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Systematic Lay-outs for Seed Orchards

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So far most seed orchards have been planted out by research workers or in close cooperation with them. However seed orchard establishment is now becoming a standard silvicultural practice. More and more the practical forester has to deal with the problem and often without a permanent help of a research officer. The result of this is that a simplification is needed of the procedures. One of the difficulties that has always required the help of a mathematically minded forest geneticist, was the preparation of the actual lay-out of the seed orchard, such that the thinnings are predetermined and the scatter of clones assured both before and after the thinning.

A few years back this topic was dealt with in Silvae Genetica. The relative merits were discussed of square and triangular planting, of systematic, random and balanced scatters of clones, and the feasibility of compromising balanced scatters with randomness for statistically valid comparisons of clones (LANGNER 1953, LANGNER and STERN 1955). The net conclusions of these papers were, that a triangular planting has a slight theoretical advantage over square planting, that each seed orchard requires its own special lay-out, depending on the number of clones, number of grafts per clone and size and shape of the available ground, best made by a random distribution of individual trees followed by transpositions to obtain a balanced clone scatter, and that when clone comparison is also needed the complex lay-out of a FISHER randomised block needs to be employed. These conclusions, though certainly valid theoretically have not met with universal acceptance in practice. Most of the seed orchands that I have had the opportunity of seeing throughout Europe use a square planting and a balanced mixture of single trees rather than a FISHER block design.

The square planting is simpler in practice since it follows the standard planting experiences of forosters, and since it provides an easier access for cultivation machinery. Furthermore, if thinnings are contemplated it is only after 75% of the triangular plantation are removed that the spacing will again reach a balanced state. Such heavy thinning can only be conceived as gradual, and in the intervening period the original advantages of the triangular planting will be lost. The square planting permits thinnings of 50% while maintaining the balanced spacing and clone scatter.

A systematic arrangement of clones will suffer from two obvious disadvantages. One is, that the clones cannot be subjected to statistically valid comparisons. The second disadvantage is that always the same clones will surround all the representatives of a given clone. This will tend to reduce variability within the progeny of a single clone.

On the other hand the systematic arrangement has several advantages. First of all it is much easier to lay out. once standards are prepared, and simplicity is an important practical consideration. Secondly it provides the best theoretically possible scatter for a given number of clones, both in the original planting and after thinnings. Thirdly the quality of the seed from any representative of the same clone is likely to be similar in view of its neighbours being the same. And finally, if it becomes necessary to collect seed or cones individually for each clone it will be a lot easier to locate the representatives of a given clone if they are arranged systematically.

The angument about need for random distribution to compare clones has perhaps been overstressed. It is now a common practice to evaluate clones from full-sib crossings, which require controlled pollinations in any case. When one has to compare productivity of the different clones it is possible to select ranidomly a fcw representatives from each clone. Thus the bias due to site variability will be eliminated. I believe therefore that advantages of a systematic clone scatter in a seed orchard seem to outweigh the disadvantages. It is the aim of this paper to present standards for a systematic distribution such that would be easy in utilization by professional foresters and that would guarantee optimal scatter of clones.

Method

In working out the standards for a systematic distribution of clones, the following three basic requirements were specified: — (1) The proposed lay-out has to be extensible in all directions by repetition of the same basic sequence. This will make the standards independent of size and shape of the available area. — (2) The scatter of clones has to be such as to provide maximum isolation between representatives of the same clone. — (3) Thinnings have to be predesigned in such a fashion so as to maintain an optimal clone scatter.

The simplest lay-out that will satisfy these conditions is the one shown in *fig. 1* for 9 clones. Numbers not underlined are to be removed in the first thinning and those underlined once in the second thinning. The remaining trees are underlined twice.

It is possible to have such a lay-out only when dealing with a number of clones equal to the square of an odd number (9, 25, 49).

With other clone numbers the situation is more difficult. The best lay-out can be obtained by running the clones in a sequence along a line. *Fig. 2* shows such a lay-out for 13 clones. In this arrangement clone 1 always follows clone 13 in a row and is below clone 9 in the next row. Thus for 13 clones 9 is the indicator value. It is the number under which clone 1 has to fall in order to obtain the optimum scatter of clones. The main objective of the present study was to work out indicator values for all numbers of clones from 9 to 65. It is unlikely that any seed orchard will have a larger or a smaller number of clones. The method of calculating the indicator values was to some extent empirical, however the labour was reduced substantially by a considered elimination of unlikely values.

If the square planting distance is taken as unity, a thinning which removes every second tree will increase the spacing to $\sqrt{2}$. In the example shown in *fig. 1* isolation (i = shortest distance between two individuals of the same clone) is equal to the square root of the number of clones — in this case 3. After one thinning it becomes $3 \times \sqrt{2}$ or 3 in the new units of spacing. In the lay-out shown in *fig. 2*, where the resultant clone scatter is in squares, the isolation is also equal to the square root of the number of clones, in this case $i = \sqrt{13} = 3.6$. After thinnings the isolation remains the same in the new units of spacing.

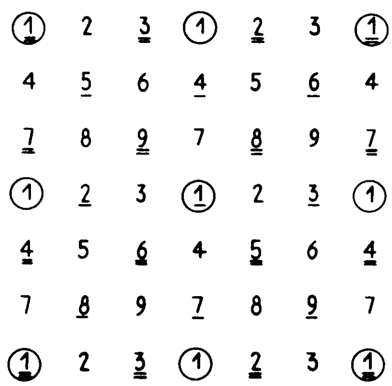

Fig. 1. — Simplest lay-out for 9 clones. (1st thinnings not underlined, 2nd thinnings underlined once.)

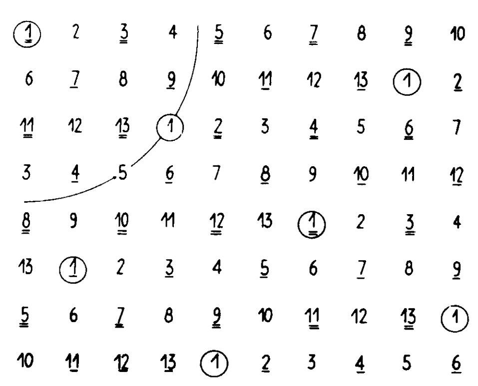

Fig. 2. — Optimal lay-out for 13 clones. (1st thinnings not underlined, 2nd thinnings underlined once.)

Assuming an ideal quadratic scatter the whole area (A) of the plantation can be divided into squares of an area A/z between z representatives of one clone. Then the isolation will be calculated from the relation

$$i^2 = A/z$$
$$i = \sqrt{A/z}$$

If the number of clones is n, and spacing is unity

$$A = 1^2 \times n \times z$$
$$\therefore i = \sqrt{n}$$

After removal of every second tree, the isolation becomes $\sqrt{2} \times \sqrt{n}$ or simply $\sqrt{n}$ in the units of the new spacing.

If the total area of the plantation is divided into hexagons (short radius = h, long radius = r), assuming a triangular scatter of clones (lay-out for 15 clones, *fig. 3*, ap-

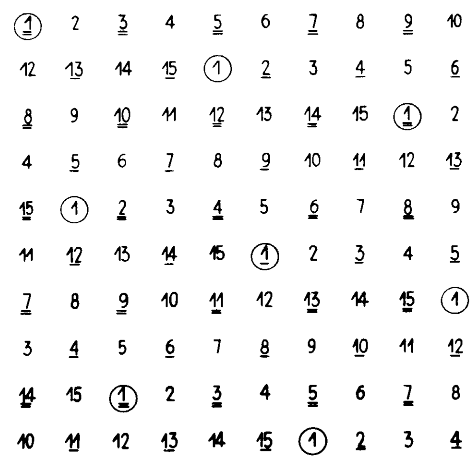

Fig. 3. — Triangular scatter for 15 clones. (1st thinnings not underlined, 2nd thinnings underlined once.)

proximates it), the isolation will be equal to the small diameter of the hexagon

$$i = 2h$$
$$A/z = 6 \times 1/2 \times h \times r$$
$$h^2 + r^2/4 = r^2$$
$$r = 2h/\sqrt{3}$$
$$\therefore A/z = 3h \times 2h/\sqrt{3} = 6h^2/\sqrt{3}$$
$$A\sqrt{3}/6z = h^2$$
$$\therefore i = 2h = 2\sqrt{A\sqrt{3}/6z} = 2\sqrt{n\sqrt{3}/6} = 1.07\sqrt{n}$$

Thus $1.07\sqrt{n}$ is the theoretically best isolation. However, after one thinning, where every second tree is removed, some trees will still maintain this same isolation (see *fig. 3)*, which in the new units of spacing becomes

$$i = 1.07\sqrt{n}/\sqrt{2} = .76\sqrt{n}.$$

From this calculation it becomes obvious, that if thinnings are anticipated a square scatter gives better isolation than a triangular scatter. (The advantage of the latter returns after the second thinning, or when 75% of the original trees are removed.)

In order to minimize the effect of thinnings on isolation indicator values were sought, which give as nearly as possible a square scatter, usually rectangular or rhomboid. Assuming that clone 1 is in the top left hand corner of the area, the nearest representative of that clone should be $\sqrt{n}$ or less distances from it (see. *fig 2)*. Assigning the top left hand corner tree to be left for 2 consecutive thinnings a position was sought $\sqrt{n}$ distances or less from the first position, which would be predesigned to removal in the first thinning (not underlined in *fig. 2).* This position should be reserved for clone 1. Often there are several such positions and they had to be tested empirically, as to which gave the best scatter. From a selected position the indicator value (x) was calculated using the following formula

$$x = n + 1 + \frac{Q - (an + 1)}{R - 1}$$

Where R and Q are respectively the row and column in which the selected postion is (counting from the top left hand corner), n is the number of clones and a is such a whole number that will make x a whole number. It sometimes turns out that more than one indicator value will place clone 1 in the selected position. Then the scatters had to be compared as to which was best. Having settled on the optimal indicator value for a given number of clones the isolation was measured for the original lay-out and for the conditions after thinnings, and expressed in units of spacing.

Results

The indicator values and isolations are gaven in *table 1.* for clone numbers from 9 to 65.

From the survey several principles have emerged that have a bearing on the choice of the number of clones. First of all it can be seen from *table 1* that when there is an even number of clones there cannot be a second thinning. Such a thinning would remove some clones and leave others. The reason for that is obvious when one imagines a lay-out for 16 clones according to the pattern shown in *fig. 1.* There even a single thinning would remove some clones and leave others untouched. Using a pattern like in *fig. 2* and selecting an indicator value from the odd numbers displaces the sequence by one, so that a single thinning becomes possible. However this removes all the possibility of having a perfect quadratic scatter for any of the even numbers. Odd numbers do not suffer from such limitations and therefore have to be considered as preferable. Any number of thinnings is possible and provided the area is large enough the clone scatter and proportions of individuals from each clone will remain unaffected by the thinnings.

Of the odd numbers some give a quadratic scatter, which as discussed earlier is deemed best. These numbers are 13, 17, 25, 29, 37, 41, 45, 53, 61, and 65. They are all sums of two squares. The reason why they give a quadratic scatter is because the square root of these numbers will be the exact distance between some two trees in the plantation (hypotenuse of a right angled triangle whose other sides are whole numbers).

Thus for the purpose of establishing a seed orchard these numbers (plus 9 and 49) are the numbers most recommended, since they provide a quadratic scatter. After a thinning of a plantation with a quadratic scatter the diagonal of the squares becomes the new isolation ($i\sqrt{2}$), which in units of the new spacing, ($\sqrt{2}$) remains the same

$$\left(\frac{i\sqrt{2}}{\sqrt{2}} = i\right).$$

The lay-out for 45 clones is a case in itself. Since it is odd, and a sum of two squares (36 + 9) it can give a quadratic distribution, but under special conditions. The squares

Table 1. — Indicator values and minimal isolations in units of spacing for optimal lay-outs of seed orchards.

Number of clones	Indicator value	Isolation original	Isolation after 1st. thinning	Isolation after 2nd thinning
9*)	4	3.0	2.2 (3)	3.0
10	3	2.3	3.1	—
11	8	3.2	2.2	3.2
12	5	3.0	3.1	—
13	9	3.6	3.6	3.6
14	11	3.6	3.1	—
15	5	4.1	3.0	4.1
16	7	3.6	3.2	—
17	5	4.1	4.1	4.1
18	5	4.1	3.2	—
19	5	4.1	3.7	4.1
20	5	4.1	4.0	—
21	5	4.1	3.6	4.1
22	5	4.1	4.5	—
23	7	4.1	4.1	4.1
24	5	4.1	4.2	—
25*)	19	5.0	5.0	5.0
26	11	5.0	4.5	—
27	22	5.0	4.1	5.0
28	7	5.3	4.0	—
29	18	5.4	5.4	5.4
30	7	5.0	5.1	—
31	10	5.0	5.0	5.0
32	7	5.3	5.1	—
33	8	5.3	5.0	5.3
34	11	5.0	5.1	—
35	15	5.0	5.4	5.0
36	23	5.4	5.8	—
37	7	6.1	6.1	6.1
38	9	5.4	5.1	—
39	7	6.1	5.4	6.1
40	9	5.0	6.3	—
41	10	6.4	6.4	6.4
42	27	6.4	5.8	—
43	19	6.4	5.4	6.4
44	9	6.4	5.1	—
45**)	37 (3 × 15)	6.7	6.7	6.7
46	7	6.1	5.8	—
47	7	6.1	6.1	6.1
48	15	6.7	6.3	—
49*)	12	6.4 (7)	6.4 (7)	6.4 (7)
50	7	6.1	5.8	—
51	20	6.7	6.1	6.7
52	31	7.3	5.9	—
53	31	7.3	7.3	7.3
54	39	6.7	7.1	—
55	16	6.4	6.1	6.4
56	9	7.0	7.1	—
57	33	7.3	6.7	7.3
58	51	7.3	7.1	—
59	14	7.8	6.4	7.8
60	53	8.1	6.3	—
61	51	7.8	7.8	7.8
62	37	7.8	7.2	—
63	40	7.8	6.7	7.8
64	15	7.8	6.3	—
65	9	8.1	8.1	8.1

*) for these numbers of clones lay-outs as in *fig. 1* are best.
**) 45 clones require a special lay-out as in *fig. 4.*

are such that they require the corners (one clone) to fall on one row or column at intervals of 15 *(fig. 4).* This means that it is not possible to run the sequence of clones consecutive, but that the whole total (45) had to be divided into 3 lots, 1–15, 16–30, 31–45, each of which will run in consecutive rows. Always clone 1 will follow clone 15, clone 16 will follow clone 30 and clone 31 will follow clone 45. The indicator value is 37, meaning that clone 1 will be below clone 37. Also clone 16 will be under clone 1 and clone 31 under clone 16. Thus the lay-out has all the advantages bid for. It is extensible in all directions, it gives a quadratic

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	16
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	31
10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10
25	26	27	28	29	30	16	17	18	19	20	21	22	23	24	25
40	41	42	43	44	45	31	32	33	34	35	36	37	38	39	40
4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4
19	20	21	22	23	24	25	26	27	28	29	30	16	17	18	19
34	35	36	37	38	39	40	41	42	43	44	45	31	32	33	34
13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13

Fig. 4. — Optimal lay-out for 45 clones. (1st thinnings not underlined, 2nd thinnings underlined once.)

scatter and permits numerous thinnings without upsetting the scatter.

In conclusion it is recommended, that before deciding on the number of clones to be employed in a seed orchard, *table 1* should be consulted. If possible one of the numbers should be chosen that can give a quadratic or almost quadratic scatter.

Summary

The arguments are discussed for and against a systematic distribution of clones in a seed orchard and it is concluded that a systematic arrangement provides more advantages. A survey was made of the best systematic arrangements for all numbers of clones from 9 to 65 that would satisfy the three basic requirements: — (1) extensibility of the pattern in all directions, (2) maximal scatter of representatives of a given clone, and (3) possibility of thinnings preassignement that would as little as possible affect the scatter. Numbers of clones that permit a quadratic scatter are considered best. Arrangement as in *fig. 1* is possible for 9, 25 and 49 clones. For other clone numbers a consecutive arrangement is needed (as in *figs. 2, and 3),* in which the scatter is determined by the clone number under which clone 1 is located (indicator value). Indicator values, and isolation in units of spacing are presented in *table 1* for clone numbers from 9 to 65. In this arrangement quadratic scatters are offered only by the following numbers of clones; 13, 17, 25, 29, 37, 41, 53, 61, and 65. With the special arrangement as in *fig. 4,* 45 clones will also give a quadratic scatter. Even numbers permit only one 50% thinning, whereas odd numbers can have any number of thinnings.

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Stimulation de la production de strobiles femelles dans un verger à graines de Pinus silvestris L. par application d'engrais

Premiers résultats

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1. Introduction

Un des problèmes parmi les plus importants qui se posent en amélioration génétique des essences forestières et dont la solution conditionne en bonne partie l'utilisation pratique du matériel génétique sélectionné, est constitué par l'induction et la stimulation de la fructification dans les vergers à graines.

Des études assez nombreuses ont déjà été effectuées dans ce domaine au sujet de l'utilisation de traitements divers tels que: la strangulation ou l'annélation de la tige, la taille des racines, la taille de la cime, etc.

En général, ces traitements ont donné des résultats positifs assez rapides. Cependant, leurs effets, à l'exception de ceux de la taille de la cime, sont souvent éphémères et deviennent même fréquemment négatifs après quelques années. En outre, ces traitements débilitants entraînent à la longue un affaiblissement plus ou moins prononcé et parfois même la mort des sujets traités.

L'application d'hormones et de substances florigènes fait actuellement l'objet d'études approfondies, en particulier de la part des chercheurs japonais. Il ne semble pas cependant que l'utilisation pratique de ces substances puisse être envisagée avant de nombreuses années.

Les effets de l'application d'engrais sur la fructification d'arbres en peuplements a fait l'objet d'études assez nombreuses, spécialement aux Etats-Unis. Ces effets sont en général fort favorables et perdurent pendant plusieurs années, tout en augmentant la vigueur et la croissance des arbres traités.

Dans les vergers à graines par contre, les études concernant l'action des engrais sur la fructification sont à notre connaissance peu nombreuses. Mergen (1959) exprime d'ailleurs le souhait que des résultats même faibles ou non significatifs soient publiés afin d'activer les recherches dans ce domaine.

Matthews (1955) propose l'emploi d'engrais phosphatés sur sols pauvres. Bergman (1955) effectue un essai de fertilisation sur jeunes pins sylvestres au moyen de sels potassiques. Il en résulte une nette augmentation du nombre de fleurs au cours des années suivantes. Hoekstra et Mergen (1957) induisent la production de strobiles femelles sur des plants de *Pinus eliottii* âgés de 6 ans par application d'un engrais composé de formule 3-12-6, combiné à l'annélation du tronc ou à la taille des racines. Zobel *et al.* (1958) signalent très brièvement l'action positive d'un engrais azoté sur la production de cônes de plants greffés. Mergen (1959) parvient à produire des fleurs femelles et mâles sur de