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An examination on the site—family interaction of tree height of open-pollinated families of hinoki (*Chamaecyparis obtusa*) plus trees in the Kansai Forest tree breeding region

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SHORT COMMUNICATION

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An examination on the site–family interaction of tree height of open-pollinated families of hinoki (*Chamaecyparis obtusa*) plus trees in the Kansai Forest tree breeding region

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Abstract Stability analyses to evaluate site–family interaction for tree height at 15 years old were conducted in trials of open-pollinated families of hinoki (*Chamaecyparis obtusa* Endl.) plus trees established in the Honshu and Shikoku area of the Kansai Forest tree breeding region, Japan. The Honshu area included 103 sites (226 families), and the Shikoku area included 27 sites (62 families). Analyses of variance indicated that the interaction between site and family was not significant in the Honshu area, whereas in the Shikoku area the interaction was significant. The stability analyses regressed the family–site means against site means. The linear regression analysis was carried out using the data for 164 families that were tested at five or more test sites from the 130 test sites. Approximately 93% of families had values of linear regression coefficient that were not significantly different from unity. These results suggest that almost every open-pollinated family of hinoki plus trees have average stability and are equally well adapted to good and poor sites. The differences in the reaction of a family to site productivity are not the main causes of the interaction.

Key words Genotype–environment interaction · Height · Hinoki plus tree · Stability

Introduction

Genotype–environment interaction is the differential response of genotypes to different environments. Such interactions complicate testing and selection in tree improvement programs and reduce overall genetic gains. The genotype–environment interaction can be diminished in two ways (Shelbourne 1972): (1) by creating groups of essentially homogeneous environments and selecting cultivars suited to each environment (Shelbourne and Low 1980; Kurinobu 1984; Clair and Kleinschmit 1986; Nishimura and Tajima 1993; Miyaura 1994) and (2) by developing stable cultivars which perform consistently over a range of environments (Finlay and Wilkinson 1963; Owino 1977; La Farge and Kraus 1981; Yeiser et al. 1981; Clair and Kleinschmit 1986; Li and McKeand 1988; McKeand et al. 1990; Yamada and Miyaura 2002).

Many studies in Japan were conducted based on the first method of diminishing interaction (Kurinobu 1984; Nishimura and Tajima 1993; Miyaura 1994). Finlay and Wilkinson (1963) reported that a linear regression coefficient (a_j) of growth traits against site productivity indicates stability and relative adaptability of a tree variety to a site. They considered a variety with a coefficient value near unity to be of average stability and equally adapted to good and poor sites. A variety with a value greater than unity is unstable and better adapted to good sites. A variety with a value less than unity is stable and better adapted to poor sites. They expected that varieties having similar values of a_j have less fluctuation in the ranking of height among forest sites. Yamada and Miyaura (2002) used the linear regression coefficient of growth traits against site productivity to examine the stability and relative adaptability to different environments within a breeding district by clonal lines and open-pollinated families of sugi (*Cryptomeria japonica* D.Don) plus trees. However, the examination of genotype–environment interactions of the growth traits of hinoki plus trees (*Chamaecyparis obtusa* Endl.) has not been conducted in the Forest Tree Improvement programs in Japan.

The objective of this study was to examine the interaction between family and site concerning to the tree height of open-pollinated families of hinoki plus trees in the Kansai Forest tree breeding region. We used the techniques of Finlay and Wilkinson (1963) and Yamada and Miyaura (2002).

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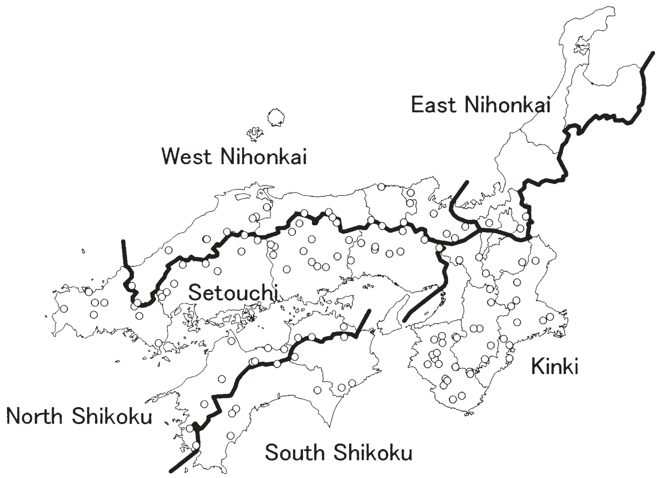

Fig. 1. Locations of progeny test sites of hinoki plus trees

Materials and methods

Test sites and families

The analysis was carried out using the height data at 15 years old of 287 open-pollinated families. The number of the analyzed test sites was 130 (Fig. 1). The tests were established in randomized complete block designs of mostly three (up to nine) replications. The number of families per test site ranged from 5 to 45. Overall, 257 families out of 287 were tested at two or more test sites.

The Kansai Forest tree breeding region is administratively divided into six breeding districts: Kinki, Setouchi, East Nihonkai, West Nihonkai, North Shikoku, and South Shikoku. A total of 160 families were measured only in the breeding district from which they had been selected, 102 families were measured in both the selection district and a neighboring district, and 25 families were measured in three or more districts. Although 127 families out of 287 were tested in two or more districts, only one family was tested in both the Honshu area (Kinki, Setouchi, East Nihonkai, and West Nihonkai breeding districts) and the Shikoku area (North Shikoku and South Shikoku districts). Therefore, each area was analyzed separately.

Analysis of variance

SPSS (2001) was used to conduct an analysis of variance of the plot mean of tree height. A linear model for the analysis is:

$$y_{ijk} = \mu + \alpha_i + \alpha\beta_{ij} + \gamma_k + \alpha\gamma_{ik} + \varepsilon_{ijk}$$

where μ is the population mean across the tests, α_i is a fixed effect of the ith test, $\alpha\beta_{ij}$ is a fixed effect of the jth replication in the ith test, γ_k is a random effect of the kth family, $\alpha\gamma_{ik}$ is a random effect of the interaction between the ith site and the kth family, and ε_{ijk} is a random plot error of y_{ijk}. We adopted typeII sum of squares of SPSS (Searle 1987). That is equivalent to the sum of squares derived by the Henderson's method 3 (Henderson 1953; Kurinobu et al. 1984).

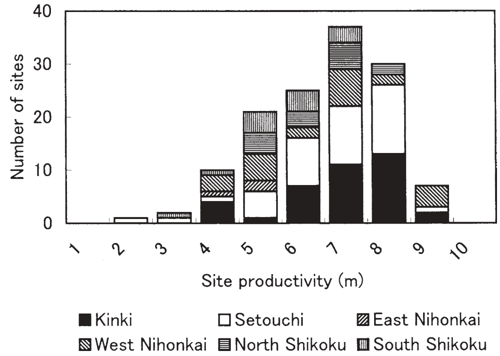

Fig. 2. Distribution of test site productivity in the six breeding districts

Regression analysis

We examined the relationships between site productivity and height of the families using the height data for 164 families tested at five or more test sites from 287 families. Linear regression equations of height against site productivity were estimated with the ordinary least squares method:

$$y_{ij} = a_j X_i + b_j$$

where y_{ij} is the mean height of the jth family at the ith test site, X_i is the site productivity of the ith test site, a_j is the linear regression coefficient of the jth family, and b_j is a constant specific to the jth family. Site productivity was evaluated as the mean height in each of the 130 test sites. We assumed that the site productivity shows the total effect of environment factors on the tree growth, such as climate, soil type, and management (Finlay and Wilkinson 1963). The confidence interval at the 95% significance level of a_j for each family was calculated to examine whether or not the value of a_j is significantly different from unity.

Results

Difference of site productivities

The test site productivity of each breeding district is shown in Fig. 2. There was a considerable range in productivities among the 130 test sites: from 2.37 m to 9.78 m. Each breeding district had test sites with productivities ranging from high to low.

Analysis of variance

The results of analysis of variance are shown in Table 1. The height was significantly different among families in both areas. There was no significant interaction between test site and family in the Honshu area, whereas in the Shikoku area the interaction was significant.

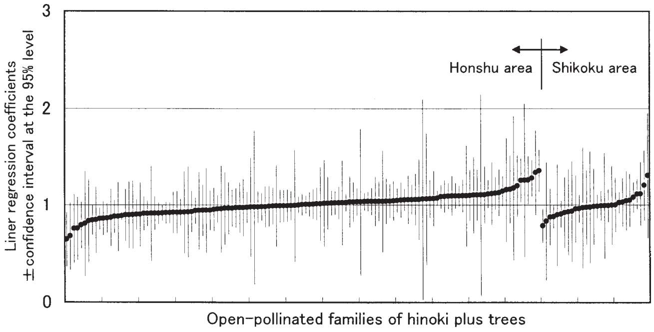

Fig. 3. Linear regression coefficients and their confidence interval at the 95% significance level plotted in ascending order of the value of the regression coefficient within each area. *Black dots* and *vertical bars* represent the linear regression coefficients and their confidence intervals, respectively

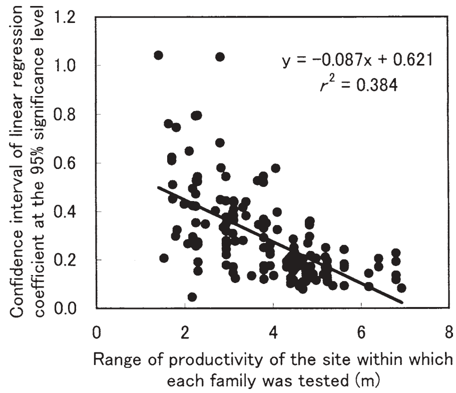

Fig. 4. Relationship between confidence interval at the 95% significance level and the range of productivity of the test sites within which each family was tested

Table 1. Analyses of variance for the plot mean of tree height for families at the 103 sites in the Honshu area and the 27 sites in the Shikoku area

	Honshu area		Shikoku area	
Source	*df*	Mean square	*df*	Mean square
Site	102	75.65***	26	59.41***
Replicate (site)	198	5.01***	67	5.17***
Family	225	0.67***	61	0.79*
Site × Family	1322	0.52^{NS}	279	0.50*
Error	3040	0.49	980	0.42

*** Significant at $P < 0.001$, * Significant at $P < 0.05$, NS nonsignificant

Regression analysis

Linear regression analysis showed a significant correlation ($P < 0.05$) between height and site productivity for 160 families out of 164 ($r = 0.740$ to 0.999). The values of the linear regression coefficient a_j of these 160 families ranged from 0.643 to 1.355 (Fig. 3). Eleven families out of 160 had values of a_j that were significantly different from unity at the 5% significance level (the Honshu area: 9 out of 130, the Shikoku area: 2 out of 30). The value of a_j of seven of these families was significantly lower than unity, and that of four families was significantly greater than unity.

Figure 4 shows the relationship between the confidence interval (95% significance level) of the linear regression coefficient and the range of productivity of the test sites within which each family was tested. The confidence interval tends to decrease as the range of site productivities increases.

Discussion

The growth traits of each plus tree are evaluated by least-square estimates from the data of multiple progeny tests in each breeding district, and the plus trees are ranked in the growth order in the Forest Tree Improvement programs of Japan. This ranking is used for the purpose of roguing seed orchards and choosing parents for the second generation breeding population. In the present study, each breeding district had test sites with considerable variations in productivity (Fig. 2). Each breeding district will include heterogeneous environments. This fact suggests that the investigation of genotype–environment interaction is required in order to apply the ranking to the Forest Tree Improvement programs. If there is strong genotype–environment interaction within a breeding district, the ranking may show great fluctuation among forest sites. In this case, the stability and relative adaptability to different environments must be examined for each plus tree together with the ranking.

We obtained several important facts concerning the existence and magnitude of any genotype–environment interactions of open-pollinated families of hinoki plus trees. There was no significant interaction between test site and family in the Honshu area, whereas in the Shikoku area the interaction was significant (Table 1). Only 11 families out of 160 had values of the linear regression coefficient a_j that were significantly different from unity at the 5% significance level (Fig. 3). Approximately 93% of families had values of a_j that were not significantly different from unity. These results suggest that almost all families had average stability and were equally well adapted to good and poor sites (Finlay and Wilkinson 1963) in spite of the fact that there was significant interaction in the Shikoku area. We expect that the open-pollinated families of hinoki plus trees show little fluctuation in the ranking of height among forest sites.

The confidence interval at the 95% significance level of the linear regression coefficient tended to decrease as the range of site productivities increased (Fig. 4). The accumulation of data from many test sites with different productivities is now in progress. The analysis using the accumulated data in the future may reveal any other families having a value of a_j significantly different from unity. Moreover, the analyzed data in this study included considerable differences in testing frequencies among the families. Further study is required to examine the existence and magnitude of any genotype–environment interaction.

The 11 families showing values significantly different from unity must be cautiously treated. Since these families are either too sensitive or fairly stable to different site productivities, these families may have great fluctuations in the ranking of height among forest sites (Finlay and Wilkinson 1963). The value of regression coefficient a_j, as an index of stability and relative adaptability of tree varieties to sites, suggests an important indicator to prevent the reduction of overall genetic gains.

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