

TABLE 15.—TOTAL COPPER AT VARIOUS DEPTHS AS AFFECTED BY PHOSPHATE AND LIME TREATMENTS (EXPERIMENT 6).

Prior Treatment†			Copper, lb/A.—6 in.				
P ₂ O ₅ lb/A/yr.	Limestone lb/A/yr.	0-6 in.	6-12 in.	12-18 in.	18-24 in.	24-36 in.	36-48 in.
0	0	111	25	9	11	9	8
0	2080	125	7	5	2	1	1
1200	2080	136	23	16	11	6	11
1200	0	122	20	9	8	1	8

† Treatment from 1951 to 1958. Copper applied in fertilizer during the same period. Soil sampled December 1961.

Discussion

The results of the research on phosphate fertilization and the growth of citrus feeder roots lead to the conclusion that the reported detrimental effects of phosphate fertilization on root growth in the field experiments were due to toxicity of copper mobilized or made more toxic by the acid phosphates. The copper could have been either that present in the soil or that applied at the same time as the phosphate fertilizers. Monocalcium phosphate, the chief constituent of most phosphate materials, forms phosphoric acid when dissolved in water. This could temporarily result in sufficiently high levels of copper in the soil solution to be highly toxic to citrus roots growing in soils containing appreciable amounts of copper.

Results of Experiment P-II showed that copper mobilized by ordinary superphosphate applications could damage citrus roots and consequently reduce growth of citrus seedlings. Acidification of the high copper grove soil by acid or by ammonia-containing phosphate compounds resulted in depressed root growth due to toxicity of copper at the lowered soil pH. In the laboratory, phosphate compounds, when applied at high rates to simulate conditions around fertilizer particles, lowered soil pH and increased the concentration of copper in solution. Liebig et al. (13) found that 0.1 ppm copper was toxic to orange and lemon cuttings growing in nutrient solutions free of aluminum. Additions of very small amounts of aluminum reduced copper toxicity in their experiments. These facts point out the extremely low concentrations of copper necessary for toxicity to citrus, and suggest the possibility of an aluminum-copper inter-action,