INCORPORATING GENETIC INFORMATION IN GROWTH AND YIELD MODELS

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Abstract.--In tree improvement programs, biological differences resulting from selection and breeding should be quantified in such a way that they can be incorporated into yield prediction systems. Only if this information is included in growth and yield models can genetic gain be estimated by comparing improved-tree yields with woods run material for specific management regimes. In this study, we selected an individual tree model for loblolly pine and modified four relationships that reflect genetic differences, then we compared yields with woods run material. Gains and losses for the various systems are reported.

Additional keywords: Genetic gain, loblolly pine, simulation

INTRODUCTION

The goal in tree improvement is to increase productivity by using genetically improved planting stock. Quantitative estimates of increased productivity are needed if forest managers are to make reliable management decisions on the production and use of improved stock.

Ideally, estimates of increased production should be based on the difference in yield of improved stock over nonimproved stock for a specific management regime (such as stocking levels, rotation age, intensive cultural methods, thinning practices and prospective utilization). This approach recognizes that the genetic gain of a given clone, family, or mixture is not stable or fixed but may vary among management regimes.

We propose that tree improvement programs should concentrate on defining biological differences produced through selection and breeding and that these differences should be quantified in such a way that they can be incorporated into yield prediction systems. In this way genetic gain can be estimated in yield prediction systems for specific management regimes. With these genetic gain estimates, managers could assess the potential value of improved stock to their operation and determine how to modify management practices to maximize gains from available improved stock.

Reasonably accurate yield prediction systems (or growth and yield models) for southern pines already exist for natural stands, plantations on old field sites, and plantations on cutover and site-prepared land (Burkhart 1979).

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Current research in this area is oriented toward extending existing models or constructing new models for intensively managed plantations--incorporating cultural methods such as thinning, fertilizing, using genetically improved stock, irrigating, bedding, and controlling vegetation. One model (Daniels and Burkhart 1975) for loblolly pine plantations incorporates some fertilizing, thinning, and site preparation alternatives but does not include using improved stock.

We selected Daniels's and Burkhart's model for loblolly pine and studied ways in which it might be modified to incorporate genetically improved stock as a cultural treatment. We have neither developed a new model nor incorporated all possible improved stock options in this one, but we hope that our ideas will stimulate interest in growth and yield modeling among tree improvement researchers. We in tree improvement have data resources for improved stock that ought to be used; and unless we become active, future growth and yield models may not incorporate our ideas or data.

The model developed by Daniels and Burkhart is implemented for digital computers in the FORTRAN language and consists of a main program (PTAEDA) and several subroutines (INPUT, PLANT, JUV, COMP, THIN, PREP, FERT, and OUTPUT). The model is basically a stochastic simulator which accepts initializing parameters such as initial spacing, site index, and cultural regimes from the user (INPUT); assigns coordinates to individual "trees" in computer memory (PLANT); "grows" the juvenile or pre-competitive "stand" according to a diameter distribution model and several growth relationships (JUV); and determines the "growth" and "survival" of each tree under a competition model based on distance and size of nearest neighbors (COMP). Cultural treatments such as fertilizing (FERT), thinning (THIN), and site preparation (PREP) may be imposed on the developing stand.

The juvenile or pre-competitive stand is "grown" in this way. First, the age (since establishment) at which crown closure will occur is predicted. This age marks the beginning of competition, and its prediction depends upon the expected number of surviving trees (TS) at each age (A) after planting with a given number of trees per acre (TP) on a site with a given site index (SI) based on 25 years. Once this age is determined, the height of dominant-codominant trees in the stand (HD) is predicted. Next, the minimum (DMIN) and average (DAVE) diameter at breast height for the stand is predicted, and a diameter distribution is generated in the form of a Weibull. Surviving trees are selected at random and assigned diameters by sampling from this distribution. Finally, each surviving tree is assigned a total height (H) by a prediction equation using DBH, HD, TS, and A as well as a crown length (CL) using total height minus clear bole length (CBL), which is predicted using H, DBH, TS, and A.

Two features of the juvenile stand likely to be modified by genetics are the height over age (site index) curve and the phenotypic variance of growth traits. We know that by selection and breeding, early height growth can be increased and genetic variance reduced. Although the height growth curve for this model is monomorphic, we modified it to accept early and/or later height growth changes--in effect, polymorphic forms. Height growth increases lasting through age 25 are equivalent to increasing the site index. We also modified the model to allow for reduced phenotypic variance in all juvenile growth traits. This is considered equivalent to restricting genetic variation as, for example, in single family plantations. Once the modified juvenile stand is established, we allowed the model to "grow" the stand through competition (COMP) without further modifications.

MODEL MODIFICATIONS

To determine the consequences of genetic modification of this model, we posed four situations representative of what might happen in a tree improvement program. For site index (SI) 50 and SI 75, we compared the results of the four situations with a nonimproved stand, designated WOODSRUN. For all situations, our "stands" started with 8 x 8 foot spacing on old-field sites with no thinning or fertilizer. These four situations are shown below as A - D.

(A) We increased height growth 6 feet above that predicted for WOODSRUN at time of crown closure, then gradually reduced this 6-foot gain to zero by age 25. We assume that site productivity is fixed, or that height at age 25 (site index) cannot be increased through genetics. We refer to this situation as JHD6.

(B) We posed the same situation as (A) but maintained the early 6-foot height gain to age 25. We assume that genetics can influence site index as measured at age 25. We refer to this as MHD6 and show SI to increase 6 feet.

(C) In tree improvement programs, a shortage of improved seed is likely to occur at some time. One way to maintain planted acreage is to mix improved seed with regular seed. We constructed a mixed juvenile stand by randomly mixing half WOODSRUN and half improved trees (MHD6) and let the model "grow" the mixture. We refer to this as MIX.

(D) Genetic variability of trees can be reduced, for example, in single family or single clone plantations. Since in this model we cannot separate phenotypic variance into genetic and environmental components, we simply reduced the total phenotypic variance by 1/2, 1/4, and 1/8 of the WOODSRUN--a situation that would result from using genetic material more uniform than WOODSRUN. We achieved this effect by transforming the diameter distribution at crown closure to a new diameter distribution with reduced variance and the same mean. Since all growth traits in this model are predicted from d.b.h., variance in all other growth traits were reduced similarly. We refer to these modifications as VAR 1/2, VAR 1/4, and VAR 1/8.

For the WOODSRUN and four modifications, we considered survival, average d.b.h., average height, standing cubic foot volume, mortality volume, trees dead since crown closure, and diameter distribution at ages 10, 15, 20, and 25. The comparisons are realistic only to the extent that the model mimics actual conditions. Also, our results serve only as an example of what can be studied and are not to be considered conclusive. A more thorough study than ours would include more variables and many more simulation runs.

RESULTS

When limited to WOODSRUN situations and comparing SI 50 with SI 75, the model predicts differences well recognized in silviculture (Fig. 1). On more productive sites trees generally are larger and the range of diameters is greater. Early survival is higher on better sites, but later mortality is greater because of more severe inter-tree competition. With situations (A - D) imposed, these principles hold.

(A) Increasing only early height growth results in a slightly higher final combined volume (standing and mortality) over WOODSRUN on SI 50 but no difference on SI 75. Average diameters and distribution of trees by diameter class basically were unchanged from those of WOODSRUN. This result suggests that in tree improvement programs where early height growth is not maintained for the rotation, volume gain by age 25 may be minimal.

(B) By adding 6 feet in the pre-competition stage and maintaining it until age 25, final yield of standing plus mortality volume was substantially increased on both SI 50 and SI 75. On SI 50 the major change was in standing volume while on SI 75 the major change was in mortality volume, apparently reflecting the principle that on better sites inter-tree competition begins earlier and kills trees sooner than on poorer sites. The mortality volume might be regarded as the volume harvested under the ideal thinning system--an operation where only trees expected to die were removed. This result suggests that in situations where early height growth gains are maintained, the increase in production can be substantial, although thinning may be required on better sites.

(C) For our MIX, total volume on SI 50 and SI 75 was higher than on WOODSRUN, but only slightly less than for improved seed as in (MHD6). For SI 50, the MIX standing and mortality volume was lower than for the 100 percent improved seed. However, the MIX exceeded average volume production of WOODSRUN and improved seed (MHD6). For SI 75, the MIX standing volume exceeded that of 100 percent improved seed (MHD6) but was less in total volume (standing plus mortality). On the basis of these results, mixing of seed would be more desirable than would separate plantings of woods run and improved seed.

(D) Reducing the phenotypic variance generally reduced total volume production over that of WOODSRUN, although it did so only slightly on SI 50. The same trend held for average diameters. Survival was better than for WOODSRUN for all levels of reduced variance. In biological terms, reduced variance produces stands in which trees grow more uniformly. Trees are crowded, but without strong expressions of dominance, and death is delayed. This result mimics that expected for poor sites--higher survival and reduced competition. The disadvantages of decreased volume by reducing variance might be offset by production of a more uniform product and other factors that determine product value. In terms of product options, reduced variation could be a disadvantage, especially if longer rotations were considered.

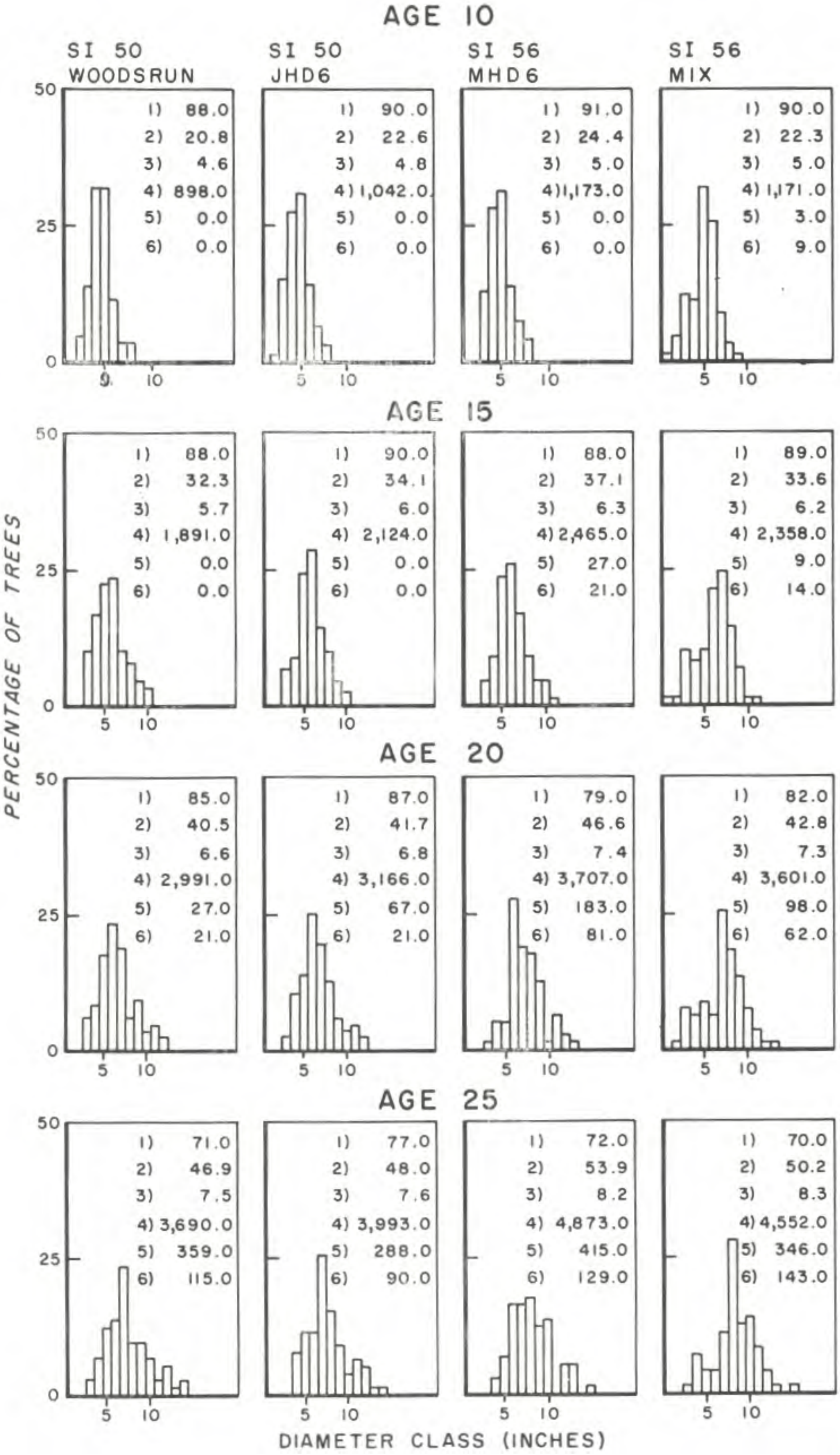
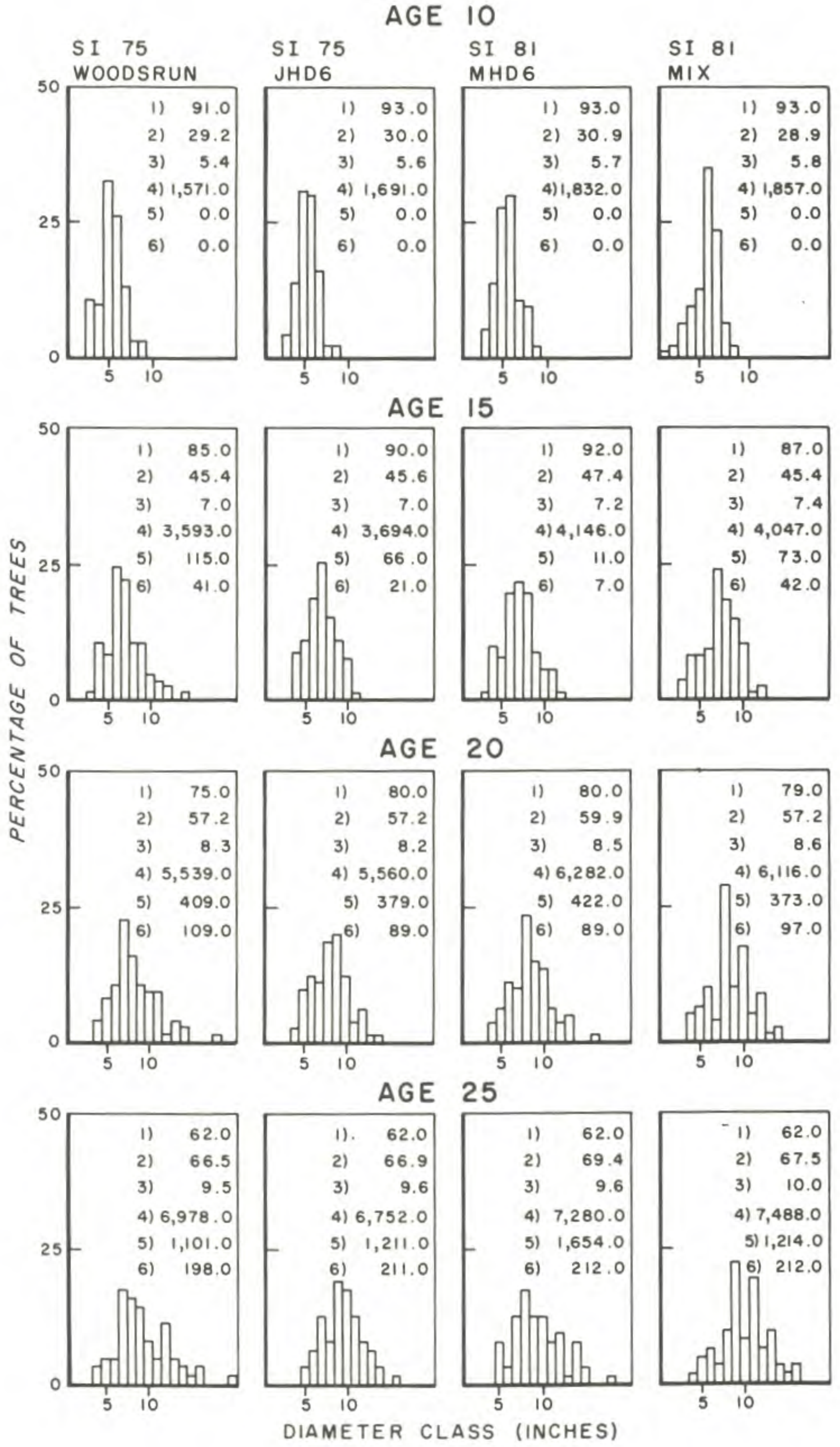


Figure 1.--Percent trees by diameter class, age, and situation. The values for each distribution include: (1) percent survival, (2) average height of dominants and co-dominants (feet), (3) average DBH (inches), (4) volume of standing trees (cu. ft.), (5) cumulative volume of trees dead (cu. ft.), and (6) number of trees dead since crown closure.



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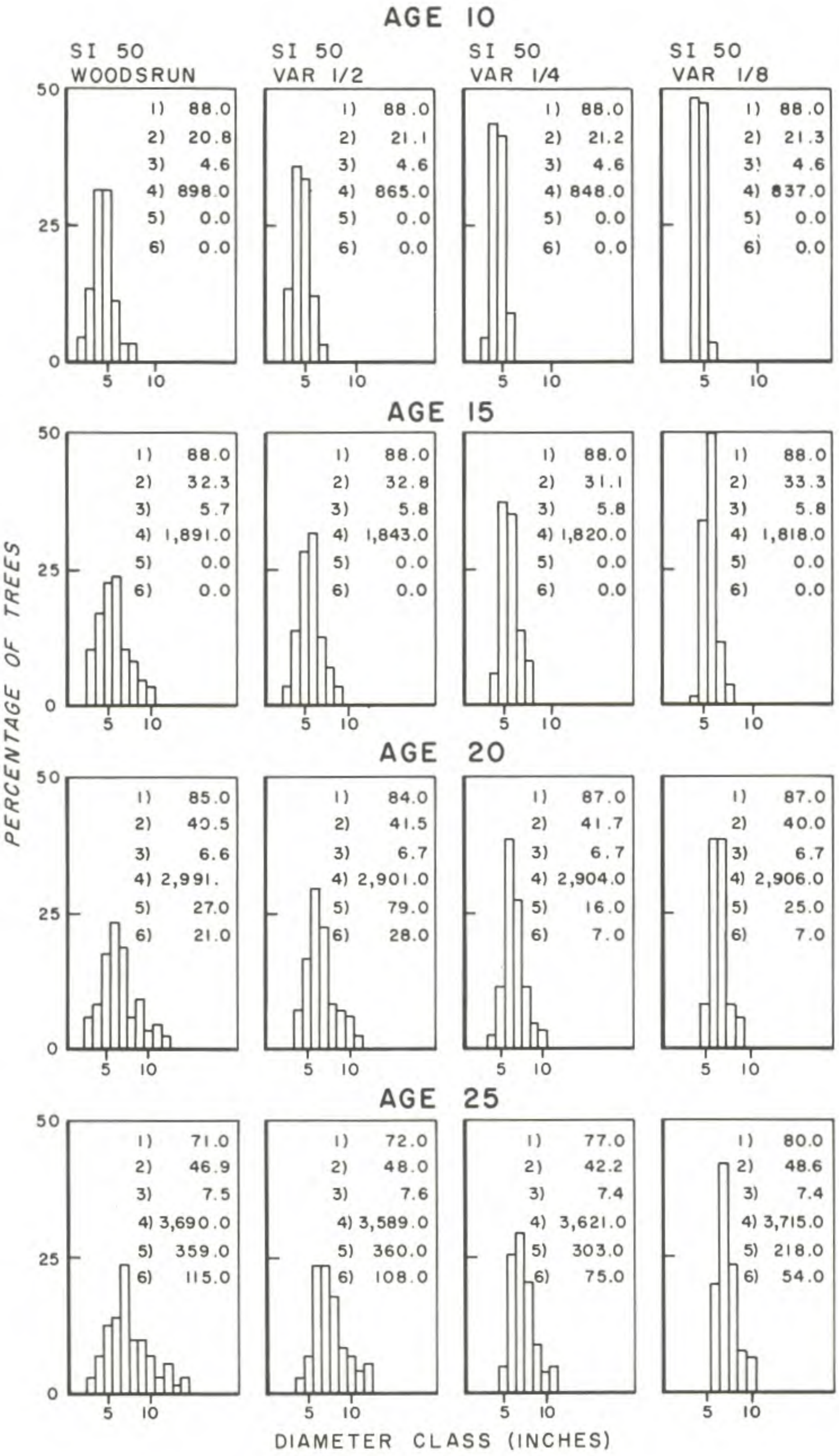

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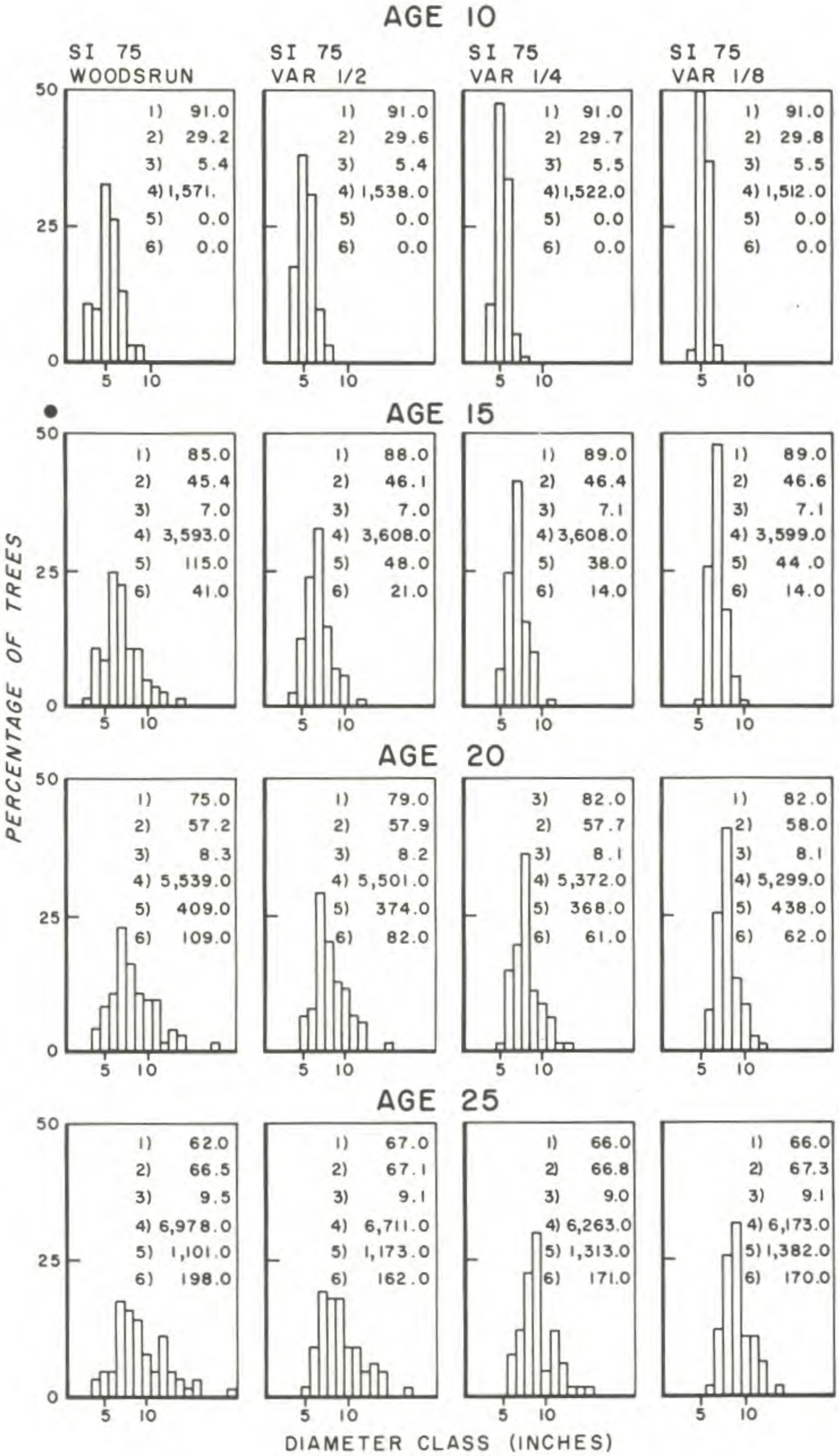

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These four situations show genetic modifications in growth and yield prediction systems. Further modifications and genetic research in the growth and yield area should be pursued. Using data from improved stands, researchers need to study the growth relationships (equations) that are the basis of the model. Through these types of genetic studies, and in cooperation with growth and yield researchers, realistic estimates of improved stock productivity can be provided.

LITERATURE CITED

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