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Jerome K. Vanclay
Southern Cross University

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Seed Orchard Designs by Computer

By J. K. VANCLAY[1])

Department of Forestry, GPO Box 944, Brisbane,
Queensland, Australia

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Summary

A computer program creates permuted neighbourhood designs for second generation seed orchards which may include a high proportion of related clones. It maximizes panmixis, and ensures isolation of all related clones. It is fast, efficient and easy to use. Copies of the program are available from the author.

Key words: seed production, seed orchard design, tree breeding.

Introduction

The objectives of most seed orchards include the need to avoid selfing, and to promote outcrossing. GIERTYCH (1975) analyzed the suitability of seed orchard designs, and concluded that only random, incomplete block and permuted neighbourhood designs satisfied these objectives. *Table 1* (after GIERTYCH, 1975) contrasts characteristics of various methods for designing seed orchards, and indicates the superiority of permuted neighbourhood designs.

[1]) Present address: Faculty of Forestry, Royal Veterinary and Agricultural University, Thorvaldsensvej 57, DK-1871 Frederiksberg C, Denmark

Permuted neighbourhood seed orchard designs have developed a reputation for being expensive of computer time (GIERTYCH, 1975). Although advances in computer technology now enable these designs to be produced cheaply and efficiently, few computer programs are available to assist the tree breeder in creating these designs.

LA BASTIDE (1967) developed a program to create permuted neighbourhood designs for orchards with staggered rows, and BELL and FLETCHER (1978a,b) offered a more flexible program, COOL, for orchards with more conventional square or rectangular spacings. Similar programs are offered by HATCHER and WEIR (1981) and SEKAR et al (1984), but none of these programs cater for designs in which it is intended to include and isolate related clones. MARSH (1985) reports a promising approach based on the "three dimensional travelling salesman problem" of the Operations Research literature, but which introduces difficulties when clones are not equally represented and when irregular orchard layouts are employed.

These restrictions conflict with current trends in seed orchard design. Tree breeders require orchard designs

Table 1. — Comparison of selected designs (after GIERTYCH, 1975).

Aspect	Random Designs		Incomplete Block Designs					Permuted Neighbourhood	
	Simple Random	Random Complete Block	Un-balanced	Balanced (BIB)	Cyclic BIB	Directional Cyclic BIB	Balanced Lattice	COOL	SOD
Avoid Inbreeding of Related Clones	–	–	–	–	–	–	–	–	++
Avoid Selfing	+	+	+	+	+	+	+	++	++
Promote Outcrossing	+	+	+	+	++	++	+	++	++
Low Design Cost	+	+	+	+	+	+	+	++	++
Ease of Use	+	+	–	–	–	–	–	++	++
Any Orchard Shape & Size	+	–	–	–	–	+	–	++	++
Any No. of Clones & Ramets	+	+	–	–	–	–	–	++	++
Permit Expansion	+	+	+	–	+	+	+	+	++
Relocate Clones	–	–	–	–	+	+	–	+	+
Systematic Thinning	–	–	–	–	–	–	–	++	+
Compare Performance	–	+	–	+	+	–	+	+	+
Experiment Replicates	–	+	–	–	–	–	+	–	–
Use Information on compatibility, flowering & combining ability	–	–	–	–	–	–	–	–	+
Accomodate Other Factors (Dioecious Spp, etc)	–	–	–	–	–	–	–	–	+

Note: — = unsuitable, + = suitable, ++ = highly suitable which allow irregular shapes, unequal numbers of ramets from each clone, and relatively large numbers of related clones. Different representation from each clone is likely to become increasingly common, as it enables use of the limited numbers of scions available from small trees, and enables better clones to have greater representation, thus providing greater gross gains. Computer programs to assist in the design of suitable orchards should accommodate all these requirements.

A computer program, SOD (Seed Orchard Designer), was written to to satisfy this need, and has now been in service for five years. It is fast, efficient, and easy to use, and has been used operationally to design several seed orchards. SOD is written in standard FORTRAN 77, and has run on several machines without modification. Typical applications require about 100 seconds execution time on a VAX 750 minicomputer. The actual time required may vary greatly according to the size of the orchard, the number of related clones, and the user's design specifications. In any case, the computer charges are trivial compared with the savings in manpower. Using SOD, a tree breeder can produce and evaluate a design for a specific composition and location within minutes.

Objectives

SOD is designed specifically to overcome the problems experienced in designing seed orchards which include a high proportion of related clones. It creates a permuted neighbourhood design, and attempts to:

· Ensure that ramets of the same or related clones are separated by the greatest possible distance, the minimum acceptable distance being defined by the user for halfsibs, fullsibs and for ramets from the same clone.

· Ensure that a ramet of each clone is located adjacent to a ramet of each and every other unrelated clone an equal number of times for each clone, subject to information on details of provenance, flowering, etc.

Three options are available for the user to vary the emphasis assigned to the second goal. Deterministic selection of the most suitable clone for any position in the orchard takes full account of both these goals, whereas the option employing simple random selection considers only the first goal. An intermediate approach employs weighted random selection, using the second goal to determine the weights. Some tree breeders believe that panmixis can be increased by explicitly ensuring that each clone is located adjacent to every other unrelated clone at least once. Others are unconcerned with this aspect, and consider only the total composition of the orchard. This option enables users to choose a design strategy according to their beliefs.

To assist the tree breeder to evaluate to what extent these objectives have been achieved, three indices are computed.

1. Panmixis is expressed as a percentage, and 100% is realized only when ramets of each clone are adjacent to ramets of every other clone an equal number of times. The eight nearest ramets are considered adjacent, but this may be modified by the user. No account is taken of the direction of this adjacency.

2. The extent to which related ramets are kept separated is also expressed as percentage, with 100% indicating that there are no ramets within five units (rows, but may be redefined by the user) of any related ramet.

3. A composite index, computed as the product of these two indices, evaluates how well the objectives have been satisfied by the design.

A further statistic indicates the difficulty experienced in completing the design. Low scores indicate that it may be possible to produce a design with more rigorous specifications.

The emphasis in designing SOD was to provide a flexible but easy-to-use package to simplify the design and documenting of seed orchards, but leaving the user in control. This was achieved by providing several options which enable the user to customize the design to satisfy his own requirements. To ensure that users understand the design criteria, these options relate to tangible rather than abstract concepts. Thus the user specifies the minimum acceptable proximity of halfsibs, fullsibs, and ramets from the same clone. These concepts are basic to tree breeding, and avoid the risk of the program becoming an incomprehensible "black box".

Method

SOD considers each position in the orchard in turn, selecting for each a clone which satisfies the prescribed conditions, until the orchard is completed. It is expedient to start at the centre, as this is usually the most complex part of the seed orchard design, where the ramets have the maximum number of neighbours. At the perimeter, the design is more straight forward as there are fewer neighbours. However, the user may specify an alternative starting position.

For each position, SOD assumes that all remaining clones are possible candidates, and computes a score for each. This score is derived after examining all the ramets between the current position and a horizon, the size and shape of which is defined by the user. Obviously, the horizon cannot exceed the square root of the number of clones to be included in the orchard, and must equal or exceed the greatest separation between clones specified by the user.

The score is the product of several factors including the remaining number of ramets of the clone, the distance to the nearest related ramet, the group identity of this clone and its neighbours, the panmixis achieved by this clone with its neighbours, and a weight progressively modified by SOD. Initially this weight is set to one, and is altered only if SOD fails to complete the design on the first iteration. If there is a related ramet within the minimum distance specified by the user, the score is set to zero. The user may specify how one of the candidate clones is to be selected: the best score, a random selection weighted by score, or a simple random selection of the non-zero scores may be chosen.

SOD places a ramet of the selected clone in the design, and progresses to the next position in the orchard. If at any stage SOD is unable to fill a given position, it returns to the last position where a choice existed, and tries one of the alternatives. SOD maintains details of positions where alternatives were available, and of the clones which have already been tried in these positions, and can thus backtrack many times.

If SOD backtracks too often before completing the design, a "failure" is recorded, and SOD abandons the attempt, alters various parameters, and starts afresh. Initially, SOD alters only the weights and the horizon. The horizon is reduced, and the weights are adjusted according to the ratio of the expected to actual numbers of ramets of each clone included in the incomplete design.

Once the horizon becomes equal to any of the specified minimum separations, SOD's strategy depends upon the user's specifications. The default is to gradually increase the number of ramets available for each clone, to allow SOD greater flexibility in arranging the design. However, the user may specify that SOD should reduce the separations between related ramets. In any case, once the number of ramets available for each clone becomes large, the separations are reduced progressively until a design is achieved.

SOD will never fail to produce a design. It may need to reduce the nominated separations and increase the number of ramets for certain clones, but it will always produce a design. However, if the design produced is for some reason unsatisfactory, more clones, preferably unrelated to those already in the design, should be included, and the program restarted.

Using SOD

SOD is designed for ease of use. It requires a minimum of input for its succesful operation. The basic input required includes a title, description of the orchard (number of clones, rows and trees in the orchard and numbering system) and the separation to be maintained between related ramets. The user must also specify the relationships between the clones comprising the orchard.

The user may also specify the size and shape of the horizon to be used when searching the vicinity of any position in the orchard for related ramets, and the location of adjacent ramets. This enables the user to take account of rectangular and staggered spacings, and of prevailing winds, etc.

Group identity may be given for two classes of groups. SOD will attempt to maximize panmixis within (and miniminze between) groups of the first class, and thus this class may be used to indicate early or late flowering, etc. SOD maximizes panmixis between (and minimizes within) groups of the second class, and thus this class may be used to indicate coastal or mountain provenances, etc.

If the orchard is not rectangular with every position occupied, a plan may be given to indicate planted positions. If the design to be created adjoins an existing orchard, it may be desirable to take the composition of the existing adjacent section into account when creating the new design by including trees from the adjoining section in the design criteria. The number of trees to be included depends on the horizon.

SOD produces a list of the clones, showing the name, pedigree, related clones and the number of ramets included in the orchard; a table showing links completed between all clones, and a value showing the panmixis achived; a list of grafting (or planting) instructions for each clone sorted by row and tree position; plans of the orchard showing the pedigrees and clone names; and a compact summary of the orchard plan in a computer file for archival purposes.

Discussion

Although SOD was developed independently of COOL (Bell and Fletcher, 1978a), and specifically for Queensland's tree breeding program, they share some similarities. SOD does not provide the systematic thinning facility given in COOL, but tests indicate that systematic thinning in a SOD design rarely alters the clonal composition. The computer costs incurred are similar for both programs. However, SOD does offer some advantages:

- It ensures separation of related clones.
- It employs information on provenance, compatibility, flowering and general combining ability.
- It provides scores to enable the breeder to assess the level of panmixis and inbreeding expected in the orchard.

Copies of the SOD program are available from the author, who can also arrange use of the program on the Queensland Department of Forestry computers.

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Variability of Juvenile Greek Firs and Stability of Characteristics with Age

By B. Fady[1]), M. Arbez[2]) and P. Ferrandès[3])

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[1]) Laboratoire de Botanique et Ecologie Méditerranéenne, Université d'Aix-Marseille III, Centre St. Jérôme, F-13397 Marseille Cedex 13. France.

[2]) I.N.R.A., Laboratoire d'Amélioration des Arbres Forestiers, Pierroton, F-33610 Cestas, France.

[3]) I.N.R.A., Domaine Expérimental du Ruscas, R.N. 98, F-83230 Bormles-les-Miomosas, France.

Summary

Two successive studies on the morphology of the leaf and branch system and on the growth strategy (phenology and height growth) of the Greek Fir (*Abies cephalonica* Loudon) were carried out on the same provenances, one in