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[Macaulay Inst. for Soil Research, Craigiebuckler, Aberdeen, Scotland and Agricultural Development and Advisory Service, Leeds, England]

Metals used in industry are often discharged into sewage and accumulate in sewage sludge. The disposal of highly contaminated sludges on agricultural land greatly increases trace element contents above their natural levels. This paper reports the total and extractable levels of many trace elements in sludges and indicates those most likely to cause toxicity problems. [The SCI® indicates that this paper has been cited in over 110 publications since 1972.]

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"Much work carried out in the department of spectrochemistry, Macaulay Institute, Aberdeen, is directed toward assessing the trace element status of soils by the use of a wide range of analytical techniques. Our interests are devoted largely to those elements which cause problems of deficiency or toxicity in plant growth or animal health. The behaviour of many other elements which have, as yet, no known biological function are also of interest from a geochemical or pedological viewpoint. Their behaviour can give new insights into processes such as mineral weathering, podzolization, and plant uptake. Multielement methods of analysis such as direct-current arc spectrochemical techniques are most useful in these research investigations and have been developed by Robert L. Mitchell and Robert O. Scott, both heads of department, between the years 1937 and 1981.[1]

"During the 1950s and 1960s, Jack Webber and his colleagues in the Agricultural Development and Advisory Service (ADAS), with whom I worked before joining the Macaulay staff, encountered a number of problems of crop growth following the use of sewage sludge as a fertilizer and consequently asked us for comprehensive analyses of soil and crop samples. Heavy metal toxicity was often identified as the cause. It was, therefore, decided that a range of sewage sludges from large industrial centres and from small rural towns should be analysed as fully as possible to determine their contents of potentially toxic elements.

"The problems included (a) obtaining representative samples—not an easy task with material as uninviting as sewage sludge; (b) ensuring freedom from contamination at all stages of sampling, pretreatment, and preparation for analysis; and (c) analytical problems such as matrix and interference effects which can arise during the spectrochemical analysis of material as variable in composition as sewage sludge.

"Problems of metal toxicity following the disposal of sludge on land were being found in many industrialised countries. In a study of the literature compiled for the EPA,[2] A.L. Page reported that in 1973 there were only three publications,[3,4] including our own, which detailed the trace element composition of sewage sludges. Since then an enormous literature has accumulated on the benefits and hazards of applying sludge to land and many countries have prepared guidelines for sludge disposal which control the amounts of potentially toxic elements added to soil. I believe that the reason our paper has been quoted so frequently is that it was the first to report the total and extractable contents of a large number of trace elements in sludges.

"In cooperation with our colleagues in ADAS we have continued to monitor, in two field experiments begun in 1968,[5] the long-term effects of sludge disposal on soils and crops. These have demonstrated the persistence of metals in plant-available form some 12 years after sludge application.[6] Heavy metals added to soil in sludge remain largely in the topsoil, but change their chemical forms with the passage of time.

"In Scotland an interesting problem has been encountered where soil has become copper-contaminated by waste from the distillation of malt whisky. Over some 70 years, copper has accumulated in topsoil to the extent that it is harmful to the growth of some crops and possibly to sheep.[7] There is little evidence that heavy metals in topsoils are removed by leaching and it is therefore important that realistic controls are adopted to ensure that valuable soils do not become permanently damaged by the buildup of elements that could be toxic to crops and grazing livestock."

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2. **Page A L.** *Fate and effects of sewage sludge when applied to agricultural lands—a literature review study.* Cincinnati, OH: Environmental Protection Agency, 1974. Report No. 670/2-74-005. 96 p.
3. **Berggren B & Odén S.** *Analysresultat Rorande Fungmetaller Och Klorerade Kolväten I Rötslam Fran Svenska Reningsverk 1968-71.* Uppsala, Sweden: Institutionen für Markvetenskap Lantbrukshögskolan, 1972.
4. **Blakeslee P A.** Monitoring considerations for municipal wastewater effluent and sludge application to the land. *Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land, 9-13 July 1973, Champaign, IL.* Springfield, VA: National Technical Information Service, 1973. p. 183-98.
5. **Berrow M L & Burridge J C.** *Trace element levels in soils: effects of sewage sludge.* London: HMSO, 1980. MAFF Ref. Book 326. p. 159-83.
6. ———. Persistence of metals in available form in sewage sludge treated soils under field conditions. *Proceedings of the International Conference on Heavy Metals in the Environment, Amsterdam.* Edinburgh: CEP Consultants, 1981. p. 202-5.
7. **Reith J W S, Berrow M L & Burridge J C.** Effects of copper in distillery wastes on soils and plants. *Proceedings of the International Conference on the Management and Control of Heavy Metals in the Environment, London.* Edinburgh: CEP Consultants, 1979. p. 537-40.