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Mosse B. Plant growth responses to vesicular-arbuscular mycorrhiza. IV. In soil given additional phosphate. *New Phytol.* 72:127-36, 1973.
[Rothamsted Experimental Station, Harpenden, Hertfordshire, England]

This paper describes the effects of progressive additions of phosphate on growth responses of mycorrhizal and nonmycorrhizal onions. With small amounts of phosphate, mycorrhizal infection improved plant growth in all soils, but in some, supraoptimal concentration of phosphate was reached earlier in mycorrhizal than in nonmycorrhizal plants, and then the mycorrhizal plants grew less well. With increasing phosphate additions plants eventually became immune to mycorrhizal infection, though some infective propagules persisted in the soil. [The *SCI*® indicates that this paper has been cited in over 130 publications.]

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When I started my career as a research worker studying graft incompatibility, my director described one of my papers, rather unkindly as I then thought, as "another installment from the rubbish heap." On rereading the above paper I feel that he may have diagnosed correctly my inability to discard any experimental result, however fragmentary. Fortunately, the main findings of the cited paper, that vesicular-arbuscular mycorrhiza (VAM) can reduce growth of plants well supplied with phosphate and that high phosphate content of the growth medium reduces and eventually suppresses VAM infection, have since been confirmed in many, more complete experiments with other plants. It was of course well known, virtually since mycorrhizal studies began, that VAM were rarely found in fertile garden soils.[1] Perhaps one merit of my paper was that it covered a range of soils and emphasized the importance of soil in mycorrhizal studies. It has since been shown that another important factor determining growth response is the difference in mycorrhizal dependency of different host species and even different genotypes of the same species.[2-5] Thus, deleterious effects of VAM infection occur at much lower soil phosphate levels in the relatively self-sufficient Gramineae than in the highly mycorrhiza-dependent Leguminoseae and perhaps never in plants like cassava or citrus.

In the *Classic* paper I tried to relate growth responses to plant phosphate concentration that was initially suboptimal but became supraoptimal when enough phosphate was added. The improved phosphate uptake that results from VAM infection accelerated this progression and could thus lead to earlier growth reductions. Decrease of VAM infection usually preceded such relative growth reduction and seemed to be related to plant phosphate concentration rather than to direct effects of soil phosphate on the fungus. It has been suggested that a possible controlling mechanism is the greater membrane permeability of phosphate-deficient plants.[6]

Explanations of mycorrhizal frequency based purely on phosphate levels are probably too simplistic. Interactions between phosphate and nitrogen levels in the growth medium affect the incidence of VAM infection, and the form of nitrogen can also influence the result. Given the slow diffusion rate of phosphate in the soil, it may be questioned whether, in agricultural soils as opposed to experimental situations, phosphate frequently reaches the level at which it depresses VAM infection. In modern agriculture the increasing use of nitrogen fertilizers may be a more important factor reducing the incidence of VAM infection.[7] In so doing, it would automatically lead to a less efficient phosphate uptake and a greater need for added phosphate fertilizer.

It has long been claimed that, by contrast, organic fertilizers stimulate the development of VAM, but there is little reliable evidence to support this claim. The controversy of mineral versus organic fertilizers is an old one. When world food production appeared likely to fall below requirements, the controversy seemed to have been settled in favour of mineral fertilizers. However, in the last decade agricultural production has greatly exceeded consumer demand, at least in Western countries. Conversely, problems of overproduction and environmental pollution, amongst others, by too much nitrate and phosphate in drainage water, have attracted attention. The market for organically grown crops is expanding, and a reevaluation of mycorrhiza in the nutrition of such crops seems timely.

1. **Mosse B.** Endotrophic mycorrhiza (1885-1950). The dawn and the middle ages. (Molina R, ed.) *Proceedings of the 6th North American Conference on Mycorrhizae*, 25-29 June 1984, Bend, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory, 1985. p. 48-55.
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