HANDLING AND CARE OF SOUTHERN PINE SEEDLINGS

Clark W. Lantz[1/]

Abstract.--The objective of most southern pine regeneration programs is to grow high quality seedlings which can be delivered to a planting site with their maximum survival and growth potential.

Small individual reductions in this seedling survival and growth potential often accumulate to cause substantial losses of plantation productivity.

Training, seedling handling standards, incentive plans, and improved communications will all help to significantly reduce these losses.

REGENERATION SYSTEMS

Southern pine seedlings are growing in forest tree nurseries worldwide, spanning roughly 80° of latitude, from China, Korea and Virginia at 40° North to South Africa and New Zealand at 40° south.

The species range from shortleaf (*Pinus echinata*) and loblolly pine (*P. taeda*) in the north to Honduras pine (*P. caribaea* var. *hondurensis*) and *Pinus occidentalis* in the tropical latitudes. In the southern hemisphere loblolly and Honduras pine are common as is slash pine (*P. elliottii*) and *Pinus radiata*, (subsection Oocarpae).

The regeneration systems used with these seedlings vary as widely as the latitudes in which they grow. In the southern U. S. bareroot loblolly pine seedlings start with sowing in March or April, the seedlings germinate and grow for 8 or 9 months through the summer and fall, and then are lifted and planted from December through March.

In other parts of the world the nursery cycle is often designed to produce plantable seedlings just prior to the start of the growing season. In some tropical areas with pronounced wet-dry seasons, seedlings must be ready to plant when soil moisture is at optimum levels. Some of these nurseries produce bareroot seedlings - others use containers.

We are fortunate over much of the South to usually have adequate rainfall throughout the winter and spring when seedling establishment is critical. When the soil is not frozen, air temperatures are above freezing, and soil moisture is adequate, seedlings may be successfully planted from mid-November thru mid-April. In most of the South, however, January and February are the preferred planting months.

SEEDLING DORMANCY

Storage and shipping of bareroot southern pine seedlings is restricted primarily by the degree of dormancy of the seedlings. Nurseries located north of roughly latitude 34°N in the southern U. S. usually experience an adequate number of chilling hours by early December. Garber and Mexal (1980) estimated that loblolly pine seedlings from southeastern Oklahoma (34°N) need about 7 weeks of cold temperatures to

1/ Nursery/Tree Improvement Specialist, USDA Forest Service, Southern Region, Atlanta, Georgia

satisfy their cold requirements. When these cold requirements are satisfied, loblolly seedlings can be lifted and safely stored for 6 to 8 weeks prior to planting (Dierauf 1974).

Seedlings grown in nurseries located on the Gulf coast and the Atlantic coast south of about 31°N latitude seldom reach a dormant condition. For this reason, the storage and shipping of seedlings from these nurseries requires special care. The most successful regeneration programs have usually minimized both storage and shipping time. The "lift in the morning-plant in the afternoon" system is very effective.

In tropical and sub-tropical areas bareroot seedlings are very difficult to handle. Often the regeneration system is made up of small nurseries developed very close to, or on, the site where the seedlings will be planted. Some seedlings may be safely moved in boxes with roots covered with sawdust or soil. In these areas containerized seedlings have a definite advantage where short-term storage is anticipated.

SURVIVAL AND GROWTH POTENTIAL

All reforestation programs have a common goal regardless of location: Grow a high quality seedling and deliver this seedling to the planting site with the maximum potential for survival and growth.

We know that the survival of seedlings handled with special care can exceed 90% (Muller 1983). We also know that operationally - planted seedlings often average only 60-70% in survival (Weaver, et al 1980; Marler 1963). Therefore there appears to be a loss of 20-30% in survival when seedlings are not handled in the best possible way. Some of this loss is possibly due to poor handling in the nursery - some may be improper storage - some may be poor shipping and handling at the planting site. In order to compensate for this frequent mistreatment we must grow the toughest seedling possible.

WHAT DOES A SOUTHERN PINE SEEDLING NEED FOR OPTIMUM SURVIVAL AND GROWTH IN THE FIELD?

1. The highest possible genetic potential for survival and growth in the field.

2. Sufficient internal moisture, nutrients, and stored carbohydrates for rapid root and shoot growth.

3. A root system with a large surface area and sufficient mycorrhizae for efficient water and nutrient intake.

4. A well-balanced seedling with a large root collar diameter and a heavy, compact root system (South and Mexal 1984).

These high quality seedlings can be grown in most southern pine nurseries using available technology and good quality-control procedures. For example:

1. The highest possible genetic potential for survival and growth can be achieved by the use of current tree breeding technology. Seedlings produced from rogued first generation seed orchards have produced 25 year-old plantations with a gain of 32% in value when compared with unimproved plantations (Talbert et al 1985).

2. Sufficient internal moisture, nutrients and stored carbohydrates can be provided by the proper nursery cultural practices. Optimum soil organic matter levels are essential in most nursery soils to provide both a friable growing medium and a high cation exchange capacity. A carefully designed program of irrigation and fertilizer applications is necessary to provide the raw materials for carbohydrate production and storage. Careful lifting and handling procedures will safeguard these good qualities.

3. The optimum morphology of pine seedling root systems is largely dependent on a soil with a low bulk density (Mitchell et al 1981). In addition to high organic matter content, subsoiling, and restricting traffic will help to avoid soil compaction.

The importance of mycorrhizae in seedling growth is well established (Marx et al 1977). In areas where southern pines are planted as exotics, systems of artificial inoculation may be necessary. Fortunately the common ectomycorrhizal species can be propagated by wind-borne spores released from above-ground sporophores. A nursery windbreak or ornamental planting of pines is often sufficient to establish a local inoculum source.

Careful lifting and handling procedures will safeguard these delicate root systems and their mycorrhizae.

4. A well-balanced seedling is essential for maximum survival and growth. Although there are numerous morphological standards proposed for southern pines, no single standard will fit all species and all planting sites. One of the best evaluations was presented by South and Mexal (1984). They have proposed that seedlings with "large diameters and heavy root systems...will often outperform smaller seedlings of equal height." In order to produce a high proportion of these seedlings in a nursery, seedbed densities must be carefully controlled and individual seedling spacing is extremely important.

The biological optimum seedbed density for loblolly pine has been estimated by Mexal (1980) at 200 seedlings per square meter (about 19/sq. ft.) This density optimized both seedling biomass in the nursery and volume production in the field. Economic considerations usually dictate higher seedbed densities in the southern U.S., with an average density between 269 and 323 per square meter (25-30 sq. ft.). When the effects of seedling quality on field performance are considered, however, the lower densities are considerably more efficient.

In summary, high quality seedlings with large stem diameters and heavy root systems can be grown efficiently with modern nursery technology. These seedlings will consistently yield the best returns on regeneration investments. Likewise, investments in improved nursery technology will increase plantation productivity dramatically (South and Mexal 1984). The authors emphasize that planting Grade 1 instead of Grade 2 seedlings can result in an increased present value of over $100 per thousand seedlings. This represents an opportunity to multiply improvements in nursery productivity by a substantial amount.

Can we afford to plant anything other than high quality seedlings? Can we afford to give them anything except the best possible care?

WHAT ACTUALLY HAPPENS IN THE NURSERY?

Nursery scenario:
(Any resemblance to an existing forest nursery is purely intentional.)

		Survival and Growth Loss	Survival and Growth Potential
The nursery production cycle starts with a clean slate:		%	100
SITUATION	PROBLEM		
1. Seed storage containers are not properly sealed.	Seed moisture content rises, seed deteriorates.	6	94
2. Seeder not properly calibrated.	Seedbed density too high, competition extreme, growth reduced.	4	90
3. Irrigation is used too often.	Lack of soil aeration produces small root volume + root rot.	5	85
4. Careless lateral root pruning.	Root + stem damage.	4	81
5. Top pruning in October (too late).	Woody stem and bud loss.	6	75
6. Belt lifter operated too fast.	Feeder roots and mycorrhizae left in the soil.	8	67
7. Lifted seedlings exposed to sun and wind prior to transport to packing shed.	Excessive heat + loss of moisture.	7	60
8. Seedlings packed in K/P bags + piled too close in cold storage.	Insufficient air flow for adequate cooling.	4	56
9. Bags stacked 6 deep in back of pickup - no cover.	Excessive pressure + heat.	6	50

At this point the seedlings are severely weakened. They have lost 50% of their survival and growth potential. If they are not planted properly and if all environmental variables (soil moisture, air temperature etc.) are not favorable, the plantation will surely fail.

HOW DO WE PREVENT THESE SMALL LOSSES WHICH DRASTICALLY REDUCE SURVIVAL AND GROWTH POTENTIAL?

1. Training to insure that nursery personnel understand why seedlings need special care. Too often we assume that this is "common knowledge" when in fact it has either never been understood or else used once and then forgotten.

2. Establish guidelines (standards) for the care and handling of seedlings. Quantify as many variables as possible. Instead of: "Move seedlings quickly to the packing shed after lifting" - "Seedlings will be moved to the packing shed within 20 minutes of lifting." Make these standards reasonable and be sure that nursery personnel understand why they are adopted. Two excellent examples of these standards are the North Carolina Operational Guidelines for Handling Seedlings (Jeffries 1982) and the Guidelines for Seedling Care (National Forests in Mississippi 1984).

The North Carolina standards were developed with a procedure similar to fire danger ratings. They are based on 3 categories of weather and soil conditions: Normal, Critical and Severe. Seedling handling is also based on 3 categories: 1. Nursery lifting and processing standards. 2. District-county delivery and storage standards, and 3. Field handling and planting standards.

Lifting operations are listed below as an example (from Jeffries 1982):

NORMAL CONDITIONS

Temperature:	35°F to 75°F
Relative Humidity:	50% +
Wind:	Less than 10 miles/hour
Soil Moisture:	75% to field capacity (100%)

Lifting

1. Use of all types of seedling lifters permissible.

2. Roots of seedlings on lifter conveyor will be exposed a maximum of three minutes.

3. Full, tightly packed boxes will be removed from the field and placed in the packing shed within 20 minutes. Partially filled boxes where roots are exposed will be covered with moist burlap, etc. to prevent drying out.

CRITICAL CONDITIONS

Temperature:	76°F to 85°F
Relative Humidity:	30% to 50%
Wind:	10 miles/hour +
Soil Moisture:	50% to 75%

Lifting

1. Use of Grayco harvesters is given top priority (if other lifters must be used--entire beds will not be undercut ahead of lifters).

2. Roots of seedlings on lifter conveyor will be exposed a maximum of 3 minutes.

3. Full, tightly packed boxes will be removed from the field and placed in the packing building within 10 to 15 minutes. Partially filled boxes of seedlings will be covered immediately with moist burlap, etc. to prevent drying out.

a. Lift fields close to facility, when possible.
b. Use additional tractor(s) for delivery from field to packing building.

4. When soil moisture reaches less than 50%, fields will be irrigated prior to lifting.

SEVERE CONDITIONS

(Freezing Conditions)

Temperature: 32°F or less and/or frozen ground conditions
Relative Humidity:
Wind:

Lifting

All lifting operations will cease.

SEVERE CONDITIONS

(Hot, Dry Conditions)

Temperature:	85°F +
Relative Humidity:	30% or less
Wind:	15 miles/hour +
Soil Moisture:	Less than 50%

Lifting

Usually will cease; however, Senior Staff Forester, Nursery and Tree Improvement, will be notified of conditions, and he will make final decision. If lifting is done:

1. Fields will be irrigated. Do not lift in sandy soil.
2. Only Grayco harvesters will be usesd.
(Roots of seedlings on lifter conveyor will be sprayed).
3. Roots of seedlings on lifter conveyor will be exposed a maximum of three minutes.
4. Full, tightly packed boxes will be removed from the field and placed in the packing building within ten minutes. Partially filled boxes of seedlings will be covered immediately with burlap, etc. to prevent drying out.
a. Lift fields close to facility.
b. Use additional tractors for delivery from fields to packing building.

3. Supervisory training for all nursery supervisors and crew leaders. Stress the advantages of proper motivation. For most people the desire to do a good job is a better incentive than fear of disciplinary action.

4. Consider incentive plans. Bill King developed an incentive plan which worked well for workers in the packing shed at the Virginia Division of Forestry New Kent Nursery (King 1970). Both productivity and worker morale improved significantly.

5. Feedback from planting contractors and landowners. Every customer, every purchaser of seedlings is a potential consultant to help improve the system. A simple checklist sent with a post-paid envelope or attached to the seedling order form can be most informative. This system also can be a good public relations tool.

6. The nursery manager must get out and talk to the regeneration foresters, the planting contractors and the landowners. Communications must flow in both directions - both to and from the nursery. Field reforestation personnel must learn to appreciate the frustrations of the nursery manager and the nursery manager must appreciate the problems of the planters and the landowners.

CONCLUSIONS

The technology is available now to grow high quality southern pine seedlings with maximum potential for survival and growth in the field. In order to keep this survival and growth potential at the highest level, we must use training, seedling handling standards, incentive plans and improved communications. Only then will we reach a truly efficient regeneration system.

LITERATURE CITED

Dierauf, T. A. 1974. Effect of time in cold storage on loblolly pine seedling survival. Occasional Rept. No. 43. Virginia Division of Forestry, Charlottesville, VA.

Garber, M. P. and J. G. Mexal. 1980. Lift and storage practices: Their impact on successful establishment of southern pine plantations. N.Z. J. For. Sci. 10(1):72-82.

Jeffries, K. F. 1982. Operational guidelines for handling seedlings. Proc. 1982. South. Nurs. Conf: 212-223. USDA Forest Service, Atlanta, GA.

King, G. W. 1970. Stock packing: Incentive pay program at New Kent Nursery. Proc. 1970 South. Nurs. Conf: 26-28. USDA Forest Service, Atlanta, GA.

Marler, R. L. 1963. A three-year tree planting survival study in Virginia. Occasional Rept. 19, Virginia Division of Forestry, Charlottesville, VA. 5 pp.

Marx, D. H., W. C. Bryan, and C. E. Cordell. 1977. Survival and growth of pine seedlings with Pisolithus ecotmycorrhizae after two years on reforestation sites in North Carolina and Florida. For. Sci. 23:363-373.

Mexal, J. G. 1980. Seedling bed density influences yield and performance, pp. 89-95. In Clark Lantz, ed. Proc. 1980. South. Nur. Conf., Lake Barkley, KY. USDA Tech. Pub. SA-TP17. USDA Forest Service, Atlanta, GA.

Mitchell, M. L., A. E. Hassan, C. B. Davey, and J. D. Gregory. 1981. Effect of soil compaction on root development and seedling establishment. Am. Soc. of Agri. Engineers Paper No. 81-1040.

Muller, C. A. 1983. Loblolly pine seedling survival study, 1979-80 and 1980-81 planting seasons. pp. 27-39. In C. W. Lantz and J. Brissette, eds. Proc. 1982 Southern Nursery Conf., 312 p. USDA Forest Service, Atlanta, GA.

South, D. B. and J. G. Mexal. 1984. Growing the "best" seedling for reforestation success. Auburn University, Forestry Department Series No. 12, Auburn, AL.

Talbert, J. T, R. J. Weir, and R. D. Arnold. 1985. Costs and benefits of a mature first-generation loblolly pine tree improvement program. J. For. 83: 162-166.

USDA Forest Service. 1984. Guidelines for seedling care. National Forests in Mississippi. 24 pp. Jackson, Ms.

Weaver, G. H.; Izlar, Bob; Broerman, F. S.; and Xydias, Ken 1980. Preliminary report on the 1979 A.P.A. pine plantation survival and nursery practices survey. Proc. S. Nurs. Conf. 1980. pp 24-30. USDA Forest Service, Atlanta, GA.

CURRENT QUALITY REQUIREMENTS OF SEEDLINGS IN FINLAND

Pasi Puttonen[1/]

Abstract. --Finland's national economy depends heavily on forestry. The need to meet future demand for high quality raw wood material and drawbacks in forest regeneration has necessitated devising and implementing measures to increase planting success and decrease regeneration costs. Size classification of bareroot planting stock was implemented in mid-1970s. In 1980 an Act became valid to enforce quality requirements for seed and seedling trade. A recommendation for the size classification of containerized Scots pine seedlings was given in 1983. The quality requirements are descriptive and do not assume vigor testing. Proper test methods are being worked out for both container and bareroot seedlings.

Additional keywords: bareroot and container seedlings, Forest Regeneration Material Trade Act, size classification.

INTRODUCTION

In Finland, forestry and forest industry products account for about 45 % of net foreign exchange earnings and 17 % of labour force. National economic reasons thus necessitate the utilization of the growing stock on a sustained and, preferably, progressive basis. This may often require legislative measures.

Concern about how to meet the future demand for high quality raw material on the one hand, and drawbacks in nursery stock production and forest regeneration on the other hand has brought about the need for new measures to increase planting success and decrease regeneration costs. First, a simple classification of bareroot planting stock into size classes, based on age, height and diameter of root collar, was enforced in mid-1970s. A more recent policy was an establishment of an Act, enforcing quality requirements in the seed and seedling trade. The Forest Regeneration Material Trade Act (No. 684/1979) relates to the trade of all regeneration material collected or growing of which has started after January, 1980. A recommendation of the measures for containerized Scots pine seedlings was given in 1983.

1/ University of Helsinki, Farm Forestry, Viikki, 00710 Helsinki 71, Finland.

ANNUAL SEEDLING PRODUCTION

The total annual area of seeded and planted sites is about 140 000 hectares, of which ca. 20 % is sown. Moreover, at least an equal area is regenerated naturally through seed tree and shelter wood methods. The annual output from state, private and company nurseries is ca. 250 million seedlings, of which 75 % is Scots pine (*Pinus sylvestris* L.), 20 % Norway spruce (*Picea abies* (L.) Karst.) and 2 % European silver birch (*Betula pendula* Roth). The share of containerized seedlings is now ca. 50 % but it is steadily increasing. The number of the active nurseries is about 45 and the total nursery area is ca. 1 100 hectares.

Table 1. shows the division of mean regeneration costs (per hectare) into expense groups. The price of seedlings is annually decided upon by the National Board of Forestry (Finnish Forestry Service), and based on the production cost of the previous year's stock. Only birch seedlings are priced according to size class.

Table 1.--The distribution of mean regeneration costs into expense groups at Scots pine sites in Finland (1984).

Expense group	Cost per hectare US$ (1 US$ = 6.50 FIM)	
Clearing of cutting area	37	
Scarification	75	
Plant material	130	(80 US$/1 000, bareroot (pine transplant)
Planting	128	
Supervision	77	
Other expenses	23	
Total costs	470 US$	

QUALITY REQUIREMENTS

Bareroot Seedlings

The official grading requirements for bareroot planting stock are primarily based on a visual definition of the seedling condition and vigor. Secondarily, the seedlings are graded into size classes. Both classifications are morphological.

The Forest Regeneration Material Trade Act comprises the statutes for the trade, import and export of all regeneration material. The material has to meet the quality requirements set by the Ministry of Agriculture and Forestry. The National Board of Forestry, as a supervising organ, can give annual specifications for the quality classification of seedlings.

The quality requirements of seedling stock as stated in the Act (Section 13) are as follows:

> "Seedling to be sold shall be healthy and vigorous as well as otherwise appropriate. The seedling is not considered to meet the above-mentioned requirements in the following cases:
> 1) the seedling has detrimental defects of the bark or other wounds than occluding cut wounds,
> 2) the seedling has more than one leader or the seedling is otherwise forked,
> 3) the seedling is not, as concerns time, perfectly woody,
> 4) the leader of a coniferous seedling has no healthy terminal bud,
> 5) the seedling has an insufficient amount of needles or buds,
> 6) the main root is stronly bent, there are not enought lateral roots or the root system is otherwise insufficient or faulty or in case of containerized seedling, the pot is not suitable for planting, and
> 7) the seedling has plant diseases, pests or their eggs.
>
> What has been said in items 3 and 4 of Subsection 1 does not apply to the containerized seedlings during the growth period or seedlings to be sold for transplantation. As an exception to what has been said in item 2 of Subsection 1 a spruce seedling may have two leaders.
>
> Of the seedlings of a seedling lot to be sold a minimum of 95 per cent shall meet the quality requirements mentioned in Subsections 1 and 2." (Inofficial translation by the National Board of Forestry).

The seedling bundle or container must not include extra, undersized or unacceptable seedlings. Local District Forestry

Boards may give supplementary intructions for their region. For the 1985 planting season, the main root must not be bent more than 45 degrees. Previously, an inclination of 90 degrees was allowed.

The size classification of both bareroot and container seedling stock is a secondary grading system. For bareroot seedlings the classification was constructed so that seedlings would fall into natural classes and consequently, culling from the lower end of the class would be minimized (Räsänen and Leikola 1974). Size classification is done using systematic samples on each seedling lot concurrently with the nursery stock inventory in the autumn. Each seedling lot is classified as a whole. A seedling lot is defined as those seedlings raised from the same seed lot of a defined area, which have been raised uniformly according to the same schedule, and in which the height and vigor of the seedlings is rather uniform. The lot may not be divided into sublots but must be sold as a whole (Räsänen and Leikola 1974). All the seedlings within each class have to meet the minimum height and diameter requirement of the class. In Table 2 are shown the size classes for Scots pine, Norway spruce and white birch seedlings. No recommendations are given on the shoot:root ratio.

Table 2.--The size classes of Scots pine, Norway spruce and European white birch seedlings.

Scots pine *Pinus sylvestris*	Size class			
	I	II	III	IV
The median height of the seedling lot, cm	- 12	13 - 18	19 - 25	26 -
The recommended height, cm	10	15	21	29
The minimum height, cm	6	10	15	21
The minimum diameter, mm (1 - 2 cm above root collar)	2.5	3.0	3.5	4.0

Norway spruce *Picea abies*	Size class			
	I	II	III	IV
The median height of the seedling lot, cm	- 27	28 - 34	35 - 42	43 -
The recommended height, cm	24	30	38	47
The minimum height, cm	15	20	26	33
The minimum diameter, mm (1 - 2 cm above root collar)	4.0	4.5	5.0	5.5

European white birch *Betula pendula*	Size class			
	I	II	III	IV
The median height of the seedling lot, cm	- 40	41 - 55	56 - 70	71 -
The minimum height, cm	25	30	40	50
The minimum diameter, mm (1 - 2 cm above root collar)	3.0	4.0	5.0	6.0

Container seedlings

The quality requirements described above are also applied to container seedlings. A recommendation for size classification of containerized Scots pine seedlings was given in 1983 based on the work by Kokkonen and Räsänen (1980) (Fig. 1) but it is not yet enforced. This is partly because new types of containers are introduced almost annually. (Currently, the number of different type and size of container seedlings is about 60.) The recommendations by the National Board of Forestry deal with the growing of seedlings and characteristics of the container stock raised. Growing density in containers must not exceed 1 100 seedlings/m^2 for Scots pine, 700 seedlings/m^2 for Norway spruce and 270 seedlings/m^2 for birch. Growing density, container volume and seedling height must be in a preset relation to each other (Fig. 1). The length of the raising period depends on container size and only one seedling per pot should be raised. Root cutting, if needed, must be done no later than two weeks before delivery. The delivered container stock must meet the regional minimum height requirements, the stem be free of basal sweep and the roots must not be twisted.

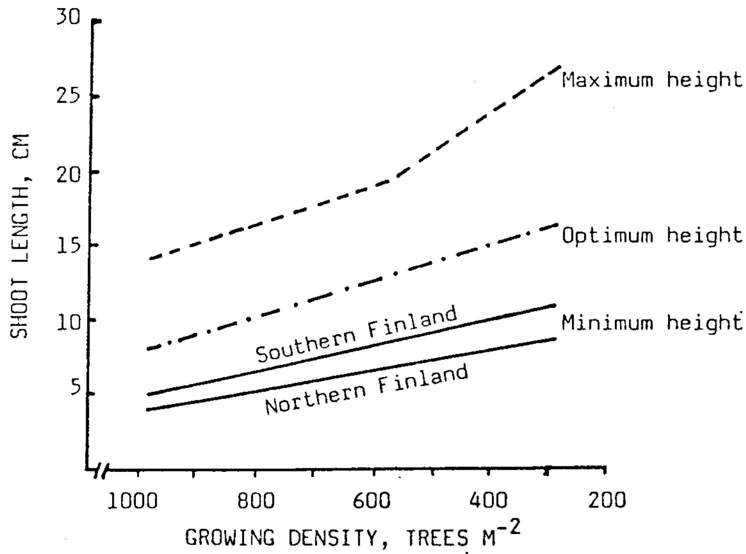

Figure 1.--The recommended shoot height for containerized Scots pine seedlings as a function of growing density.

Consumer Protection

When selling the planting stock, the consignee must be provided with the details of: 1) stock producer, 2) tree species and origin of the seed (location and type of seed collection), 3) code of the seed lot, 4) number of seedlings, 5) growing method, period and site of seedlings, 6) lifting date, and 7) delivery date from the nursery.

During spring delivery, officers of the National Board of Forestry make spot checks of the stock quality at nurseries. In the field, the planting material for private forest owners is usually checked by the local Forest Management Association - an interest organisation of private forest owners. The consignee can make a reclamation of the stock quality to the National Board of Forestry within eight days of the delivery. The supplying nursery is responsible for the information about the seedlings and stock quality.

CURRENT SEEDLING QUALITY PROBLEMS

In the autumn of 1984, exceptionally abundant disturbances in bud development of Scots pine and of frost damaged Norway spruce seedlings were found. Therefore, special guidelines were given for the 1985 planting season to cull these seedlings. Bud disturbances are found both in 2 - 3-month-old pine germinants and in raised 2 - 3-year-old seedlings. The disturbances have been attributed to various causes, including unbalanced fertilisation, deficiency of micronutrients, aphid feeding, viruses, and drought. It is probably a combination of several factors. Fortunately, slight overproduction of Scots pine seedlings in 1985 allowed a more strict culling.

Although Finnish nurseries produce some 250 million seedlings annually, worth 15 million US$ and increasing to 80 million US$ when planted, the current nursery research is insufficient, depending only on the efforts of a few part-time scientists. The recent drawbacks in nursery production may be an indication of outdated research base.

Development of transplanting and root cutting techniques will probably reduce the occurrence of root system distortion, but the improvement will be gradual as the production period of a planting stock is 2 - 3 years. The nursery lifting and grading phase in the spring is very short, 2 - 3 weeks, which creates problems both at the nursery and at outplanting. Use of casual, seasonal workers in lifting, grading and planting is necessary, but it somewhat compromises the quality of grading. The springtime spot checks at the nurseries have revieled large variability in seedling quality. But based on a few years experience, the new legislation has improved nursery practices and seedling quality (Räsänen 1984).

The current quality requirements of seedlings are morphological and decriptive and do not assume physiological vigor testing. A drought stress test, as described by Hermann and Lavender (1979), has been experimented with but the short lifting and planting season in the spring, after the thaw of soil frost, precludes the rational use of this test. A size classification for containerized spruce and birch seedlings is being worked out.

LITERATURE CITED

Forets Regeneration Material Trade Act (No. 684/1979) and the Decision of the Ministry of Agriculture and Forestry on the Trade of Forest Regeneration Act (No. 685/1979). 9 p. (Inofficial translation by the National Board of Forestry.)

Hermann, R.K. and Lavender, D. 1979. Testing the vigor of coniferous planting stock. Oregon State Univ., For. Res. Lab., Res. Note 63. 4 p.

Kokkonen, M. and Räsänen, P.K. 1980. Characteristics of containerized seedlings and recommendations for quality classification (Summary in English). The Foundation for Tree Breeding in Finland, Information 4/1980.

Räsänen, P.K. 1984. The quality control of forest regeneration material in Finland. Voluntary paper at the IUFRO (S1.05-04 and S2.01-06) symposium "Methods of Production and Quality Control of Forest Seeds and Seedlings", March 19 - 23, 1984, Curitiba, Brazil. 2 + 9 p.

Räsänen, P.K. and Leikola, M. 1974. Morphological and physiological qualities of forest plants, their valuation and signification for succesful planting. Contr. paper, IUFRO Joint Meeting, Div. 1 and 3., "Symposium Stand Establishment", Wageningen, The Netherlands, October 15 - 19, 1974. 7 p.

ASSESMENT OF SEEDLING VIGOR ATTRIBUTES: OUTLINE FOR INTEGRATION

Pasi Puttonen[1/]

Abstract. -- The demand for physiological tests of vigor will increase as seedling production becomes increasingly oriented to biotechnology, while the variability for morphological traits will decrease. Any measure of seedling vigor can be considered as a model of the seedling's future development. The time and structure hierarchy of physiological processes forms a basis for examining the underlying assumptions and implications of the measurements for a vigor model. An outline is proposed for a model incorporating morphological and physiological attributes of quality for the root system, the most readily manipulated part of nursery grown bareroot stock.

Additional keywords: acclimation, seedling morphology and physiology, structure and function.

INTRODUCTION

Seedling Stock Grading

The assessment of seedling quality from seed to a planted seedling is an essential part of stock raising and regeneration management. Seedling quality has proved difficult to describe in terms of measurable characteristics of the stock. "Quality is fitness for purpose" summarises the theme, but is too conclusive a definition to be operational. A measure of seedling quality should reflect a multitude of morphological and physiological characteristics.

[1/]University of Helsinki, Farm Forestry, Viikki, SF-00710 Helsinki, Finland.

Morphological Characteristics

Morphological variables are attributes which describe structure and form attributes of seedlings, measured on a nominal scale (bud burst - no bud burst), an ordinal scale (stage of bud development in four classes), an interval scale (bud development stages have a measured difference) and a ratio scale (bud length). The measurement scale delimits the possible methods of analysis. Morphological characteristics can be manipulated in the nursery by altering seeding density, root pruning, transplanting, irrigation and fertilization. Morphological traits give an indication of seedling performance after planting out. The results on the correlation of seedling size to postplanting success are somewhat inconsistent (see Hermann and Lavender 1976 for a review). However, the use of morphological traits is extensive (Schmidt-Vogt 1980) and its adoption has improved the rating of seedling quality. Its major benefit lies in its ease of application on a large scale. Whenever the stock is subjected to heating, drying of roots, loss of moisture, or when the stock is planted on difficult sites, the planting success is even more influenced by the physiological condition of the stock (e.g. Schmidt-Vogt 1981).

Physiological Characteristics

Since Wakeley (1948) proposed physiological grading of nursery stock, with the purpose of defining seedling quality on the basis of internal chemical or metabolic properties, numerous physiological methods for planting stock grading have been proposed, tested, and applied. Such measures are the widely applied plant water status (Cleary 1971), electrical impedance (Glerum 1970), dead plant tissues (Zaerr 1972), food reserves (Krueger and Trappe 1967), mineral nutrients (van den Driessche 1971), hormones (Zaerr and Lavender 1980), root-growth potential (Stone 1955), stress resistance (Hermann and Lavender 1979), chlorophyll content of needles (Linder 1974), and CO_2 exchange (Troeng 1982). Irrespective of the objective of the assessment, these methods have been classified according to the measurement technique applied; physical parameters, quantitative chemical parameters, or an electrical test.

Results on the grading of seedling stock indicate that the physiological condition has a strong influence on survival and growth potential. Moreover, components of physiological condition are numerous and the physiological condition cannot be visually determined. Whereas the morphological traits are more easily assessed, the crux of defining the quality attributes of seedlings concerns physiological characteristics.

In this paper I will discuss the biological hierarchy of seedling quality attributes and draw conclusions regarding quality testing. Finally, I shall present an outline incorporating morphological and physiological characteristics of quality.

ORGANISATIONAL HIERARCHY IN PLANTS

In the biological sciences one can distinquish various levels of organization within plants; atoms and molecyles, tissues, organs, plants, and populations. Mesarovic' and Macko (1969) have described the main properties of layered or hierarchially organized systems. Some of the main features are: 1) Each level has its own language, concepts, and principles. For instance, the term crop productivity has little meaning on the cell or organelle level. 2) Interpretation of a phenomenon at one level with reference to a lower level provides us with explanations, while interpretation with reference to a higher level hints at the significance of the phenomenon studied. 3) The relationship between levels is not symmetrical; a higher level requires accounting at all the lower levels in order to explain operation effectively, but not _vice versa_.

An other important hierarchy involves the temporal scale of plant physiological processes. Different levels of structural hierarchy are associated with processes possessing different response times to environmental variables (cf. Thornley 1980). The rate of photosynthesis can alter rapidly but changes in the rate of water uptake are slower. Also a physiological attribute can have several rates of change. Changes in leaf conductance are instantaneous but the change in maximum leaf conductance is slow, taking place through the conditioning of stomata. Physiological attributes change rapidly and independently of one another with time, and thus the period over which the data remain valid is short. Significantly, these changes, if precisely determined, can be used to determine critical phases in the production and handling of seedlings.

SEEDLING QUALITY AS A MODEL

A model is a formal statement of hypotheses which summarizes the knowledge of how a system at a particular level of organisation responds to environmental stimuli (Hall 1982). A measure of seedling vigor provides a model of the seedling's future development. Correspondingly, the measure of quality should be evaluated as a model structure. The model should provide consistent predictions of survival and initial growth over the expected range of field and seedling conditions. As regards the testing of seedlings, the model is more concerned with management than with the mechanisms of the response. Explanatory models describe the internal function or regulation of a plant. Explanatory models are mechanistic and are tested with respect to internal consistency and overall prediction. Indeed, a model which is mechanistic at one level of organisation (e.g. the tissue level) is not mechanistic at a lower level (the cell or organelle level) (Hall 1982). Models built for managerial purposes are likely to be more useful and reliable if they incorporate mechanisms of the response (Landsberg 1981).

Transpiration and water relations are plant processes with a response time of seconds, minutes or hours. Correspondingly, the model of stomatal responses and leaf water relations, designed to reveal process rates is a very short-period model (level 1, Landsberg 1981). Integration of model responses on level 1 in space and time results in short period models (level 2) whose response times are hours and days. The outputs are hourly rates (e.g. transpiration) and daily totals or averages (e.g. average plant water status). The still longer period models at level 3 are mostly based on empirical relationships where the response time is in days or weeks. Shoot and root growth are examples of processes studied at this level. The structure and time hierarchy of physiological processes forms a basis for examining the underlying assumptions and implications of the measurements for a vigor model.

MEASUREMENT OF QUALITY CHARACTERISTICS

Morphological characteristics of seedling quality are measured as states at the plant level, e.g. shoot height and diameter of root collar. In practice, root collar diameter can be measured with an accuracy of one millimetre and even then is highly subject to measurement errors. In stock grading, the class interval of the root diameter is usually less than 1 mm. The class intervals are based on a larger sampling during the development of the classification. Statistically the classes can differ significantly. However, a difference of one millimetre in root collar diameter can correspond to a difference of 20 cm in shoot length. Therefore, I question the relevance of using the root collar diameter in grading.

Ritchie (1984) used the terms "performance" and "material attributes" as concepts in assessing planting stock quality. The performance attributes (root growth potential, frost hardiness and stress resistance) integrate the combined function of many physiological and morphological subsystems within the seedling. Material attributes (water relations, nutrition and seedling morphology) can be investigated by analyzing some of these subsystems, e.g. carbohydrate concentrations of seedling components and leaf water potential. Although Ritchie (1984) classifies bud dormancy as a material attribute, it is normally evaluated as a performance attribute. Conversely, there is at present no direct material measure available for bud dormancy. The concept of material and performance attributes combines both state and rapid process variables of seedlings in a confusing manner.

Characteristics of physiological seedling condition are measured on plant or organ level and they often represent a process changing through time, e.g. water potential, transpiration, root growth potential, or speed of bud break all of whose response times differ. In a seedling test, the response of a process is studied as the state of a biological system at a given time instant. Thereafter the outcomes, e.g. leaf water potential and survival, of the two instants are correlated. However, the response time is totally different for a dying seedling than for the transpiration rate of a plant.

At a lower level of plant organisational hierachy, measurements of seedling quality variables are carried out with devices which give estimates of fluxes between plant and environment, e.g. a porometer gives values for stomata conductance. The value of conductance may, however, be a process variable with a rapid rate of change, or in the case of maximum leaf conductance a state variable. At model level 2, the pressure-chamber technique is used to determine average plant water potential. However, weighted averages of the components of water potential lack physiological meaning (Weatherley 1970). Huss and Koch (1982) found that plant moisture tests made with the Scholander bomb had no forecasting value. At model level 3, rate of bud break and shoot growth are typical slow response processes studied e.g. in the stress test described by Hermann and Lavender (1979). Process variables quantify the rate of change of the state variables. Their values are determined by the state variables and knowledge of the underlying ecological, physiological and physical processes. Therefore, in physiological grading attention should be paid to identifying, measuring and interpreting the behavior of variables defining also physiological processes, as opposed to variables defining only a state.

In monitoring physiological quality characteristics of seedlings, measurements of state and process variables of plants should be synchronized with the environmental factors affecting quality. Many states and processes which are significant at smaller scales or lower levels may be irrelevant at a population level. Moreover, transmutations may occur when a process, or a function describing it, alters as one moves from one level of organisation to the next (O'Neill 1979). Therefore, the integration of small scale processes should be done with care, as the assumption that a population responds similarly to the mean individual may not be warranted (O'Neill 1979). Nevertheless, the logical association of states and processes in the space-time scale helps in the formation of hypotheses and designing tests for significant relationships.

MODEL ACCLIMATION OF SEEDLINGS

Integration of Structure and Function

It has been recognized that exposure of a plant to one particular stress (e.g. heat) provides resistance to a stress of another kind (e.g. drought, Levitt 1972). This hints at the possibility that a single indicator of the planting stock could be used to evaluate vigor and to predict postplanting success of seedlings. A number of researchers have used heat stress to reflect drought resistance (Sullivan and Ross 1979, Hermann and Lavender 1979). Van den Driessche (1976) regards electrical tests in a similar manner. The dose and duration of a stress depends on the particular stress factor which renders the comparison and integration of different type of stress difficult. Kauppi (1984) presented a method to analyze the relationships between the fast stress variables and the slow injury variables.

There seems to be no single physiological or morphological trait of the seedling which would facilitate control over seedling quality. Morphological changes are too slow, and measures of physiological processes have a large proportion of error variation (poor signal-noise ratio) for the purpose of measurement. Nonetheless, physiological and morphological traits of seedling quality are inseparable since no physiological process can occur in the absence of a morphological anatomical basis. Wakeley (1948) cited evidence that morphological grades and physiological qualities do not necessarily coincide, nor are they necessarily identical with the plant's capacity to survive and grow. Therefore, it is prudent to integrate structure (morphology) and function (physiology) of a seedling as an entirety with the proper time response. Morphological traits describe the overall suitability of a seedling <u>for</u> a planting site but physiological traits describe the acclimation of the plant <u>to</u> the site.

The initial performance of forest plantations is the outcome of an interaction between the planted stock and its environment. The ability of seedlings to acclimatise to a planting site is crucial. As acclimation to the planting site is the ultimate test of seedling quality, the concept of planting stock quality is deduced here from the physiology and early acclimation processes of the root system of the bareroot stock. Seedling characteristics which are known to influence planting performance are easily described but seldom combined into a quantitative approach. However, the model approach by Timmis (1980) must be recognized.

Model of Root Action

The development of the model starts with the specification of environmental, external and internal plant variables that influence root acclimation and growth at the planting site (here called root action). Next, the influence of individual variables on root action is determined at appropriate levels of the other variables. Thirdly, equations are developed to describe the effects of individual variables and their interactions. In the fourth stage, the values of input parameters are examined, e.g. by regression analysis. Fifth, the predictive ability of the root action model is tested with independent data. Finally, as the predictions of the model are likely to be imperfect, sources of error are analyzed and corrected. The whole process then repeated.

The characteristics of root action to be included in the model are root morphology (root area or length, root growth), plant water relations or their components(root water potential, hydraulic conductivity of root, evaporative demand, leaf mass), and soil-water relations (soil water content and/or potential, hydraulic conductivity of water). The model of root acclimation integrates essential root morphological and physiological attributes of plant water relations under the imperatives of environmental variables. The driving variables for the model, albeit at any level, are environmental factors.

The approach described would result in a phenomenological model (Jarvis 1976) of seedling quality which states the environmental and biological variables of the acclimation. It avoids the limitations of an empirical model in dealing with different environments. Characteristics of seedling growth, as well as the driving variables of growth, are functions of time, a fact which should be recognized in analyses. This may lead to a dynamic model (see Hari et al. 1983) of root action. In any case, the model should take into account the tempo of the environmental variables around a planted seedling.

Multiple correlation models based on the same variables of root morphology and physiology as in the dynamic approach, are static but relatively easily computed. This analysis could give weight ratios of importance for different morphological and physiological variables included in the model. As a result, operational quality indecies could be derived for specific conditions. The correlation model serves also as a step towards a dynamic root action model. The root action model has been outlined for bareroot seedlings, but a model can be developed for container seedlings by incorporating or modelling the acclimation of the shoot.

DISCUSSION

The root system is perhaps the most essentially manipulated component of the acclimatised stock. Root growth characteristics (root growth potential, RGP or root regeneration potential, RRP) are significant as quality indicators (Burdett 1979, Ritchie and Dunlap 1980, Coutts 1981, Kauppi 1984). Many of the commonly employed root growth test methods are laborious except that proposed by Burdett (1979). Unfortunately, all test procedures involve inherent variability which precludes significant statistical and practical correlations of RGP or RRP to field performance (e.g. Sutton 1980). In addition, attempts at correlation imply a far greater control over the raising of seedlings at the nursery than it is currently imposed. Sandvik (1977) stated that the growing conditions in the nursery should be strictly controlled with respect to light, temperature, and physical properties of the growing medium if a defined physiological condition of the seedlings is to be achieved. A framework for this purpose is proposed by Räsänen (1980). It could have its data base in the computerized record maintenance of the nursery. The need for morphological grading will be much less in precision grown planting stock than in conventional non-uniform stock, but physiological grading will then be all the more important (Sutton 1979).

An ideal vigor index would be physiologically invariable with no dependence upon the environment. The rate of acclimation could be divided into two components, the driving variables and the internal plant properties. The internal properties could be separated from the effects of environmental variables enabling one to derive a "pure" quality index. This index would be independent of the environment.

Preconditioning techniques at the nursery can produce morphological, anatomical and physiological characteristics of seedlings that can promote the establishment of plantations. However, it still remains to be examined which are the conditioning processes best designed to prepare seedling stock for a particular environment.

There are considerable differences in the ease and reliability of tests for measuring physiological characteristics of seedling vigor. Current physiological vigor tests require a considerable sample size for a chosen confidence level, which precludes rational and rapid analysis. The current use of a vigor test, whether morphological or physiological, implies that differences between seedling lots exist. If we cannot assume differences between lots, we would have to resort to testing seedlings on an individual basis. For example, the pressure-chamber technique would result in the destruction of large numbers of seedlings. A study of the variability of an attribute between seedlings and between seedling lots would make up a part of the analysis of variability for each phase of forest re-generation from seed to a sapling stand.

Further development of seedling vigor indecies may require us to conceptualize the quality term. "Quality is fitness for purpose" is a conclusive, posterior statement which needs to be developed into an operational, predictive statement. Models are accepted for controlling operational costs at the nursery. For shortening the trial and error sequence in the developement of quality standards, forest seedling producers should perhaps evaluate recent developments in the ecophysiological modelling of plants, too.

LITERATURE CITED

Burdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine quality. Can. J. For. Res. 9:63-67.

Cleary, B.D. 1971. The effect of plant moisture stress on the physiology and establishment of planted Douglas-fir and ponderosa pine seedlings. Ph.D. dissertation. Oregon State University, Corvallis, Oregon. 85 p.

Coutts, M.P. 1981. Effects of root or shoot exposure before planting on the water relations, growth, and survival of Sitka spruce. Can. J. For. Res. 11:703-709.

Glerum, C. 1970. Vitality determinations of tree tissues with kilocycle and megacycle electrical impedance. For. Chron. 46:63-64.

Hall, A.E. 1982. Mathematical models of plant water loss and plant water relations. In O.L. Lange, P.S. Nobel, C.B. Osmond and H. Ziegler (eds.), Physiological Plant Ecology II. Part 12 B, p. 231-261. Springer-Verlag. Berlin-Heidelberg.

Hari, P., Sievänen, R. and Salminen, R. 1983. On measuring in plant ecological studies. Flora 173:63-70.

Hermann, R.K. and Lavender, D.P. 1976. Large stock: is it really superior ? XVI World Congress. Contributed paper, Working group S.1.05.04. Mimeo. 8 p.

Hermann, R.K. and Lavender, D.P. 1979. Testing the vigor of coniferous planting stock. Forest Research Laboratory, Oregon State University, Corvallis. Res. Note 63.

Huss, J. and Koch, W. 1982. Frischezustand und Anwuchserfolg unterschiedlicher Kiefernpflanzen. Forstw. Cbl. 101:13-24.

Jarvis, P.G. 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Philos. Trans. R. Soc., London, Series B 273:593-610.

Kauppi, P. 1984. Stress, strain, and injury: Scots pine transplants from lifting to acclimation on the planting site. Acta For. Fenn. 185.

Krueger, K.W. and Trappe, J.M. 1967. Food reserves and seasonal growth of Douglas-fir seedling. Forest Sci. 13:192-202.

Landsberg, J.J. 1981. Number and quality of the driving variables needed to model tree growth. Stud. For. Suec. 160:43-50.

Levitt, J. 1972. Responses of plants to environmental stresses. Academic Press.

Linder, S. 1974. A proposal for the use of standardized methods for chlorophyll determinations in ecological and eco-physiological investigations. Physiol. Plant. 32:154-156.

Mesarovic', M.D. and Macko, D. 1969. Foundations for a scientific theory of hierarchial systems. In Whyte, L.L., Wilson, A.G. and Wilson, D. (eds.), Hierarchial structures, p. 29-50. American Elsevier, New York.

O'Neill, R.V. 1979. Transmutations across hierarchial levels. In Innis, G.S. and O'Neill, R.V. (eds.), Systems analysis of ecosystems, p. 59-78. International Cooperative Publishing House, Fairlands, MD, USA.

Räsänen, P.K. 1980. Modelling processes of planting stock production and establishment: framework of the model and its use in practise. N.Z. J. For. Sci. 10:12-20.

Ritchie, G.A. 1984. Assessing seedling quality. In Duryea, M.L. and Landis, T.D. (eds.), Forest nursery manual: Production of bareroot seedlings, p. 243-259. Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, for Forest Research Laboratory, Oregon State University, Corvallis.

Ritchie, G.A. and Dunlap, J.R. 1980. Root growth potential: its development and expression in forest tree seedlings. N.Z. J. For. Sci. 10:218-248.

Sandvik, M. 1977. Growth cessation and overwintering of Picea abies (L.) Karst. seedlings. (English Summary). In Experimental genecology, p. 117-123. Royal College of Forestry, Dep. For. Gen., Stocholm.

Schmidt-Vogt, H. 1980. Characterization of plant material. Proc. IUFRO Meeting "Characterization of Plant Material", Working Group S.1.05-04, June 23-26, 1980, Freiburg in FRG. 193 p.

Schmidt-Vogt, H. 1981. Morphological and physiological characteristics of planting stock: present state of research and research tasks for the future. In Proc. IUFRO XVII World Congress, Kyoto, Japan, p. 433-446.

Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. Forest Sci. 1:90-94.

Sullivan C.Y. and Ross, W.M. 1979. Selecting for drought and leaf resistance in grain sorghum. In Mussel, H. and Staples, R.C. (eds.), Stress physiology in crop plants, p. 263-281. John Wiley & Sons.

Sutton, R.F. 1979. Planting stock quality and grading. Forest Ecol. Manage. 2:123-132.

Sutton, R.F. 1980. Planting stock quality, root growth capacity, and field performance of three boreal conifers. N.Z. J. For. Sci. 10:54-71.

Thornley, J.H.M. 1980. Research strategy in the plant sciences. Plant, Cell and Environment 3:233-236.

Timmis, R. 1980. Stress resistance and quality criteria for tree seedlings: Analysis, measurement and use. N.Z. J. For. Sci. 10:21-53.

Troeng, E. 1982. Possibilities of using gas exchange measurement in the evaluation of plant condition. In Puttonen, P. (ed.), Vitality and Quality of Nursery Stock, p. 98-104. Proc. a Nordic Symp., Hyytiälä, January 12-13, 1982. Univ. Helsinki, Dep. Silviculture, Res. Note 36.

Van den Driessche, R. 1971. Response of conifer seedlings to nitrate and ammonium sources of nitrogen. Plant and Soil 34:421-429.

Van den Driessche, R. 1976. How far do seedling standards reflect seedling quality. Proc. XVI IUFRO World Congress:50-52.

Wakeley, P.C. 1948. Physiological grades of southern pine nursery stock. In Proc. of the Society of American Foresters' Meeting, p. 311-322.

Weatherley, P.E. 1970. Some aspects on water relations. Adv. Bot. Res. 3:171-206.

Zaerr, J.B. 1972. Early detection of dead plant tissue. Can. J. For. Res. 2:105-110.

Zaerr, J.B. and Lavender, D.P. 1980. Analysis of plant growth substances in relation to seedling and plant growth. N. Z. J. For. Sci. 10:186-195.