

Much remains to be learned about the mechanistic basis and the ecological implications of the  $A_{\max}$ -N relationship. Mechanistically, the distribution of quantitative limitations is still unknown, as is the nature of the controls on the relative levels of limiting factors. At the interface between mechanisms and implications, much work needs to be done on the sensitivity of the nature and magnitude of the limitations to changes in the environment. Ecologically, it is of great interest to quantify the relationship between  $A_{\max}$  and photosynthesis under natural conditions and to use the  $A_{\max}$ -N relationship for cost-benefit analyses of plant structure and function.

### Acknowledgments

Thanks to N. Chiariello, J. A. Berry, T. J. Givnish, and J. Comstock for useful discussions and comments on preliminary drafts of this chapter. The experiments in the VINE survey were supported by NSF grant DEB 78-02067 to H. A. M.

### References

- Badger, M. R., and G. J. Collatz. 1977. Studies on the kinetic mechanism of ribulose-1,5-bisphosphate carboxylase and oxygenase reactions, with particular reference to the effect of temperature on kinetic parameters. *Carnegie Inst. Washington Yearbook* 76:355-361.
- Björkman, O. 1968. Carboxydismutase activity in shade-adapted and sun-adapted species of higher plants. *Physiol. Planta*. 21:1-10.
- 1981. Responses to different quantum flux densities. Pp. 57-107 in O. L. Lange, P. S. Nobel, C. B. Osmond, and H. Ziegler (eds.), *Physiological plant ecology*, I, vol. 12A, encyclopedia of plant physiology, new series. Springer-Verlag, Berlin.
- Björkman, O., and P. Holmgren. 1963. Adaptability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats. *Physiol. Planta*. 16:889-914.
- Bolton, J. K., and R. H. Brown. 1980. Photosynthesis of grass species differing in carbon dioxide fixation pathways. V. Response of *Panicum maximum*, *Panicum miliodes*, and tall fescue (*Festuca arundinacea*) to nitrogen nutrition. *Plant Physiol.* 66:97-100.
- Brown, R. H. 1978. A difference in N use efficiency in C<sub>3</sub> and C<sub>4</sub> plants and its implications in adaptation and evolution. *Crop Sci.* 18:93-98.
- Brown, R. H., and J. R. Wilson. 1983. Nitrogen response in *Panicum* species differing in CO<sub>2</sub> fixation pathways. II. CO<sub>2</sub> exchange characteristics. *Crop Sci.* 23:1154-1159.
- Bryant, J. P., F. S. Chapin II, and D. R. Klein. 1983. Carbon/nutrient balance of boreal plants in relation to vertebrate herbivory. *Oikos* 40:357-368.
- Chapin, F. S., III. 1980. The mineral nutrition of wild plants. *Ann. Rev. Ecol.*

- Chapin, F. S., III, and R. A. Kedrowski. 1983. Seasonal changes in nitrogen and phosphorus fractions and autumn retranslocation in evergreen and deciduous taiga trees. *Ecology* 64:376-391.
- Collatz, G. J., M. Badger, C. Smith, and J. A. Berry. 1979. A radioimmune assay for RuP<sub>2</sub> carboxylase protein. *Carnegie Inst. Washington Yearbook* 78:171-175.
- Comstock, J., and J. Ehleringer. 1984. Photosynthetic responses to slowly decreasing leaf water potentials in *Encelia frutescens*. *Oecologia* 61:241-248.
- Ehleringer, J. 1983. Ecophysiology of *Amaranthus palmeri*, a sonoran desert summer annual. *Oecologia* 57:107-112.
- Evans, J. R. 1983. Nitrogen and photosynthesis in the flag leaf of wheat (*Triticum aestivum* L.). *Plant Physiol.* 72:297-302.
- Farquhar, G. D., M. C. Ball, S. von Caemmerer, and Z. Rosskandik. 1982. Effect of salinity and humidity on  $\delta^{13}\text{C}$  value of halophytes - evidence for diffusional isotope fractionation determined by the ratio of intracellular/atmospheric partial pressure of CO<sub>2</sub> under different environmental conditions. *Oecologia* 52:121-124.
- Farquhar, G. D., M. H. O'Leary, and J. A. Berry. 1982. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Aust. J. Plant Physiol.* 9:121-137.
- Farquhar, G. D., and T. D. Sharkey. 1982. Stomatal conductance and photosynthesis. *Ann. Rev. Plant Physiol.* 33:317-345.
- Farquhar, G. D., S. von Caemmerer, and J. A. Berry. 1980. A biochemical model of photosynthetic CO<sub>2</sub> assimilation in the leaves of C<sub>3</sub> species. *Planta* 149:78-90.
- Field, C. 1981. Leaf age effects on the carbon gain of individual leaves in relation to microsite. Pp. 41-50 in N. S. Margaris and H. A. Mooney (eds.), *Components of productivity of Mediterranean-climate regions - basic and applied aspects*. Dr. W. Junk, The Hague.
- 1983. Allocating leaf nitrogen for the maximization of carbon gain: Leaf age as a control on the allocation program. *Oecologia* 56:341-347.
- Field, C., J. Merino, and H. A. Mooney. 1983. Compromises between water-use efficiency and nitrogen-use efficiency in five species of California evergreens. *Oecologia* 60:384-389.
- Field, C., and H. A. Mooney. 1983. Leaf age and seasonal effects on light, water, and nitrogen use efficiency in a California shrub. *Oecologia* 56:348-355.
- Friedrich, J. W., and R. C. Huffaker. 1980. Photosynthesis, leaf resistances, and ribulose-1,5-bisphosphate carboxylase degradation in senescing barley leaves. *Plant Physiol.* 65:1103-1107.
- Gulmon, S. L., and C. C. Chu. 1981. The effects of light and nitrogen on photosynthesis, leaf characteristics, and dry matter allocation in the chaparral shrub, *Diplazium aurantiacum*. *Oecologia* 49:207-212.
- Hall, N. P., A. J. Keys, and M. J. Merrett. 1978. Ribulose-1,5-diphosphate carboxylase protein during flag leaf senescence. *J. Exp. Bot.* 29:31-37.
- Hesketh, J. D., E. M. Larson, A. J. Gordon, and D. B. Peters. 1983. Internal factors influencing photosynthesis and respiration. Pp. 381-411 in J. E. Dale and F. L. Milthorpe (eds.), *The growth and functioning of leaves*. Cambridge University Press.