

ACCELERATED-OPTIMAL-GROWTH:
APPLICATIONS IN TREE IMPROVEMENT

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ABSTRACT .--The concept of accelerated-optimal-growth (AOG) refers to the rapid production of large tree seedlings in protective culture facilities using programmed control of growth factors, especially photoperiod. AOG systems can help to increase the efficiency of several phases of a tree improvement program. The application of AOG to studies of genetic variation and selection, progeny testing, seed orchard establishment and management, hybridization, vegetative propagation, and mass production of improved stock are discussed.

Progress in the genetic improvement of many tree species has been hampered by their relatively slow and periodic early growth habit and by the long interval between generations. New techniques for either increasing the efficiency or hastening any phase of tree improvement are needed. In Michigan for the past 11 years, we have been developing a system for accelerating tree growth and development which now has both commercial and research applications (Hanover et al, 1976; Hanover and Reicosky, 1972; Hanover, 1976, 1977). We call the system accelerated-optimal-growth, Accel-O-Gro, or simply AOG. Here we will briefly describe the components of the system and then discuss its application to specific phases of the Michigan State Cooperative Tree Improvement Program (MICHCOTIP).

Components Of AOG

The Accel-O-Gro concept is based upon the Programmed control of tree growth by the use of light and temperature regimes that prevent height growth cessation and dormancy. Thus, seedlings can be grown continuously to the desired size or developmental stage. The main components of the AOG system are summarized in Fig. 1. The primary factor in growth control of most tree seedlings is photoperiod. Either natural light or red light (660 m μ) applied contin-

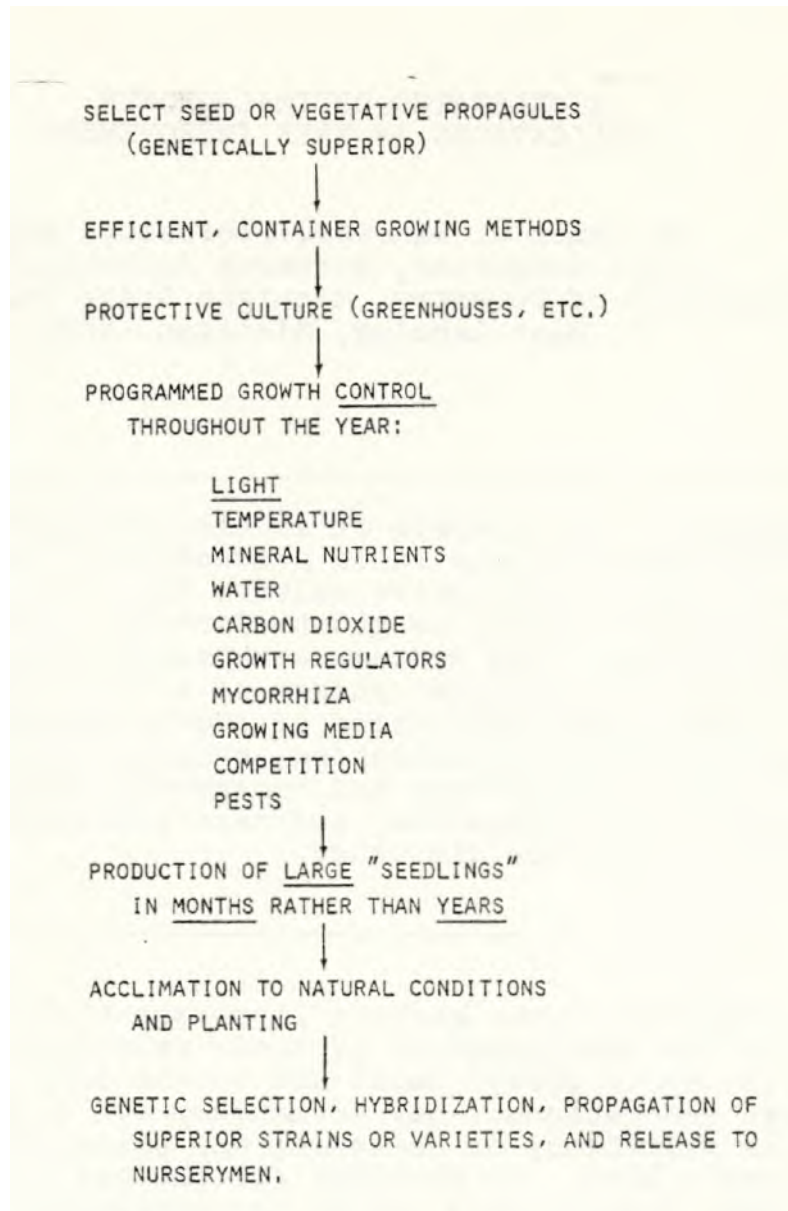


Fig. 1. Components of the Michigan State accelerated-optimal-growth system

uously or intermittently during the dark period at very low intensities (50 fc. of fluorescent source) maintains the phytochrome pigment in a form which prevents onset of physiological dormancy.

In addition to light and temperature other environmental factors such as mineral nutrients, water, and carbon dioxide can impose stresses on trees that may restrict or halt growth. In the AOG system these and other factors including mycorrhizae, growing media, growth regulators, competition and pests are controlled to obtain optimal growth of tree seedlings.

Of course, in order to achieve year-round growth control protective structures such as greenhouses or other buildings must be used. At Michigan State University we use both fiberglass houses and insulated buildings to produce AOG stock in the tree improvement program (Hanover et al, 1976).

Accelerated growth in protective culture facilities can be accomplished by growing trees directly in the ground or in a container system. Ground beds require lower investment and operating costs but container growing allows better control of the growth factors and more flexibility in handling the growing stock. Of the many different container types now available for growing trees (Tinus, Stein, and Balmer, 1974) we have developed a system that is well suited to tree improvement programs. We use square containers made from milk carton stock and which can vary in dimensions from 1 to 6 inches or more square and from 6 to 24 inches deep. These plant bands are placed in plastic cases 1 foot square which have a small mesh bottom to prevent growing media from falling through, yet allow for air pruning of the roots growing out of the bottom. The plastic cases are placed on benches or wood pallets after filling with the proper media.

The Primary objective of the AOG system is to produce very large seedlings for outplanting or research in months rather than years. In order to assure good survival and optimum performance after the accelerated-growth phase, some acclimation to natural conditions may be necessary. Depending upon species and timing this is done by either manipulating the growth factors to induce dormancy, stem stiffness, or cold or wind hardness, or by simply placing the growing trees out-of-doors with some protection from excess wind or solar radiation.

Other details of the cultural techniques we use are given elsewhere (Hanover et al, 1976; Hanover, 1976, 1977).

With this brief description of the basic components of our accelerated-optimal-growth system we will now consider its application to the various phases of an on-going tree improvement effort in Michigan.

Application In Tree Improvement

Tree improvement programs including ours in Michigan usually involve some or all of the following activities: (1) studies of natural variation and selection; (2) progeny testing; (3) seed orchard establishment and management; (4) hybridization; (5) vegetative propagation; and (6) mass production of improved stock. The concept and

methods of accelerated tree growth may be applied to any or all of these activities. However, the relative effectiveness of the conventional versus AOG methods for accomplishing each phase needs to be critically evaluated. It is too early to provide a complete biological and economic evaluation, but we have progressed enough to offer some insight into the advantages and disadvantages of the AOG system for each phase of tree improvement.

Natural Variation, Selection And Progeny Testing

To illustrate the use of Accel-O-Gro methods for identifying genetic variation and selecting superior breeding materials, I will use one of our experiments with blue spruce (Picea pungens Engelm.), a relatively slow growing species (Hanover and Reicosky, 1972).

In September, 1969, we obtained seed collections from more than 400 single trees located throughout the range of blue spruce. In May, 1970, we sowed the seed in our irrigated nursery at a transplant spacing which was the normal Procedure. However, in January, 1970, another portion of the seeds were sown in containers and grown under accelerated-growth conditions for 6 months. After the desired growth phase the 6,000 containerized trees were transferred outdoors in July, 1970. Two months later, in September, the seedlings were barerooted and planted by machine in a plantation at Kellogg Forest near Battle Creek, Michigan. At time of planting the seedlings averaged over 9 inches in height. After 3 years the nursery-grown seedlings also averaged 9 inches in height and were then planted at the same site as the AOG seedlings 2 years earlier. These two groups of materials offer some interesting comparisons.

After 7 years from seed the survival in the accelerated-growth Plantation was 95.4% versus 84.5% for the non-accelerated planting. The overall mean height of the accelerated trees was 112 cm. compared with 64 cm. for the non-accelerated trees. Thus, both survival and growth are increased substantially in blue spruce through use of the accelerated growth techniques.

An indication of the relative effects of seed source and accelerated growth conditions on height growth of the trees 7 years from seed is provided by the data in Table 1. Two seed sources have been compared. One is from the general area of the Kaibab Forest in northern Arizona which has been a favored seed source for blue spruce in the past. The other source is near Coyote, New Mexico, which we have identified as being superior for both growth and blue color. By selecting the better seed source there was

Table 1. Effects of accelerated growth and seed source on height of blue spruce 7-years from seed and growing in Michigan.

Seed Source and Treatment	Height at Planting (1970 & 1973)	Height in 1976
		ft-
Kaibab area (a favored source in the past)		
AOG (8-months)	0.75	3.64
Conventional (3-0)	0.75	2.01
Coyote (an M.S.U. selected source in northern New Mexico)		
AOG (8-months)	0.75	4.23
Conventional (3-0)	0.75	2.36

Percent improvement due to seed source = 17%

Percent improvement due to AOG = 81%

Percent improvement due to seed source
and AOG = 110%

-a 17% improvement in height growth and an 81% improvement by using AOG methods to produce the seedlings. The combined effect of selection by progeny testing and AOG gave 110% greater height growth than using an unselected seed source and growing it under conventional nursery practices. This is a conservative comparison because neither the best nor the worst sources were used and the degree of accelerated growth was much less than we now practice (Hanover, 1977).

It is apparent from these data and our other shorter term results with conifers and hardwoods that the plantation establishment phase of tree improvement can be shortened considerably by using AOG methods. How much shorter will depend on the species involved.

If accelerated-growth methods are used to produce tree seedlings more quickly for plantation establishment, the question arises as to whether or not we can also make meaningful early measurements on these materials. For early measurements to be reliable two conditions must be met: (1) environmental factors do not interact to modify the trait and, (2) there is no genotype-environment interaction. Many important traits such as height growth and disease resistance would not meet these assumptions. Therefore, early measurements of progenies grown under AOG conditions may be misleading. Furthermore, one must assume that the correlation between juvenile or early performance and mature performance is strong which often does not follow. These problems in early evaluation of progenies are the same ones forest geneticists have had to cope with when growing seedlings in the outdoor nursery (Burdon and Sweet, 1976; Morgenstern, 1976). They may be either reduced or compounded when seedlings are grown rapidly under protective culture.

If a tree breeding program focuses on one or few species and a specific trait of the species, environmental simulation using AOG methods could be quite useful. Expression of the trait to be improved by selection could be maximized by imposing a growing regime that would be more effective than that found in the outdoor nursery test site. For example, in Michigan we are attempting to improve blue spruce foliage color by breeding for heavier and more stable wax deposition on the leaves. Although this trait is fairly complex both genetically and physiologically, we are making progress towards developing an early screening technique to identify blue trees during the first few months of accelerated-growth.

An accelerated-growth facility can be very useful in a tree improvement program whose seedling production facilities must serve a wide range of climatic zones. In Michigan, seedlings are grown in East Lansing at latitude 43° for planting as far north as latitude 47° in our Upper Peninsula. This has caused problems because our outdoor nursery seedlings developed considerably in advance of optimum planting dates in the north. Under protective culture we are now able to adjust our growing schedules to coordinate seedling development with the best planting times at any location in the State. Of course, the use of containerized trees makes the system even more flexible with regard to the plantation establishment phase of our program.

Seed Orchard Establishment And Production

Based on our experiences with both conifers and hardwoods there is no question that the AOG system can facilitate the rapid production of superior genotypes. When a tree breeder has identified genetically superior seed and wishes to establish an orchard quickly, the seed can be sown immediately. Using photoperiodic control of growth, spruce seedlings (white, blue, hybrids) have been grown to heights of 24" to 36" within one year (Fig. 2). These



Fig. 2. Accelerated growth white spruce seedlings average 24" in height at 12 months.

jumbo seedlings have good caliper and can be planted in an orchard in spring, summer, or fall. Once established they resume the normal growth pattern and annual increments typical of larger seedlings. We have preliminary evidence that accelerated growth trees are also physiologically older than outdoor-grown trees of similar age and possibly of similar height (Young and Hanover, 1976). Thus, species which exhibit a conservative or slow growth habit in young seedlings (e.g., white pines, spruces, oaks, maples) may be induced to assume the faster growth habit associated with aging. These age or size-related growth responses of many tree species may not only accelerate the establishment of seed orchards but also hasten their maturation and productivity.

The same benefits of AOG in seed orchard establishment pertain to plantations established for other purposes such as archives, breeding arboreta or possibly advanced generation progeny tests. Of course, in the latter case some of the same concerns associated with early progeny testing would be present. As with other early measurements, the strength of the correlation between early and longer-term performance must be strong to have any value. Certainly the early establishment of test materials by accelerated growth procedures allows the trees to begin adapting sooner than the nursery grown stock planted several years later. If we consider Christmas tree, ornamental, pulpwood, energy or other short rotation uses of trees, the validity of AOG and subsequent early evaluation of progenies increases substantially.

Another benefit of the AOG system to seed orchard management is the earlier induction of flowering than can be achieved by conventional nursery practices. White spruce accelerated growth seedlings planted in a breeding arboretum in southern Michigan initiated female strobili at age 4 years from seed (Young and Hanover, 1976). This is much younger than reported previously for the species or that occurred in other white spruce plantings at the same location. Furthermore, the cone and male strobili production of these materials has steadily increased since flowering began.

Flowering in European white birch (Betula verrucosa Ehrh.) has been induced within one year from seed by application of a cycle of accelerated growth-dormancy plus cold treatment-accelerated growth. Both male and female flowers were produced in substantial quantities by this regime and flowering has continued after transplanting (Fig. 3). White birch is reported by Johnsson (1974) to flower as young as 2 years old but it normally flowers at a minimum of 15 years under stand conditions (Schopmeyer, 1974). Apparently a significant reduction in the time to flower production can be achieved by AOG methods. In fact Fin-



Fig. 3. Precocious flowering in 1-year-old European white birch after accelerated growth followed by dormancy and chilling.

nish tree breeders are producing birch seed crops in large plastic structures (Lepisto, 1973).

Much more research is needed on various aspects of accelerated growth and flowering in spruces, birches and many other species of interest to forest geneticists. But it is apparent from our initial experiences that a great potential exists for controlling growth and development in trees and thereby increasing the rate of progress and efficiency of these phases of tree improvement.

Hybridization - A third major phase of tree improvement programs that will benefit by the application of accelerated-growth is hybridization. First generation seed orchards may yield stock with significant but limited genetic improvement. Controlled pollination among both parental selections and their tested half-sib progenies is the next step towards capturing additional increments of improvement in a given trait. Wide hybridization between races of a species or between different species is also widely practiced in order to create new genetic diversity and materials for further selection.

Most aspects of advanced generation breeding may be accomplished more quickly if generation times are shortened. As mentioned earlier, telescoping the juvenile phase of several spruce species and European white birch has stimulated early flowering in these species. Additional studies are underway to provide more rigorous controls than were used in our early work. Also, we need to optimize the conditions for early flower induction in each species and to quantify the responses.

Using AOG techniques on the spruces our hybridization work has been carried through F_2 and back cross generations within a period of nine years. An F_1 hybrid seed orchard of white spruce was established in 1976 using AOG seedlings. We expect this orchard to begin producing cones within three years. Interspecific hybridization of North American spruces has been carried on in the breeding arboretum at Kellogg Forest, Battle Creek, Michigan during the last 5 years (Fig. 4). The arboretum was established with AOG seedlings and flowering on most species and hybrids has been prolific. In 1975 white x blue spruce hybrids bore female strobili which were pollinated with red spruce and yielded the tri-hybrid spruce which we have designated the American spruce. The seedlings obtained from the few seeds from this cross have been grown to 2 feet in height for out-planting.

Vegetative propagation - Greenhouse culture has long been used for vegetative propagation of woody plants. My first experience was in the winter of 1960 when I grew several thousand western white pine stock plants in the greenhouse to prepare them for grafting (Hanover, 1962). When the stock had just begun to grow, dormant, blister rust resistant scions were side grafted into the stock and allowed to grow through spring. After unions were complete the grafted seedlings were used to establish a seed orchard near Sandpoint, Idaho (Bingham et al, 1964).

The application of both standard greenhouse culture plus continuous light has proven effective for rooting



Fig. 4. Spruce breeding arboretum at Kellogg Forest established with AOG stock showing early, prolific flowering and pollination bags.

cuttings of young spruce species and hybrids (Hanover, 1975). Although not commonly used extended photoperiods do stimulate the initiation of root primordia of woody plants (Stoutmeyer and Close, 1946). We have found that cuttings from young spruce (white, blue, black, and hybrids) will maintain continuous height growth once roots have been initiated under long photoperiods. This provides a technique for producing a large seedling within months after a cutting is rooted.

Since the techniques of vegetative propagation are important tools to the forest geneticist, any means for stimulating the processes should be evaluated. It is apparent that for many species AOG methods may not only help in the propagation process itself but also stimulate subsequent growth. By so doing valuable genetic materials can be placed in seed orchards or test plantations more quickly which may lead to earlier flower production.

Mass production of improved stock - Tree improvement programs are often separate and distinct from the actual mass production of improved stock. This is because either the mass producer or user of superior strains cannot afford the long term investments required to do selection, progeny testing, hybridization, and possibly even seed orchard operations. Exceptions to this are, of course, the very large companies and public agencies which may be able to carry out all phases of tree improvement including large scale seedling production.

For those companies or agencies which wish to grow improved stock for their own use or distribution to others, AOG systems offer many advantages. Since many of the advantages from the production standpoint have been discussed elsewhere (Hanover and Reicosky, 1972; Hanover, 1976a, b, 1977; Tinus, Stein, and Balmer, 1974; Tinus, 1974) we will not elaborate further here. The production of seedlings in containers for reforestation has become a well established practice in the northwestern U. S. where 60 nursery operations produced a total of 52.4 MM seedlings in 1976-77 (Ter Bush, 1977).

Most of the container nurseries do not employ the year-round AOG concept with photoperiodic control of growth, although several in Michigan and in the Rocky Mountain states do. Dr. Tinus will describe some of the procedures followed in growing trees in containers with programmed environments.

Other applications of AOG - In addition to the major phases of tree improvement we have found that the AOG system has applications in several related activities worth mentioning.

Forest biologists frequently need to design experiments for both nursery and field plantation phases of their research. It is important that losses in such experiments be minimal in order not to disrupt experimental designs of either phase. In our experience the use of unitized container systems provides experimental flexibility and safety that is sometimes difficult to achieve in an outdoor, bareroot nursery. For example, by growing tree seedlings in large containers which are themselves contained in a larger container we are able to, (1) insert extra stock into a design should there be losses in the primary materials, (2) move the entire experiment within or between growing facilities if necessary, (3) impose other treatments such as light, CO₂, water, etc., during the course of a developmental study, (4) hold the materials to be outplanted if planting conditions are unfavorable, (5) condition planting

stock to prepare them for outplanting in a climatic zone different from the growing facility, (6) protect young seedlings from certain pests, especially animals that could disrupt experiments, and (7) plant the stock plus the degradable container with no root disturbance. Most of these functions lead to increased survival of experimental materials. This is not to imply that protective culture and container growing of trees is without problems and hazards (Hanover, 1977). But with the proper information and experience the forest biologist should find AOG systems quite useful as a research tool.

There is another feature of the unitized, moveable container system used in our AOG program that makes it useful for tree physiology research. At any stage in the development of a tree from germination on it can be moved into the laboratory or elsewhere for measurements such as gas exchange and returned to its experimental position without disturbing the plant. This is in contrast to trees grown in outdoor nurseries or even greenhouse seedlings grown in plug type containers commonly used in industrial programs. Free movement of these seedlings, especially hardwood species, is usually impossible without some degree of physiological disturbance.

Finally, the AOG concept of tree production offers the researcher or grower the potential for literally "designing" the proper architecture of a tree by manipulation of the environmental parameters controlling growth. That is, by varying light quality, duration, or intensity, temperature, moisture, spacing, etc., we can determine root/shoot ratios, amount of branching, stem caliper, and other attributes of the optimal tree for the desired use. The range of morphological variation in seedlings inducible by varying the growing conditions is large. Much remains to be learned about the specific requirements for directing environmental variation in each species. But the possibility of designing a tree seedling to assure maximum chances of survival after outplanting is an important tool for forest geneticists as well as commercial nurserymen. Coupled with the additional potential of designing the physiological status of the seedling, we should be able to virtually assure higher performance of the valuable genetic materials with which we work. The accelerated-optimal-growth concept which we have described here provides the means for accomplishing this goal.

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