energy provided by solar radiation, as indicated by degree-days, was highest at Wooddale in 1978 and 1979, followed progressively by Robinson River, Goose Arm and Millertown Junction Road. This combination of higher percentage of available nutrients and solar energy with their interaction appears to be conducive to best survival at Wooddale. Temperature regime appears to be critical for survival under boreal conditions.

For juvenile growth a combination of several factors is important. The annual snowfall in the 1979—1981 period has been the highest at Goose Arm, providing maximum protection against winter damage, The solar radiation, as reflected by degree-days in 1979, was slightly higher at Goose Arm than other sites which resulted in better growth there than elsewhere. The better growth at Goose Arm over the four year period is a carryover of the faster growth of 1979.

Conclusions

The important conclusions are summarized below.

1. Rooting ability and growth are inherited by the hybrids, which also show heterosis in growth.
2. Use of rooted cuttings, scarification, weed eradication and liming of the planting site are essential for success in field planting as well as for minimizing within-plot variation in growth.
3. The best time for field planting is the last week of June to the first week of July.
4. *Table 8* and *9* provide guidelines for selection of clones best suited for the locations represented by the four test sites under study.

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The Potential of Poplars in the Boreal Regions
II. Genotypic Stability and Productive Quality of Clones

By M. A. K. Khalil

Research Scientist, Newfoundland Forest Research Centre,
Canadian Forestry Service, Environment Canada,
St. John's, Newfoundland, Canada

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Summary

The data from a six-replicated four-location clonal trial of hybrid and exotic poplars was analysed to verify and quantify locations × clones interaction and to identify superior clones on the basis of genotypic stability and productive quality of the tested clones. Analyses of variance over locations were performed for survival, height and diameter at 0.3 m at four years after field planting. Locations × clones interaction was 14.9%, 14.7% and 12.4% for survival, height and diameter respectively and was statistically significant in each case (0.005 or 0.001 level). Superior clones have been identified for the environmental conditions represented by each test site on the basis of genotypic stability and productive quality. It is recommended that genotypic stability should be given more weight than productive quality if the environmental conditions at the planting site are not known. Superior clones on this basis have also been identified.

Key words: Poplars, locations × clones interaction, genotypic stability, productive quality.

Zusammenfassung

Auf vier Standorten wurden Versuche mit Klonen von Pappelbastarden und exotischen Pappeln mit sechs Wiederholungen durchgeführt. Die Daten aus diesen Versuchen wurden analysiert, um die Wechselwirkung Standort—Klon

zu prüfen und zu quantifizieren und um die besten Klone auf der Grundlage der genotypischen Stabilität und Wuchsleistung zu ermitteln. Vier Jahre nach dem Auspflanzen ins Freiland wurden standörtliche Varianzanalysen auf Überlebensrate, Höhenwuchs und Durchmesser in 30 cm Höhe durchgeführt. Die Wechselwirkung Standort/Klon betrug bei der Überlebensrate 17,9%, beim Höhenwuchs 14,7% und beim Durchmesser 12,4% und war in allen Fällen signifikant (Sicherheitsstufe 0.005 oder 0,001). Ausgehend von der genotypischen Stabilität und der Wuchsleistung wurde festgestellt, welche Klone sich am besten für die Umweltbedingungen eignen, die den jeweiligen Versuchsstandort charakterisieren. Sind die Umweltbedingungen am Standort der Pflanzung unbekannt, so empfiehlt es sich, der genotypischen Stabilität größere Bedeutung beizumessen als der Wuchsleistung; auch auf dieser Grundlage wurden die geeignetsten Klone ermittelt.

Résumé

Les résultats d'un test clonal à six répétitions réalisé à quatre emplacements sur des clones de peupliers hybrides et exotiques ont été analysés afin de vérifier et de quantifier l'interaction emplacements × clones et de déterminer les clones supérieurs du point de vue de la stabilité génotypique et de la productivité. Des analyses de la variance pour tous les emplacements ont été effectués pour les caractères de survie, de hauteur et de diamètre à 0,3 m, quatre ans après la plantation. L'interaction emplacements × clones s'élève à 14,9, 14,7 et 12,4% respectivement pour chaque caractère et est statistiquement significative dans chaque cas (seuil: 0,005 ou 0,001). Les clones supérieurs quant à la stabilité génotypique et la productivité dans les conditions d'environnement représentées par chaque station expérimentale ont été déterminés. On recommande de donner plus de poids à la stabilité genotypique qu'à la productivité lorsque les conditions de l'environnement de plantation ne sont pas connues. Des clones supérieurs de ce point de vue ont également été déterminés.

Mots clés: Peupliers, interaction emplacements × clones, stabilité génotypique, productivité.

Introduction

The need for broadening the ecological and economic base of Newfoundland's forests has been felt in the last two decades. This provided the incentive for research on exotic species in an effort to identify those which would flourish in the harsh boreal climate of the region and would equal or excel the local ones. Hybrid and exotic poplars constituted an important part of this research on account of their fast growth, adaptability to variable sites, easy vegetative propagation of intact superior genotypes and high potential for multiple use. A study of 32 clones has been in progress since 1972 in a nursery and four field test sites. Some of the results of this study have been described in Part I (Khalil 1984), which has identified superior clones for the environments represented by the four test sites.

The above study revealed considerable variation in the performance of these clones among the four sites, indicating genotypic instability, with variation in the response of the genotypes to the test sites. The data were further analysed to verify and quantify these differences and to establish criteria for selection of clones which would combine superiority with genotypic stability in variable sites. The results of these analyses are presented in this paper.

Statistical and Genetic Analyses

Analyses of variance over locations were performed on the data of the 20 clones common to all locations, to determine the overall performance of these clones in the boreal forests of insular Newfoundland, as well as to evaluate the role of locations and locations × clones interactions as sources of variation. This was necessary to verify the locations × clones interaction indicated by difference in the performance of clones at the four sites.

The 20 clones common to the four locations were also evaluated for genotypic stability and productive quality. Genotypic stability is defined as the ability of a genotype or clone to maintain the same rank of performance within the array of genotypes tested under diverse test environments. It also indicates heterozygosity of a genotype. Productive quality is defined as the quantitative expression of the relative response potential of a genotype or clone when tested in combination with other genotypes or clones at different locations.

The need for this analysis arose from the high percentage of variation due to the locations × clones interaction in the analyses of variance and its statistical significance. Height growth during the 1978—81 period was the response variable selected for this study because it completely reflected the response of the clones to the environments of the field experiments. The methods used were those of Tai (1971) and Wricke (1962).

In the Tai's method the genotype × environment interaction effect of a clone i is partitioned into two components, (1) the linear response of the genotype to the environmental effects, designated α_i and (2) the deviation from the linear response, designated λ_i. A perfectly stable genotype or clone would not change its relative response from environment to environment. This is equivalent to stating that in this situation $\alpha_i = -1$, $\lambda_i = 1$. Perfectly stable genotypes or clones probably do not exist and the researcher has to be satisfied with obtaining levels of stability which would have $-1 \leqslant \alpha_i \leqslant 0$ and $0 \leqslant \lambda_i \leqslant 1$, which would be the values of these parameters in the clones with average genotypic stability. The parameters α_i and λ_i are calculated from equations (1) and (2) respectively.

$$\alpha_i = \frac{\Sigma[(\ell_j)\ (g\ell_{ij})]/(\ell-1)}{(MSL - MSB)/cr} \qquad \ldots\ldots (1)$$

$$\lambda_i = \frac{[\Sigma(g\ell)^2_{ij}/(\ell-1)] - \alpha_i\ \Sigma[(\ell_j)\ (g\ell)_{ij}]/(\ell-1)}{[(P-1)MSE]/cr} \qquad \ldots\ldots (2)$$

where l_j = Location effect = $\bar{X}_{.j} - + \bar{X}_{..}$
$(gl)_{ij}$ = Genotype × environment interaction
= $X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..}$
l = Number of locations
MSL = Mean squares due to locations
MSB = Mean squares due to replications
c = Number of clones
r = Number of replications within locations
MSE = Mean squares due to error
X_{ij} = Height of the ith clone at location j
$\bar{X}_{i.}$ = Mean height of ith clone over locations
$\bar{X}_{.j}$ = Mean height of all clones at location j
$\bar{X}_{..}$ = Mean height of all clones over all locations

Wricke's Ecovalence (Wricke 1962) is defined as the quantitative measure of the ecological adaptation of the individual genotypes to the environmental conditions under investigation. The smaller the contribution of the genotype to the interaction the smaller is its ecovalence and the greater is the advantage of a broad ecological range. Ecovalence is calculated from equation (3).

$$E = \Sigma(g\ell)^2_{ij} \quad \ldots\ldots \quad (3)$$

where E - Ecovalence

$(g\ell)_{ij}$ = Genotype x environment interaction

$= X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..}$

where the symbols have the same meaning as in equation (2).

Productive quality is measured by Productive Quality Index (PQI), which is the quotient of the clone effects and the environmental effects. Clone effects are defined as the deviation of the mean response of the *ith* clone over all the environments from the overall mean of all the clones across all the environments (equation 4).

$$C_i = \bar{X}_{i.} - \bar{X}_{..} \quad \ldots\ldots \quad (4)$$

C_i = Clone effects of clone i

$\bar{X}_{i.}$ = Mean of clone $\underline{i}$ over all environments

$\bar{X}_{..}$ = Overall mean

Environmental effect is the sum of absolute deviation of the mean response of all the clones in the *jth* environment from the overall mean of all the clones over all the environments (equation 5).

$$E_j = \frac{\Sigma|(\bar{X}_{.j} - \bar{X}_{..})|}{\ell} \quad \ldots\ldots \quad (5)$$

where the symbols have the same meaning as in equation (2)

Then the Productive Quality Index is obtained from equation 6.

$$PQI = \frac{C}{E} = \frac{[\bar{X}_{i.} - \bar{X}_{..}]}{\Sigma|(\bar{X}_{.j} - \bar{X}_{.})| \div \ell} \quad \ldots\ldots \quad (6)$$

Results and Discussion

The results of statistical analyses are summarized in *Tables 1—3*. The over-locations analyses of variance confirm the variation in the growth of the clones among locations *(Table 1)*. In these analyses all sources of variation are statistically significant (0.001 or 0.005 levels). However, the locations × clones interaction is important in that it confirms the differential response of clones to different environments in all the three variables tested and corroborates the results of ranking of clones discussed in Part I. The magnitude of the variation due to the interaction is approximately the same for all the three variables tested.

Studies in genotypic stability and productive quality indicate that a rational approach to selection of suitable clones is to select them on a combination of these parameters so as to obtain clones which are not only superior in performance but are also stable over a wide range of environments. This is particularly necessary if the locations × clones interaction in the analysis of variance over locations is statistically significant.

Suitable clones should be selected first for a positive and high pre-selected PQI. Such clones should then be screened for genotypic stability by one or both of the above mentioned methods. In the Wricke's method all clones with the ecovalence below the mean of the experiment are acceptable. In the Tai's method the selected clones should have the property $-1 \leqslant \alpha_i \leqslant 0$ and $0 \leqslant \lambda_i \leqslant 1$.

The results are summarized in *Table 2* from which selections were made on the basis of the above criteria. Eight fastest growing clones were first selected on the basis of positive productive quality index. Out of them only two clones, DN.16 and DN.17 qualify under Wricke's ecovalence method and none qualify under Tai's method. This shows that these eight fastest growing clones are genotypically unstable and have a high individual contribution to the overall locations × clones interaction. Consequently, they cannot be safely recommended for use in all environments represented by the four test sites.

In these circumstances there are two options for selecting the most suitable clones. In the first option the initial selection should be restricted to the eight fastest growing clones with positive productive quality index. The top four should then be selected for each test site or similar conditions. The selections made on this basis are presented in *Table 3*.

In the second option the initial selection should be made on the basis of a value of Wricke's ecovalence $\leqslant$ mean,

Table 1. — Summary of over-locations analyses of variance.

Source of variation	Degrees of freedom expected	Degrees of freedom actual	Expected mean square	Survival Variance %	Survival F	Height Variance %	Height F	Diameter at 0.3 m Variance %	Diameter at 0.3 m F
Locations (L)	L-1	3	$\sigma^2 + C\sigma^2_R + CR\Sigma L^2_i$	20.1	17.14 (0.001)	25.0	17.54 (0.001)	24.5	6.68 (0.005)
Clones (C)	C-1	19	$\sigma^2 + \frac{RL}{C-1}\Sigma C^2_k$	17.2	6.65 (0.001)	19.1	9.09 (0.001)	19.2	12.63 (0.001)
Locations x clones (LXC)	(L-1)(C-1)	57	$\sigma^2 + \frac{R}{(C-1)(L-1)}\Sigma_i\Sigma_k(LC)^2_{ik}$	14.9	1.92 (0.005)	14.7	2.33 (0.001)	12.4	2.73 (0.001)
Replications within locations	(R-1)L	16	$\sigma^2 + C\,\sigma^2_R$	6.3	2.87 (0.005)	7.6	4.29 (0.001)	19.6	15.29 (0.001)
Clones x replications within locations	(C-1) x [(R-1)L]	304	σ^2	41.5		33.6		24.3	

The figures in parentheses in F column indicate the probability of significance. The mixed mathematical model associated with this analysis is presented by the formula:
$X_{ijk} = \bar{x} + L_i + R_{ij} + C_k + (LC)_{ik} + e_{ijk}$ where X_{ijk} is the measurement of the kth clone in the jth replication in the ith location; $\bar{x}$ is the overall mean; L_i is the location effect (fixed); R_{ij} is the effect of the jth replication within the ith location (random, error a); C_k is the clonal effect (fixed); $(LC)_{ik}$ is the location × clone interaction effect (fixed), e_{ijk} is the lowest error component (random, error b). Error a has been used to test locations and error b to test clones and the locations × clones interaction.

Table 2. — Genotypic stability and productive quality for height.

Rank	Clone	Mean height (cm)	Tai's α	Tai's λ	Wricke's ecovalence	PQI
1	Jac. 15	140.75	-0.1607	4.8038	1 611.3522	2.4281
2	GA. 88	133.78	0.6271	1.1374	857.6878	1.9567
3	Jac. 17	123.58	-0.4918	2.2706	1 044.0938	1.2668
4	DN. 5	119.75	0.6984	0.2929	696.2642	1.0078
5	DN. 16	115.28	0.1560	0.5525	211.6058	0.7054
6	CAG. 23	115.23	0.7560	0.1232	743.4418	0.7021
7	Jac. 16	114.63	-0.9722	-0.0349	1 151.0078	0.6615
8	DN. 17	107.63	0.5764	0.0798	434.9118	0.1880
9	DN. 7	102.30	-0.1864	0.4146	179.0802	-0.1725
10	DN. 42	101.28	-1.1848	1.0733	2 079.4758	-0.2415
11	DN. 2	99.43	0.2518	0.6223	282.5998	-0.3666
12	Jac. 4	99.03	0.2224	1.0763	414.7578	-0.3936
13	D. 38	95.70	-0.1261	2.3954	807.2162	-0.6189
14	IH.78B	95.08	-0.1383	0.7141	258.3338	-0.6608
15	DN. 28	93.25	0.5013	0.6450	521.1422	-0.7846
16	C. 147	94.13	-0.4515	1.7248	817.8558	-0.7251
17	IH.45/51	88.83	-0.2633	2.4818	901.3438	-1.0835
18	CAG. 26	87.43	-0.1648	-0.0007	33.8498	-1.1782
19	DN. 30	85.58	0.6031	0.1168	485.7898	-1.3033
20	D. 89	84.35	-0.2524	0.7286	317.9082	-1.3865

Table 3. — Clones selected for various sites under option 1.

Clone	Goose Arm	Millertown Jct. Road	Robinson River	Wooddale
Jac. 15	+	+		+
GA.88	+	+	+	+
Jac. 17		+	+	+
DN.5	+			
DN.16			+	
CAG.23	+			+
Jac. 16		+	+	
DN.17				

which is 692.4859 in this case. This gives 10 clones, DN.16, DN.17, DN.7, DN.2, Jac. 4, IH.78B, DN.28, CAG.26, DN.30 and D.89. Out of these, four clones, DN.7, IH.78B, CAG.26 and D.89 qualify under TAI's method. These four clones can be recommended for environmental conditions resembling those at any of the test sites under study.

The first option identifies clones which are fast growing as well as best suited for the environmental conditions represented by the test sites specified. This method is recommended if the environmental conditions at the planting sites are known and match those represented by the test sites used in this study. The second option identifies clones which may not be the best in growth but are genotypically stable. This method is recommended for situations in which environmental conditions at the planting site are unknown or do not match those at any of the test sites planted in this study.

Conclusion

The important conclusion is that if environmental conditions of the planting sites are known to resemble those at the four test sites, *Table 3* should be used as a guideline for selection of suitable clones. Clones DN.7, IH.78B, CAG.26 and D.89 seem to be the best suited for boreal regions if the environmental conditions of the planting site are not known.

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Variation and Heritability of Wood Density and Fibre Length of Trembling Aspen in Alberta, Canada

By A. D. YANCHUK, B. P. DANCIK and M. M. MICKO[1])

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Abstract

Fifteen putative trembling aspen (*Populus tremuloides* MICHX.) clones in north-central Alberta were sampled to examine patterns of variation and determine the heritability of wood density and fibre length among clones. Large increment cores from the southern radius at breast height of each of five to nine trees in each clone were divided into four-year sections from the pith outward. All trees sampled were at least 36 years of age. Wood density measurements were made on each four-year section, and fibre lengths were measured on every second four-year increment period.

There were significant clonal differences for both wood density and fibre length. Broad-sense heritabilities for wood density and fibre length were 0.35 and 0.43, respectively. Wood density is generally high near the pith, decreases substantially a short distance from the pith, then increases in the mature wood zone. Fibre length is short near the pith and increases markedly across the radius. There was a slight negative phenotypic correlation between

[1]) Graduate Assistant and Associate Professor, Department of Forest Science; and Associate Professor, Department of Agricultural Engineering, University of Alberta, T6G 2G6, Edmonton, Alberta, Canada.