9. Kattan, G. H., Correa, D., Escobar, F. and Medina, C., Leaf-litter arthropods in restored forests in the Colombian Andes: a comparison between secondary forest and tree plantations. *Restor. Ecol.*, 2006, **14**, 95–102.
10. Andersen, A. N., A classification of Australian ant communities, based on functional groups which parallel plant life-forms in relation to stress and disturbance. *J. Biogeogr.*, 1995, **22**, 2297–2311.
11. Andersen, A. N., Parallels between ants and plants: implications for community ecology. In *Ant–Plant Interactions* (eds Huxley, C. R. and Cutler, D. C.), Oxford University Press, Oxford, England, 1991, pp. 539–558.
12. Grime, J. P., Primary strategies in the established phase. In *Plant Strategies and Vegetation Processes*, John Wiley and Sons, Chichester, UK, 1979, pp. 3–115.
13. Majer, J. D., Ant recolonization of rehabilitated bauxite mines of Pocas de Caldos, Brazil. *J. Trop. Ecol.*, 1992, **8**, 97–108.
14. Majer, J. D. and de Kock, A. E., Ant recolonization of sand mines near Richards Bay, South Africa: an evaluation of progress with rehabilitation. *S. Afr. J. Sci.*, 1992, **88**, 31–36.
15. Otonetti, L., Tucci, L. and Santini, G., Recolonization patterns of ants in a rehabilitated lignite mine in central Italy: potential for the use of Mediterranean ants as indicators of restoration processes. *Restor. Ecol.*, 2006, **14**, 60–66.
16. Champion, H. G. and Seth, S. K., In *A Revised Survey of the Forest Types of India*, Government of India Press, 1968.
17. Majer, J. D., Brennan, K. E. C. and Bisevic, L., Terrestrial invertebrates. In *Handbook of Ecological Restoration: Principles of Restoration* (eds Perrow, M. R. and Davy, A. J.), Cambridge University Press, UK, 2002, vol. 1, pp. 279–299.
18. Brown Jr, W. L., Diversity of ants. In *Ants: Standard Methods for Measuring and Monitoring Biodiversity* (eds Agosti, D., Majer, J. D., Alonso, L. E. and Schultz, T. R.), Smithsonian Institute Press, USA, 2000, pp. 45–79.
19. R Development Core Team, R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2008; www.R-project.org.
20. Colwell, R. K., EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5, 2005; http://purl.oclc.org/estimates.
21. Shea, K., Roxburgh, S. H. and Rauschert, E. S. J., Moving from pattern to process: coexistence mechanisms under intermediate disturbance regimes. *Ecol. Lett.*, 2004, **7**, 491–508.

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Overlap index: a measure to assess flowering synchrony among teak (*Tectona grandis* Linn. f) clones in seed orchards

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One of the most important aspects in a seed orchard is the synchrony among the clones for reproductive phenology. This will decide the extent of random mating among the constituent clones and hence the genetic gain in the resultant progeny. In the present study, synchrony among clones for flowering and peak flowering was estimated through the phenogram as well as through a novel overlap index. Rating of an entire orchard for its relative degree of flowering synchronization is effective with this new measure. The present study was conducted in teak clonal seed orchard (CSO), Manchikere, Karnataka using 25 clones to study the clonal variation for flowering phenology. There are two peak periods in flowering. The first period during early May to July corresponds mainly to the clones of central and southern origin; the second period during July to August corresponding to those of northern origin. Further, these two peaks are also more apparent considering the peak flowering periods of clones. Perhaps, this is the first empirical evidence among the CSOs of teak in India where asynchrony has been documented and quantified through meticulous observations as well as by developing a new index.

Keywords: Geographic variation, genetic gain, panmixis, phenology, teak clones.

THE knowledge of reproductive phenology is a fundamental requirement for the successful operation of any seed orchard because it affects the extent of gene exchange between clones and consequently, the genetic composition of the seeds produced[1]. Clonal seed orchard (CSO) is a plantation where phenotypically superior individuals of a species are deployed as vegetatively propagated plants, in isolation, to achieve a big genetic gain through the process of random mating. Since superior genotypes identified from diverse regions are used in a CSO, understanding the flowering phenology of the constituent clones becomes imperative to achieve maximum synchrony. A large number of reports are available for temperate species, which document asynchronous flowering among the clones in a seed orchard, especially among monoecious species[2].

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Low fruit production has been an important limitation of many tree improvement programmes[3,4]. The establishment of CSO would be a genetic dead-end unless full potential of an orchard is realized through harvesting of genetically improved seed crops. Although, there seems to be a direct association between the extent of flowering synchrony among the constituent clones and the fruit production in a seed orchard, surprisingly, there are no reports in India that focus on these issues. However, a few authors have also identified this gap of information earlier in teak[5–8].

Evaluating the effectiveness of gamete exchange in a cross pollinated species requires a standard measure of the relative probabilities of crossing between all possible pairs of parents or clones. Askew and Blush[9] have developed an index to measure the overlap between male and female flowering synchrony in a monoecious loblolly pine. However, their measure does not correspond to species with bisexual perfect flowers such as teak. In the present study, a general overlap index has been developed to quantify the exact overlap in flowering among different clones. The index may provide a tool for tracking the development of young orchards and in monitoring the stability of established orchards.

The present investigation was undertaken in a teak CSO established at Manchikere in Uttara Kannada District, Karnataka, India[8]. This CSO was established in 1980 using 24 superior teak clones identified in various provenances of Karnataka (Table 1). The planting was done adopting completely randomized design with unequal replications over an area of 4 ha and being monitored by Karnataka Forest Department. Flowering phenology was studied by tagging the known clones and their ramets ($n = 407$). The site was visited every week to make observations on flowering phenology using standard scores as mentioned in Table 2 (i.e. during April 1999–August 1999)[10]. The average time of initiation and average duration for flowering, peak flowering, immature fruiting and mature fruiting were worked out[11]. Peak flowering is defined as that duration, where more than 75% of ramets in a clone are in bloom. Time of peak flowering was used to compute overlap index to assess flowering synchrony among the clones. The time taken for flower bud initiation, flowering initiation and peak flowering initiation were calculated as the number of days from 1 January to the date of first appearance of their respective phenophases for every tree. The average duration was also worked out for these phenophases.

The overlap between two clones for their flowering period was calculated based on the following formula adopted from the Morisita index of similarity[12] and Horn's index of similarity[13]. The time of peak flowering was used for analysis of overlap index.

$$\text{Overlap index } (C) = \frac{2\sum_{i=1}^{n}(P_{ij} \times P_{ik})}{\left(\sum P_{ij}^2 + \sum P_{ik}^2\right)},$$

where P_{ij} is the proportion of ramets of jth clone in peak flowering for a given period i, P_{ik} the proportion of

Table 1. Passport data of teak clones of Manchikere clonal seed orchard

Clone I.D.	Clone number	Forest range	Forest division	Latitude	Longitude	Altitude
MYHD1	1	Barchi	Haliyal	15°17′	74°38′	573
MYHD2	2	Barchi	Haliyal	15°17′	74°38′	573
MYHD3	3	Barchi	Haliyal	15°17′	74°38′	573
MYHD4	4	Barchi	Haliyal	15°17′	74°38′	573
MYHV1	5	Gundvamoli	Haliyal	15°06′	74°36′	570
MYHV3	7	Gundvamoli	Haliyal	15°06′	74°36′	570
MYHV4	8	Gundvamoli	Haliyal	15°06′	74°36′	570
MYHV5	9	Virnoli	Haliyal	15°06′	74°36′	570
MYHV6	10	Virnoli	Haliyal	15°06′	74°36′	570
MYHV7	11	Virnoli	Haliyal	15°06′	74°36′	570
MYSA1	13	Arasake	Shimoga	13°53′	74°28′	571
MYSA2	14	Arasake	Shimoga	13°53′	74°28′	571
MYSS2	16	Sacrebyle	Shimoga	13°53′	74°28′	571
MYHuT1	17	Thithimatti	Hunsur	12°13′	76°00′	850
MYHuT2	18	Thithimatti	Hunsur	12°13′	76°00′	850
MYHuT3	19	Thithimatti	Hunsur	12°13′	76°00′	850
MYHuT6	22	Thithimatti	Hunsur	12°13′	76°00′	850
MYHuT7	23	Thithimatti	Hunsur	12°13′	76°00′	850
MYHuT8	24	Thithimatti	Hunsur	12°13′	76°00′	850
MyBL1	31	Bhadravati	Lakkavalli	13°40′	75°39′	571
MyHaK1	32	Kulagi	Haliyal	15°11′	74°41′	500
MyHaK2	33	Kulagi	Haliyal	15°11′	74°41′	500
MyHaK3	34	Kulagi	Haliyal	15°11′	74°41′	500
MyMK3	37	Kakanakote	Mysore	11°55′	76°11′	690

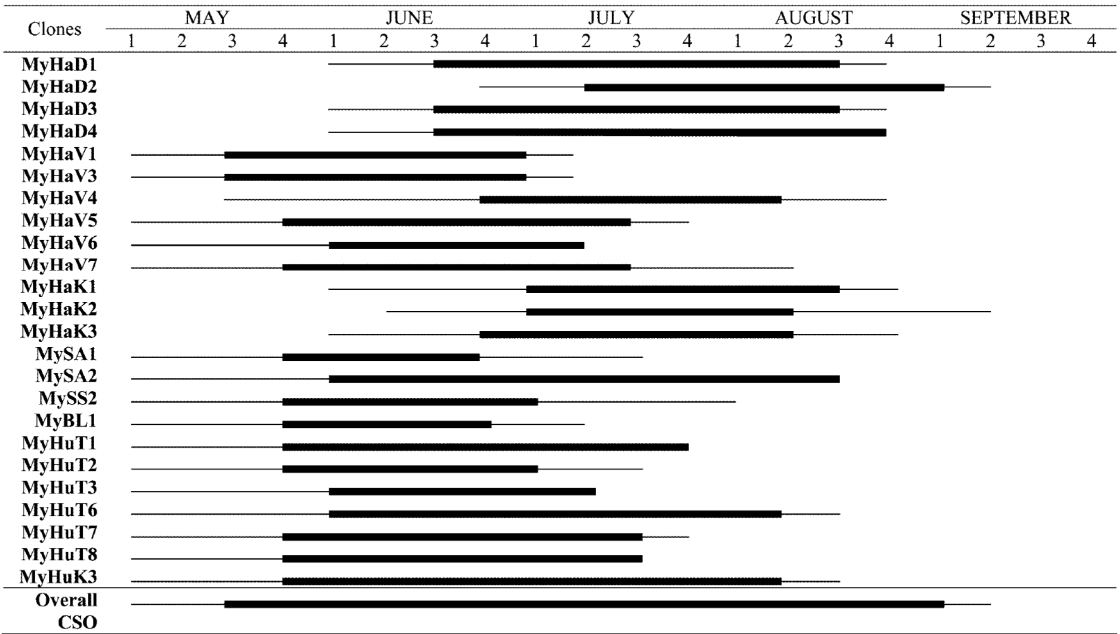

Figure 1. Phenogram showing clonal variation for duration of flowering (thin line) and peak flowering (bold line) in a clonal seed orchard (CSO) of teak at Manchikere, Karnataka.

Table 2. Details of the scores given for flowering phenology in teak

Phenophases	Scores
Flower less	0
Flower bud initiation	1
0–25% flowers in bloom	2
25–50% flowers in bloom	3
50–75% flowers in bloom	4
>75% flowers in bloom	5

ramets of *k*th clone in peak flowering for a given period *i*, *n* the number of weeks in which the flowering was observed, $P_{ij} \times P_{ik}$ is the joint probability of flowering by two clones.

The value of overlap index ranges from 0 (when there is no overlap between two clones) to 1 (when there is full overlap between two clones). This index can be used to compute overlap of flowering between any two clones or between groups of clones belonging to different provenances or to know the flowering synchrony between a clone and rest of the clones in a CSO.

In the present study, synchrony among clones for peak flowering was assessed through phenograms (Figure 1) as well as through a novel overlap index (Table 3). The perusal of trend in the phenogram suggests that generally there are two peak periods in flowering. The first peak during early May to July corresponds mainly to the clones of central and southern provenances; the second peak during July to August corresponds to those from northern provenance (Figure 2).

A higher value of the overlap index is suggestive of greater overlap. The values of the overlap (synchrony) indices between two clones as well as between a clone with rest of clones in a CSO are shown in Table 3. In nearly one-fifth of the bi-clonal interaction with respect to peak flowering period, there was less than 0.6 overlap suggesting a lack of synchrony (Figure 3). In fact in 12.55% of interactions, the overlap was less than 0.5. This suggests a gross violation of basic assumption of random mating among clones, made while establishing a CSO. Clones from Dandeli (clone numbers 1–4) and Kulagi (clone numbers 32–34) provenances exhibited highest overlap among themselves (more than 0.95, Table 3). Clones from Shimoga (clone numbers 13, 14, 16, 31) and Kodagu (clone numbers 17–19 and 22–24) provenances also showed higher values of overlap, i.e. from 0.922 to 0.991 (Table 3).

Strong provenance effect on flowering phenology was also observed in the present study (Table 4). Comparison of overlap index between groups of clones from different provenances yielded several interesting results (Table 4). The overlap index between northern clones and those from central was least (0.778); while it was 0.798 between northern clones and those of southern. Highest overlap of 0.997 was found between clones of southern and central provenances. Clones from central and southern provenances were early in commencement of flower buds, flowers and peak flowering (by about 30–40 days) when compared to clones from northern provenance (Figure 1). It clearly indicates that a significant proportion of ramets of clones from southern and central provenances

Table 3. Overlap index for peak flowering among 25 clones in a teak CSO at Manchikere, Karnataka. The third column represents the overlap index of that clone with all other clones of the CSO (except with itself)

Clone ID	With all other clones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
MyHaD1	0.798	–																					
MyHaD2	0.554	0.953	–																				
MyHaD3	0.701	0.989	0.953	–																			
MyHaD4	0.702	0.989	0.969	0.995	–																		
MyHaV1	0.889	0.624	0.424	0.603	0.560	–																	
MyHaV3	0.830	0.719	0.532	0.695	0.661	0.983	–																
MyHaV4	0.546	0.924	0.794	0.910	0.883	0.851	0.906	–															
MyHaV5	0.751	0.740	0.550	0.715	0.681	0.973	0.996	0.921	–														
MyHaV6	0.862	0.669	0.460	0.641	0.603	0.985	0.982	0.878	0.981	–													
MyHaV7	0.714	0.725	0.531	0.697	0.661	0.976	0.988	0.916	0.991	0.985	–												
MyHaK1	0.734	0.970	0.991	0.974	0.982	0.504	0.604	0.843	0.617	0.532	0.596	–											
MyHaK2	0.626	0.983	0.965	0.990	0.993	0.583	0.680	0.890	0.694	0.615	0.672	0.984	–										
MyHaK3	0.720	0.991	0.952	0.998	0.995	0.622	0.715	0.917	0.733	0.659	0.712	0.975	0.991	–									
MySA1	0.733	0.719	0.532	0.700	0.660	0.986	0.992	0.907	0.989	0.976	0.983	0.607	0.678	0.717	–								
MySA2	0.893	0.738	0.564	0.714	0.676	0.975	0.983	0.922	0.977	0.967	0.983	0.636	0.701	0.731	0.983	–							
MySS2	0.483	0.602	0.400	0.573	0.530	0.991	0.968	0.839	0.962	0.981	0.975	0.477	0.550	0.592	0.971	0.969	–						
MyBL1	0.597	0.663	0.469	0.631	0.595	0.991	0.983	0.871	0.974	0.986	0.983	0.544	0.616	0.653	0.981	0.986	0.989	–					
MyHuT1	0.775	0.728	0.551	0.791	0.680	0.974	0.985	0.915	0.983	0.967	0.976	0.629	0.699	0.736	0.988	0.981	0.963	0.968	–				
MyHuT2	0.637	0.584	0.382	0.553	0.512	0.994	0.975	0.821	0.965	0.977	0.971	0.460	0.536	0.573	0.973	0.967	0.991	0.988	0.956	–			
MyHuT3	0.586	0.619	0.413	0.587	0.547	0.979	0.970	0.850	0.971	0.985	0.983	0.480	0.560	0.603	0.962	0.959	0.986	0.979	0.950	0.984	–		
MyHuT6	0.851	0.774	0.608	0.757	0.723	0.962	0.976	0.932	0.970	0.966	0.968	0.679	0.743	0.775	0.980	0.980	0.947	0.970	0.980	0.940	0.937	–	
MyHuT7	0.730	0.734	0.539	0.704	0.668	0.972	0.986	0.919	0.993	0.983	0.995	0.604	0.678	0.720	0.985	0.978	0.973	0.978	0.977	0.965	0.979	0.967	–
MyHuT8	0.898	0.793	0.640	0.766	0.740	0.944	0.981	0.933	0.978	0.940	0.963	0.705	0.764	0.786	0.975	0.975	0.926	0.954	0.971	0.934	0.922	0.970	0.966
MyHuK3	0.726	0.718	0.528	0.691	0.652	0.985	0.986	0.913	0.987	0.983	0.990	0.599	0.667	0.708	0.993	0.987	0.983	0.987	0.985	0.975	0.976	0.978	0.922

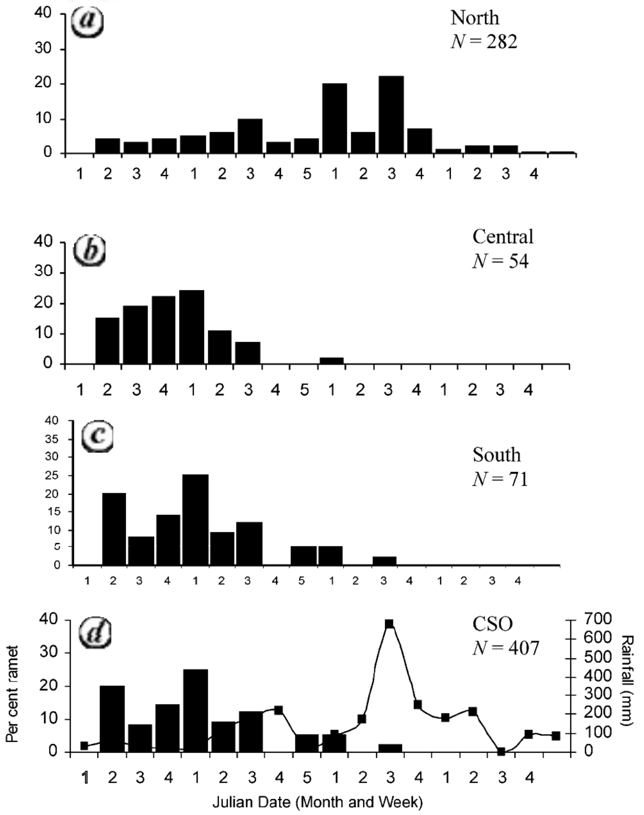

Figure 2. Distribution of teak ramets of 24 clones from different provenances (***a–c***) and from overall CSO (***d***) with respect to initiation of flowering across time. The line diagram in (***d***) represents rainfall pattern.

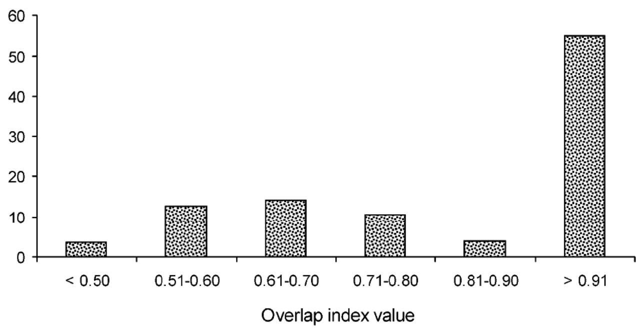

Figure 3. Distribution of number of clones into classes of overlap index value.

Table 4. Overlap index for peak flowering between provenances

Overlap of clones of	Index value
Northern and central provenances	0.778
Northern and southern provenances	0.798
Southern and central provenances	0.997

escape early showers in the orchard when compared to those from northern provenance.

Genetically based geographical variation was recorded in the present study and it was also shown to occur in several plant species. Hence, simple geographical continuity of the clonal origin could be considered as thumb rule while selecting right clones for seed orchard. Effimov has also suggested the selection of plus trees based on[14] synchronized flowering while establishing second-generation CSOs. In fact, in Australia constraints for *Pinus caribaea* seed production has prompted a co-operative arrangement wherein special CSOs would be established using local clones alone.

The overlap index between 'early flowering clones' (those clones blooming during May to June corresponding to Figure 2 *b* and *c*) with 'late flowering clones' (those bloomed during July to August corresponding to Figure 2 *a*) was 0.739. This suggested that about 70% synchrony can be expected between clones which flowered early, i.e. during June, with clones that flowered late (during July to August, Figure 1).

In order to improve the seed production level in CSO, seed orchards need to be established considering the flowering synchrony of the constituent clones. Early flowering and late flowering clones could very well be separated into two different CSOs. Clones such as MySA2, MyHuT1, MyHuT6 and MyHuK3 recorded wider flowering duration which could be deployed in both types of orchards.

Having a measure of flowering synchrony of each clone with the remaining clones in the orchard, plays an important role in assessing the genetic value of the orchard crop[9]. Rating an entire orchard for its relative degree of flowering synchronization is effective with this new measure. This helps to track the changes in flowering on a quantitative scale throughout the orchard life and hence help in evaluating the panmixia/genetic gain.

1. Weir, R. and Zobel, B., Advanced generation seed orchards. *For. Commun. Bull.*, 1975, **54**, 118–127.
2. Gunaga, R. P., *Genetic Variation for Phenology in Clonal Seed Orchards of Teak* (*Tectona grandis* Linn. f) submitted to the Department of Forest Biology and Tree Improvement, University of Agricultural Sciences, Dharwad, 2000, p. 128.
3. Gunaga, R. P. and Vasudeva, R., Causes for low fruit production in clonal seed orchards of teak (*Tectona grandis* Linn. f): a special reference to India. In *Quality Timber Products of Teak from Sustainable Forest Management* (eds Bhat, *et al.*), KFRI and ITTO, 2005, pp. 352–358.
4. Indira, E. P., Why teak seed orchards are low productivity? International Teak Conference on Quality Timber Products of Teak from Sustainable Forest Management, held at Kerala Forest Research Institute, Peechi, Kerala, 2–5 December 2003, pp. 348–351.
5. Subramaniam, K. N., Nicodemus, A. and Radhamani, A., Teak improvement in India. *For. Gen. Resour.*, 1994, **22**, 33–36.
6. Nagarajan, B., Mohan Varghese, Nicodemus, A., Sashidharan, K. R., Benet, S. S. R. and Kannan, C. S., Reproductive biology of teak and its implication in tree improvements. Proceedings of the QFRI–IUFRO Conference on Tree Improvement for Sustainable Tropical Forestry (eds Dieters, M. J. *et al.*), Caloundra, Queensland, Australia, 1996.
7. Radhamani, A., Nicodemus, A., Nagarajan, B. and Mandal, A. K., Reproductive biology of tropical tree species. In *Forest Genetics*

and Tree Breeding (eds Mandal, A. K. and Gibson, G. L.), CBS Publishers and Distributors, New Delhi, 1998, pp. 1–268.
8. Gunaga, R. P., Vasudeva, R., Hanumantha, M. and Swaminath, M. H., Blooming variation among clones of different provenances in teak. *My Forest*, 1999, **35**, 237–247.
9. Askew, G. R. and Blush, Th. D., Short note: an index of phenological overlap of flowering for clonal coniferous seed orchards. *Silvae Genetica*, 1990, **39**, 168–172.
10. Gunaga, R. P. and Vasudeva, R., Variation in flowering phenology in a clonal seed orchard of teak. *J. Tree Sci.*, 2002, **21**, 1–10.
11. Vasudeva, R., Gunaga, R. P. and Hanumantha, M., Implication of variation in reproductive traits among teak clones to management and genetics of seed orchards. *Adv. For. Res. India*, 2001, **24**, 120–135.
12. Morisita, M., Measuring inter-specific association and similarity between communities. *Mem. Fac. Sci. Kayushu Univ. Ser.* (*Biol.*), 1959, **3**, 65–80.
13. Horn, H. S., Measurement of overlap in comparative ecological studies. *Am. Nat.*, 1966, **100**, 419–424.
14. Effimov, Yu. P., Seed production and growth of scots pine in orchards of vegetative and seed origin. *Lesn. Khoz.*, 1987, **12**, 38–41.

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Strain estimation from the fabrics of deformed rocks

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The paper presents a simplified method of estimating strain from the fabrics of weakly deformed rocks, where it is difficult to measure the longer and shorter dimensions of deformed objects. In this method, the plot of the average normalized length of deformed objects against the orientation of lines of constant length, at different angular spacing exhibits a sinusoidal curve. The ratio of maximum to minimum length of curve provides strain ratio. Further, the orientation of the maximum and minimum provides the orientation of principal strain axes. The method requires only a few measurements at different angular spacings, resulting into quick estimate of strain.

Keywords: Homogeneous deformation, monomineralic and polymineralic rocks, sinusoidal curve, strain ratio.

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SEVERAL methods of estimating two dimensional strains from the deformed rocks have been proposed[1–10]. The methods require the measurement of longer and shorter dimensions of the deformed objects, called strain markers. It is easy to measure the longer and shorter dimensions of the deformed objects in moderately to highly deformed rocks, whereas it is difficult to identify with precision the longer and shorter axes of individual objects/particles in weakly deformed rocks. The relatively few methods that do not require the identification of longer and shorter axes of particles are centre to centre method[7,11], Fry method[3], regular and inverse SURFOR wheel method[5,6] and intercept method[10].

The centre to centre method[7,11] assumes that the particles are well dispersed and distributed uniformly so that the grain centre approaches an isotropic pattern in the unstrained state. In such distributions, length of the lines 'd' from the centre of one object to the centre of its nearest neighbour is statistically constant in the initial state. During deformed state, the distance between the centre of randomly deformed particles is systematically altered to 'd'' in such a way that changes in the distances are related to the direction and amount of strain. On a sheet of tracing paper the centre of all particles are marked. A line is then drawn joining the centre of the nearest neighbour particle. The distance 'd'' and orientation of the tie from line '$\propto$' from the known reference are determined. The value of 'd'' and '$\propto'$' are plotted as abscissa and ordinate respectively, to provide a bell shape curve. By measuring the distance between the maximum and minimum values of 'd'' on the curve of best fit, the ellipticity (R) of the strain ellipse can be found from $R = d'_{max}/d'_{min}$.

The Fry method[3] is based on an arguments; when a set of points with statistically uniform distribution are deformed, the average distance between the neighbouring points in any direction increases or decreases in the same ratio as the length of a marker line in that direction[12]. The maximum increase takes place in the direction of longer axis of the strain ellipse. The average distance between the points decreases the most in a direction parallel to the short axis of the stain ellipse. In this method, centre of all the grains are traced on an overlay by keeping the centre of the grain on a central reference point. After tracing several times all the centre points, a vacancy field of ellipsoidal shape gives directly as long and short axes. The orientation of the ellipse also gives the orientation of the strain ellipse.

The SURFOR wheel method[5] (SURFace Orientation) is a computer based method for the estimation of two dimensional strain from the orientation of lines in a plane. The method assumes that the grain boundary surfaces or other surfaces of the undeformed rocks have no preferred orientation. Homogeneous strain of the bulk rock volume is then assumed to produce a preferred orientation. The method involves digitization of outlines by a set of small straight lines on the enlarged photographs. The orienta-