Dynamic optimization of plant growth

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ABSTRACT

The growth and reproductive schedule of terrestrial plants can be usefully studied as the dynamic optimal allocation of material between different organs. This idea, pioneered by Dan Cohen, has been formalized as an optimal control problem and analysed using Pontryagin’s maximum principle or dynamic programming. Here, I review several examples of dynamic resource allocation models. First, the seasonal timing of reproduction of annuals is discussed. This can be extended to plants with multiple vegetative organs and the optimal shoot–root balance is assessed. Secondly, the growth schedule over multiple seasons is examined, and the reproductive effort, the leaf phenology of deciduous perennials, and the conditions under which perenniality is more advantageous than annuality are considered. With some modifications, the same model can handle intermittent reproduction and monocarpic perennials (one large reproduction after many years). Thirdly, growth in an unpredictably fluctuating environment is analysed for the case in which a sudden disturbance (herbivory or fire) removes the photosynthetic system altogether, followed by recovery using stored material, and for the case in which environmental productivity fluctuates in a Markovian process. Finally, the optimal level of chemical defence against herbivory is formalized and used to explain the intensity of alkaloid defence decreasing with leaf age. These examples illustrate the usefulness of dynamic resource allocation models in understanding plant life-history adaptation.

Keywords: defence against herbivory, dynamic programming, growth schedule, life-history strategy, phenology, Pontryagin’s maximum principle, shoot–root balance, stochastic environment.

INTRODUCTION

Every day in a growing season, a plant obtains material by photosynthesis and allocates it to various organs, such as leaves, roots, stems, flowers and fruits. The plant may also invest in storage for the future and defence against fire or herbivory (van der Meijden et al., 1988). Diverse patterns of plant growth and life history are observed in nature, and these are presumably the result of adaptation to each environment. Evolutionary outcome of plant life history can be viewed as the optimal schedule of resource allocation, chosen under physical and informational constraints.
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