Phosphorus in Soils and Fertilizers

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THE PROBLEMS associated with soil phosphorus, the use of phosphatic fertilizers, and the phosphorus nutrition of plants are very complex. First of all, the chemistry of orthophosphoric acid and its compounds is highly involved, and problems multiply when phosphates are introduced into a wide range of soils varying in content of clay, organic matter, lime, and particularly compounds of iron and aluminum. Additional problems arise when plants are introduced into the system, for plants vary widely in their phosphorus requirement, and in their ability to grow at different phosphorus levels. It is not surprising, therefore, that despite extensive research in this field there are many unsolved problems. These problems interest the whole American fertilizer industry, which was founded on phosphates, beginning with the manufacture of superphosphates in Baltimore in 1850. Today the industry produces approximately 10 million tons of 20 percent superphosphate or its equivalent.

An adequate supply of radioactive phosphorus is making possible extensive use of the tracer technique in soil, fertilizer, and plant nutrition investigations. This season will conclude three years of rather extensive field experiments which have been supplemented with laboratory and greenhouse studies.

Before considering results of our radioactive phosphorus investigations it may be of interest to review some of the broader aspects of soil and fertilizer phosphorus problems in the United States.

Phosphorus content of soils. The total phosphorus content of surface soils in the United States in their virgin condition is indicated by Fig. 1. The most deficient area is the coastal plain of the South Atlantic and Gulf Coasts. From this low level, the phosphorus content increases, generally speaking, to the north and west, and is particularly high in the soils of the Blue Grass Region of Kentucky and the Central Basin of Tennessee.

Total phosphorus of itself is a poor index of the phosphorus fertility status of soils, but it indicates the reserve supply, which is important. Phosphorus exists in the soil in three major forms: primary minerals, adsorbed phosphorus on the surface of clay minerals, and organic phosphorus, a constituent of the soil organic matter. The last two forms are the more important from the standpoint of immediate plant nutrition. The relative proportions of the three forms vary widely in different soils.

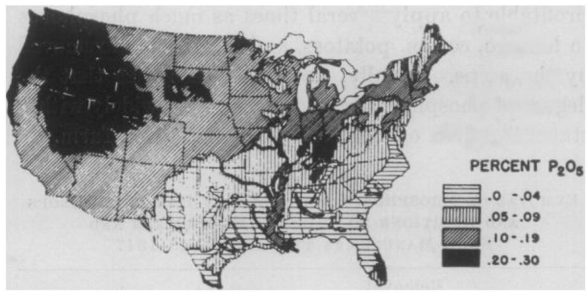

FIG. 1. Phosphoric acid in surface foot of soil.

Phosphorus is being removed from the soil by crops and is being returned in the form of crop residues, farm manures, and commercial fertilizers. The relationships between the quantity removed by harvested crops and the quantity applied as farm manures and fertilizer enables us to visualize trends in soil fertility and improvement. Fig. 2 shows this relationship by states for 1947. Note that five southeastern states and four northeastern states applied more than four times as much phosphorus as was removed by all harvested crops. Virginia and twelve other states applied between two and four times as much phosphorus as was removed by cropping. On the other hand, the Great Plains states returned less than 25 percent as much as was being removed.

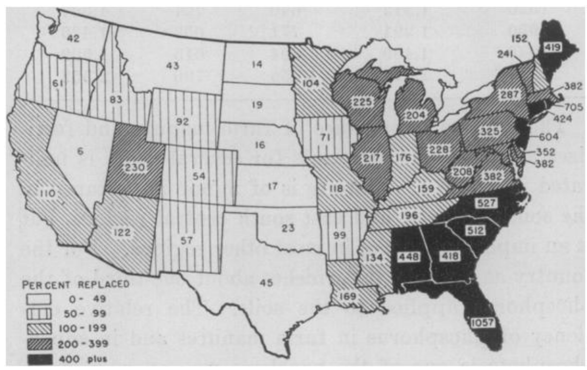

FIG. 2. Relation between phosphorus removed from the soil by harvested crops and that applied in fertilizers and manures.

This figure must be interpreted with caution. First, let's note that the heavy applications are being made in the general region where phosphorus deficiency was initially great. Conversely, the lowest return is in a region of moderate to high total phosphorus content of the soil. Second, the use of phosphorus should be related to economic return from its use rather than to the amount removed by crops. In the Great Plains, water is so often the factor limiting growth that the use of any fertilizer has been generally uneconomic. On the other hand, field experiments in the humid region have conclusively shown that it is generally profitable to apply several times as much phosphorus to tobacco, cotton, potatoes, and alfalfa as is removed by the crops. Finally, we should recognize that the degree of phosphorus replacement varies widely within states and even on different fields of a given farm.

TABLE 1

REMOVAL OF PHOSPHORIC ACID, P_2O_5, BY HARVESTED CROPS AND ADDITIONS TO SOILS AS FERTILIZERS AND FARM MANURES IN THE U. S., 1910–1947

Year	Removal by harvested crops	Applied to crops in—		
		Fertilizers	Manures	Total
	Thousands of tons			
1910	1,103	490	631	1,121
1920	1,372	640	727	1,367
1930	1,291	771	655	1,426
1940	1,439	894	615	1,509
1947	1,815	1,756	796	2,552

The relative importance of farm manure and fertilizer as phosphate materials for several years is indicated in Table 1. Manure is of minor importance in the south Atlantic and east south central regions, but is an important source in most other regions. For the country as a whole, it furnishes about one-third of the phosphorus applied to the soils. The relative efficiency of phosphorus in farm manures and in superphosphate is one of the problems we can now study critically for the first time with radiophosphorus.

Note from the table that in 1947 we returned about 50 percent more phosphorus to the soil than was removed by crops. As was indicated by Fig. 2, the return in Virginia was approximately fourfold and in several states it was even greater. Since phosphorus is not lost by leaching, these data indicate that the phosphorus content of soils in some states may be increasing. In some areas losses of added phosphorus by erosion may be serious.

A few years ago a study was made of the available phosphorus in soils used for the production of potatoes in Northampton County, Virginia. Soils from 56 farms contained an average of 662 pounds of available phosphoric acid per acre, whereas adjacent virgin soils contained only 25 to 70 pounds of available phosphoric acid. This improved phosphorus fertility status resulting from heavy fertilization raises certain questions. For example, to what extent can a farmer reduce his fertilizer bill and cash in on the residual phosphorus? Do crops differ in their ability to utilize these reserves?

By way of sharp contrast we might compare the phosphorus situation in Virginia and North Carolina with that in the Great Plains. Our research program indicates that the time is approaching when it will be economical to increase phosphorus fertilization, to offset, partially at least, the continuous removal by crops during the last 50 to 100 years.

So much for the broader aspects of the phosphorus fertility problem in this country. We will now direct our attention to the recent work with radioactive phosphorus.

Underlying principles of tracer studies. In the experiments we are to consider,[1] radioactive phosphorus, P^{32}, is used simply as a tracer. Only an infinitesimal proportion of the phosphorus in fertilizer is radioactive, but appropriate calculations enable us to determine how much of the phosphorus in a fertilized crop was derived from the fertilizer and how much from the soil. Experimental quantities of nine different radioactive fertilizers have been made at Beltsville for cooperative field experiments with state agricultural experiment stations in all sections of the country. Our experiments indicate that radioactivity per se does not influence plant growth at the levels of P^{32} used in these studies.

The experiments have included studies on (a) the comparative utilization of different phosphorus materials, (b) the utilization of soil and fertilizer phosphorus by different crops, and (c) the influence of phosphorus fertility of soils on the utilization of applied phosphorus. We shall consider some of the data from these investigations.

Comparative use of different phosphate materials. Phosphorus may be applied to the soil in any one of a wide variety of materials. All fertilizer phosphates are made from rock phosphate, which is also used for soil applications to the extent of nearly a million tons annually in recent years. Phosphorus in rock phosphate is in the fluorapatite form, highly insoluble. Superphosphate, the most commonly used phosphate fertilizer, is produced by treating rock phosphate with sulfuric acid. Its main constituents are monocalcium phosphate and calcium sulfate. The phosphorus is readily soluble in water.

[1] The data discussed were, with one exception noted, selected from twelve articles on radioactive phosphorus investigations that were published in *Soil Science*, Vol. 68, pages 113–202, August 1949.

TABLE 2

THE EFFECT OF SOURCE OF PHOSPHORUS, RATE OF APPLICATION, AND SOIL HISTORY ON THE YIELD AND PHOSPHORUS UPTAKE OF VETCH

Rate of application	Soil history		Total yield† of four cuttings	Phosphorus‡ in the plant	Phosphorus‡ derived from the fertilizer
	Treatment*	pH			
lb/acre P_2O_5			g/culture	%	%
None					
	R	4.9	8.5	0.27	...
	R + L	5.5	7.0	0.29	...
	M + L	5.8	10.1	0.28	...
	Soils treated with rock phosphate				
350	R	4.9	17.7	0.36	66.4
	R + L	5.5	15.4	0.37	46.4
	M + L	5.8	14.1	0.34	30.6
700	R	4.9	18.9	0.39	81.6
	R + L	5.5	16.4	0.38	64.6
	M + L	5.8	15.8	0.38	49.5
1400	R	4.9	19.2	0.42	94.6
	R + L	5.5	16.6	0.42	87.2
	M + L	5.8	16.6	0.40	72.9
	Soils treated with superphosphate				
87.5	R	4.9	18.3	0.33	58.0
	R + L	5.5	16.8	0.35	51.8
	M + L	5.8	17.9	0.35	50.8
175	R	4.9	18.6	0.38	79.4
	R + L	5.5	19.4	0.40	75.6
	M + L	5.8	18.2	0.39	68.3
350	R	4.9	21.3	0.46	92.3
	R + L	5.5	20.5	0.50	90.3
	M + L	5.8	21.2	0.51	86.3

* R = Residues ; R + L = residues + lime ; M + L = manure + lime.

† L.S.D. = 1.5.

‡ Mean of triplicates of three cuttings.

In a recently completed study, neutron pile-irradiated rock phosphate was used in comparison with superphosphate (*1*). The soils were from three plots of the Joliet, Illinois, experiment field. Their reaction varied from pH 4.9 to 5.8. Alfalfa, vetch, and rye grass were used as crops in this greenhouse experiment. The results obtained with vetch on the soil of pH 5.8 are shown in Table 2.

The first column indicates the rates of fertilization. Note the lowest rate for rock phosphate is the same as the highest rate of superphosphate. There was a good growth response to both fertilizers, but superphosphate was distinctly superior to rock phosphate. Fertilization increased the percentage of phosphorus in the plant. If this is used as an index of efficiency, superphosphate is again the superior source.

The last column of the table supplies data obtained by the use of P^{32}. It shows that the vetch grown with increasing rates of rock phosphate derived from 30 percent to 73 percent of the phosphorus from the fertilizer. The corresponding figures for superphosphate were 50 percent to 86 percent.

The results obtained with four successive cuttings of alfalfa are shown graphically in Fig. 3. It illustrates several points. First, we should note that in this figure the comparison is between 700 pounds of phosphoric acid in rock phosphate and 150 pounds of phosphoric acid in superphosphate. The figure shows that the utilization of rock phosphate declined with increasing pH, but the utilization of superphosphate was not materially affected by the soil reaction. At the rates compared, rock phosphate was superior to superphosphate on the most acid soil at all harvests. Superphosphate, however, was superior to rock phosphate on the least acid soil. On the soil of intermediate acidity, superphosphate was superior on the first two cuttings and rock phosphate on the last two. The experiments noted here show influences of the different phosphorus carriers for a single season only. Residual effects as shown in crop yields over a period of years must also be considered. Irradiated materials are not suitable for such studies.

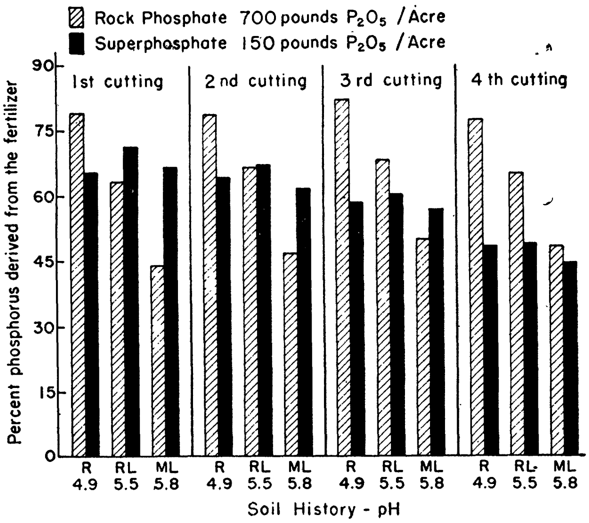

FIG. 3.

The field experiments have included the common phosphate materials produced by the fertilizer industry—superphosphate, double superphosphate, ammonium phosphate, and liquid phosphoric acid. They also included dicalcium phosphate, calcium metaphosphate—a TVA product—and alpha tricalcium phosphate. The last named is the phosphate compound in the furnace products produced by Coronet Phosphate Company and TVA.

The results of an experiment with three materials for corn grown on an acid soil in North Carolina are given in Fig. 4. This shows that the crop obtained twice as much phosphorus from superphosphate and

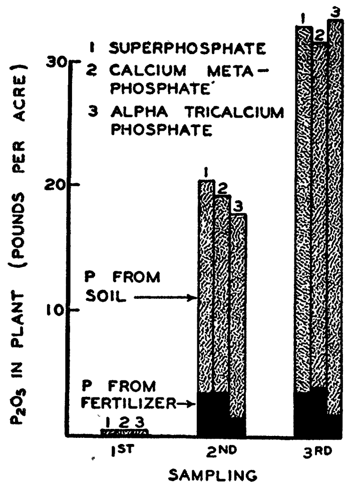

FIG. 4. Corn—Norfolk series (412 lb P_2O_5/acre).

calcium metaphosphate as from alpha tricalcium phosphate. It may be noted that most of the phosphorus in the crop came from the soil on all treatments. The supply of native soil phosphorus in much of this area is low. It may be assumed, therefore, that a large part of the so-called soil phosphorus taken up is in reality from fertilizer residues of former years.

An experiment in Iowa with oats as a test crop indicated a slight superiority of superphosphate. There were no significant differences between the other three materials. In this experiment, fertilization

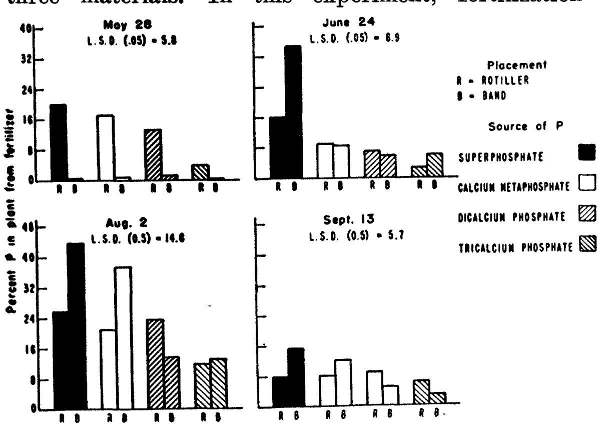

FIG. 5.

materially increased the phosphorus content of the crop. A moderately large percentage of the phosphorus was derived from the fertilizer.

The last experiment with different materials was with sugar beets in Colorado. It involved two methods of fertilizer placement. In the first, the fertilizer was mixed in the seedbed with a rototiller and the seed planted in the fertilized soil. In the second, the fertilizer was placed in a band six inches from the seed. The results are shown in Fig. 5.

The first bar of each pair represents the percentage of phosphorus in the plant derived from the fertilizer when the rototiller placement was used. At all sampling dates superphosphate was superior, but calcium metaphosphate was a close second.

The effect of placement is of interest. At the first sampling the beet roots apparently had not reached the band of fertilizer. At the second and subsequent samplings the band placement resulted in the better utilization of superphosphate and calcium metaphosphate.

Our studies with materials indicate the general superiority of superphosphate under most conditions. Canadian workers, however, have some evidence that ammonium phosphate is superior to superphosphate for wheat on calcareous soils.

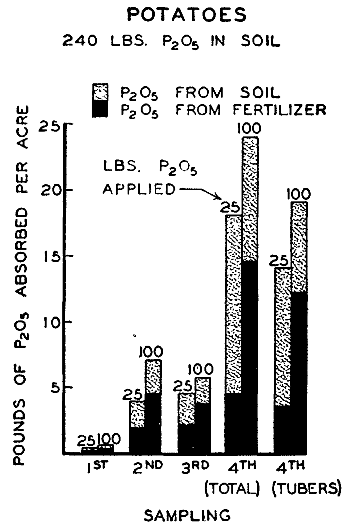

FIG. 6.

Earlier mention was made of the importance of farm manures as a source of phosphorus. Cornell investigators have compared farm manure and superphosphate, both containing P^{32}, in greenhouse experiments. Their data indicate that the phosphorus in the two materials is utilized to approximately the same degree by rye grass. Somewhat similar results were obtained at Beltsville in greenhouse experiments comparing green manures and superphosphate as sources of phosphorus for rye grass. In this instance, green manures supplied about 70 percent as much phosphorus to the rye grass as did superphosphate. The preliminary work, therefore, indicates that the phosphorus in green manures and farm manure is approximately as efficient as phosphorus applied in superphosphate.

Utilization of applied phosphorus by different crops. The experiments indicate that crops differ widely in their capacity to utilize soil and fertilizer phosphorus. The results of an experiment with potatoes are given in Fig. 6, in which the amount of phosphorus absorbed per acre is plotted against four sampling dates. The experiment was on a soil containing 240 pounds of available phosphorus per acre, which is a moderate quantity. In the experiment potatoes were fertilized with 25 and 100 pounds of phosphoric acid per acre. The bars show the amount of phosphoric acid in the crop at each sampling date. The solid black portion of each column indicates phosphorus derived from the fertilizer, whereas the shaded portion represents phosphorus from the soil. Note first that at all sampling dates and at both rates of fertilization almost one-half of the phosphorus was from the fertilizer, second that increasing the rate of fertilization increased both the total and fertilizer phosphorus on sampling dates except the first, and third that at final harvest only 15

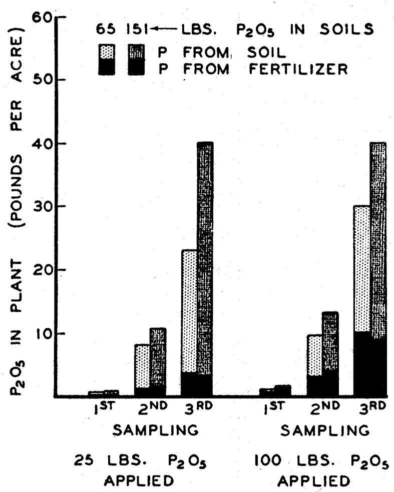

FIG. 7. Corn—Bladen series.

percent to 25 percent of the applied phosphorus was found in the crop. A similar experiment with corn affords an interesting contrast (Fig. 7). Here we have two rates of fertilization—25 and 100 pounds—just as in the potato experiment. We also have two soils—one with 65 and the other with 150 pounds per acre of available phosphoric acid. Neither soil is as fertile as that in the potato experiment, which had 240 pounds per acre of available phosphoric acid. It is immediately evident that, after the first sampling date, corn obtains most of the phosphorus from the soil. The total phosphorus absorbed is influenced more by the initial level of soil phosphorus than by the rate of fertilization. Finally, recovery of fertilizer phosphorus is lower than in the case of potatoes.

A comparison of the utilization of fertilizer phosphorus by corn, soybeans, and potatoes is given in Fig. 8. With corn the percentage of phosphorus derived from the fertilizer dropped from 80 percent to 25 percent from the first to the last sampling. It is interesting to note that potatoes at all sampling dates derived 50 percent to 60 percent of the phos-

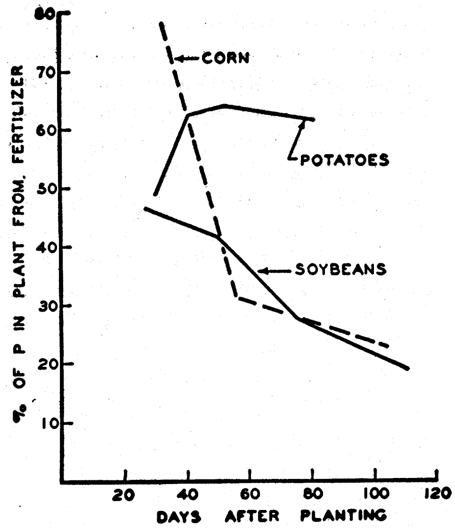

FIG. 8.

phorus from the fertilizer. Soybeans were similar to corn except that the initial utilization of fertilizer phosphorus was not nearly as great. In this connection it may be noted that the initial response of corn to phosphorus fertilization was much greater than was the case with soybeans. By the end of the growing

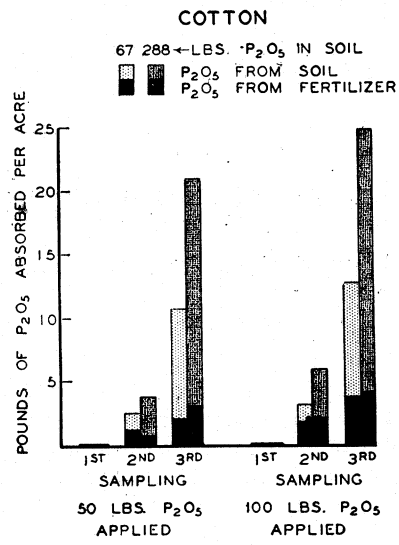

FIG. 9.

season, however, neither crop showed a significant yield response from the phosphate fertilization.

These and other experiments clearly indicate that potatoes absorb most of their phosphorus from a limited volume of soil and that they utilize applied phosphorus more fully than most crops. Corn initially draws on the band of fertilizer but very rapidly extends its root system and obtains most of its phosphorus from the soil. From this we may assume that corn would utilize the accumulated phosphorus in wellfertilized soils more effectively than would potatoes, cotton, or tobacco. Tobacco uses fertilizer phosphorus in the seedling stage more than cotton. Both appear less efficient than corn in using soil phosphorus.

Influence of phosphorus fertility of soils on the utilization of fertilizer phosphorus. In an experiment with cotton, 50 and 100 pounds of phosphoric acid were applied as superphosphate on two soils. One soil contained 67, the other 288 pounds of available phosphoric acid per acre. The data are given in Fig. 9. The striking thing about the figure is that the really big difference in the phosphorus content of the crop is due to the difference in the two soils. The phosphorus fertility level of the soil did not materially influence the utilization of fertilizer phosphorus. Similar results have been obtained with both corn and potatoes. The potato experiments were on Long Island and in North Carolina. At both locations three rates of phosphorus fertilization were compared on two soils of widely different phosphorus fertility. Here again, as with cotton and corn, the phosphorus content of the soil did not materially influence the utilization of fertilizer phosphorus when applied in bands. The soil fertility level, however, did greatly influence the amount of soil phosphorus used, and the total phosphorus absorbed by the crop.

Such data give convincing evidence of the importance of increasing the phosphorus fertility status of soils to a reasonably good level. They also indicate that the various crops studied used to good advantage residual phosphorus from previous fertilization.

In conclusion, we feel that radioactive phosphorus is a very useful tool for certain studies. It has its limitations, however; one is that the rate of decay is such that it can be followed only one season. The residual effects of phosphorus fertilizers, therefore, have to be determined by less direct methods. We are also conducting, as supplementary to this field approach and closely integrated with it, fundamental investigations on plant nutrition, soil chemistry, and soil-fertilizer reactions, both rapid and long term. Our knowledge of soil and fertilizer phosphorus is steadily increasing. It appears that, for the most part, we are gradually increasing the phosphorus fertility status of our soils. If the present high level of fertilizer phosphate use is maintained, and somewhat better distribution is achieved to certain sections of the country, phosphorus will gradually become less of a limiting factor in crop production.

Reference

1. Fried, Maurice and MacKenzie, Arnold J. *Proc. soil sci. Soc. Amer.*, to be published.

Based on a paper presented at a meeting of the Virginia Section of the American Chemical Society, at Petersburg, Virginia, October 20, 1949.

The First Year of the SCLP

The Scientists' Committee on Loyalty Problems,[1]

Princeton, New Jersey

IN THE FALL OF 1948 a committee of the Federation of American Scientists was formed to deal with the security and loyalty problems confronting scientists. This report summarizes the activities of that committee, the SCLP, in its first year.

In order to make the committee's operation more effective, members have been chosen from a fairly small geographical area. The committee has a panel of 80 sponsors and consultants, however, who are broadly representative, geographically and professionally.

Because other groups were studying the long range legal (*1*) and sociological (*3*) implications of the security program, the SCLP has concentrated its attention on the immediate and practical problems facing scientists. The first action of the committee was to collect and study the available information on clearance procedures (*13*). It then undertook to obtain for individuals, without judging the merits of any case, the full protection of existing regulations. And on the basis of this knowledge and experience, it has urged upon government agencies the adoption of specific reforms and procedures.

One point deserves particular emphasis at the outset. Although the SCLP has worked consistently for more equitable and judicial clearance procedures, it does not believe that a poor security risk should be given clearance. The steps it has taken and the measures it has recommended are all designed to ensure

[1] Present members of the committee are: Lyman Spitzer, Jr., chairman; William A. Higinbotham, associate chairman; Arthur S. Wightman, secretary; Donald R. Hamilton, treasurer; Kenneth W. Ford, Samuel A. Goudsmit, Herbert R. Muether, T. Alexander Pond, and Irving Wolff.