SEASONAL YELLOWING OF SCOTCH PINE
ITS IMPLICATION THE GENETIC IMPROVEMENT OF CHRISTMAS TREES

Henry D. Gerhold

Pennsylvania State University, School of Forestry
University Park, Pennsylvania

In recent years the production of plantation-grown Christmas trees has increased rapidly in the northeastern quarter of the nation and in neighboring Canada. Scotch pine is the major species in this industry, with over 8 million seedlings being planted annually in Pennsylvania alone. One of the main problems encountered in growing Scotch pine Christmas trees is the seasonal yellowing inherent in many of the varieties, which In its extreme form renders the trees unsaleable. The numerous questions raised by growers on this topic usually are in one of two forms: "How can the yellowing be prevented?" and "Where can seed or seedlings be obtained that will not yellow?"

The best long-range answer to these questions will come from the application of genetic principles in developing a reliable source of trees which will not discolor noticeably. This paper is not concerned with the immediate problems of seed source and what to do with discoloration-prone trees that are already planted. Articles by Bramble and Cope (3), Den Uyl (4), Eliason (5), and Nodwell (13) are among those which have discussed these problems. Rather, this paper deals with the current status of knowledge about the cause of the seasonal yellowing, and the implications of such facts and theories in a genetic improvement program.

The literature contains indirect, but ample, evidence that the seasonal discoloration of Scotch pine is under rather strict genetic control. Provenance tests by Baldwin (1, 2), Engler (6, 7), Langlet (12), and others all point toward a definite geographic pattern of variation. Most of these tests were established before the usefulness of statistical replication was known, but the similarity, of results provides a sense of confidence in the findings which in part compensates for the lack of replication. Trees which originate from northern latitudes and high elevations become more yellow in the winter than those from farther south, the lowlands, and maritime regions. Winter colors may range from golden yellow to bluish green, depending on the seed source. There appears to be a relationship between the severity of winter weather at the point of origin and the degree of discoloration exhibited by trees at the planting site.

The discoloration process begins in the latter part of August in central Pennsylvania, and continues gradually until the time of the first autumn frost, at which time it becomes much more noticeable and continues at an accelerated rate. In late December, January, and February there is little change in needle color. During the discoloration period some trees may lose up to two-thirds of the chlorophyll in their needles, and at the same time the carotinoid content increases by about 50 percent. In other trees there is a much smaller loss of chlorophyll, but the carotinoids increase by the same amount. The normal green color returns rather rapidly with the advent of warm weather in the spring.

A series of experiments (8, 9, 10) has revealed that short photoperiods, intense sunlight, and low temperatures are prerequisites for the discoloration to occur. No effect could be attributed to relative humidity. Neither could my relationship be established between needle color and the elements nitrogen, phosphorus, potassium, magnesium, calcium, iron, manganese, copper, or boron. So a nutrient deficiency is not a likely cause of this seasonal color change. The details of these experiments will appear in forthcoming issues of Forest Science and Silvae Genetica. At present the findings will only be summarized briefly as they relate to the topic.

Intense sunlight is the agency responsible for the destruction of chlorophyll. By reducing the intensity of sunlight incident on the needles to about 13 percent of full sunlight, discoloration of Scotch pine was almost entirely prevented. The effect of light intensity appears to be linear above 13 percent, The most active wavelengths are in the vicinity of 450 and 650 microns, which correspond to the regions of visible light in which chlorophyll absorbs most strongly. Yellowing was prevented by filtering out these wavelengths through the use of green-coated cellulose acetate sheets.

Discoloration does not occur during the growing season because photoperiods are long. When daylengths were artificially shortened, discoloration occurred prematurely. When the light period was extended, or when the dark period was divided in half by an hour of illumination, yellowing did not occur at least until December. In order for these treatments to be successful, they must begin about the middle of August; early September is too late. Although it is not known why chlorophyll is destroyed under short-day conditions, the following theory may be advanced to explain the phenomenon. Scotch pine becomes dormant in response to decreasing daylengths. In the dormant state it is likely that photosynthesis is inhibited, and that there is a scarcity of easily-oxidized compounds in the vicinity of the chloroplasts. Under these conditions, it is known that photautoxidation of chlorophyll can occur.

Low temperatures also play an important role in the yellowing process. When temperatures were maintained above 600 F. under short day conditions, discoloration of Scotch pine needles was almost imperceptible. The mere protection against, freezing temperatures served to prevent a con siderable amount of discoloration. But when trees were exposed to freezing temperatures under long day conditions, there was no loss of green color. Thus it appears that the main effect of low temperatures is to prevent the synthesis of chlorophyll. It is also possible that frost disrupts the cell contents, thereby exposing more chlorophyll to destruction by sunlight.

Although the available information on the yellowing of Scotch pine may be described as more somatic than genetic. It will nevertheless be useful in designing an efficient improvement program for Christmas trees when used in conjunction with inheritance data as these become known. Such a program would of course be concerned with other characteristics, but these will not be considered in the present discussion.

Selection in a single generation combined with vegetative propagation to produce seed orchards would result in an appreciable improvement in needle color, since the heritability of this characteristic is high. This approach would yield rapid results. It would be based on the geographic variation of the species which is manifest in the previously mentioned provenance tests, and could also utilize superior plantations wherever they occur. Holst (11) has described this variation in some detail in a manuscript which he kindly made available some time ago. As a matter of fact, several nurserymen and growers have already utilized such an approach in a more limited way for a number of years.

A program embodying selection and controlled breeding over several generations could be expected to yield much better results, including greater uniformity, a higher percentage of progeny with more desirable needle color, and in better combination with other traits. Such a program would be time-consuming, and therefore expensive, and can best be carried on by research organizations and Christmas Tree Growers Associations, rather than individuals.

The necessary information on the inheritance of needle discoloration is as yet lacking, but inferences can be drawn from other living material as to what may be expected. The skin color of man (perhaps a farfetched comparison) is controlled by a series of independent genes, the effects of which are additive, with dominance absent or incomplete. In corn, chlorophyll development is dependent on at least 75 different genes. Multiple factor inheritance may also be expected to operate in the needle color of Scotch pine, because it is dependent on several different physiological reactions, and perhaps also on various intra and extra-cellular proper ties such as the reaction of chloroplasts to light and frost, and the light-shielding action of cutinous layers. Maternal inheritance may also be involved, since plastids and chlorophyll production are inherited in this manner in some plants. Another distinct possibility which should not be overlooked is a pleiotropic effect, with the same genes controlling the discoloration tendency and the ability of trees to withstand severe winter weather.

While the information on inheritance is as yet highly theoretical, testing and selection techniques have already been developed, and these are on a sound foundation. In both the location and layout of test plantings, and in the method employed in taking color measurements, the main consideration is to minimize all variation due to non-genetic causes.

At an ideal location, the following conditions should be met: maximum light intensity (that is, no shade of any kind and a minimum of cloudiness in the autumn), low temperatures early in the autumn, and short daylengths early in the autumn. In applying these principles, only the latter condition poses a real problem, for the others depend on the straightforward interpretation of climatic data, as modified by local conditions. But the daylength at a northern location is longer before September 21, and shorter after that date, than at a more southern location. And it follows that the relative rate of change is greater in the north. Is it possible that the rate of change in daylength has some influence, as well as the absolute length of the dark period? Further investigation of this point would be helpful, although in actual practice the north-south range from which planting sites are to be chosen would probably be rather limited.

In collecting needles for color measurements, it is important that a standard sampling technique be employed. Comparisons should be planned only among individual trees of the same age in a single test planting at the same date, for it is not known, but entirely possible, that needle discoloration changes with age, and it is very likely that the progress of discoloration would differ at varying locations and dates. The months of December, January, and February are the best time for measuring needle color, for there is very little change during this period and the discoloration is at a maximum. Needles should be collected from a comparable position on each tree, for example from the midpoint of the terminal shoot on the south side. At the selected point there should be a minimum of mutual shading of needles.

At least two good devices are available for measuring needle color directly, namely color charts and reflectometers. Both of these have a common source of error, which is the variation in color within a single needle. This difficulty can be overcome in part by specifying that the color is to be measured at the midpoint of the needle. By using "Hue" notations of Munsell Color Charts, excellent correlation has been obtained with the chloroplast pigment content. The color chart method is rapid and inexpensive, but it has the disadvantage that a certain amount of bias can be introduced. Therefore it becomes necessary that measurements be taken in a random order, and all by the same person. This disadvantage does not exist when measurements are taken with a reflectometer with a monochromatic light source, such as the "Spectronic 20" with reflectance attachment and an adapter to hold needles. This device is somewhat slower because the needles must be carefully positioned, is of course more expensive, and increases somewhat the variability of the data. Its greatest advantage is that the measurements are completely objective, and operators can be interchanged. For greater precision total chlorophyll may be extracted and mea sured by means of a monochromatic colorimeter, but this method is more time-consuming, and introduces storage problems.

There are good possibilities for developing methods of rapid juvenile selection to improve the efficiency of a breeding program. For example, if the discoloration rate remains a linear function of light intensity at intensities greater than full sunlight, arc lamps may be used to speed up the discoloration rate. And if this proves to be feasible, selection may be carried on throughout the year by growing two year seedlings at suitable temperature and daylength conditions, followed by exposure for short periods to intense light sources.

There are exciting opportunities in breeding Scotch pine for Christmas trees, especially when the time element is considered. The commercial rotation is from six to eight years, and therefore juvenile selections can be made with a high degree of confidence. It is fortunate than a rather high percentage of seedlings of this species flower at an age as young as two years. And finally, there are good indications that the heritability of several characteristics is high, not only needle color, but also such important traits as needle length, straightness of stem, the number of branches per whorl, and the angle of branching.

A start has already been made in a Regional Research Project (NE 27) in which Experiment Stations at Cornell, Rutgers, and Penn State are cooperating. Single-parent progeny tests were established in the spring of 1959 at nine locations in the three states represented. A number of controlled crosses were successfully made in 1958, and the ensuing 2-parent progeny tests should provide valuable information on the inheritance of needle discoloration and other traits. Seed production areas are under development to provide, within a few years, seed superior to any that is now available commercially. Selection, testing, and breeding will be continued in a long range improvement program.

Literature Cited.

1. Baldwin, H. I. 1955. Winter foliage color in Scotch pine from different geographic sources. Fox Forest Note 61. 3 pp.
2. ------ ---- 1956. Winter foliage color of Scotch pine. Proc. Third Northeast, Forest Tree improve. Conf.: 23-28.
3. Bramble, W. C., and H. N. Cope. 1947. Races of Scotch pine and Christmas tree growing. Penna. Christmas Tree Growers' Assoc. Bul. 10: 3-4.
4. Den Uyl, D. 1956. Foliage color of pines. Ind. Christmas Tree Growers, Assoc. Bul. 5: 12-15.
5. Eliason, E. J. 1955. On the yellowing of Scotch pine Christmas Trees and its reduction through storage. N. Y. State Christmas Tree Growers' Assoc. Bul. 6. 4 pp.
6. Engler, A. 1908. Tatsachen, Hypothesen and Irrtumer auf dem Gebiete der Samen-provenienz Frage. Forstwiss. Centbl. 30: 295-314.
7. -------- 1913. Einfluss der Provenienz des Samens auf die Eigenschaften der forstliehen Holzgewachse. Mitt. schweiz. Central. forstl. Versuchsw. 10: 189-386.
8. Gerhold, H. D. 1958. Environmental effects on the seasonal discoloration of geographic races of Scotch pine (Pinus sylvestris L.) Unpubl. Ph. D. dissertation, Yale Univ., New Haven, Conn.
9. ------------- 1959. Seasonal discoloration of Scotch pine in relation to microclimatic factors. Manuscript accepted for publication in Forest Science.
10. --------- 1959. Seasonal variation of chloroplast pigments and nutrient elements in the needles of geographic races of Scotch pine. Manuscript accepted for publication in Silvae Genetica.
11. Holst, M. Breeding of the perfect Scots pine Christmas tree. Unpublished manuscript.
12. Langlet, O. 1936. Studier over tallens fysiologiska variabilitet och dess samband med klimatet. Medd. Stat. Skogsforsokanst. 29: 219-1470. (Engl. trans., U.S.F.S. Translation No. 293)
13. Nodwell, W. E. 1955. Some problems in selection of Scotch pine seed for better Christmas tree type, Penna. Christmas Tree Growers Assoc. Bul. 45: 4-6.