

SOD

Seed Orchard Designs by Computer

J.K. Vanclay

Abstract

SOD 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. SOD is fast, efficient and easy to use.

1. Introduction

Permuted neighbourhood seed orchard designs developed an early reputation for being very expensive of computer time (Giertych 1975). However, advances in computer technology have changed this, and these designs can now be produced efficiently and cheaply. Unfortunately, very few computer programs are available to assist the tree breeder in designing seed orchards. 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.

During the past decade, the Queensland Department of Forestry favoured randomized complete block designs, with provision for irregular orchard shapes and isolation of ramets of the same or related clones. Recently, however, new orchards have included increasing numbers of related clones, and it became clear that this approach was unsuited to the current seed orchard program.

A new program, SOD (Seed Orchard Designer), has been in service for over two years, and has been used operationally to design several seed orchards. It is fast, efficient, and easy to use. SOD is written in standard FORTRAN 77, and has run on both UNIVAC and VAX (under UNIX) 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.

Although SOD was developed independently of COOL, and specifically for Queensland's tree breeding program, it does have similarities to COOL. 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 tree breeder to assess the level of panmixis and inbreeding expected in the orchard.

2. 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 kept as distant as possible.
- 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.

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. No account is taken of the direction of this adjacency.
2. The extent to which related clones are kept separated is also expressed as a percentage, with 100% corresponding to the best, and 0% to the worst possible case. This index is computed for all ramets within five positions of the subject position, and related ramets at distance 1 incur a penalty of 2.5%, at distance 2 a penalty of 1.25%, etc.

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.

3. Method

SOD considers each position in the orchard in turn, commencing at the centre and spiralling outwards towards the perimeter until the orchard is completed. It is often expedient to start at the centre, as this may be 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.

For each position, SOD assumes that every clone is a possible candidate, and computes a score for each. This score is derived after examining all the ramets between the current position and the horizon. The size and shape of the horizon is defined by the user.

The score is the product of several factors including:

- the number of ramets of this clone still available,
- the distance to the nearest related ramet,
- the group identity of this clone and its neighbours,
- the panmixis achieved with this clone, and
- a weight progressively modified by SOD.

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 by one, 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.

4. Instructions for Use

SOD is designed for ease of use. It requires a minimum of input for its successful operation.

4.1 Input from Terminal

A minimum of three images are required.

1. Title up to 80 characters in length.
2. Eight integers in free format indicating:-
(The first 3 are mandatory, the remaining 5 optional)

- The number of clones to be included in the orchard.
 - The number of rows in the orchard.
 - The maximum number of trees in any row.
 - The separation to be maintained between half-sibs. Default is 2.
 - The separation to be maintained between full-sibs. Default is 2.
 - The separation to be maintained between ramets of the same clone. Default is 2.
 - The horizon to be used in designing the orchard. This must not be less than the largest separation, and must not exceed the square root of the number of clones. Default is 4.
 - An integer to initialize the random selection process. Default is 0.
3. Filename(s). Three filenames may be specified. The first is mandatory, and the remaining two are optional.
- The first filename is mandatory and contains the additional input data. See Section 4.2.
 - The second (optional) filename indicates the destination of the fieldsheet data, if this is to be retained for archival purposes.
 - The third (optional) filename is required only if information on an existing section of the seed orchard is to be supplied. See Section 4.3.
4. Options. These options are optional.
- Input Option.
OCTAL allows compressed input of the orchard plan given in the data file. Instead of specifying a row as, say 000011110, it can be specified as 036.
 - Design Option. This defines the strategy to be adopted in designing the orchard.
DETERMINISTIC selection (default).
WEIGHTED random selection (also recommended).
SIMPLE random selection (generally not recommended).
 - Horizon Option. This determines the shape of the area scanned when determining the presence of related neighbours. This option is significant in computing the proximity score, and in creating the design when the horizon exceeds two. Three options are available, CIRCULAR, SQUARE and OWN. CIRCULAR and SQUARE employ system-defined horizons, and are most commonly used:

SQUARE	CIRCULAR (Default)
5555555555	555555
5444444445	55444455
5433333345	5543333455
5432222345	5432222345
54321112345	54321112345
54321012345	54321012345
- OWN enables the user to define his own horizons in a 15 by 15 matrix (Figure 1). The OWN command must be followed by 225 entries representing this matrix.
- Failure Option. When SOD fails to complete a design, it alters internal parameters and makes a new attempt. SOD begins by altering the weights it assigns to each clone, and by altering the horizon. If it is still unsuccessful, it will either increase the number of ramets for each clone, or decrease the separation of relatives:
RAMETS are progressively increased (default).
SEPARATION is progressively reduced.
 - Output Options. SOD generally assumes that trees are numbered from left to right across the page, and that rows are numbered from the top to the bottom of the page. The following options may be used to vary this (Figure 2).
REFLECT the axes, so that the trees are numbered from right to left across the page. Note that the reflection is performed before rotation.

- ROT1. Rotate the axes 90 degrees clockwise.
- ROT2. Rotate the axes 180 degrees clockwise.
- ROT3. Rotate the axes 270 degrees clockwise.

Note that reflection and rotation do not alter the alignment of the design on paper, but alter the placement and numbering of the axes, viz. the labels ROW and TREE.

- OFFR n. Offset rows by n, so that the rows are numbered from (n+1) to (n+m), instead of from 1 to m.
- OFFT n. Offset trees by n.

4.2 Input of Proposed Plan

The data file must give details of each clone. A plan of the orchard is optional.

4.2.1 List

giving name, pedigree number of ramets and group identity for each clone.

The pedigree is specified as a binomial of up to two characters. Thus 11AA is a full-sib of 11AA and AA11, and a half-sib of 12AA, 11AB, AAXY and 2211. Spaces may be used to indicate unknown or open pollinated pedigrees, but do not imply any relationship. Thus 11 is a half-sib of 11AA, but is not related to 12.

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

The file should contain the name, binomial, number of ramets and group identities for each clone in format (a8,a4,i4,2a2), viz.

```
2CH4-123AAaa 12 e c
2CH4-234BBaa 12 l m
etc.
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4.2.2 Plan. If the orchard is not rectangular with every position occupied, a plan may be optionally given to indicate planted positions. If the plan is not given, SOD assumes that all of the positions are to be grafted. When the plan is given, 0 is used to indicate a position which is not to be grafted or planted (or an existing ramet - see below), and 1 indicates a grafting or planting position. This plan may be compressed with the OCTAL option.

The plan is read under format (80i1):

Default	OCTAL
001100011	143
011110111	367
111111110	776

4.3 Input of Existing Orchard

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. To do this, trees from the adjoining section should be included in the design criteria. The number of trees to be included depends on the current value of the horizon.

The principal input file should contain the name and pedigree of the existing trees, but must specify zero ramets for each of these unless they are also to be included in the new section. The plan given in the principal input file should show a zero for each existing tree.

The supplementary input file must specify two items, the orchard plan showing locations of existing trees, and the clone numbers of the trees occupying those positions.

4.3.1 Existing Plan.

This plan is similar to the one already given, but in this plan, zeroes indicate positions not to be, or still to be grafted, and ones indicate existing trees.

Note that if the two plans are superimposed, there should be no superimposed ones.

4.3.2 Clone numbers.

The clone numbers are implied from the sequence in which they appear in the clone name and pedigree list. Clone numbers must be provided for all the existing positions. They are read in free format, but a new record must be commenced for each new row.

5. Output Produced

Seven items of output are produced.

- Details of inputs, and diagnostics of the design criteria.
- A basic plan of the orchard showing only the internal numeric references.
- 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 achieved.
- A list of grafting (or planting) instructions (Figure 3). This is a list, sorted by row and tree position, of the grafting or planting positions for each clone.
- A detailed plan of the orchard showing the pedigrees.
- A detailed plan of the orchard showing clone names.

In addition, details of the orchard plan may be recorded on file for archival purposes.

6. Acknowledgements

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7. References

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Figure 1. Examples of OWN Option

Prevailing Wind	Staggered Rows
999999777777777	777777799999999
999999666666667	766666679999999
999999555555567	765555567999999
999999544444567	765444456799999
9999995433334567	765433334567999
9999995322234567	765432223456799
9999995111234567	765432112345679
9999995101234567	765432101234567
9999995111345567	976543211234567
999999555555999	997654322234567
999999999999999	999765433334567
999999999999999	999976544444567
999999999999999	99999765555567
999999999999999	99999976666667
999999999999999	999999977777777

Figure 2. Output Options Available

Command	Default	REFLECT
Default	+-Trees-> R o w s v	<-Trees-+ R o w s v
ROT1	<-Rows-+ T r e e s v	^ T r e e s <-Rows-+
ROT2	^ R o w s <-Trees-+	^ R o w s +-Trees->
ROT3	^ T r e e s +-Rows->	+-Rows-> T r e e s v

Figure 3. Grafting (Planting) Instructions

Clone 1	Clone 2
CH4-123	CH4-135
# Row Tree	# Row Tree
1 2 11	1 1 3
2 3 6	2 1 14
3 3 20	3 5 4
4 5 1	4 5 11
5 8 5	5 8 1
6 8 11	6 8 18
7 11 15	7 11 4
8 14 11	8 15 11
9 15 19	9 16 1
10 18 8	10 17 5
11 20 17	11 20 9
12 22 2	12 20 20
13 24 10	13 21 14
14 27 3	14 25 1
15 29 17	15 25 11
16 30 12	16 30 11

Table 1. Comparison of Selected Design

Design Type	Random		Incomplete Block					Permuted Neighbourhood		
Aspect	a	b	c	d	e	f	g	h	i	SOD
Avoid Selfing	+	+	+	+	+	+	+	+	++	++
Avoid Inbreeding of Related Clones	-	-	-	-	-	-	-	-	-	++
Promote Outcrossing	+	+	+	+	++	++	+	++	++	++
Systematic Thinning	-	-	-	-	-	-	-	-	++	+
Experiment Replicates	-	+	-	-	-	-	+	-	-	-
Compare Performance	-	+	-	+	+	-	+	+	+	+
Relocate Clones	-	-	-	-	+	+	-	-	+	+
Permit Expansion	+	+	+	-	+	+	+	-	+	++
Any Orchard Shape and Size	+	-	-	-	-	+	-	-	++	++
Any Number of Clones and Ramets	+	+	-	-	-	-	-	+	++	++
Utilize Information on compatibility, flowering, and combining ability	-	-	-	-	-	-	-	-	-	+
Special Considerations (Prevailing Winds, Dioecious Species, etc)	-	-	-	-	-	-	-	-	-	+
Ease of Use	+	+	-	-	-	-	-	-	++	++
Low Design Cost	+	+	+	+	+	+	+	-	++	++

a - Completely Random

b - Random Complete Block

c - Unbalanced

d - Balanced (BIB)

e - Cyclic BIB

f - Directional Cyclic BIB

g - Balanced Lattice

h - La Bastide (1967)

i - COOL (Bell & Fletcher)
