OVERVIEW of the FOREST NUTRITION COOPERATIVE'S SILVICULTURAL DECISION SUPPORT SYSTEM

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The Forest Nutrition Cooperative's (FNC) Decision Support System (DSS) utilizes an expert system approach to model the effects of site conditions, site preparation, and first year silvicultural treatments on plantation survival and growth. At the core of the expert system is the FASTLOB2 growth and yield system (Amateis et al. 2001), a whole stand growth and yield model that includes options to evaluate thinning and/or established stand fertilization.. FASTLOB2 is the further evolution and development of several widely used models developed by the Virginia Tech Growth and Yield Cooperative. The DSS system was originally developed by Cristian Montes and Lee Allen and was first presented as Cristian's MS thesis "A Silvicultural Decision Support System for Loblolly Pine Plantations" (Montes 2001).

The major reasons for using the expert system approach include:

1. There is a large qualitative knowledge base concerning the impact of site preparation and early cultural treatments on survival and early growth that has yet to be incorporated into existing growth and yield models. An expert system approach allows the incorporation of this knowledge into a growth and yield system without having to completely reparameterize the system.
2. Survival and early growth across the South varies greatly due to the inherently different soil and site conditions upon which loblolly pine plantations are established. A flexible approach, such as an expert system, is needed that can accommodate this variability.
3. Site specific treatments are often applied at time of plantation establishment to improve survival and enhance growth. Some of these treatments can affect plantation growth and development throughout the rotation. Thus, an approach is needed that can be seamlessly integrated into growth and yield models used to model stand development after stand establishment. An expert system approach can be added easily to the "front end" of many types of growth and yield models.

The expert system incorporates the concept of a loblolly pine "base" site index (25 year) for each of the major soil types in the Southeast and soil specific responses to various treatments including herbaceous weed control, hardwood vegetation control, bedding, combination plowing, and at time of P fertilization. The FNC soil matrix, base site index values, and treatment response estimations were originally developed by Lee Allen, Bob Campbell, and Jim Gent for the Forest Nutrition Cooperative's Forest Productivity – Silvicultural Relationships workshops in the early 1990s and have been modified and updated as new information has become available during the last 15 years. The soil matrix differentiates major soil groups based on drainage, subsoil texture, and depth of the A horizon and presence or absence of a spodic horizon. The importance of these soil properties for southern pine productivity has been long recognized (Coile 1952, Morris

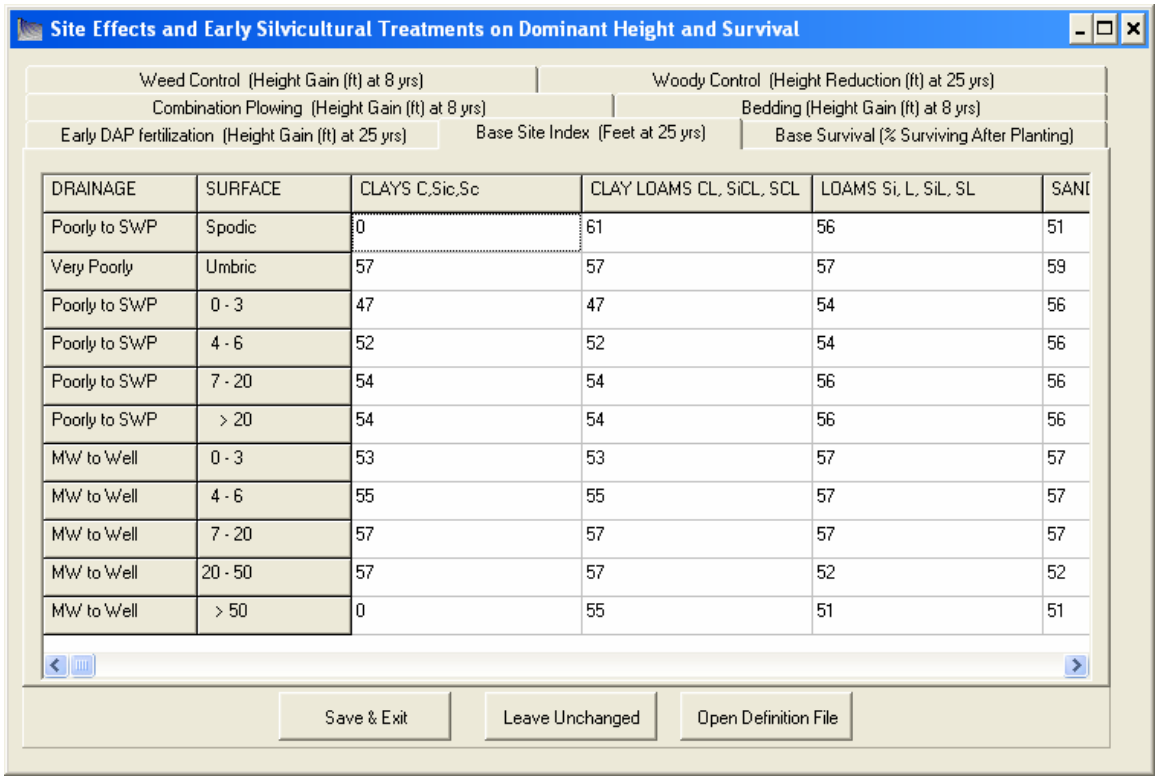
and Campbell, 1991). These same properties serve as the basis for the CRIFF Soil Groups (Fisher and Garbett 1980) and are known to be important determinants of response to several silvicultural treatments (Fisher and Garbett 1980, Morris and Campbell 1991, Fox 2000, Allen et al. 2005.)

Base Site Index and Response to P Fertilization and Hardwood Control

Site index, the average height of the dominant tree in a stand at age 25, is the most commonly used metric of site quality in loblolly pine growth and yield models. At plantation establishment, when trees are absent on the site, estimating site index can be problematic. The DSS expert system provides an estimate of a base site index for new stands based on the FNC soil matrix, the level of phosphorus deficiency, and the presence or absence of hardwood or shrubby vegetation (toggles on the main input page). If desired, the expert system can be bypassed by toggling the "bypass expert system" under soil type and by specifying the desired site index.

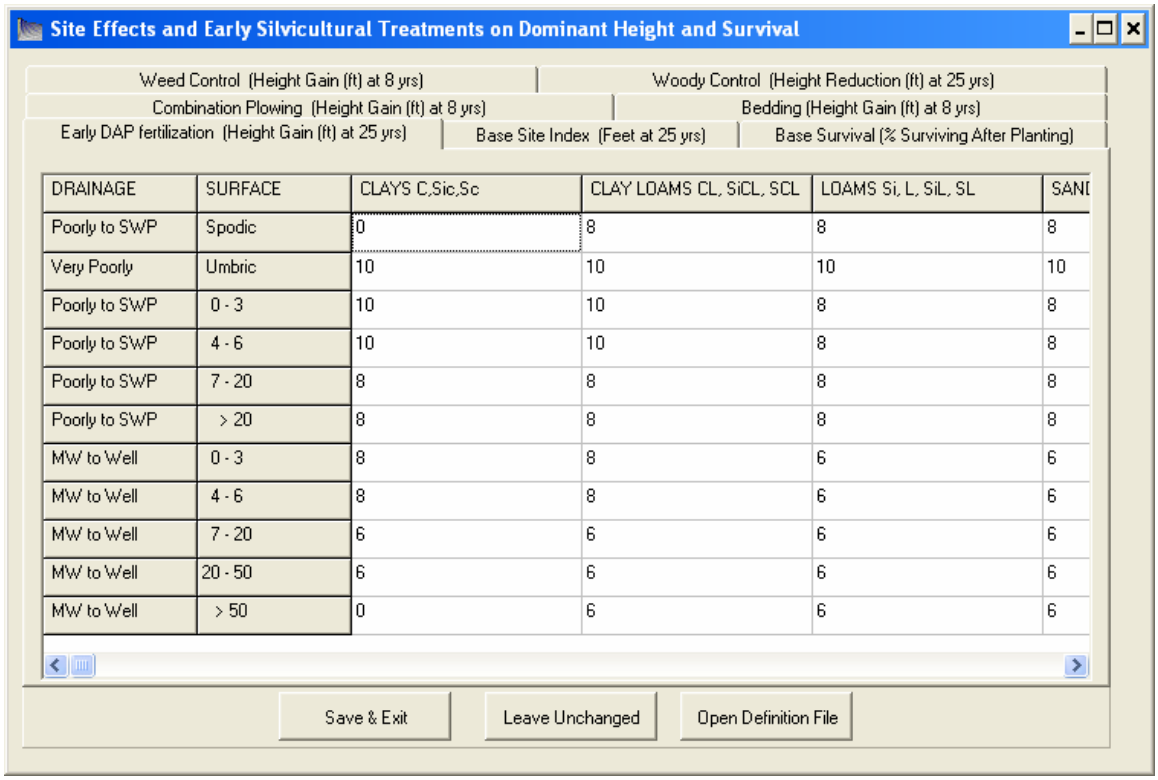
The FNC soil matrix groups soils by drainage, subsoil texture, depth of the A horizon, and presence or absence of a spodic horizon. Four groups of subsoil texture are considered: clays, clay loams, loams, and sands and three levels of soil drainage: very poorly, poorly to somewhat poorly, and moderately well to well drained. For very poorly drained soils, the surface condition of the A horizon is by definition umbric (thick, dark high organic matter surface). For the other two drainage classes, A horizon thickness is broken out into several groups ranging from 0-3 inches to greater than 40 inches. Poorly drained soils that have subsoil textures of clay loam or coarser are also broken out based on the presence or absence of a spodic horizon. Based on our collective experience, estimates of base site index for these soil groups were determined assuming the soil was highly phosphorus deficient (Figure 1). Within the DSS, these estimates can be found under Tools > Soil Matrix Response > Base Site Index.

The base site index estimates are also affected by the level of phosphorus deficiency. The expert system categorizes phosphorus deficiency into three levels: severe, moderate and low and these levels are directly linked with the magnitude of response estimates following at time of planting fertilization with 200 lbs/acre of diammonium phosphate (Figure 2). Within the DSS, these estimates can be found under Tools > Soil Matrix Response > Early DAP fertilization. On sites that have been identified as severely P deficient (P deficiency toggle on the main input page), the magnitude of response to early fertilization varies by soil type as given in the Early DAP fertilization table (Figure 2). Because stands typically exhibit a "Type A" response to P fertilization, the site index used for a run with P fertilization is the sum of the base site index plus the P fertilization response estimate. If moderate P deficiency is selected, the base site index values for each cell of the soil matrix are increased by ½ of the P response given for that cell. However, because the site is only moderately P deficient the response to P fertilization is then reduced to ½ of the P response given in the Early DAP fertilization table. If low P deficiency is selected, the base index values for each cell of the soil matrix are increased by the P response given for that cell, and the response to P fertilization is then set to 0 because the site is not P deficient. As a result of these linkages among base site index and



DRAINAGE	SURFACE	CLAYS C,Sic,Sc	CLAY LOAMS CL, SiCL, SCL	LOAMS Si, L, SiL, SL	SANI
Poorly to SWP	Spodic	0	61	56	51
Very Poorly	Umbric	57	57	57	59
Poorly to SWP	0 - 3	47	47	54	56
Poorly to SWP	4 - 6	52	52	54	56
Poorly to SWP	7 - 20	54	54	56	56
Poorly to SWP	> 20	54	54	56	56
MW to Well	0 - 3	53	53	57	57
MW to Well	4 - 6	55	55	57	57
MW to Well	7 - 20	57	57	57	57
MW to Well	20 - 50	57	57	52	52
MW to Well	> 50	0	55	51	51

Figure 1. Example of base site index estimates used in FASTLOB2 for bare ground simulations for several soil groups assuming the soils were highly P deficient.

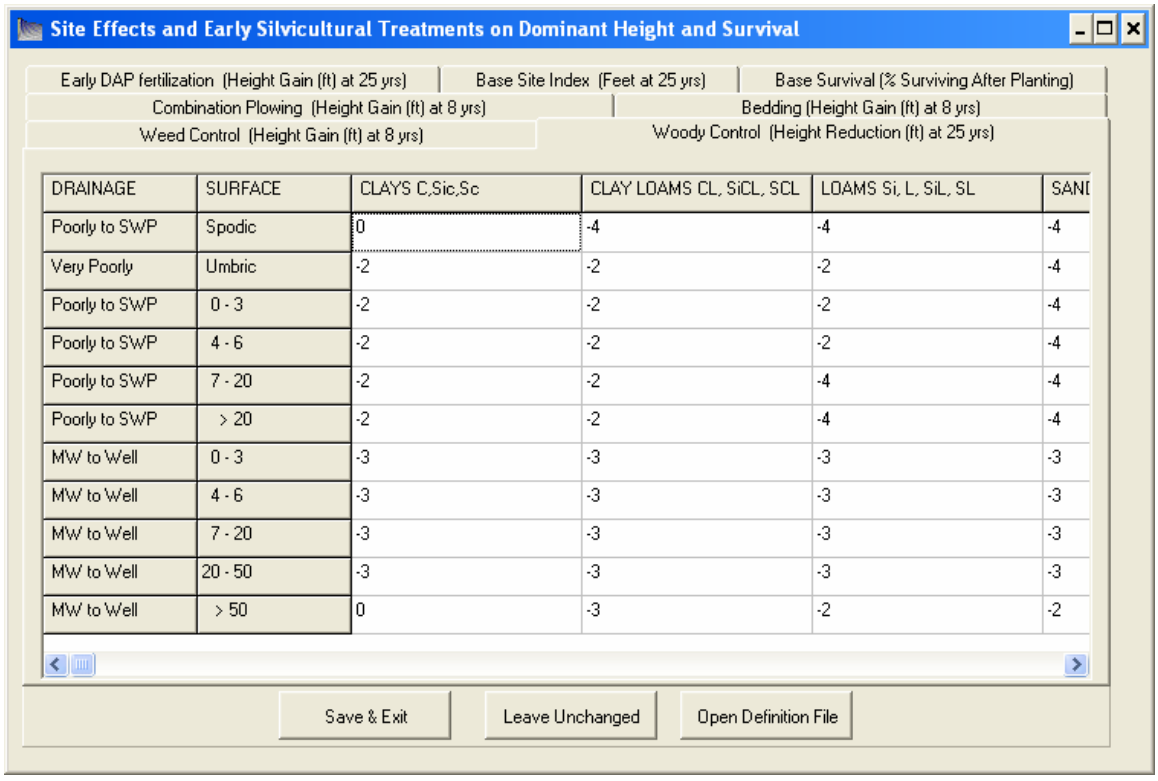


DRAINAGE	SURFACE	CLAYS C,Sic,Sc	CLAY LOAMS CL, SiCL, SCL	LOAMS Si, L, SiL, SL	SANI
Poorly to SWP	Spodic	0	8	8	8
Very Poorly	Umbric	10	10	10	10
Poorly to SWP	0 - 3	10	10	8	8
Poorly to SWP	4 - 6	10	10	8	8
Poorly to SWP	7 - 20	8	8	8	8
Poorly to SWP	> 20	8	8	8	8
MW to Well	0 - 3	8	8	6	6
MW to Well	4 - 6	8	8	6	6
MW to Well	7 - 20	6	6	6	6
MW to Well	20 - 50	6	6	6	6
MW to Well	> 50	0	6	6	6

Figure 2. Early DAP fertilization site index gains (feet at age 25) used in FASTLOB2 for severely phosphorus deficient soils.

level of P deficiency, the same index is used for severe, moderate, and low P deficiency once P fertilization is applied. Please note that the response to P fertilization on low P deficient sites does interact with vegetation type and vegetation control treatment as described in a following section.

The base site index estimates are also affected by the presence or absence of hardwood vegetation. Hardwoods hinder loblolly pine growth because they utilize site resources that would otherwise grow pines. Therefore, the expert system adjusts the base site index down when hardwoods are present on the site and a chemical site preparation treatment is not applied. If the competing vegetation type is none or weeds (competing vegetation toggle on the main input page), the base site index remains unchanged. If the hardwoods or weeds+hardwoods toggle is selected then the expert system adjusts the base site index down based on the values in the Woody Control table (Figure 3). Within the DSS, these estimates can be found under Tools > Soil Matrix Response > Woody Control. If chemical site preparation (hardwood control) is selected (under the establishment and first year treatment tab on the right hand side of main page) then site index is not reduced in the presence of hardwood. If hardwoods are not present, chemical site preparation will not affect site index or stand growth but will reduce NPV due to the its cost.



DRAINAGE	SURFACE	CLAYS C,Sic,Sc	CLAY LOAMS CL, SiCL, SCL	LOAMS Si, L, SiL, SL	SANI
Poorly to SWP	Spodic	0	-4	-4	-4
Very Poorly	Umbric	-2	-2	-2	-4
Poorly to SWP	0 - 3	-2	-2	-2	-4
Poorly to SWP	4 - 6	-2	-2	-2	-4
Poorly to SWP	7 - 20	-2	-2	-4	-4
Poorly to SWP	> 20	-2	-2	-4	-4
MW to Well	0 - 3	-3	-3	-3	-3
MW to Well	4 - 6	-3	-3	-3	-3
MW to Well	7 - 20	-3	-3	-3	-3
MW to Well	20 - 50	-3	-3	-3	-3
MW to Well	> 50	0	-3	-2	-2

Figure 3. Reduction in site index (feet at age 25) due to the presence of competing hardwoods when chemical site preparation is not applied for several soil groups.

Note that in this version of the DSS, the presence or absence of hardwoods and the responses to woody control only affect site index. They are not linked to and therefore do not affect the % basal area in hardwoods (at crown closure and beyond) within FASTLOB2. If % basal area in hardwoods (toggle on main screen) is left blank then the

value defaults to 5%, the average value found in the data used to parameterize FASTLOB2. Users are encouraged to specify different levels of % hardwood basal area depending on their stand conditions and experience with woody control to more completely account for the positive effects of woody control on loblolly pine growth and yield.

Early DAP fertilization and hardwood control treatments are considered "Type A" adjustments to the base site index. They have an effect that persists over the rotation and are expressed as a change in the base site index.

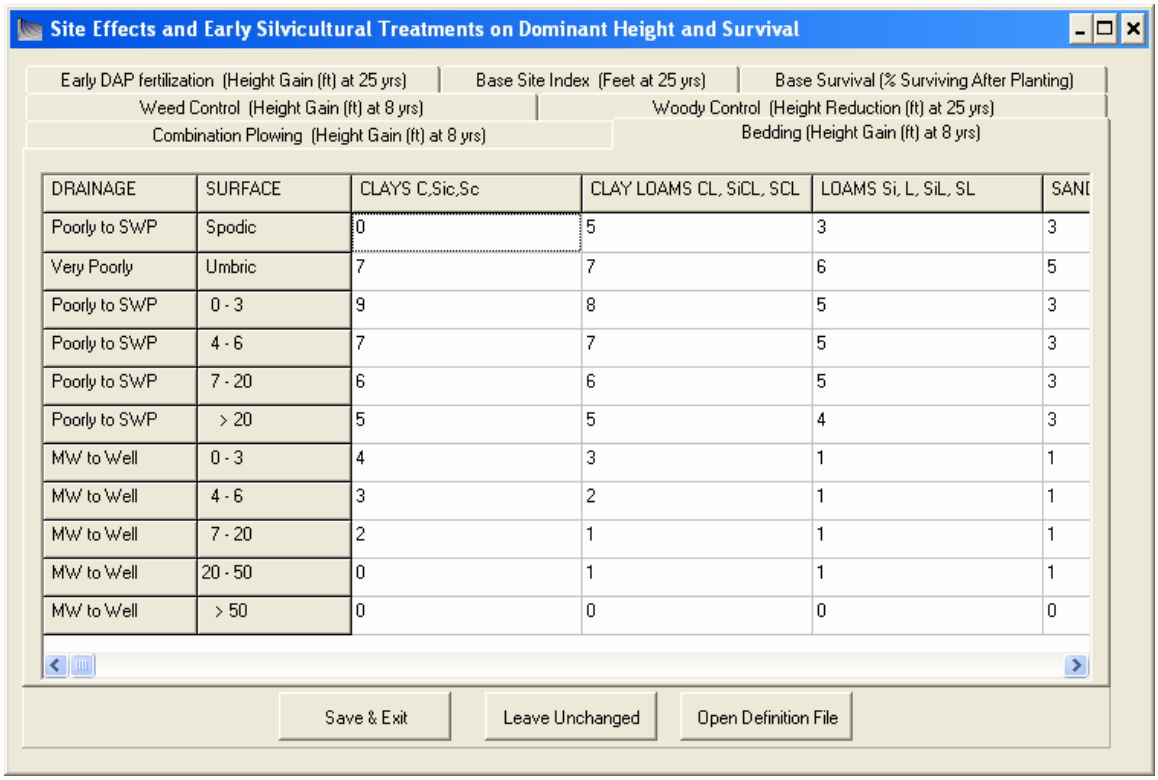
As an example of how the base site index is adjusted for P deficiency and hardwood competition, suppose a site is characterized as a clay loam, with poor to somewhat poor drainage, a surface horizon of only 0-3 inches and it is severely phosphorus deficient. From Figure 1, the base site index is 47 feet. From Figure 2, an increase of 10 feet is achieved **if** an early DAP treatment is applied. If no early DAP treatment is applied, then the base site index remains at 47 feet. If hardwood competition is present on the site, the base site index is adjusted down by another two feet (Figure 3) if chemical site preparation (hardwood control) is **not** applied.

The site index and treatment response estimates can be modified by the user and saved for future runs (the filename containing the response estimates is "default.som"). In addition, the site index value generated by the expert system can be overridden by typing the desired value on the site index line after all other data have been entered on the site information panel. Because of the strong biological links among the estimates of base site index and treatment responses, users need to use considerable caution when overriding or making changes in these tables.

Additional Adjustments for Bedding, Combination Plowing, and Weed Control

Once the base site index has been adjusted according to the level of P deficiency and its amelioration, and/or the presence or absence of hardwoods and their control, then additional adjustments for early cultural treatments such as bedding, combination plowing, and weed control are implemented. These three treatments are considered "Type B" responses where the dominant height responses listed in the tables are realized by age 8 years. These absolute differences in dominant height are then maintained through the rotation.

Dominant height adjustments for bedding (Tools > Soil Matrix Response > Bedding) vary by soil type with the best responses occurring on the wet clay sites Tools > Soil Matrix Response > Woody Control (Figure 4). The annual dominant height response from age 1 through age 8 years is computed by dividing the total response in the cell by 8 and adding it to the dominant height for that age computed from the adjusted base site index. After age 8, the total response in the cell is added to the dominant height computed from the adjusted base site index.



DRAINAGE	SURFACE	CLAYS C,Sic,Sc	CLAY LOAMS CL, SiCL, SCL	LOAMS Si, L, SiL, SL	SANI
Poorly to SWP	Spodic	0	5	3	3
Very Poorly	Umbric	7	7	6	5
Poorly to SWP	0 - 3	9	8	5	3
Poorly to SWP	4 - 6	7	7	5	3
Poorly to SWP	7 - 20	6	6	5	3
Poorly to SWP	> 20	5	5	4	3
MW to Well	0 - 3	4	3	1	1
MW to Well	4 - 6	3	2	1	1
MW to Well	7 - 20	2	1	1	1
MW to Well	20 - 50	0	1	1	1
MW to Well	> 50	0	0	0	0

Figure 4. Dominant height gains at age 8 years resulting following bedding for several soil groups.

For example, in the scenario presented above where an adjusted base site index of 57 has been identified for a clay loam site with poor to somewhat poor drainage, a surface of 0-3 inches, and treatments of DAP and chemical hardwood control (base site index of 47 feet and 10 feet of additional site index due to P amelioration), then from Figure 4, a dominant height gain of 8 feet due to bedding on the site is achieved. One foot of height gain at ages one through 8 is added to the dominant height computed from the adjusted base site index. For every age after 8, the dominant height gain is held constant at 8 feet.

Dominant height adjustments for combination plowing (Tools > Soil Matrix Response > Combination Plowing) also vary by soil type with the best response occurring on well drained clays (Figure 5). We are not currently recommending combination plowing for wet sites so responses on these soil types are set to 0. The same adjustment procedure for combination plowing is applied as for bedding. Continuing the example above, since there is a zero in the clay loam, poor to somewhat poor drainage and 0-3 surface (Figure 5) then no adjustment in dominant height gain is made for combination plowing. It should be noted that combination plowing and bedding are mutually exclusive treatments. The DSS will not recognize both treatments on the same site.

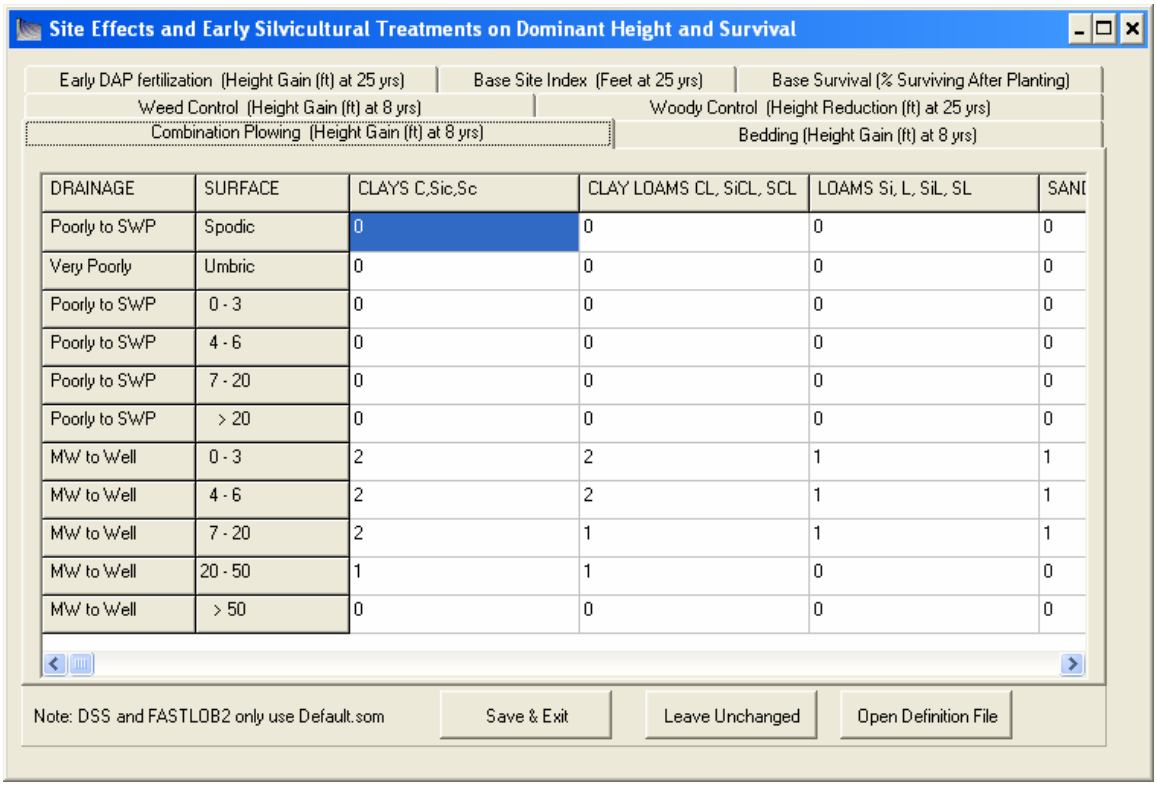


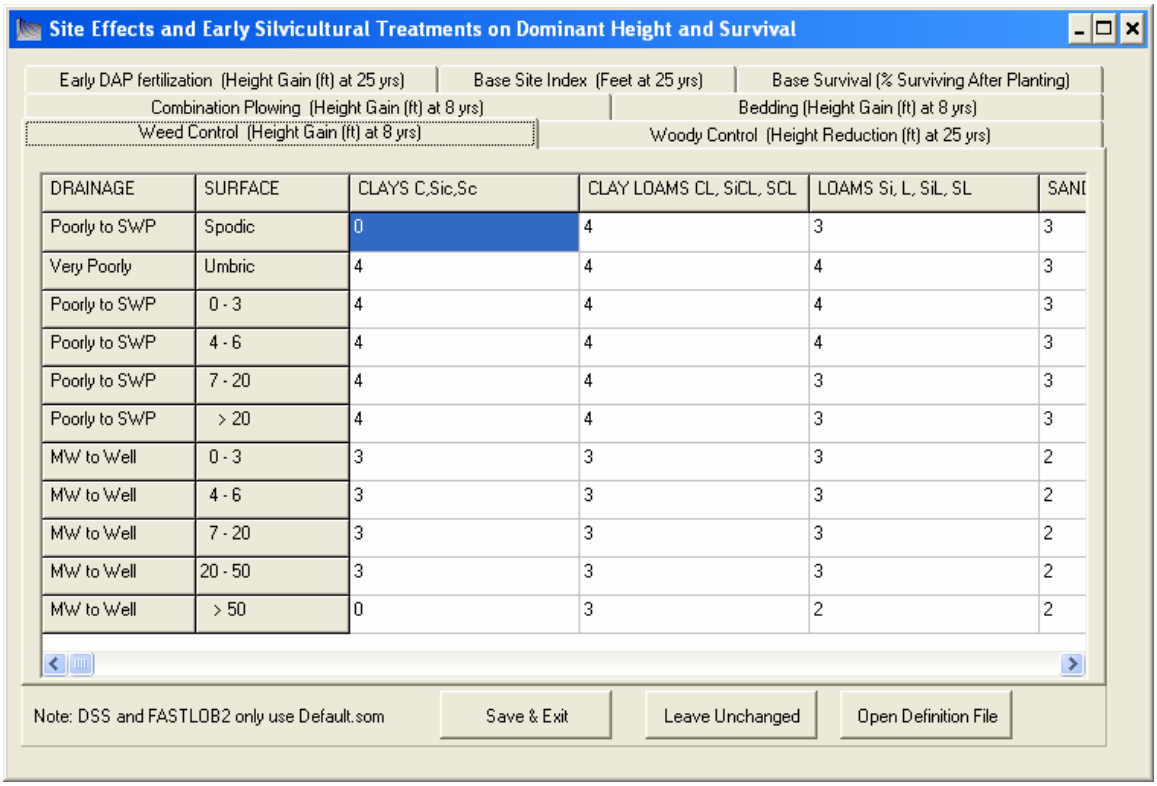
Figure 5. Dominant height gains at age 8 years following combination plowing for several soil groups.

Dominant height adjustments for herbaceous weed control (Tools > Soil Matrix Response > Weed Control) are little affected by soil type (Figure 6). The same adjustment procedure is followed for weed control as for bedding and combination plowing. For clay loams on poorly to somewhat poorly drained sites with 0-3 surface horizon depth, a dominant height gain of 4 can be realized from an early herbaceous weed control treatment (Figure 6). One-half foot per year of gain is realized cumulatively from ages 1 through 8 and for ages after 8 the total gain is held constant at 4 feet.

Interactions among Treatments

For most treatment combinations, responses are treated as additive within DSS. In the current version of DSS, two exceptions exist:

1. Response to herbaceous weed control is reduced by 25% when combined with bedding or combination plowing. This is because the response to tillage and weed control is not additive.
2. If P deficiency is low, competing vegetation is none, and DAP is applied, a P response of 2 feet is added to the adjusted base site index as a “type A” response. Similarly, if P deficiency is low, competing vegetation is present (weed, hardwoods, weeds+hardwoos) AND any type vegetation control is undertaken (herbaceous weed control, chemical site preparation, or both), and DAP is applied, 2 feet is added to the adjusted base site index. If vegetation is present and not controlled, the response to DAP on low P deficiency sites is 0 feet.



DRAINAGE	SURFACE	CLAYS C,Sic,Sc	CLAY LOAMS CL, SiCL, SCL	LOAMS Si, L, SiL, SL	SANI
Poorly to SWP	Spodic	0	4	3	3
Very Poorly	Umbric	4	4	4	3
Poorly to SWP	0 - 3	4	4	4	3
Poorly to SWP	4 - 6	4	4	4	3
Poorly to SWP	7 - 20	4	4	3	3
Poorly to SWP	> 20	4	4	3	3
MW to Well	0 - 3	3	3	3	2
MW to Well	4 - 6	3	3	3	2
MW to Well	7 - 20	3	3	3	2
MW to Well	20 - 50	3	3	3	2
MW to Well	> 50	0	3	2	2

Figure 6. Dominant height gains at age 8 years in response to herbaceous weed control for several soil groups.

Survival of Planted Seedlings

First year survival in loblolly pine plantations is highly dependent on soil and site conditions and time of planting silvicultural treatments. When initializing a new plantation, the DSS reduces the number of trees planted to account for base survival (Tools > Soil Matrix Response > Base Survival) at year one based on the soil type, drainage and surface condition (Figure 7). These base survival percentages are only applied only when the plantation is initialized at age 0 and no tillage treatments (bedding or combination plowing) are applied at plantation establishment. When tillage treatments are been applied, then base survival is set to a default value of 95% of the number of stems planted and no additional mortality occurs until intra-specific competition begins as represented in FASTLOB2.

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For the example discussed above, if 550 trees were planted on a clay loam with poor to somewhat poor drainage and a surface depth of 0-3 inches, then only 303 trees (55%) would survive to age 1 if no tillage or bedding was applied at time of planting.

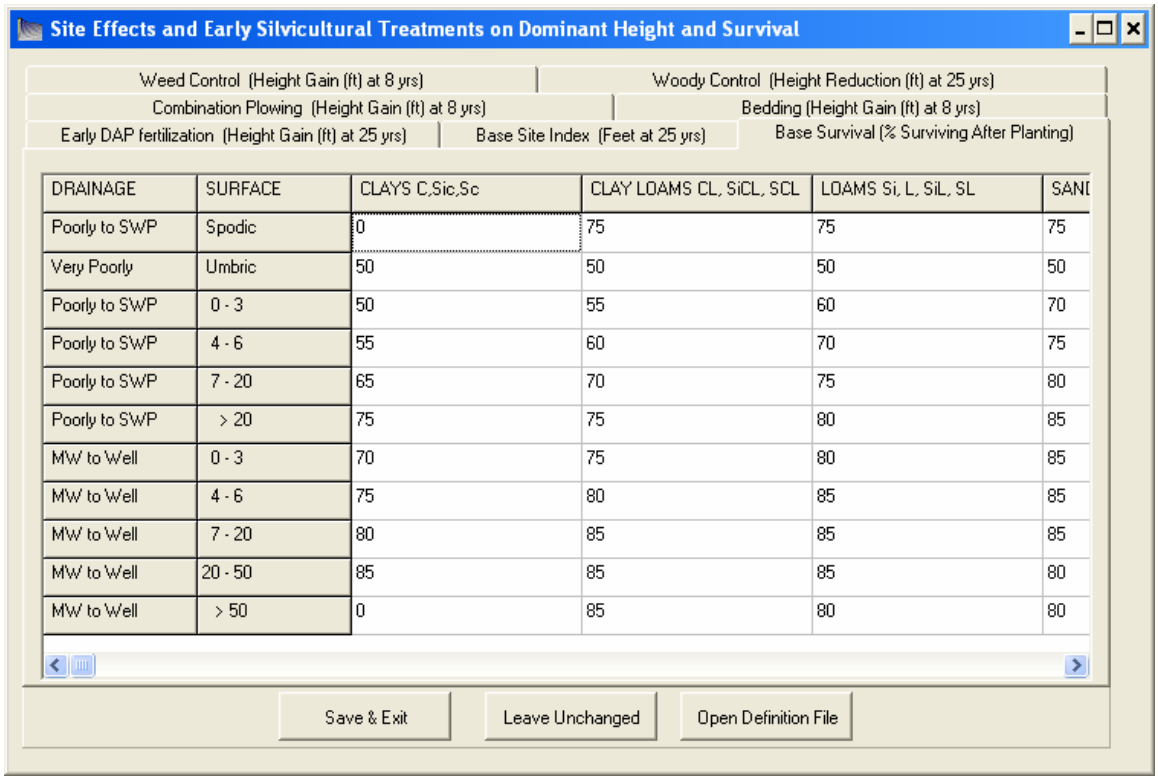

Figure 7. Percent survival at one year after planting in the absence of tillage treatments.

Established Stand Treatments

Established stand treatments including thinning and fertilization are handled by FASTLOB2 as described in the FASTLOB2 manual. In the current DSS, thinning and established stand fertilization responses are not site specific to the extent they are not directly based on soil type, P deficiency, and presence or absence of hardwoods as found with site preparation and early cultural treatments. Thinning and established stand fertilization responses are impacted by the site index and survival inputs into FASTLOB2 as a result of selections made within the expert system.

Up to four established stand fertilization and two thinning events are allowed within the DSS. These events are prescribed under the tab "Stand Management" located on the right hand side of the main page. Required inputs for fertilization include age, nitrogen rate (elemental N rate in lbs/acre) and whether or not P is applied (yes=1, no=0). The rate of P is not specified as results from the Regionwide trial indicate no differences in the 25 and 50 lb/acre P rates. The cost of adding P (under the costs > fertilization tabs) should reflect the desired P application rate. FASTLOB2 calculates the fertilizer response based on the N rate, whether or not P is added, and stand conditions including site index, age, and stocking (Amateis et al 2001). Responses to multiple fertilizer applications are additive unless the predicted basal area growth exceeds 25 ft^2/acre/year or basal area exceeds 250 ft^2/acre. If these limits are reached no further increases in fertilizer response are allowed regardless of the rates or timing of application.

Two thinning events are allowed. Required inputs are age and either residual trees per acre or residual basal area per acre. If both the residual trees per acre and residual basal area per acre are provided the model uses the residual basal area. An option for row thinning (every 2nd to 5th row removed) is provided for the first thinning. Under this option trees are removed based on spacing (no change in average diameter); otherwise trees are removed starting from the smaller diameter classes.

The current DSS is not configured to handle mid rotation vegetation control.

Financial Analysis

If realistic financial results are desired appropriate prices, costs, and interest rate should be specified under product and cost tabs on the right hand side of the main menu. Up to three product classes may be specified under the product tab. For convenience, these three classes are labeled as pulpwood, chip'n'saw, and sawtimber; however, any three classes are allowed. Minimum DBH, minimum top diameter, and price per ton must be specified for each class. Board foot volume is calculated using one of three log rules (Doyle, Scribner, or International ¼ inch) for all product classes exceeding 8 inch DBH.

Costs can be specified for all treatment options under the cost tab. Fertilizer costs can be broken down or reported as the cost of application per acre, the cost per lb of N, and the cost of P/acre. Not all of these costs need to be specified. For example if you always plan to use 200N+25P, a fixed cost of $90 per acre could be used with the other costs set to $0. If variable rates of N are desired and P may or may not be applied then the costs per lb of N and/or the cost of P application need to be included.

Site preparation and early cultural treatment costs are specified on a per acre basis. Planting cost can be broken into per acre and per seedling costs (to account for different planting densities).

Harvesting costs can generally be set to $0 if stumpage prices are used under the product tab. Harvesting costs can be used to differentiate wood prices between thinned and final harvest or if delivered product prices are used.

The global tab under the cost tabs provides for the specification of an interest rate, annual management costs, and annual revenues.

Outputs

Several graphical and tabular outputs are provided and can be easily copied using the edit command (on the top to the output sheet) into EXCEL or other software packages. The model outputs should be reviewed closely to compare model performance with your vision of reality. No model is ever going to accurately and precisely predict what will happen for a particular stand; however, the model should provide a reasonable representation of what several stands having the same characteristics and treatment regimes should do on average.

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