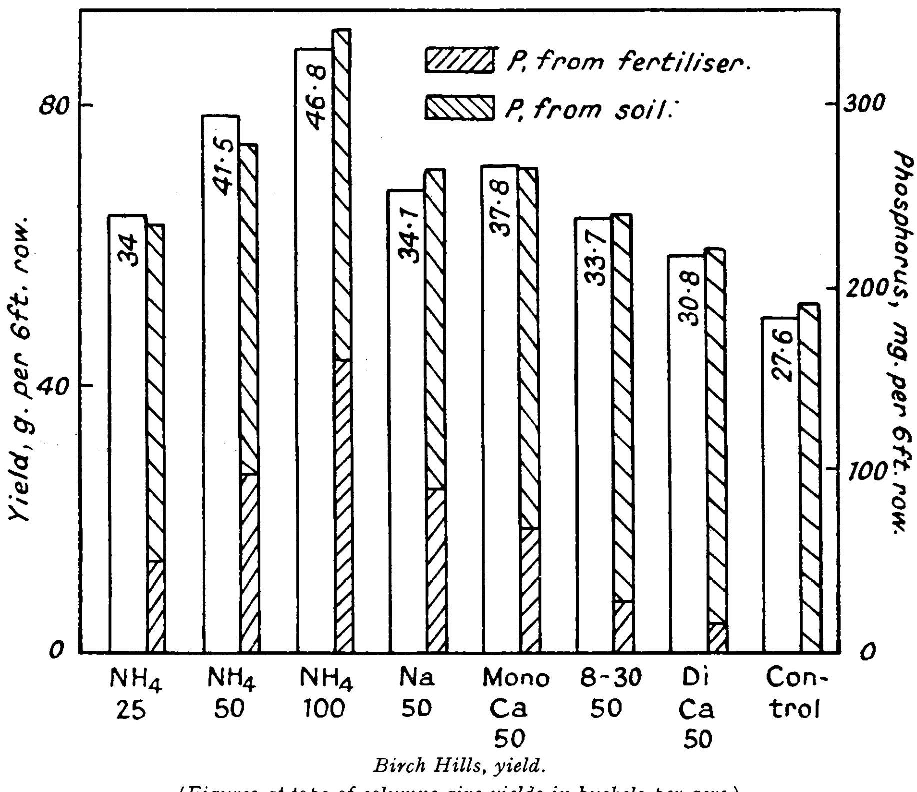
FIG. 3.



A. No fertiliser. B. 25 lb./acre. C. 75 lb./acre. D. 225 lb./acre.

Percentage of phosphorus in the plant from soil and fertiliser for different rates of phosphate application.

FIG. 4.



Birch Hills, yield.

(*Figures at tops of columns give yields in bushels per acre.*)

Yield and phosphorus uptake for various types of fertiliser at Birch Hills.

A number of experiments have been carried out both in the field and in the greenhouse, with a variety of soils, fertilisers, and rates of application, in an attempt to cast some additional light on these questions.

The first experiments used ammonium phosphate at **25** lb. per acre, dissolved in water applied with the seed of Thatcher wheat, sown in a chestnut silty loam soil. The results as indicated in Fig. **1** (Spinks and Barber, *locc. cit.*) show that for the first two weeks of growth, about **80**% of the phosphorus in the plant has come from the fertiliser, while as growth proceeds, the uptake of soil phosphorus becomes progressively larger proportionately, until at maturity, **80**% of the phosphorus comes from the soil. Quantitatively, fertiliser phosphorus and soil phosphorus both continue to increase during the life of the plant. About **22**% of the applied fertiliser phosphate was taken up by the plant, the rest being considered " fixed " and unavailable.

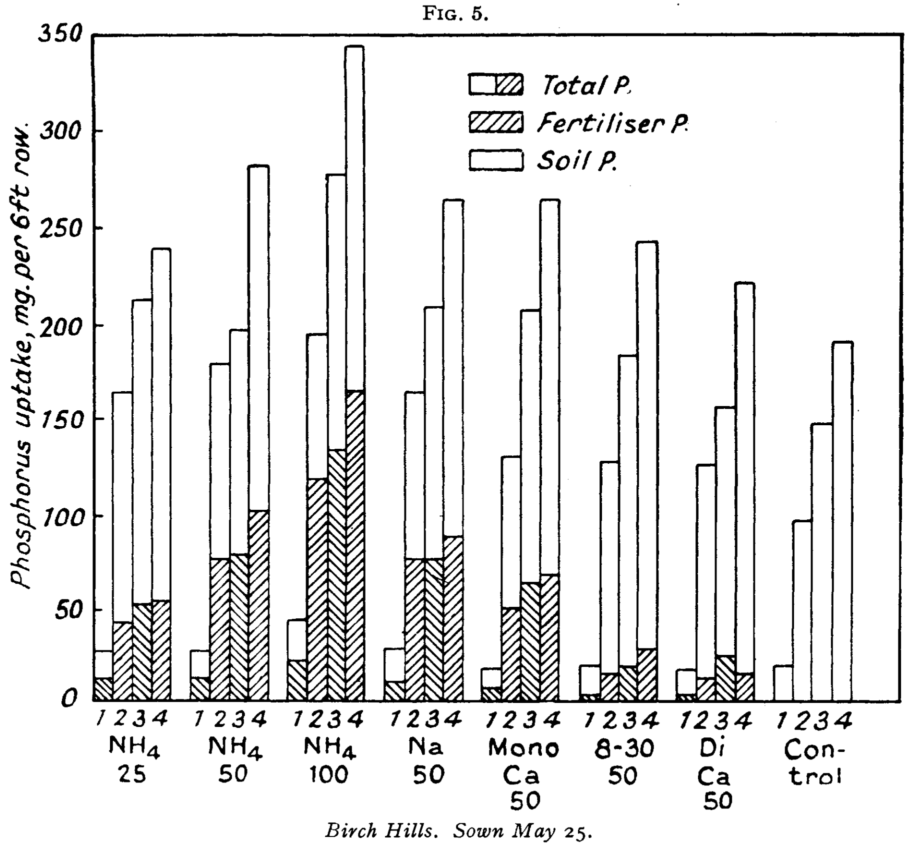
A subsequent greenhouse trial on rate of application, involving rates of **0**, **25**, **75**, and **225** lb. of ammonium phosphate per acre, showed, as indicated in Figs. **2** and **3** (Spinks, Dion, Reade, and Dehm, *loc. cit.*), that with increasing rate of phosphate application, the *amount* of fertiliser phosphorus taken up increases, while the *percentage* of fertiliser used decreases. The uptake of soil phosphorus in this trial was depressed with fertiliser application, indicating the danger of assuming that the difference between fertilised and unfertilised plots in phosphorus uptake represents phosphorus from the fertiliser. In this experiment, part of the series of plots were cropped a second time, and the indications are that only very small percentages of the original phosphorus applied could be available to subsequent crops.

Another experiment has indicated that, although greater uptake of applied phosphate may be obtained by applying it during the growing season, the greatest yields with wheat are obtained by applying it with the seed (Barber, Thesis, Saskatchewan, **1947**).

Field Experiments.—In **1948**, three rather large field experiments were laid out at widely scattered places in the province of Saskatchewan. At each location, **8** different treatments, randomised in blocks, were arranged as a modified Latin square so as to have **4** replicates available for each of **4** harvest dates. The plot for each individual treatment consisted of **5** rows, the two outside rows being guard rows, while the three centre rows received the designated fertiliser treatment, with only the centre row being treated with radioactive fertiliser.

The various treatments are listed in Table I to show the amounts and the form of the nutrients applied. The results for one location are presented in Table II, and in Figs. **4** and **5**. The complete results will be published elsewhere (Dion, Dehm, and Spinks, *Sci. Agr.*, **1949**, **29**, **512**), and since the other locations give very similar data, they are not presented here.

FIG. 5.



Birch Hills. Sown May 25.

Harvest dates: 1. *June* 21. 2. *July* 7. 3. *July* 23. 4. *August* 24.

Uptake of soil phosphorus and fertiliser phosphorus for different types of fertiliser and at various harvest dates.

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TABLE I.

Fertiliser treatments—field trials, 1948.

Material.	Lb. of nutrients per acre. P_2O_5.	N.	Material.	Lb. of nutrients per acre. P_2O_5.	N.
1. $NH_4H_2PO_4$ (half rate)......	12	2·8	5. $CaH_4(PO_4)_2$	24	—
2. $NH_4H_2PO_4$	24	5·5	6. $Ca_2H_2(PO_4)_2$	24	—
3. $NH_4H_2PO_4$ (double rate)	48	11	7 $Ca_2H_2(PO_4)_2$ + $Ca(NO_3)_2$	24	6·4
4. NaH_2PO_4	24	—			

TABLE II.

Yield and analysis of radio-phosphorus fertiliser trial, Birch Hills, Sask., 1948.*

Harvest date†	Treatments. $NH_4H_2PO_4$, half rate.	$NH_4H_2PO_4$.	$NH_4H_2PO_4$, double rate.	NaH_2PO_4.	$CaH_4(PO_4)_2$.	$Ca_2H_2(PO_4)_2$.	$Ca_2H_2(PO_4)_2$ +$Ca(NO_3)_2$.	Unfert.
	Average plant weight (g./6′ row).							
I	10·9	10·8	12·3	10·5	9·6	7·6	8·3	7·7
II	62·4	70·2	69·4	67·3	49·6	50·3	52·8	38·6
III	127·2	120·2	143·4	119·8	121·4	89·9	106·6	93·2
IV	142·9	165·0	189·9	150·5	153·4	125·8	136·2	108·5
	Total phosphorus (mg./6′ row).							
I	25·7	27·0	39·3	28·2	18·2	16·9	19·3	19·5
II	162·3	177·2	194·0	161·5	128·9	124·2	126·1	95·0
III	211·8	190·6	276·1	200·7	206·6	153·1	173·5	148·7
IV	236·3	280·7	343·4	261·9	262·3	219·5	240·7	188·3
	Fertiliser phosphorus taken up (mg./6′ row).							
I	11·7	13·2	20·5	9·5	6·7	2·9	1·5	—
II	41·4	75·5	117·2	74·4	49·3	12·6	15·1	—
III	52·3	80·9	138·1	74·2	66·4	20·4	17·6	—
IV	52·8	100·7	163·6	87·5	66·4	13·8	21·9	—
	Soil phosphorus (mg./6′ row).							
I	14·0	13·8	18·8	18·7	11·5	14·0	17·7	19·5
II	120·9	101·7	76·8	88·0	79·7	111·6	111·0	95·0
III	159·3	109·0	138·0	126·5	140·2	132·7	153·1	148·1
IV	183·5	180·1	179·8	174·4	195·9	205·8	218·7	188·3
	Fertiliser phosphorus taken up, as % of fertiliser phosphorus applied.							
I	7·2	4·0	3·1	2·9	2·0	0·9	0·5	—
II	25·3	23·0	17·9	22·4	15·0	3·9	4·6	—
III	31·8	24·7	21·1	22·6	20·3	6·2	5·4	—
IV	32·2	30·7	25·0	26·7	20·3	4·2	6·7	—
	Fertiliser phosphorus taken up, as % of total phosphorus in plant.							
I	46·9	48·3	52·0	33·3	36·7	16·7	8·1	—
II	27·7	42·7	60·2	45·4	38·6	11·0	12·4	—
III	25·5	42·4	50·0	36·7	32·8	13·2	10·1	—
IV	22·5	36·0	49·4	33·0	25·6	6·4	9·4	—

* Each result is an average of four replicates.

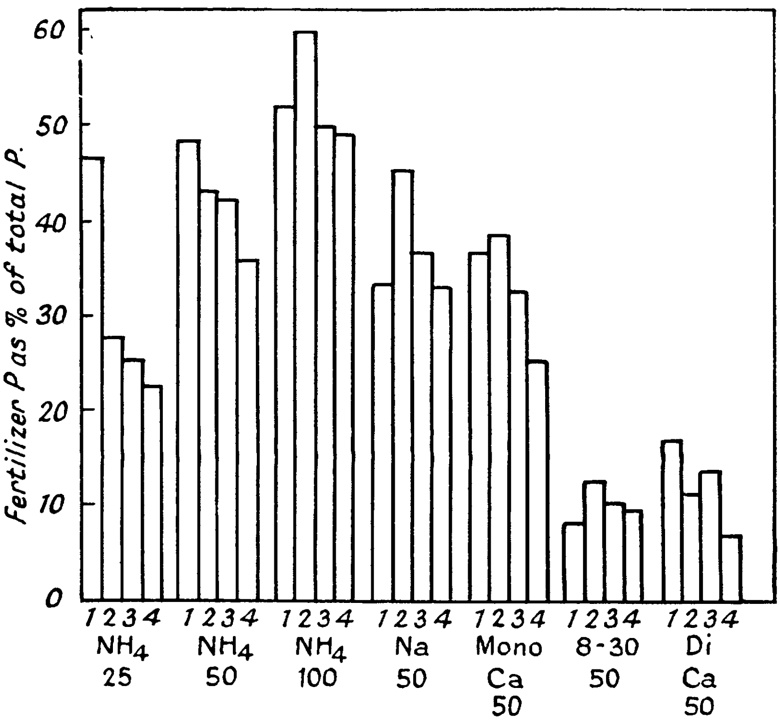
† Seeded May 25 with Thatcher spring wheat. Harvested : I, June 21 ; II, July 7 ; III, July 23 ; IV, August 24.

The data indicate that : (*a*) An increase in the rate of application of ammonium phosphate results in an increase in plant weight, total phosphorus uptake, and fertiliser phosphorus uptake, and a decrease in the percentage of applied fertiliser taken up. (*b*) At equal phosphate application (50 lb. of 11—48—0 ammonium phosphate per acre), the order of decreasing availability of the carrier is as follows : $NH_4H_2PO_4$, NaH_2PO_4, $CaH_4(PO_4)_2$, $Ca_2H_2(PO_4)_2 + Ca(NO_3)_2$, $Ca_2H_2(PO_4)_2$. (*c*) The close similarity between $NH_4H_2PO_4$ and NaH_2PO_4 indicates that the superiority of the former over the calcium phosphates is due to its solubility, and probably to the slower conversion into unavailable $Ca_3(PO_4)_2$. This leads to the conclusion that "11—48—0" (ammonium phosphate) owes its superiority to the fact that it is not a calcium phosphate, rather than to the direct nutrient role of the nitrogen it carries. This is borne out by a comparison of $NH_4H_2PO_4$ and $Ca_2H_2(PO_4)_2 + Ca(NO_3)_2$. (*d*) Monocalcium phosphate is much more available than dicalcium phosphate, which is best attributed to a relatively slower conversion into $Ca_3(PO_4)_2$ in the case of the former salt.

A determination of radioactive phosphorus on rows adjacent to the " tracer " row indicate that these adjacent rows take up only a very small part of the fertiliser supplied in the neighbouring rows—that is, that the root systems are fairly separate at the level at which the seed is sown. The maximum uptake by adjacent rows, of fertiliser applied to the central row, was less than 1% of the fertiliser applied.

A further study of the yield of the wheat plants from the radioactive row and the adjacent non-active rows, fertilised with the same kind of material at the same rate, indicates that the activity has no detectable harmful effects on the plants, the yield of the above-ground parts being used as the criterion. Although it is known that large amounts of activity will adversely affect the growth of plants (Scott-Russell and Martin, *Nature*, 1949, **163**, 71; Arnason, Cumming, and Spinks, *Canadian J. Res.*, 1948, **26**, *C*, 109), the data obtained in this trial indicate that it is easily possible to keep the applied activity below the limit at which it appreciably affects the growth, and at the same time have enough activity present to follow the path of the fertiliser phosphorus through to maturity.

FIG. 6.



Birch Hills.

Harvest dates: 1. *June* 21. 2. *July* 7. 3. *July* 23. 4. *August* 24.

Fertiliser phosphorus as % of total phosphorus in plant, for various types of fertiliser.

Additional experiments are planned for other aspects of these problems, and it is hoped that the additional knowledge obtained will be of real value to our agriculture. The data obtained in 1948 aided in proving to industry that the $Ca_2H_2(PO_4)_2 + Ca(NO_3)_2$ (which is an "8—30—0" analysis) was not satisfactory in the region of neutral or alkaline soils for which it was intended.

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