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This Week's Citation Classic®

Foy C D, Chaney R L & White M C. The physiology of metal toxicity in plants. *Annu. Rev. Plant Physiol.* 29:511-66, 1978.
[Plant Stress Lab. and Biological Waste Management and Soil Nitrogen Lab., USDA, ARS, Beltsville, MD]

This review updated knowledge of the physiology of important metal toxicities in plants. It emphasized mechanisms of differential metal tolerances among plant species and cultivars within species. The chapter has provided a stimulus to plant breeders in developing cultivars having greater tolerances to mineral toxicities in problem soils. Such cultivars are particularly valuable in low input (subsistence), sustainable agriculture in acid soils of the tropics and in other areas in which toxicities are not always economically correctable with current technology. [The *SCI*® indicates that this paper has been cited in more than 505 publications.]

Metal Toxicity Review Stimulates Plant Breeders

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When invited to write this chapter, I debated the wisdom of taking the time to do it, but my laboratory director, M.N. Christiansen, said, "I think this one will do you some good." Because my experience had been largely with aluminum and manganese toxicities in acid soils, I enlisted the help of R.L. Chaney and M.C. White with the heavy metals part of the chapter.

Prior to the 1970s, the major emphasis in soil fertility research was directed toward modifying the soil to fit the plant. But in many cases the plants were what I later called "incubator babies." They were bred in the absence of major mineral stress factors and hence could not tolerate the stresses of the outside world. For example, Sonora 63, a Green Revolution wheat cultivar which produced high yields on neutral and alkaline soils, was a total failure on some acid, aluminum-toxic soils of Brazil.

Many soil problems, such as subsoil acidity, are not economically correctable with current technology. An alternative or supplemental approach is to tailor plants more specifically to fit such problem soils.[1] This approach is especially important in subsistence agriculture, which prevails in much of Africa and South America.

An important part of this plant-genetic approach is understanding the genetic, physiological, and biochemical mechanisms by which plants tolerate mineral stress. Such understanding could expedite the breeding of metal-tolerant, drought-tolerant cultivars and also promote the development of improved liming, fertilization, tillage, and drainage practices for problem soils. I believe that our chapter has been cited frequently because it proposed a multidisciplinary approach to problems of metal toxicity. Prior to this time, close collaboration between soil and plant scientists was rare in both state and federal research institutions.

One impact of the chapter was as follows: In 1983, Gregory Taylor had just completed his PhD in botany at Queens University, Kingston, Ontario, Canada, and had been granted a postdoctoral fellowship to continue his studies on metal toxicity at a place of his own choosing. Because Greg did not normally read the agronomic literature, he had not seen any of my earlier publications. However, his reading of this chapter led him to spend a productive 18 months working with us at Beltsville on aluminum toxicity. Upon returning to Canada (Botany Department, University of Alberta, Edmonton), he initiated collaboration with Keith Briggs and John Hoddinott to develop Al and Mn tolerant wheat cultivars for the acid soils of western Canada. This led to the organization of an international conference.[2] Worldwide interest generated by this conference led to a second meeting[3] in 1990. A third conference is scheduled in Brisbane, Queensland, Australia in 1993.

The function of a review chapter is to locate the frontiers of knowledge on a subject and to suggest approaches for extending these frontiers and for applying research findings toward the solution of problems. We are gratified that others have found our chapter useful in these respects. Since it was written, many other reviews on metal toxicity have been published,[4-6] and worldwide progress is being made in tailoring plants to tolerate unavoidable mineral stresses in problem soils.

1. **Christiansen M N & Lewis C F,** eds. *Breeding plants for less favorable environments.* New York: Wiley, 1982. 459 p.
2. **Taylor G J,** ed. Plant-soil interactions at low pH: a symposium jointly sponsored by Agriculture Canada Research Station, Beaverlodge, Alberta and University of Alberta, 20-24 July 1987, Grand Prairie Regional College, Alberta, Canada. (Whole issue.) *Commun. Soil Sci. Plant Anal.* 19(7-12), 1988.
3. **Wright R J, Baligar V C & Murrmann R P,** eds. *Plant-soil interactions at low pH. Proceedings of the Second International Symposium on Plant-Soil Interactions at Low pH,* 24-29 June 1990, Beckley, West Virginia. Boston, MA: Kluwer, 1990. 1,104 p.
4. **Foy C D.** Soil chemical factors limiting plant root growth. *Advan. Soil Sci.* 19:97-149, 1992.
5. **Kinraide T B.** Identity of the rhizotoxic aluminum species. *Plant Soil* 134:167-78, 1991.
6. **Taylor G J.** Current views of the aluminum stress response: the physiological basis of tolerance. *Curr. Topics Plant Biochem. Physiol.* 10:57-93, 1991.

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