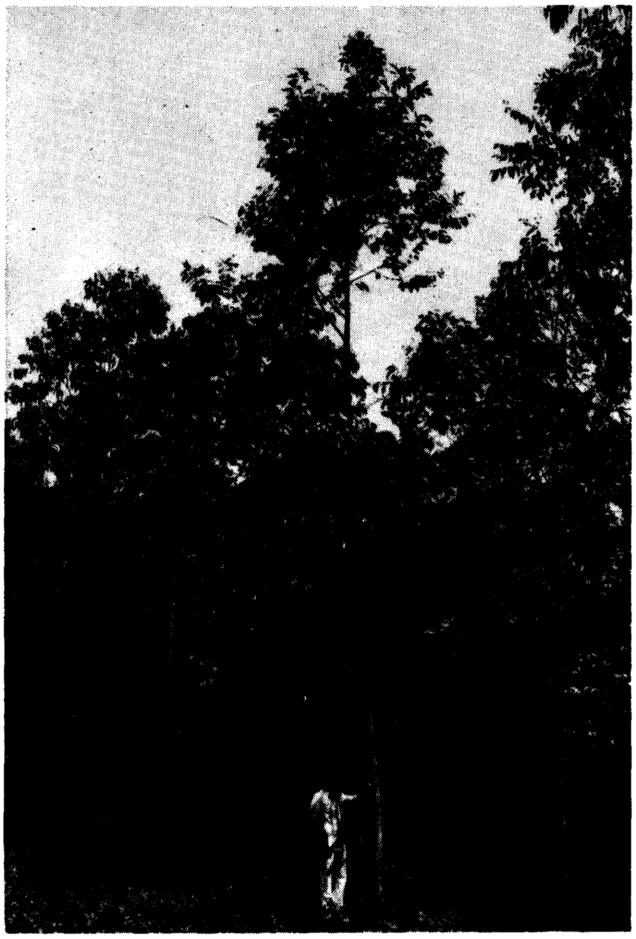

Fig. 7. — 5 Year old plant of natural hybrid F_1 *E. citriodora* × *E. torelliana* growing in the field.

and *E. torelliana* may serve as donor species for dense crown for better site control and resistance to pink disease (FAO, 1981) because such hybrids have been observed under the present studies in the two species. New plant types having quite different properties of wood and oil may also be picked up from the subsequent segregating populations. A tree type having a dense crown like *E. torelliana* and sweet smell like *E. citriodora* would be a desired recombinant having a potential use for the perfumery industry and as a shade tree for the tea gardens.

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Graphic Solution in Relating Seed Sources and Planting Sites for White Ash Plantations

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Abstract

A contour plot with latitudes of seed sources and of planting sites as independent variables is useful to deter mine the range of suitable seed sources and suitable planting sites for the best growth and survival of white ash seedlings. The relative importance of seed source selection, planting site selection and seed source × plantation location interaction can be evaluated from the plot.

Key words: Provenance test, seed collection zone, site selection, white ash.

Zusammenfassung

Konturdiagramme mit der geographischen Breite der Samen-Herkunft und des Pflanzortes als unabhängige Variablen erweisen sich zur Bestimmung der geeigneten Herkunfts- und Pflanzortbereiche für das optimale Wachstum und Überleben einer Art als nützlich. Die relative Bedeutung des Herkunftsortes, des Pflanzortes und der Wechselwirkung zwischen der Kombination von Herkunft und Pflanzort kann mit Hilfe der Konturdiagramme interpretiert werden.

Introduction

Forest trees must be planted on sites where they will survive and grow well in order to maximize yields. However, matching a species to site is difficult and uncertain when it has not previously been used as a plantation tree. Widely distributed species pose the greatest problem due to the genetic variation among populations that can be expected in response to climatic, edaphic, and other environmental differences throughout the natural range. Because each population is adapted to a particular combination of environmental conditions, it is important to know

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the geographic variation pattern of the species. Therefore, the first step in most tree improvement programs has traditionally been the provenance test. Provenance tests have been conducted in more than 50 temperate zone tree species. In some species there are 4:1 differences in growth rate and correspondingly large differences in other traits between provenances (WRIGHT 1976).

At present, the standard method of determining the best seed source-site combinations is to collect seed from many widely scattered stands and grow the seedlings in a number of different geographic locations. The results of such tests have varied from species to species. If natural selection has acted against the migrants and genetic segregants not suited to the local environment, trees of local origin would be expected to have the best growth. Sugar maple *(Acer saccharum* MARSH.) is an example of this pattern (SCANLON 1976).

On the other hand, if variations in climate, soil, or other environmental factors are large, it can be advantageous for populations to remain more conservatively adapted to the harsher environments. Although it would be advantageous for a species not to respond to selection pressure for what may prove to be transiently favorable site factors, the transient site improvements may prove permanent enough for the tree breeder (NAMKOONG 1969). For example, slash pine *(Pinus elliottii* ENGELM.) and ponderosa pine *(P. ponderosa* LAWS.) seed sources from the center of their respective ranges are superior to local seed sources (SQUILLACE 1966, CONKLE 1973). WELLS and WAKELEY (1966) found that vigor can be improved up to 10 or 20 percent by moving seed of loblolly pine *(P. taeda* L.) up to 200 miles to the north and west. In Illinois, Indiana and Michigan plantations, black walnut trees from the south are taller than local trees, while in Iowa, Ohio and Minnesota plantations, the 200-mile zone immediately south of the plantation produces trees as tall as local sources (BEY 1979). More rarely, as in white spruce *(Picea glauca* (MOENCH) VOSS), trees of northern origin are superior to local or southern trees (NIENSTAEDT and TEICH 1972).

To locate the high-vigor zones, a surface of response is useful. Variables in the source environment such as length of growing season, seasonal rainfall, elevation, and soil properties that influence vigor are first identified. For tests at one planting location, multiple regressions of all yield variates on all environmental variables can then be determined. For progeny tests with multiple plantations, the differences in reaction to sites indicate different levels of genotype-site interactions which can also be studied by regression. The practical problem is that the optimum seed source environment and favorable interaction with site for one trait may not be optimum for others. Furthermore, in addition to problems of evaluating a multiple-regression surface for multivariate decisions, a tree breeder is seldom interested in just one planting site. He usually has to consider what single source or combination of sources may be suitable over a range of sites and how they will change for a set of planting environments. NAMKOONG (1979) suggested that a complete factorial sampling of all sources on all sites would provide a complete picture of vigor value at each combination. The reduction of environmental variables to a few independent variables and the reduction of growth and yield traits to a few dependent variables can be done by component analysis.

In the eastern United States, climatic and other environmental gradients are usually correlated with latitude. In white ash *(Fraxinus americana* L.) we have found that growth and survival are more closely related to latitude than to longitude or elevation of the seed sources. For simplification, we assume that latitude is a major component of environmental variation. A simple quadratic surface can then be constructed by using latitude of the seed sources and of the plantations as independent variables and height growth or survival as the dependent variables. Such a three-dimensional illustration to show where superior seed sources and plantations should be located is much easier to comprehend than an abstract multivariate regression formula. When several traits are considered simultaneously, a composite picture drawn by individual trait contour plotting can be used.

In this paper, we first describe the contour plot technique and then show its application using data from a white ash provenance test.

Graphical Interpretation of the Contour Plot

Using the latitude of the seed sources and the latitude of the planting sites as independent variables, observations on growth and survival can be fitted into a second degree regression model. However, the technique need not be limited to two-dimensional, quadratic functions. The reader may find that other polynomial regression models may fit his data better. A quadratic function may produce a peak or a valley, while polynomial regression models of higher degree may result in several maxima and minima. The presence of minima indicates unique sources to avoid rather than unique sources to choose as seed origins for particular planting sites. Unfortunately, interpretation becomes more complicated with complex models.

Let $Z_{ij} = aX_i^2 + bX_iY_j + cY_j^2 + dX_i + eY_j + f + E_{ij}$

where: Z_{ij} is the vigor of the jth seed source at the ith plantation.
X_i is the latitude of the ith planting site.
Y_j is the latitude of the jth seed source.
a is the quadratic effect of the planting site latitude.
b is the joint effect or interaction of seed source and planting site.
c is the quadratic effect of the seed source latitude.
d is the linear effect of the plantation latitude.
e is the linear effect of the seed source latitude.
f is the intercept of the model.
E_{ij} is the residual error of fitting individual observation to the response surface.

We assume that vigor and latitudes are measured without error and that the residual errors are normally and independently distributed with a zero mean and a common variance. The validity of the assumptions for our given example will be discussed later. The unknown parameters (a through f) are first derived from known observations (vigor and degree of latitude) by the method of least squares; then a response surface is drawn by substituting various values of X_i and Y_j. Because extrapolation may not be as trustworthy as interpolation, the range of latitudes used for making a contour plot (SAS 1982) should not be extended too far from the original data base.

Given that there is one optimal region for seed source and planting site, the adequacy of the regression surface depends on the sampling design. Ideally, the range of seed sources and planting sites should cover the complete species habitat, and heavier sampling around expected optimal regions is desirable. The reasons are that wider spread of the independent variable gives a more precise estimate of the coefficients and more intensive sampling near the optimal region increases the robustness of the regression. However, in a least squares estimate, the points far from the optimum may govern the function strongly. It is recommended that after the initial fitting, residuals should be examined for outliers, especially for those points near the extremes of the range. An outlier among residuals is one that is far greater than the rest in absolute value and perhaps lies three or four standard deviations or further from the mean of the residual. If the outliers can be traced to causes such as errors in data recording or exogenous factors not related to the experiment, then the outliers should be deleted from the data base and the response surface should be refitted (ANSCOMBE and TUKEY 1963).

When the contour plot procedures (SAS 1982) are followed, the plotted response surface appears to be a series of ellipses with different shading. The darker the area, the greater is the predicted performance. The shape, location and orientation of the ellipse can be interpreted as follows.

An ellipse has a major and a minor axis. The direction of the long axis indicates shallow slope, and the direction of the short axis indicates steep slope along the response surface. Therefore, if the major axis is horizontal (*Figure 1*), the slope is shallow across the planting latitudes but is steep across the seed source latitudes. Thus, a horizontal ellipse emphasizes the importance of seed source selection. The linear and quadratic effects of the seed sources (coefficients e and c) are large in comparison to those of the planting sites (coefficients d and a).

If the major axis is vertical (*Figure 2*), the slope is shallow across the seed source latitudes but is steep across the plantation latitudes. This emphasizes the importance of plantation selection. The range of latitudes for the best planting sites is narrower than that for the best seed sources. In relationship to the model, the coefficients a and d are large and coefficients c and e are small.

The major axis may also be tilted. The angle of tilt is computed by 0.5 * arc Tan (b/(a-c)); therefore, if the coefficient b is zero (i.e., no seed source × planting site effect), the major axis is either horizontal or vertical. On the other hand, the presence of seed source × planting site interaction can be detected by the tilted axis.

When the range of seed sources on the Y-axis and the range of planting sites on the X-axis are identical, the diagonal line of the contour plot represents local seed sources. If the major axis of the ellipse coincides with the diagonal line (*Figure 3*), it indicates that local seed sources are superior to distant seed sources.

The center of the ellipse can be located graphically at the intersection of the major and minor axes, or algebraically from the coordinate pair: $(2dc - be)/(b^2 - 4ac)$, $(2ae - bd)/(b^2 - 4ac)$. The center of the ellipse is the point of maximum performance. If the center of the ellipse is below the diagonal line (*Figure 4*), then the majority of the best performers would be those seed sources south of the planting site. On the contrary, if the center of the ellipse is above the diagonal line, then, in general, seed sources to the north of the planting site would be recommended. The intersection between the diagonal line and the ellipse indicates the applicable range of local seed sources.

In order to determine the range of suitable seed sources for a given planting latitude, a vertical line can be drawn from that latitude through the desirable ellipse. The line segment within the ellipse indicates the choice of seed sources one can make for that specific plantation (*Fig-*

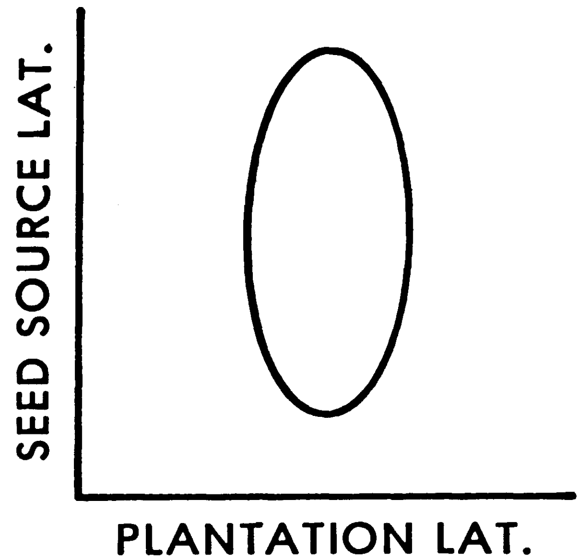


Figure 2. — An ellipse with a vertical major axis in the contour plot emphasizes the importance of planting site selection.

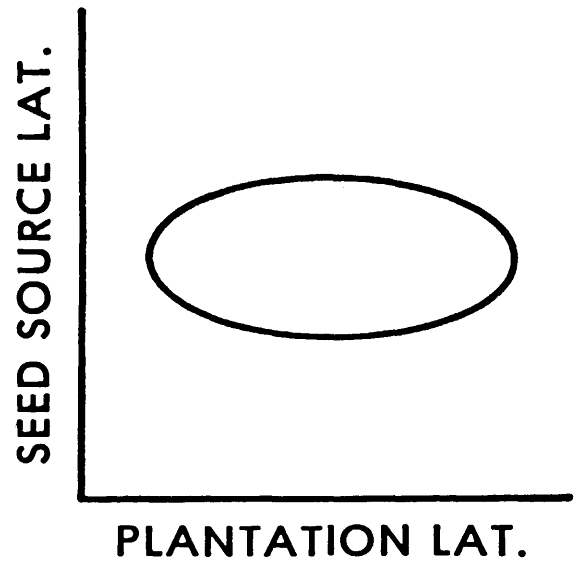


Figure 1. — An ellipse with a horizontal major axis in the contour plot emphasizes the importance of seed source selection.

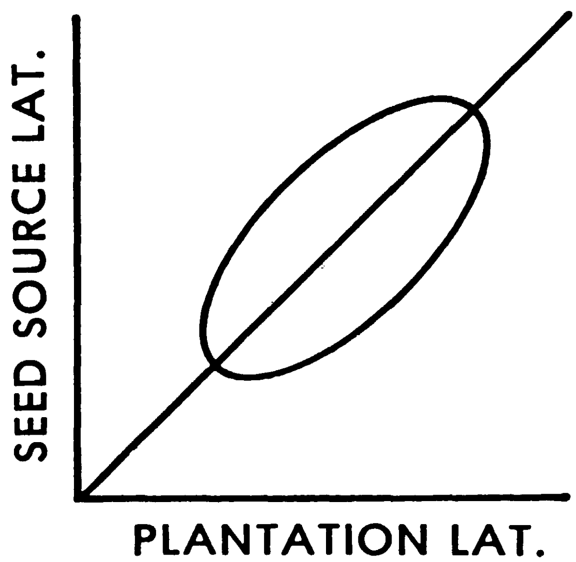


Figure 3. — A tilted ellipse emphasizes the importance of interaction between seed sources and planting sites.

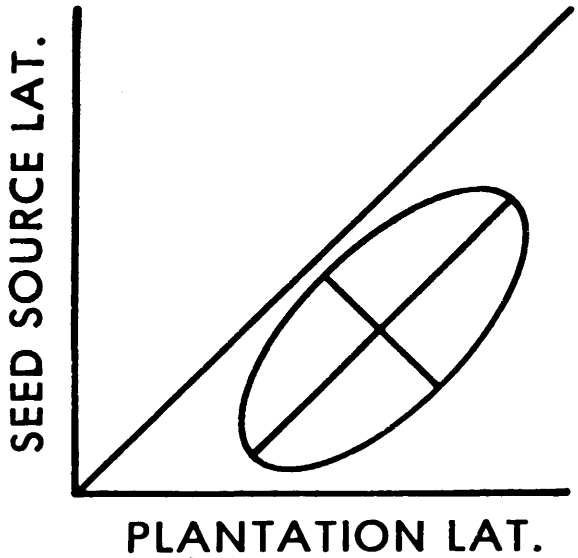


Figure 4. — If the center of the ellipse is below the diagonal line, the center of the recommended seed sources is south of the planting site.

ure 5). For example, the line segment AC is the total range of desirable seed sources. Since point B is the local seed source, one can go further northward than southward in seed source selection, as it can be easily seen that line segment AB is longer than line segment BC. The situation is different for line DEF on the upper part of the ellipse in *Figure 5,* where E is the local seed source, D is the northern limit and F is the southern limit for the range of desirable seed sources. The imbalance is due to the tilted axis of the ellipse; in other words, due to the presence of a seed source × plantation interaction.

To find the applicable planting range for a given seed source, we can also draw a horizontal line through the desired ellipse from the latitude of a known seed source. The line segment within the ellipse indicates the limits of suitable planting sites. For example, in the lower part of *Figure 6,* line segment PQR is the total latitudinal allowance for planting sites. Point Q is the local area, P is the southern limit and R is the northern limit of planting latitudes. Since line segment QR is longer than line segment PQ, seedlings from that stand can be planted further northward than southward. The reverse is true for line segment STU on the upper part of the ellipse in *Figure 6,* where the seed sources can be planted further down into lower latitudes (i.e., point S) than up to the higher latitudes (i.e., point U). Again, the imbalance in the range of planting latitudes is due to the tilting of the axis, or the presence of a seed source × planting site interaction.

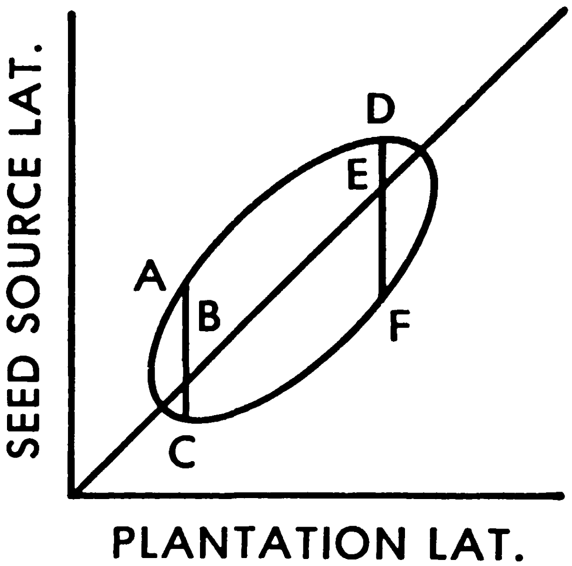


Figure 5. — Ranges of suitable seed sources at two planting sites. B and E are local seeds, A and D are the northern limits, and, C and F are the southern limits, respectively, for the two sites.

Experimental Procedures

White Ash Provenance Test

Seed for the provenance test was collected throughout the natural range of white ash in 1973 and 1974 and later sown in a southern Illinois nursery (Bey *et al.* 1977). In the spring of 1976, the one-year-old seedlings were established in 22 plantations throughout the eastern United States and Canada. However, in this paper we only used data from four plantations purposely designed to have 19 provenances

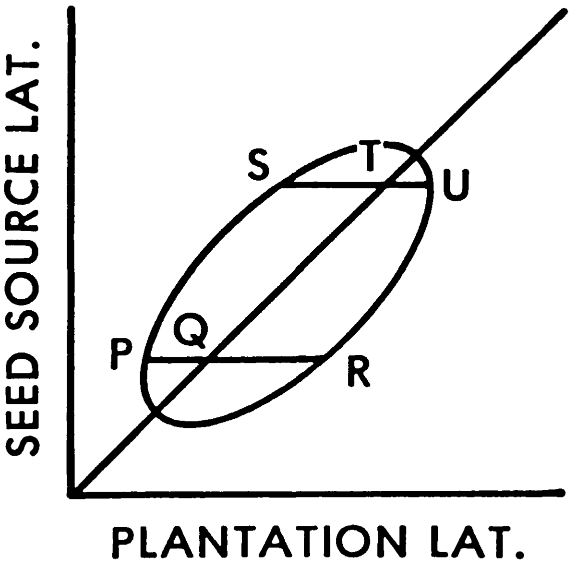


Figure 6. — Ranges of suitable planting sites for two given seed sources. S and P are the southern limits, and U and R are the northern limits of the planting latitude, respectively, for seed source T and Q.

in common. The plantations were established as randomized complete blocks with five-tree plots and five replications at the following locations:

State	County	Latitude (Degrees N.)	Longitude (Degrees W.)	Elevation (Meters)
Louisiana	St. Landry	30.4	92.0	17
Illinois	Union	37.5	89.3	130
Ohio	Muskingum	40.0	82.0	275
Wisconsin	Oneida	45.6	89.5	488

Survival and height of the provenances were recorded periodically and the data collected after five years in the field *(Table 1)* were used in this paper.

Data Analysis

The procedure for response-surface regression model of the statistical analysis system (SAS 1982) was followed. Total height in cm and survival percentage were used as dependent variables and latitude of the seed sources as well as latitude of the plantation were used as independent variables.

Both response surface models are significant at the 0.0001 levels of probability, and the height model is even

Table 1. — Five-year survival and height of white ash provenances in four plantations.

Provenance No.	State	Lat Deg. W	Long Deg. N	Elevation	Survival (%) LA	IL	OH	WI	$\bar{x}$	Height (cm) LA	IL	OH	WI	$\bar{x}$
6768	TX	94.4	30.3	30	92	92	65	08	64	157	279	208	40	171
6738	LA	91.0	30.5	9	71	60	15	01	37	154	243	208	42	162
6737	MS	88.8	30.8	76	94	76	74	34	70	116	252	246	34	162
6740	MS	88.8	33.4	116	83	91	66	24	66	135	322	275	43	194
6733	AL	86.5	34.5	305	84	78	43	48	63	89	229	232	38	147
6728	TN	85.9	35.3	338	93	96	96	63	87	92	244	319	40	174
6871	TN	85.2	35.5	335	84	100	86	76	86	144	263	302	38	179
6734	KY	88.1	36.9	132	79	99	94	57	82	88	265	314	35	176
6792	KY	87.3	37.3	155	78	94	100	74	86	78	250	352	32	178
6721	IL	89.3	37.7	156	89	99	91	67	86	100	278	323	44	186
6795	IN	86.1	38.3	210	83	100	92	80	71	73	271	342	46	183
6778	WV	79.6	38.9	874	52	92	91	59	74	55	141	278	65	135
6771	IL	88.4	39.0	177	96	100	97	88	95	89	228	361	52	182
6794	CT	73.0	41.3	77	63	96	81	85	81	64	173	267	64	142
6782	VT	72.9	44.0	46	58	90	95	68	78	52	140	320	83	149
6785	ME	68.6	44.9	30	71	93	61	72	74	57	149	237	70	128
6779	MI	83.5	45.2	189	59	88	56	76	70	52	158	261	55	132
6723	WI	89.0	45.7	510	64	100	100	48	78	62	162	299	80	151
6736	MI	89.6	46.6	385	63	96	86	71	79	54	146	261	67	132
			$\bar{x}$		77	92	78	58		88	221	284	51	
Plantation Latitude					30.4	37.5	40.0	45.6		30.4	37.5	40.0	45.6	

more precise than the survival model; the coefficients of determination being 0.84 and 0.63, respectively *(Table 2)*. In other words, more than half of the variation in height and survival can be explained by the latitudinal effect of the seed sources and the planting sites, while less than half of the variation must be explained by other unknown factors.

Following the contour plot procedure in the statistical analysis system, we obtained the plots for height *(Figure 7)* and for survival *(Figure 8)*.

These figures were created by reduction of the original computer printout so that the reader may envisage the capability of the contour plot. For example, up to 10 classes with 9 significant digit intervals can be printed. The range of the plotting was set from 30 to 47 degrees north latitude to show the capability of extrapolation from the data base which has a range of latitude from 30.3 to 46.6 degrees North. It can be seen that the negative growth at the upper left hand corner and the extreme lower right hand corner of *Figure 7* can not be trusted. To highlight the graphical interpretation, the diagonal line, the center and the periphery of the innermost ellipse were added on *Figures* 7 and *8*.

Table 2. — Response surface model for height and for survival percentage based on five-year provenance test[1]).

Coefficient	Height	Survival
a	-2.8535	-0.2836
b	0.5884	0.3008
c	-0.3271	-0.3310
d	195.5999	9.0900
e	-0.0346	14.8478
f	-3424.5632	-361.7117
r^2 Contribution		
Linear	0.0200	0.1548
X	0.0056	0.1039
Y	0.0144	0.0509
Quadratic	0.7875	0.3118
X^2	0.7812	0.1704
Y^2	0.0063	0.1414
Crossproduct	0.0285	0.1641
XY	0.0285	0.1641
Total Regression	0.8360	0.6307
F-Value	71.36	23.91
PR > F	0.0001	0.0001

[1]) The model is $Z_{ij} = aX_i^2 + bX_iY_j + cY_j^2 + dX_i + eY_j + f + E_{ij}$, where Z_{ij} is height or survival and X_i and Y_j are latitudes of planting sites and seed sources, respectively.

Defining Seed Sources and Planting Sites for best Height Growth

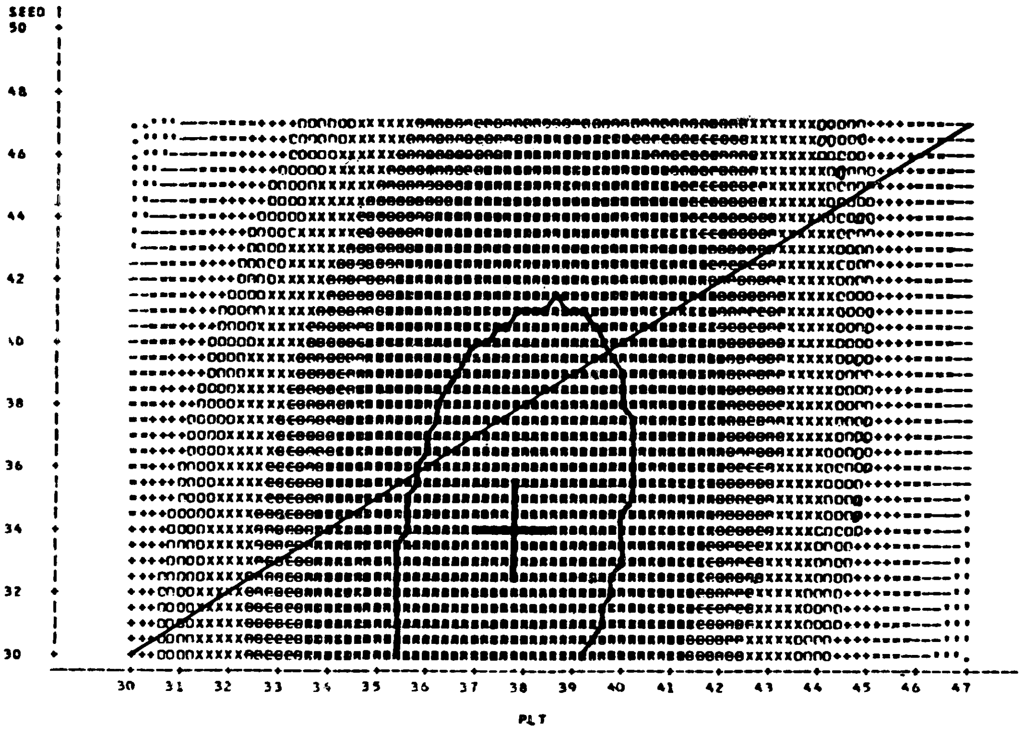
The relationship between height growth, the origin of seed sources, and the location of planting sites can be interpreted on the basis of the ellipse with the darkest shaded area in the contour plot *(Figure 7)*.

The first striking feature of the ellipse is that it is incomplete. Therefore, the southern limit of the best seed sources is not well defined. However, by extrapolation, we would expect that seed sources from south of the 30th parallel (which we have not tested yet) may also be useful for some mid-latitude plantations.

The next striking feature of the ellipse is that its major axis is almost vertical. A precise calculation based on the coefficients in *Table 2* yields an angle of tilt for the X axis of the ellipse at:

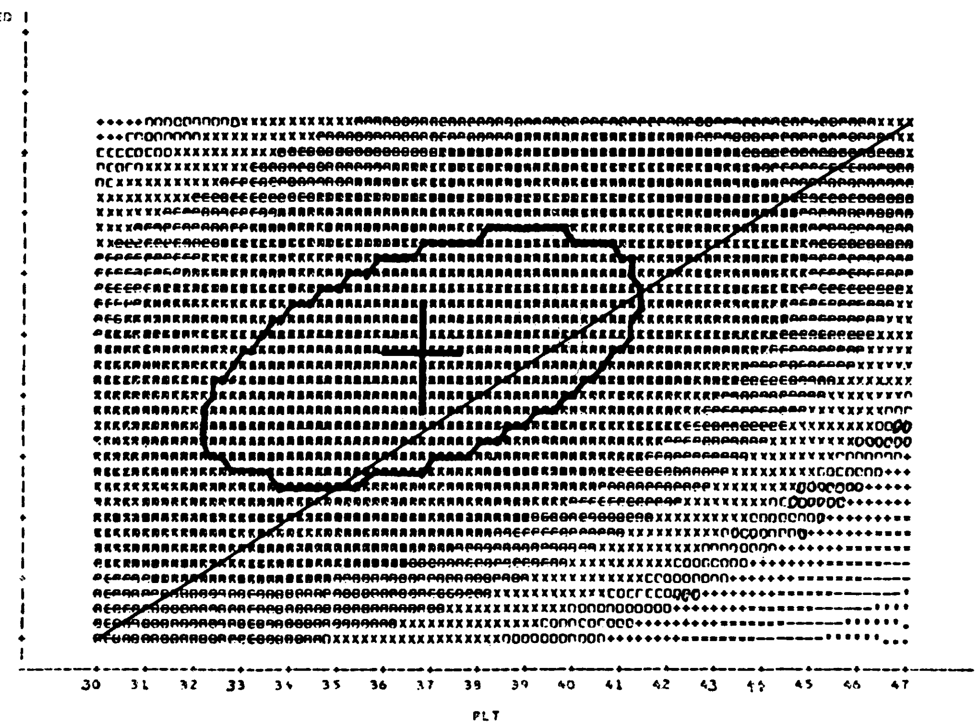
0.5 * arc TAN (0.5884/(-2.8535 + 0.3271)) = − 6.56 degrees

Because the major axis is almost vertical, the first interpretation is that seed source X planting site interaction is not very important in height growth of white ash. In *Table 2* we can see that the interaction contributes only 3 percent to the coefficient of determination. The next interpretation is that selection for planting site is more important than the selection for seed source. As represented by the darkest area in *Figure 7*, the tallest 10% of seedlings on the height scale (or seedlings taller than 255 cm at age 5) can be found in plantations ranging in latitude from 35.4 to 40.2 degrees, and in seed sources ranging from 30.0 to 41.8 degrees of latitude. The span of the best sites for height growth is only 4.8 degrees of latitude or roughly about 330 miles (530 km) wide. In contrast, the span for the best seed sources is more than twice as long. We can also see in *Table 2* that the regression coefficients associated with plantations (i.e., a and d) are much greater



SYMBOL		HTHAT	SYMBOL		HTHAT	SYMBOL		HT
......	-12.567117 -	3.188282	++++++	97.720679 -	129.231478	■■■■■■	223.763874 -	255.274
''''''	3.188282 -	34.699081	000000	129.231478 -	160.742276	■■■■■■	255.274673 -	271.030
------	34.699081 -	66.209880	XXXXXX	160.742276 -	192.253075			
======	66.209880 -	97.720679	@@@@@@	192.253075 -	223.763874			

Figure 7. — Contour plot of five-year height in white ash.



SYMBOL		SUHAT	SYMBOL		SUHAT	SYMBOL		SUHAT	SYMBOL		SUHAT
......	10.80573 -	15.55471	======	34.55063 -	44.04859	XXXXXX	63.04452 -	72.54248	■■■■■■	91.53840 -	96.28738
''''''	15.55471 -	25.05267	++++++	44.04859 -	53.54656	@@@@@@	72.54248 -	82.04044			
------	25.05267 -	34.55063	000000	53.54656 -	63.04452	■■■■■■	82.04044 -	91.53840			

Figure 8. — Contour plot of survival percentage at age five in white ash.

than those associated with seed sources (i.e., c and e). The center of the ellipse is not well defined graphically. Based on our calculations, it should be at the coordinate point (37.8, 34.0). Because the center of the ellipse is the peak of projected performance, we would postulate that the center of the best planting sites is at 37.8 latitude, while the center of the fastest growing genotypes is at 34.9 latitude. It can be seen from the darkest area that near the center of the most favorable environments we would have the widest choice of seed sources. Similarly, near the center of the most desirable gene pool, we would have the most freedom in selecting planting sites.

Since the center is well below the diagonal line, most of the darkest area is below the line of local seed sources. We can say, in general, that southern seed sources tend to grow taller than local or northern seed sources.

The diagonal line intersects the ellipse at latitudes 36.0 degrees and 39.6 degrees. Thus, within this range, local seed sources can be used without much reduction in height growth. Seed sources above 39.6 degrees latitude can express their growth potential better in southern plantations than at local or northern sites.

Defining Seed Sources and Planting Sites for best Survival

In order to help the reader to appreciate the graphical interpretation of contour plots, we would like to ask the reader to examine *Figure 8* and answer the following questions:

1. Where is the best planting site in terms of survival percentage?
2. Where is the location for the best source?
3. At the best planting site, how wide is the selection range for seed sources?
4. Given the best seed source for survival, how wide is the range for planting sites?
5. How important is the seed source X planting site interaction?
6. In general, for any given planting site, should we choose northern seed sources, southern seed sources, or local seed sources?

Defining Seed Sources and Planting Sites for Optimum Response in Growth and Survival

If the ellipses for best survival and best height growth are superimposed, the overlapping portion defines the area of optimum response for the two traits. Seedlings within the overlapping area have a survival rate greater than 91 percent "and" a height growth more than 255 cm. Note that the word "and" is in quotes to signify the statistical meaning of intersection, not the union, of two traits. In our example there is no given mathematical function in terms of exchange rate between two traits. An alternative in multiple-trait selection is to construct an objective function which is a linear or multiplicative model of vigor values. For example, using data from Wells and Wakeley (1966), Namkoong (1979) was able to construct two response surfaces for loblolly pine. Equivalent and linear economic weight was given for height and survival for the first one, while height was considered to be 10 times more important than survival in the second model. Because an infinite number of functions could be written for the relationship between these two traits and we do not yet have criteria for evaluation, we will confine our interpretation to the overlapping area between the two graphs.

Interpreting from the combined graph *(Figure 9)* we would expect that white ash seed sources from latitude 35 degrees would be the best ones to use if plantations were planned at about latitude 35.6 degrees. At latitude 37.5 degrees, however, sources ranging from 36 degrees to 40.5 would be recommended and at latitude 40 degrees only sources from 38 degrees latitude should be used. If seed sources from particular origins are available, similar re-

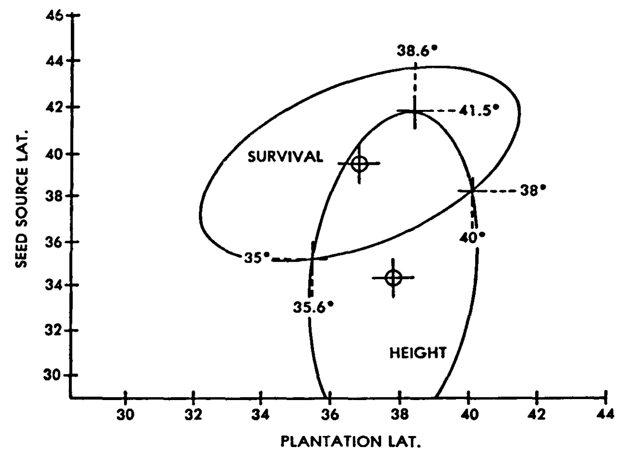


Figure 9. — Superimposition of *Figure 7* on *Figure 8*. The overlapping area is optimum for height growth and survival.

commendations can be made. For example, sources from latitude 36 degrees could be used successfully between 35.8 degrees and 38 degrees latitude. Those from latitude 38 degrees would perform well at latitudes ranging from 36.2 degrees to 40 degrees and those from latitude 40 degrees could be used between 37 degrees and 39.6 degrees latitude.

As expected, the interval of suitable seed origins is narrower for plantations located in the southern and northern parts of the species range than it is for mid-range plantations. The greatest span of good seed sources is found at latitude 38.6 degrees where seed from a 5 degree wide band can be used. This amounts to about 350 miles or 560 km. Similarly, seed sources from 38 degrees latitude can be used over a wider range of planting sites than those from either 36 degrees or 40 degrees. In this case, it would be a band of 3.8 degrees or 260 miles (420 km).

Discussion

The disadvantage of the currently used method of determining the best seed source-site combinations for a species is that a large number of seed sources must be tested in a large number of locations. Therefore, large expenditures of effort and funds are required. Although our graphical method does not obviate the need for testing, it does allow interpolation and some degree of extrapolation from results obtained with a moderate number of sources in a small number of locations. It has several additional advantages. First, from the graphs it is possible to determine the latitudinal range of seed sources and of planting sites that will give the best results in terms of survival, height growth, or both. Second, one can readily define the range of suitable seed sources for a particular planting latitude and the suitable planting range for a seed source from a given latitude. Third, from the graphs one can decide whether it is best to use local seed, seed from farther south or seed of more northern origin. Fourth, the graphs show clearly whether the choice of planting locations is more or less important than the selection of seed sources. Fifth, the presence or absence of seed source × planting location interaction can be observed directly.

The graphic solution used here is mainly for exploratory data analysis. It is not intended to replace other more vigorous statistical methods of estimation. For example, seed source × planting location interaction can be better quantified and tested by analysis of variance tables. The greatest value of a picture is when it forces us to notice what we never expected to see. Today, exploratory and confirmatory analysis can--and should--proceed side by side (TUKEY 1977).

During the development of the linear quadratic regression model we assumed that vigor and latitudes were measured without error. In practice, trees seldom respond exactly alike and any repetition of the provenance test, even using the same seed sources at the same locations, would probably exhibit some variation in vigor. Therefore, the regression coefficients are not without variance; variation in estimating coefficients depends on the behavioral variance in vigor. Fortunately, latitudes can be measured without appreciable error. The regression coefficients solved by the method of least squares with fixed independent variable are unbiased. Thus, the response surface plotted from the regression, on the average, is expected to be true, but some variation of the response surface should be expected under similar test conditions.

The response surface model can be fitted by the method of least squares without distributional assumptions. However, the test of regression coefficients requires the usual assumptions that the residuals are independent, have zero mean, a constant variance, and follow a normal distribution. When we examined the fitting errors within each plantation in order to check the validity of the assumptions, we found no outliers and most assumptions appeared to be valid, except that the Wisconsin plantation has a smaller residual variance in height growth than the Illinois and the Ohio plantations. We also applied the natural logarithm transformation to the height data as suggested by a reviewer. The within-plantation error variance does become stable, but the resulting response model has a center of superior seed sources at 58 degrees south latitude. Because we feel that the original measurement unit, cm., is easier to comprehend and to compare than the logarithm of cm. and that the original model is more believable, we sacrified somewhat the rigorousness of hypothesis testing for the practical convenience. Although the height model is not a perfect example for statistical testing, it is nevertheless a suitable descriptive model.

According to our present experimental design which has no truly repeated runs, we were not able to test the goodness of fit of the response surface model. It has been shown that an equation should be regarded as a satisfactory predictor, if the observed F-ratio of the model is at least four times greater than the selected percentage point (DRAPER and SMITH, 1981). Because the observed F-ratios in *Table 2* are more than six times greater than the 99 percentile of the F-distribution, we accept the adequacy of the proposed model for white ash.

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Stock-scion compatibility in Teak (Tectona grandis)

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Summary

While setting up a National Teak Clone Bank of Plus Trees, large numbers of scions were collected from different states of India with varying environmental conditions; these scions were grafted on root stocks from a single source Tunacadavu in Tamil Nadu. Grafts were kept in a mist-chamber for the first 30 days and thereafter under natural environmental conditions until the 60th day. Analysis shows that scions from different states differed in mortality on 30th day and in 60th day. Under natural tree shade condition mortality was higher. This indicated that unfavourable environment accentuates mortality. Individual state-data analysis shows that mortality in Karnataka and Andhra Pradesh materials differed significantly indicating ecotypic difference leading to incompatibility. However, much more study is necessary to confirm this view.

Key words: *Tectona grandis*, bud grafting, environmental conditions, root stock, scion, incompatibility.

Zusammenfassung

Im Rahmen der Einrichtung einer nationalen Teak *(Tectona grandis)* Klonsammlung mit Plusbäumen wurde aus den verschiedenen Staaten Indiens mit variierenden Um-