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INVESTIGATIONS INTO BEHAVIORAL MODES OF A FOREST GROWTH MODEL

J. S. PANDEY

A. SHANKAR

P. KHANNA

National Environmental Engineering Research Institute
Nagipur, India

ABSTRACT

Application of sensitivity analysis for a tree growth model is discussed. The detailed tree growth model has been designed to test and augment general understanding of the processes involved in vegetative growth, and to predict the behavioral modes of the model under different levels of pollution stress. The effect of pollutants has been modeled and studied through sensitivity analysis in terms of changes in the conversion efficiency parameter for the foliage, assimilate partitioning coefficients, and coefficients dependent upon losses due to mortality, grazing and litter fall. The sensitivity analysis provides better understanding of the component subprocesses, and helps in deciding research priorities for useful application of the model in environmental management.

INTRODUCTION

Forest decline is widespread in those highly industrialized parts of the world that are affected by high emission loadings of the air pollutants [1]. Well known damage symptoms and empirical data on the physiological responses of plants to pollutants [2] have established the importance of the role played by air pollution in large-scale forest die-back.

There are direct and indirect effects of pollutants [3, 4]. They can affect the assimilate organs directly [5] or they can affect the roots through soil acidification.

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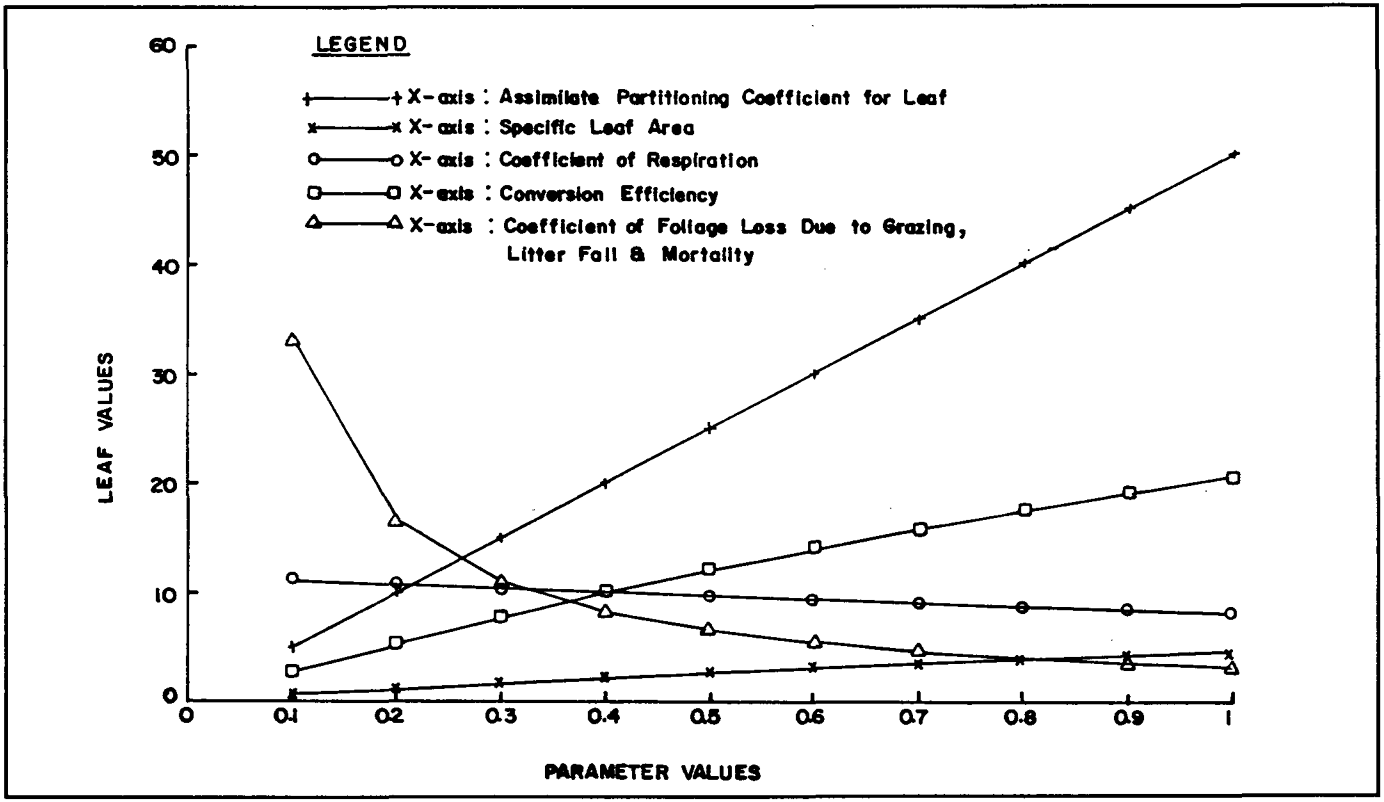

Figure 1. Polluted forest: Behavioural modes.

The assimilate produced through the photosynthetic process is partly used for maintenance respiration of leaves, permanent woody biomass and feeder roots. Utilization of the remaining assimilates leads to leaf growth, root growth, fructification and biomass increment. It has been established [6] that because of higher concentrations of air pollutants, photosynthetic production is reduced, and factors like nutrient deficiencies are not the cause but consequences of pollution loads.

The model is based on the assumption that forest die-back occurs mainly at the level of the individual tree. Tree is treated as a complex dynamic network composed of many interrelated and interacting elements, which are functionally different. The emphasis is on studying how impairments of essential functions viz. photosynthesis feeder root renewal etc., affects the overall growth of a tree. The effect of pollutants has been modeled in terms of changes in the conversion efficiency parameter for the foliage, assimilate partitioning coefficients and coefficients dependent on losses due to mortality, grazing and litter fall. The leaf biomass, stem biomass and root biomass are the state variables considered. (See Figure 1.)

Modeling exercises, such as the one presented here, invariably involve problems regarding assumptions involved in the formulation of structure of the model, parameter values chosen and initial values of the state variables. Sensitivity analysis helps provide a better understanding of internal working of the system sub-processes. Model results have, thus, been investigated through sensitivity analysis of the state variables with respect to conversion efficiency parameter, assimilate partitioning coefficients, specific leaf area index and the coefficients dependent on losses due to mortality, grazing and litter fall.

THE MODEL

The model is represented through the set of differential equations, which can be written in the matrix form [7] as follows:

$$\frac{d(LRS)}{dt} = [1-\exp(-k \times (SLA) \times (Leaf)] \times (LRS)_A - (LRS)_B \times (LRS) \qquad (1)$$

Where,

$$(LRS) = \begin{bmatrix} (LRS)_{1,1} \\ (LRS)_{2,1} \\ (LRS)_{3,1} \end{bmatrix} \qquad (2)$$

$(LRS)_{1,1}$ = Leaf dry weight (t/ha)
$(LRS)_{2,1}$ = Root dry weight (t/ha)
$(LRS)_{3,1}$ = Stem biomass (t/ha)

$$(LRS)_A = \begin{bmatrix} (assp)_R \times (cep) \times (photo)_0 \\ (assp)_S \times (cep) \times (photo)_0 \\ (assp)_L \times (cep) \times (photo)_0 \end{bmatrix} \quad (3)$$

$$(LRS)_B = \begin{bmatrix} (LRS)_{B\ 1,1} & O & O \\ (LRS)_{B\ 2,1} & (LRS)_{B\ 2,2} & O \\ (LRS)_{B\ 3,1} & O & (LRS)_{B\ 3,3} \end{bmatrix} \quad (4)$$

$$(LRS)_C = 1 - \exp(-kx\,(SLA) \times (Leaf) \quad (5)$$

Where,

$(photo)_0$ — Photosynthetic production assuming complete light interception
cep — Conversion efficiency parameter (dry matter production per unit CO_2)
SLA — Specific leaf area
k — Canopy light extinction coefficient

$$(LRS)_{B\ 1,1} = (glm)_L + (resp)_L\,(assp)_L\,(cep) \quad (6)$$

$$(LRS)_{B\ 2,1} = (resp)_L\ (assp)_R\ (cep) \quad (7)$$

$$(LRS)_{B\ 2,2} = (glm)_R + (resp)_R\ (cep) \quad (8)$$

$$(LRS)_{B\ 3,1} = (resp)_L\ (assp)_S\,(cep) \quad (9)$$

$$(LRS)_{B\ 3,3} = (glm)_S + (resp)_S\,(cep) \quad (10)$$

$(assp)_i$ = assimilate partitioning coefficient (i = leaf, root, stem)

$(resp)_j$ = respiration coefficient (j = leaf, root, stem)

$(glm)_k$ = coefficient for grazing, litter fall and mortality (k = leaf, root, stem)

Sensitivity analysis has been carried out using partial derivatives of the state variables with respect to $(assp)_{L,R,S}$, cep, SLA, $(resp)_{L,R,S}$ and $(glm)_{L,R,S}$. The expressions for state variables in regard to 'Leaf' are given below:

$$\text{SLea-Assp} = \frac{F_1\,[F_2 - F_3]}{F_4\,[F_4 - F_5]} \quad (11)$$

$$\text{SLea-Cep} = \frac{F_1\,[F_6 - F_7]}{F_4\,[F_4 - F_5]} \quad (12)$$

$$\text{SLea-SLA} = \frac{F_8}{F_4 - F_9} \quad (13)$$

$$\text{SLea-gem} = \frac{F_1 \quad F_{11}}{F_4\,[F_5 - F_4]} \tag{14}$$

$$\text{SLea-Resp} = \frac{F_1 \quad F_{11}}{F_4\,[F_5 - F_4]} \tag{15}$$

Where,

$$F_1 = 1 - \exp(-k \times SLA \times (Leaf) \tag{16}$$

$$F_2 = (cep)\,(photo)_0[glm)_L + (resp)_L\,(assp)_L\,(cep)] \tag{17}$$

$$F_3 = (assp)_L\,(resp)_L\,(photo)_0\,(cep)^2 \tag{18}$$

$$F_4 = (glm)_L + (resp)_L\,(assp)_L\,(cep) \tag{19}$$

$$F_5 = k\,(cep)\,(SLA)\,(photo)_0\,(assp)_L\,\exp(-k\,(SLA)\,(Leaf) \tag{20}$$

$$F_6 = (assp)_L\,(photo)_0\,[(glm)_L + (resp)_L\,(assp)_L\,(cep)\,] \tag{21}$$

$$F_7 = (assp)_L2\,(resp)_L\,(cep)\,(photo)_0 \tag{22}$$

$$F_8 = (assp)_L\,(cep)\,(photo)_0\,k\,(Leaf)\,\exp(-k\,(SLA)\,(Leaf) \tag{23}$$

$$F_9 = k\,(cep)\,(assp)_L\,(photo)_0\,\exp\,[-k\,(SLA)\,(Leaf)] \tag{24}$$

$$F_{10} = (assp)_L\,(cep)\,(photo)_0 \tag{25}$$

$$F_{11} = (assp)_L2\,(cep)^2\,(photo)_0 \tag{26}$$

RESULTS

Expressions (11) through (26) are the expressions for analyzing sensitivity of Leaf w.r.t. assimulate partitioning coefficient, conversion efficiency parameter, specific leaf area, coefficient depicting losses due to grazing, litter fall and mortality and respiration coefficient respectively.

Simulation of the model has been carried out with an objective of studying the sensitivity of the state variables of the system to changes in the various parameters of which the state variable is a function. This has been done first through the analytical expressions, which have then been compared with their graphical counterparts. Graphs have been obtained by plotting the state variable (Leaf) w.r.t. the parameter being varied; keeping the value of other parameters constant.

A finer analysis of results points to the following conclusions:

1. The values of state variable (Leaf) are more sensitive to coefficient to foliage loss due to grazing, litter fall and mortality, to the values of assimilate partitioning coefficient for leaf and to changes in conversion efficiency parameter.

2. Changes in the values of specific leaf areas and coefficient of respiration affect the variable very insignificantly.
3. Investigation of the graphical outputs also confirm this observation.

DISCUSSION

The method employed in the present research endeavour helps set priorities for model refinement and quantification of the degree to which model output can be trusted when it is being used for prediction purposes in environmental management. However, application of the model to real life situations depends on its structural and empirical validity.

Simulation runs suggest that there is essentially no difference in principle between the effect of leaf damage and of feeder root damage, because both result in the reduction of assimilate availability on the same life processes. Considerable amount of inertia is observed in the response of trees to pollution reduction. This means that taking more rapid and drastic measures against emissions of air pollutants is essential. Moreover, the importance of systems analysis and ecological systems modeling for systematically revealing the causes behind different behavioral modes of the ecosystem is strongly indicated.

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Direct reprint requests to:

Dr. J. S. Pandey
Computer Applications Division
National Environmental Engineering Research Institute
Nehru Marg
NAGPUR-400 020, India