A SIMPLE MATHEMATICAL MODEL TO INVESTIGATE SHOOT:ROOT PARTITIONING IN RESPONSE TO LIGHT AND NITROGEN

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ABSTRACT

A simple mathematical model called "SRCN" (shoot-root-carbon-nitrogen) has been developed to describe growth and partitioning in tree seedlings in response to nitrogen fertility, daily light and ambient or elevated carbon dioxide levels. SRCN is a whole plant level model, and although mechanistic, it uses phenomenological descriptions (equations) within which the biochemical details are highly aggregated.

The model was constructed to accommodate several goals: (a) it uses conventional crop level inputs (shoot and root masses, fresh:dry weight ratios, %N, daily light integral); (b) the model is sparse, containing only enough structural information about growth relations to correctly make predictions in a limited range of environments; (c) flows to and from the shoot and root pools of mass are described with a minimum number of simple, understandable differential equations, and; (d) a "hormonal balance" explanation is used simplistically to control partitioning (not explicitly shown in the mass pools in Fig.1). One specific limitation, based on published experimental data in the literature, is that plants are assumed to be capable of, and seek to achieve, balanced exponential growth (BEG) – a condition wherein the relative growth rate of the shoot and root masses are constant and equal to one another. This condition results from imposing an exponentially increasing but still limiting supply of nitrogen.

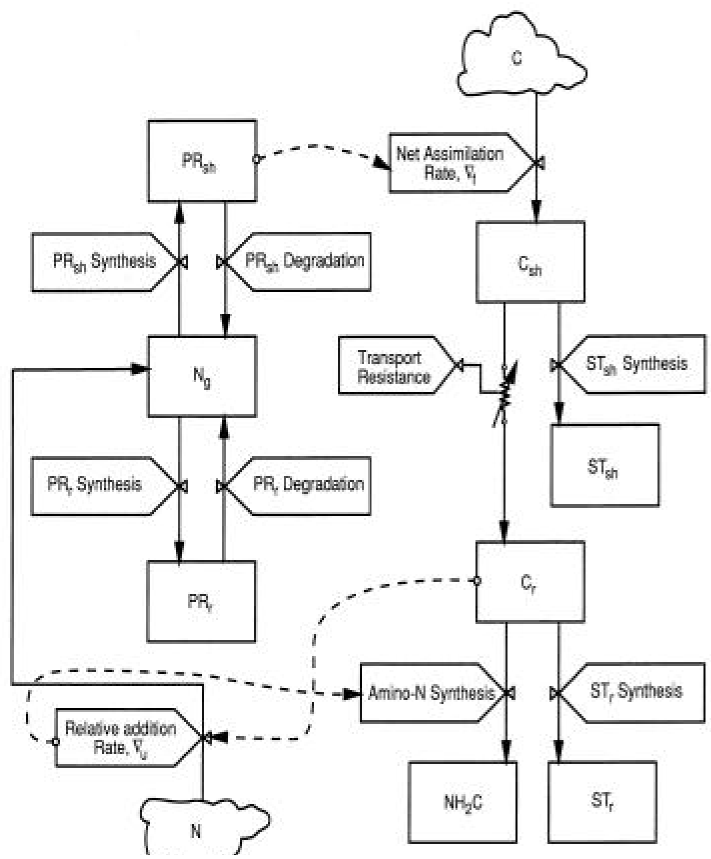

Fig. 1 Forrester diagram of the SRCN partitioning model

To describe shoot/root partitioning, the activities of two PGR's – notionally, a cytokinin (ZZR) and an auxin (IAA) – produced by the root and shoot, respectively, are invoked to control protein synthesis, carbohydrate transport and the formation of cellulose structure (the majority of the plant dry matter). Protein, PR_i, can degrade (for redistribution through a common amino-N pool), but structure, ST_i, cannot. The PGR's are presented as phenomenological descriptions – a "concentration" produced by only one portion of the plant, and rapidly distributed throughout to modify growth in the other portion. [ZZR} and {IAA] are proportional to the non-protein amino

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N pool and the daily light integral respectively. Two parameters – carbon transport and structure formation – are the product of both PGR concentrations. The model plant explicitly seeks to establish a ratio of the two PGR's concentrations equal to one, at which point BEG is achieved. As a growth resource (light, nitrogen) becomes more limiting, the proportioning of the new mass in the growing plant shifts to accumulate shoot or root mass in order to "acquire" more of the limiting resource. In this way partitioning is accomplished in response to environmental cues. Root C allocated for amino-N formation limits the exponential N addition rate at low light.

The programming software environment "Simile 3.3" (Simulistics Ltd., Edinburgh UK) was used to program the model. Simile has an excellent visual interface within which the numerical portions (e.g., integration of differential equations) are hidden, and which allows modular construction and easy substitution of sub-models. The model was written in five modules or sub-models: the C and N mass pools (protein and amino N, and structure, carbohydrate C and amino-C); two small explicit modules: one for each of IAA and ZZR; and finally a "real world" module. The last module was added because the model runs on units based on elemental C and N to simplify the description. Conversions are needed to and from g C and g N into "real-world" units of dry weight, amino-C, %N, CO_2 etc. which form the description of a "real" modeled plant.

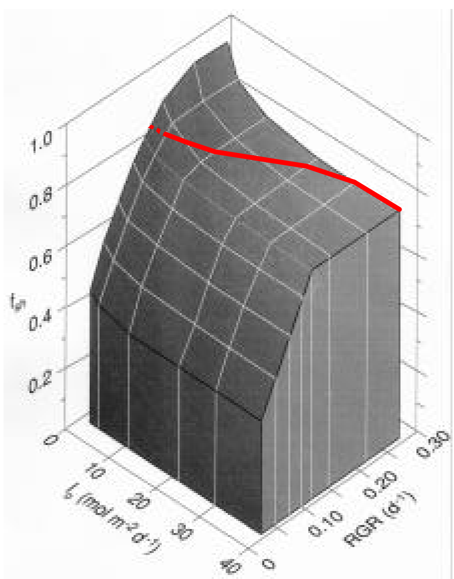

Fig.2 Modelled shoot fraction, f_{sh}, parameterized for birch as a function of daily lght integral, I_o, and the N-limited relative growth rate, RGR. The line across the response surface is the I_o-limited maximum RGR.

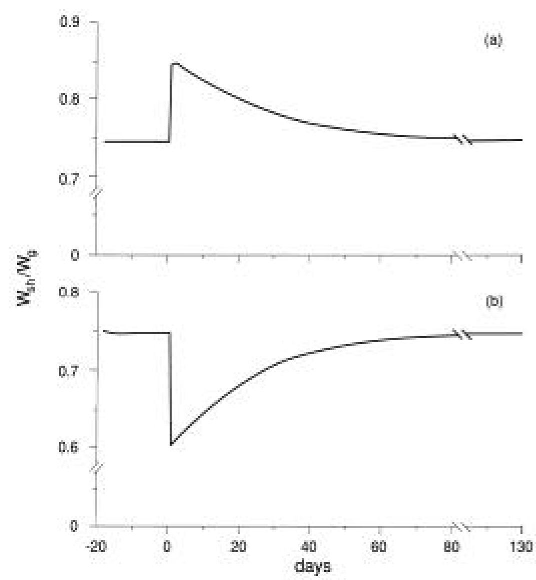

Fig.3 Modelled compensatory response of the shoot fraction (expressed as the "real-world" mass) W_{sh}/W_g to a simulated removal of 50% of the mass from either (a) the shoot, or (b)the root.

The model successfully simulates many elements of partitioning behavior. Fig.2 is the response surface of for partitioning as a function of light intensity and N supply. The line across the surface is the limit to growth rate and shoot fraction imposed by the amino-C (light) limited N uptake rate. Fig. 3 shows the ability of the model to demonstrate compensatory behavior to a "removal" of either shoot or root mass. This is an example of goal-seeking partitioning behavior.