DETERMINING NUTRIENT REQUIREMENTS FOR INTENSIVELY MANAGED LOBLOLLY PINE STANDS USING THE SSAND (SOIL SUPPLY AND NUTRIENT DEMAND) MODEL

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Abstract—Nutrient management represents a central component of intensive silvicultural systems that are designed to increase forest productivity in southern pine stands. Forest soils throughout the South are generally infertile, and fertilizers may be applied one or more times over the course of a rotation. Diagnostic techniques, such as foliar analysis and soil testing are available, yet have not been highly successful in identifying fertilizer responsive sites. In most cases recommendations, based on these approaches, lack site-specificity. The Soil Supply And Nutrient Demand (SSAND) model is a mechanistic computer simulation model developed to: (1) diagnose nutrition limitations and (2) determine site-specific fertilization regimes necessary to achieve preset production goals. With this model, the user sets a desired level of production and the model is used to calculate stand nutrient demand. Using mass/flow diffusion theory, the model then simulates the soil supply and compares it to the demand. If the demand is more than supply, fertilization regimes can be tested in order to see which may be the most efficient in meeting plant nutrient demand. This paper provides an overview of the SSAND model and its application.

INTRODUCTION

Forest productivity of southern pine plantations is well below their biological potential (Farnum and others 1983, Neary and others 1990a), and low soil fertility is one of the major constraints to their potential being realized (Neary and others 1990b). It is not surprising, therefore, that during the last two decades genetic improvement, competition control, and water and nutrient management have increased productivity (Colbert and others 1990, Jokela and Martin 2000, Neary and others 1990a,b, Prichett and Comerford 1982).

Current fertilization recommendations are based on soil testing, foliar analysis, and field trials. However, recommendations lack site-specificity, which is most likely due to the empirical nature of these techniques. Consequently, a process-based assessment of the nutrient requirements of southern pine plantations and the bioavailability of soil nutrients are required. The Soil Supply And Nutrient Demand (SSAND) model is a process-based computer simulation model that combines the processes controlling nutrient uptake by plants and nutrient supply by soil in order to diagnose the depth of a nutrition limitation and to determine a site-specific fertilization regime. This paper provides an overview of the model and presents examples of how it is used.

MODEL STRUCTURE AND FUNCTIONS

SSAND is written in Microsoft Visual Basic 6.0, using Microsoft Excel worksheets and text files as inputs. Output is provided in *.txt files and Excel worksheets. Figure 1 shows the main interface of SSAND and the four steps that it performs.

Step 1. Desired Plant Growth

The user chooses the species of interest and inputs the production goal, called Desired Plant Growth. The Desired Plant Growth is provided, by the user, via an Excel worksheet and can be specified as biomass growth data over time (biomass input file; figure 2a). A second input file documents nutrient use efficiency (NUE) for producing the biomass over time (figure 2b). These input files are used to compute and generate a file of the nutrient demand necessary to achieve the production goal. Figure 3 shows an example of the output of nutrient demand with time.

Step 2. Nutrient Uptake Model

This step computes the soil supply and nutrient uptake by the plant using mass flow/diffusion theory for soil processes and root characteristics as the soil boundary condition definition. The model uses soil parameters (soil volume, bulk density, water content, nutrient diffusion coefficient in water, mineralization rate, and nutrient adsorption-desorption isotherm characteristics; figure 4a) and plant parameters (rate of water flux into roots, the

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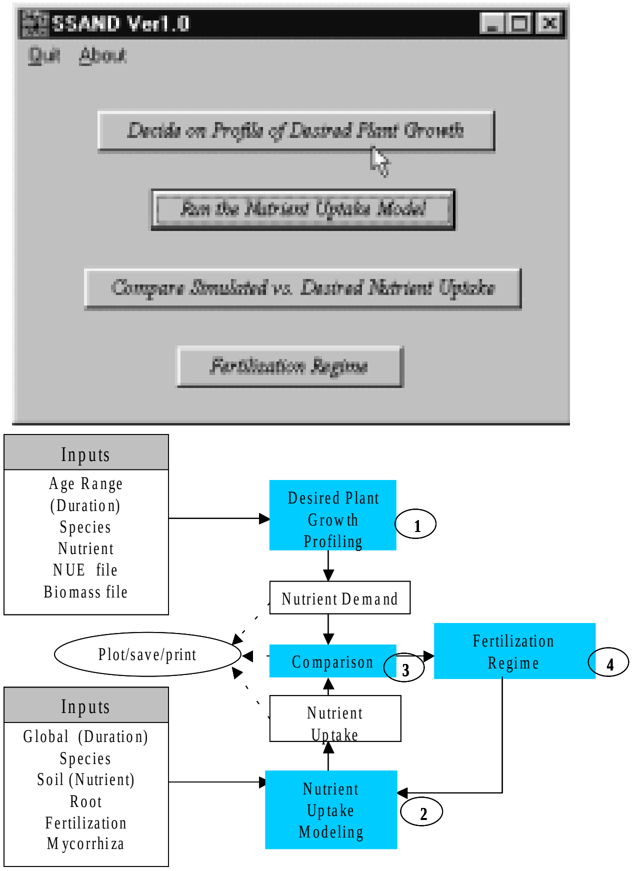


Figure 1—The SSAND model's main interface and structure.

average fine root radius, the root length density and nutrient uptake kinetics parameters; figure 4b) to evaluate the processes responsible for plant nutrient uptake by roots. Additional features allow the user to simulate nutrient uptake by extramatrical mycorrhizal fungi or the roots of a second, competing plant species, or both. The output from this step is the predicted nutrient uptake for which an example is found in figure 5.

Step 3. Comparison of Predicted Uptake and Demand

The third step compares the predicted nutrient uptake to the nutrient demand over time, as well as a user-defined limit around the result. If the predicted uptake is above or within the user-defined limit, the interpretation is that nutrient bioavailability is not a limitation to the desired productivity. If the uptake is below the user-defined limit of the uptake/demand curve, then the nutrient demand may be limiting productivity and fertilization should be useful. Such a nutrient limitation, beginning after 250 days, is shown in figure 6.

Step 4. Fertilization Regime

This fourth step allows the user to design a fertilization regime using multiple fertilization events. Each fertilization event is defined by the day of fertilization and the amount of elemental nutrient applied as fertilizer (figure 7a). A fertilization regime can have as many events as desired.

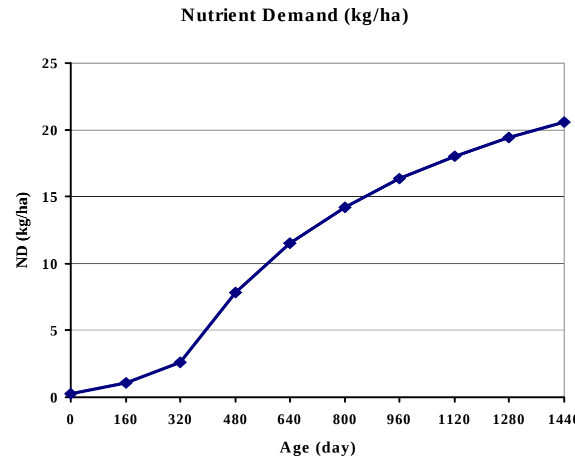


Figure 3—An example of the nutrient demand profile required to achieve predetermined production goals.

Final Modeling Outcome

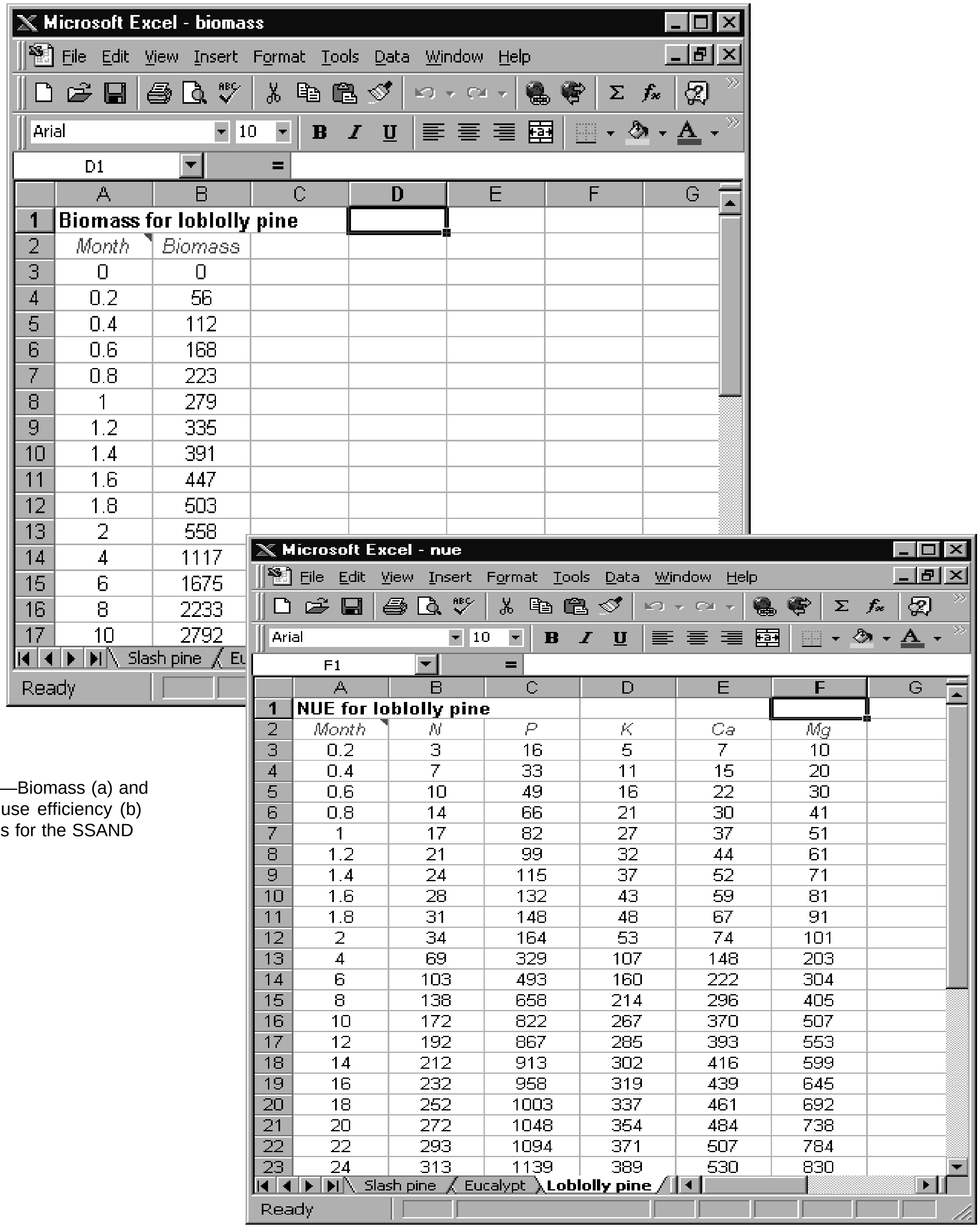
After inputing a fertilization regime, the nutrient uptake model (step 2) is run again and a new comparison is made between nutrient uptake and demand (step 3). The user can iteratively and interactively try various fertilization regimes until the predicted uptake meets the demand of the desired production. The example in figure 7b shows a fertilization regime that supplies the plant demand necessary to achieve the predetermined production goal.

TESTING AND VALIDATING THE SSAND MODEL

A process-based model requires detailed inputs from which the necessary processes can be simulated. Required data include:

- Temporal curves of total plant biomass for the desired level of production
- Nutrient concentrations of tree biomass components (including roots) and temporal curves of nutrient use efficiency
- Soil bulk density
- Water content changes by horizon over time
- Nutrient mineralization rates
- Fine root and/or mycorrhizal fungi characteristics (average fine-root radius by horizon, root length density by horizon, average water influx rate to roots by horizon, nutrient uptake kinetic parameters)
- Adsorption and desorption isotherms by horizon

During the past two years, our efforts have focused on acquiring the biomass, fine root data, plant tissue nutrient data and soil chemical and physical data necessary to test this model in intensively managed, juvenile (age 1 through 4) stands of loblolly pine growing on Spodosols of the Coastal Plain of southeastern Georgia. Above- and belowground components of 104 trees were harvested and



Biomass for loblolly pine

Month	Biomass
0	0
0.2	56
0.4	112
0.6	168
0.8	223
1	279
1.2	335
1.4	391
1.6	447
1.8	503
2	558
4	1117
6	1675
8	2233
10	2792

NUE for loblolly pine

Month	N	P	K	Ca	Mg
0.2	3	16	5	7	10
0.4	7	33	11	15	20
0.6	10	49	16	22	30
0.8	14	66	21	30	41
1	17	82	27	37	51
1.2	21	99	32	44	61
1.4	24	115	37	52	71
1.6	28	132	43	59	81
1.8	31	148	48	67	91
2	34	164	53	74	101
4	69	329	107	148	203
6	103	493	160	222	304
8	138	658	214	296	405
10	172	822	267	370	507
12	192	867	285	393	553
14	212	913	302	416	599
16	232	958	319	439	645
18	252	1003	337	461	692
20	272	1048	354	484	738
22	293	1094	371	507	784
24	313	1139	389	530	830

Figure 2—Biomass (a) and nutrient use efficiency (b) input files for the SSAND model

separated into sub-components for biomass and nutrient analysis. Fine root biomass, radius, and length were measured on 240 soil samples collected from 39 soil pits.

The development of the SSAND model is still in progress. After the model has been tested and validated for loblolly pine on Spodosols, the goal will be to evaluate its application to other soil types and forest tree species.

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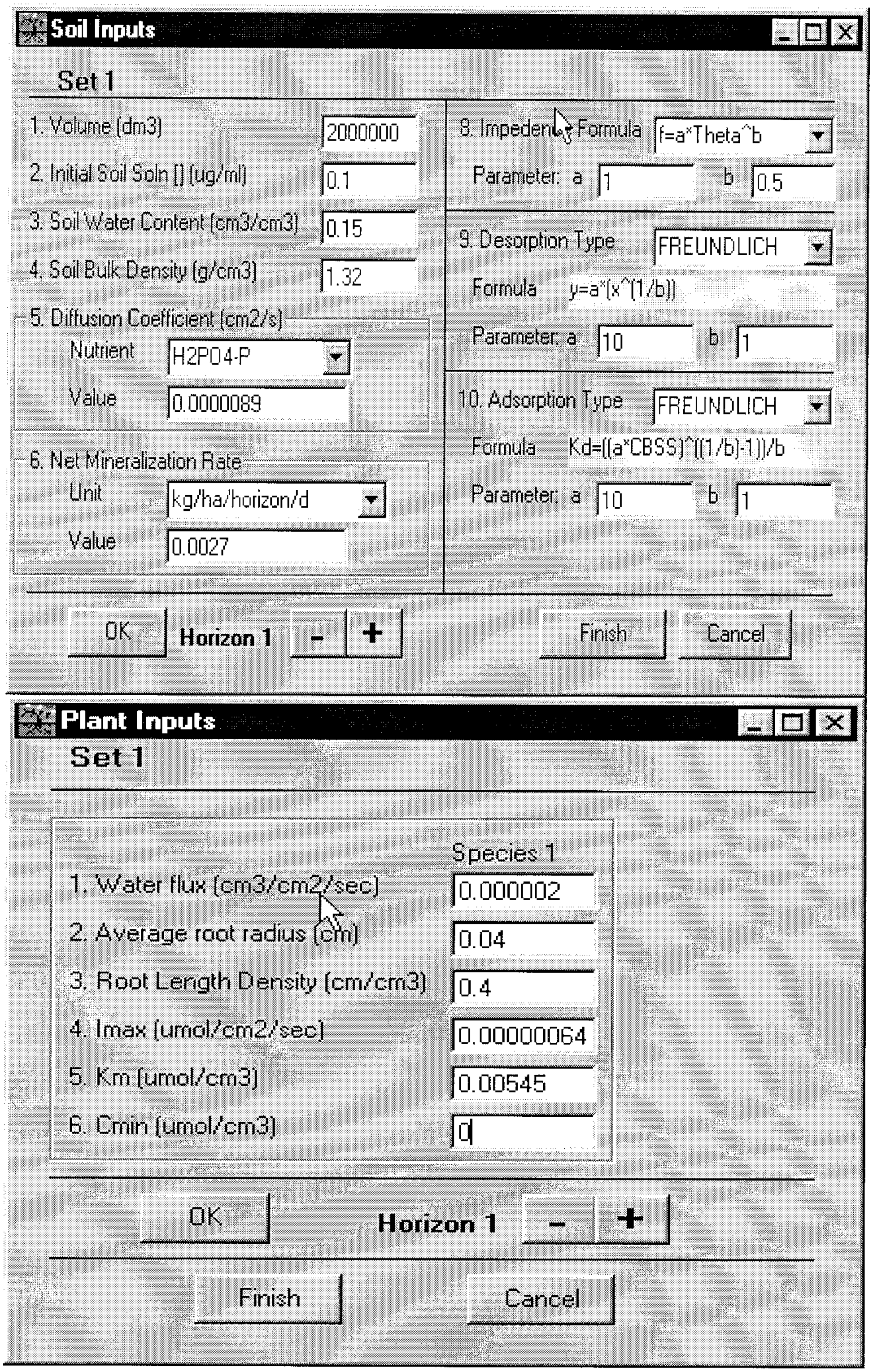

a

b

Figure 4—Parameters used in the SSAND nutrient uptake model: (a) soil inputs and (b) plant root and uptake kinetics inputs.

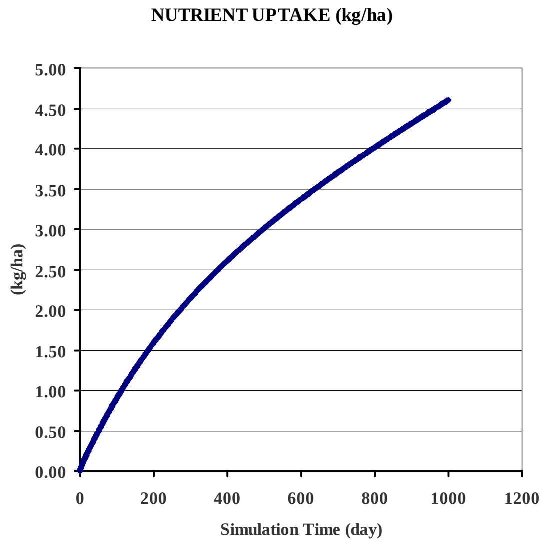

Figure 5—Simulated nutrient uptake over time for a hypothetical loblolly pine stand

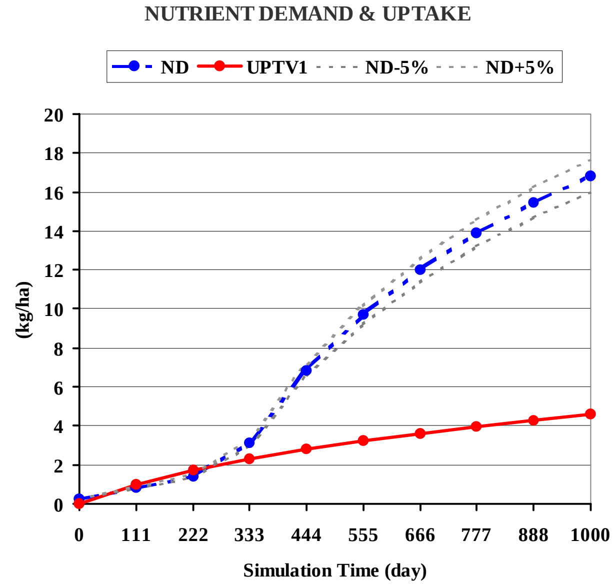

Figure 6—Comparison between required nutrient demand and simulated nutrient uptake. A nutrient limitation is shown to begin after 250 days. ND is nutrient demand and UPTV1 is simulated nutrient uptake.

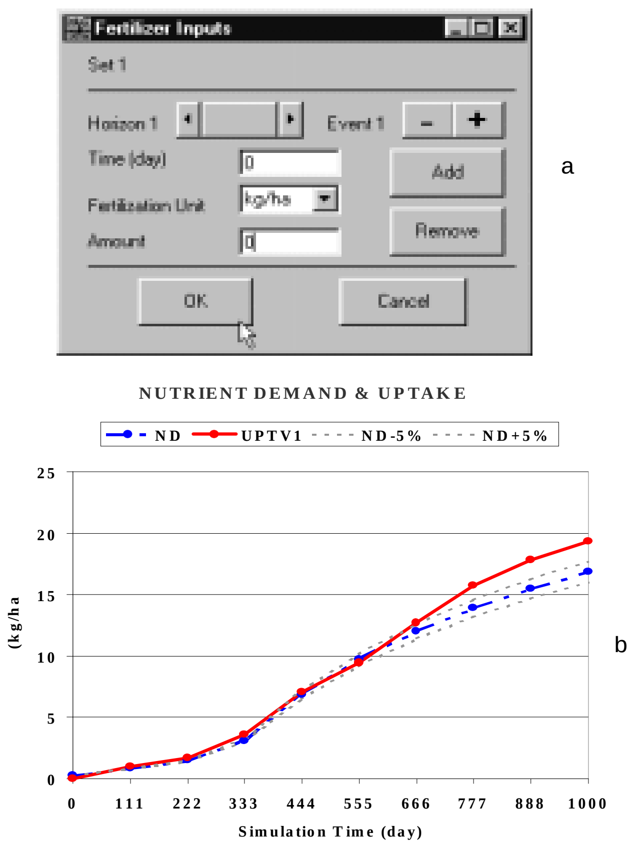

Figure 7—Fertilizer input interface (a) and an evaluation of a fertilization regime designed to meet the nutrient demand of a stand growing at a predetermined production goald (b). ND is nutrient demand and UPTV1 is simulated nutrient uptake.

REFERENCES

Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. Forest Science. 36: 995-1014.

Farnum, P.; Timmis, R.; Kulp, J.L. 1983. Biotechnology of forest yield. Science. 219: 694-702.

Jokela, E.J.; Martin, T.A. 2000. Effects of ontogeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. Canadian Journal of Forest Research. 30: 1511-1524.

Neary, D.G.; Jokela, E.J.; Comerford, N.B.; Colbert, S.R.; Cooksey, T.E. 1990b. Understanding competition for soil nutrients – the key to site productivity on southeastern Coastal Plain Spodosols. In: Gessel S.P., Lacate D.S., Weetman G.F., and Powers R.F., eds. Proceedings of the Seventh North American Forest Soils Conference; 1988 July 24-28; Vancouver, BC: Faculty of Forestry, University of British Columbia: 432-450.

Neary, D.G.; Rockwood, D.L.; Comerford, N.B.; Swindel, B.F.; Cooksey, T.E. 1990a. Importance of weed control, fertilization, irrigation, and genetics in slash and loblolly pine early growth on poorly drained Spodosols. Forest Ecology and Management. 30: 271-281.

Prichett, W.L.; Comerford, N.B. 1982. Long-term response to phosphorus fertilization on selected southeastern Coastal Plain soils. Soil Science Society of America Journal. 46: 640-644.

Wood, C.W.; Mitchell, R.J.; Zutter, B.R.; Lin, C.L. 1992. Loblolly pine plant community effects on soil carbon and nitrogen. Soil Science. 154: 410-419.