

Minchin F R & Pate J S. The carbon balance of a legume and the functional economy of its root nodules. *J. Exp. Bot.* 24:259-71, 1973.
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Budgets for carbon and nitrogen in shoot, root, and nodules of pea are drawn up for a 9-d interval in the life cycle. These synthesis data on nitrogen fixation, carbon accumulation, respiration of plant organs, and organic solute exchange between shoot and nodulated root. [The *SCI*[®] indicates that this paper has been cited in over 115 publications since 1973, making it the most-cited paper published in that journal since 1970.]

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"This paper reports some of the work from my PhD thesis, which was supervised by John Pate. To distinguish the novice from the expert, before joining Pate's laboratory I had rarely seen legume root nodules. Over the next three years I picked, counted, weighed, dissected, and chemically analysed a vast number of these strange, pinkish 'lumps.' Despite the necessary tedium of such work, the fascination with the functioning of nodules induced by Pate's enthusiasm has proved lasting (although I now delegate nodule picking, counting, etc., whenever possible).

"The experiments reported in the paper were conceived as an attempt to combine carbon analysis studies with those methods for studying nitrogen cycling in plants which had already been developed by Pate. Our overall ambition was to produce a synthesis picture of the cycling of both elements within a nitrogen fixing legume, to demonstrate

the close interrelationships between these two cycles, and to obtain some insight into the carbon costs of nitrogen fixation by legume nodules.

"That we succeeded in these quests is, no doubt, part of the explanation for the citation record of this paper. However, much of its 'success' can probably be attributed to the timing of its publication. Within one year of this event the price of oil had risen dramatically producing renewed interest in nitrogen fixation as an alternative to the energy intensive production of nitrogen fertilizers. Researchers were looking for new insights into the functioning of legume nodules, and were also questioning the energy costs of the nitrogen fixation process. Our paper provided some clues for the direction of future research in these areas.

"However, the paper is 'showing its age' in the light of continued developments in nitrogen fixation in the decade since its publication. Not only has the original synthesis concept been surpassed by several more elegant and complete pictures of carbon and nitrogen cycling in legumes (e.g., reference 1), but also errors in some of the original assumptions have been demonstrated. Thus, the carbon costs of nitrogen fixation and nitrate reduction may be similar if both occur in the root and rely on reductants supplied by carbohydrate catabolism; but it now appears that nitrate-fed plants can escape most of these costs by using photophosphorylation to supply reductants to leaf-based nitrate reduction.² In hindsight, a comparison of shoot gas exchange in our nitrogen fixing and nitrate-fed plants may well have demonstrated this feature. Secondly, the costing of carbon usage in nitrogen fixation, which relied on Warburg respirometer measurements of detached nodules, was rather crude. Results from more sophisticated and accurate techniques suggest that our original values markedly underestimated the true costs."³

1. Pate J S, Atkins C A & Rainbird R M. Theoretical and experimental costing of nitrogen fixation and related processes in nodules of legumes. (Gibson A H & Newton W E, eds.) *Current perspectives in nitrogen fixation*. Canberra: Australian Academy of Science, 1981. p. 105-16.
2. Schubert K R & Ryle G J A. The energy requirements for nitrogen fixation in nodulated legumes. (Sumnerfield R J & Bunting A H, eds.) *Advances in legume science*. London: Her Majesty's Stationery Office, 1980. p. 85-96.
3. Minchin F R, Witty J F & Sheehy J E. A new technique for the measurement of the respiratory costs of symbiotic nitrogen fixation. (Davies D R & Jones D G, eds.) *The physiology, genetics and nodulation of temperate legumes*. London: Pitmans. In press, 1983.