CC/NUMBER 25
JUNE 18, 1984

This Week's Citation Classic™

Williams R F. Redistribution of mineral elements during development.
Annu. Rev. Plant Physiol. 6:25-42, 1955.
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Evidence for the redistribution of mineral elements during plant development was reviewed. Each vegetative organ passes through phases of intake, constant content, and export. Intake by the roots is often restricted to the extent that the nutrient is more readily available within the plant. [The *SCI*® indicates that this paper has been cited in over 140 publications since 1955.]

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January 27, 1984

"During a visit to Philadelphia in 1949, I was invited by David Goddard to give a seminar on the Adelaide studies of plant growth and nutrition. This gave me the opportunity to report the work of the small but active group under A.H.K. Petrie, whose studies of physiological change during ontogenesis were based on the alteration of ontogenetic drifts by the level of nutrient supply and, in tobacco, by preventing inflorescence development.

"The reason for the frequent citation of the paper is thought to be that it appeared in the right place at the right time. That it appeared in the *Annual Review of Plant Physiology* can reasonably be traced to Goddard, who was a founding member of the editorial committee. That it was the right time is attested to by the fact that no fewer than 676 references to mineral nutrition and closely related subjects appeared in volumes one through five of the *Annual Review of Plant Physiology*.

"Mineral nutrition continued to be a popular field of research, and the *Annual Review* was even more relied upon than now as a source of ideas. The Adelaide studies, which stressed the significance of relationships at the higher levels of organization of the plant body, thus provided a framework of interpretive ideas and concepts for use in a field that was heavily empirical.

"The Adelaide group then turned its attention to nitrogen metabolism, and this work was reviewed[1] after Petrie's untimely death at the age of 38. The group was scattered, but I and my colleagues at Griffith, New South Wales, and Canberra have applied its ideas to a field problem and to precise quantitative studies of the shoot apex of higher plants.[2]

"One of the legacies of a too rigid application of mechanistic ideas to biology has been an uncritical acceptance of the notion that the only meaningful causal relations *must* be couched in terms of entities and relations at the lower or *fundamental* level of organization. We, however, have been forced to the view that many biological problems yield only upon acceptance that organisms display hierarchic organization. Indeed, 'all complex structures and processes of a relatively stable character display hierarchic organization, regardless whether we consider galactic systems, living organisms and their activities, or social organization.'[3] However, Koestler insists, 'The hierarchic approach is a conceptual tool—not an end in itself,' and its acceptance quickly demonstrates that qualitatively different laws hold good at different levels of the hierarchy.

"Any application of hierarchy theory to biology demands as a prerequisite the precise quantitative description of relevant biological systems. Examples of such descriptions are those for the fourth leaf of subterranean clover[4,5] and the growth of tillers in wheat.[6,7] These studies lead naturally to the elucidation of theoretical problems such as phyllotaxis—the geometry of leaf arrangement at the shoot apex in plants."[8]

1. **Petrie A H K.** Protein synthesis in plants. *Biol. Rev.* 18:105-18, 1943.
2. **Williams R F.** *The shoot apex and leaf growth. A study in quantitative biology.* London, UK: Cambridge University Press, 1974. 256 p.
3. **Koestler A.** *Janus: a summing up.* New York: Random House, 1978. 354 p.
4. **Williams R F & Bouma D.** The physiology of growth in subterranean clover. I. Seedling growth and the pattern of growth at the shoot apex. *Aust. J. Bot.* 18:127-48, 1970.
5. **Williams R F & Rijven A H G C.** The physiology of growth in subterranean clover. II. The dynamics of leaf growth. *Aust. J. Bot.* 18:149-66, 1970.
6. **Williams R F, Sharman B C & Langer R H M.** Growth and development of the wheat tiller. I. Growth and form of the tiller bud. *Aust. J. Bot.* 23:715-43, 1975.
7. **Williams R F & Langer R H M.** Growth and development of the wheat tiller. II. The dynamics of tiller growth. *Aust. J. Bot.* 23:745-59, 1975.
8. **Williams R F & Brittain E G.** A geometrical model of phyllotaxis. *Aust. J. Bot.* 32:43-72, 1984.

