PERFORMANCE OF SOME BIODEGRADABLE PAPERS USED FOR TREE SEEDLING CONTAINERS

E.A.N. Sugden[1] and J.B. Scarratt[2]

Abstract.--Four experimental papers, composed of various mixtures of natural and synthetic fibres, were developed and tested in greenhouse trials with black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus* banksiana Lamb.). Mass and tensile strength retentions of the papers and quality of the seedlings were determined and compared with those of commercial controls. Mass and strength retentions and seedling quality varied with paper type.

Résumé.--Au cours d'expériences, on a mis au point quatre types de cartons composés de divers mélanges de fibres naturelles et synthétiques et on les a essayés en serre avec l'épinette noire *(Picea mariana* [Mill.] B.S.P.) et le pin gris *(Pinus banksiana* Lamb.). Pour chaque carton on a déterminé la capacité de rétention de la masse et de la force de tension ainsi que la qualité des pousses et on les a comparées avec celles de témoins du commerce. Ces caractéristiques ont varié selon le type de carton.

INTRODUCTION

Tree seedling containers have been developed, manufactured and used for many years. Materials used in the various systems have included hard plastics, Styrofoam, compressed peat, polyethylene sheet, and composite papers. Much discussion has centred around the relative merits of different container systems, and undoubtedly this will continue in the future.

The concept of 'containerizing' tree seedlings is based on the premise that seedlings grown in this manner will have a protected root system which will develop without restraint after the seedling is outplanted. For container systems in which the seedling is outplanted complete with container -- as opposed to container-grown 'plug' seedlings -- there are obvious difficulties relating to the development and choice of a suitable container material. Full protection of the seedling's roots can be effected by the use of a robust container, although root egress after outplanting may be adversely affected. At the other extreme, a container which allows early normal root development may be impractical because of difficulties in separating individual containers prior to planting.

Thus, the choice of a suitable material for tree seedling containers is generally based on a compromise between pre-planting strength and post-planting destruction. Clearly, biodegradable materials are preferred. Microbiological agents that will assist in the eventual destruction of a biodegradable container at the planting site are already present in the greenhouse. The container material is therefore subjected to microbiological stress immediately upon being placed in service in the greenhouse. A successful container material will have a controlled rate of biodegradability, retain-

[1]Senior Research Scientist, Ontario Research Foundation, Mississauga, Ontario, and
[2]Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

ing enough strength during the greenhouse phase, but continuing to become weaker and allowing normal root development after outplanting.

An obvious choice, and perhaps the best, is a thin layer of material which incorporates components that will be destroyed under microbiological attack as well as components that are resistant. A composite paper is such a material. Papers containing wood pulp fibres, synthetic staple fibres and one or more bonding agents blended in a variety of different combinations will have varying rates of biodegradation. The choice of component blend will be dictated by the container performance required in relation to species, length of greenhouse production cycle, desired size and age of planting stock, etc. This paper describes a study to evaluate the suitability of a number of experimental composite paper blends for use as container materials for growing and planting black spruce *(Picea mariana [Mill.]* B.S.P.) and jack pine *(Pinus banksiana* Lamb.).

EXPERIMENTAL METHOD

Work on biodegradable papers suitable for tree seedling containers was initiated in 1979 at the Ontario Research Foundation (ORF). The work was sponsored by the Ontario Ministry of Natural Resources in order to develop papers compatible with a process for container production being developed by the Ministry. Greenhouse trials and seedling evaluations were carried out at the Great Lakes Forest Research Centre (Canadian Forestry Service).

In the initial work, two commercially available papers and several experimental papers developed at ORF were evaluated. The results of this initial trial indicated that the commercial papers[3] were totally unsuitable for use in the greenhouse culture of tree seedlings, and that the experimental papers left a lot to be desired. However, they did provide us with considerable insight into what was required for the next generation of experimental papers.

A second study was begun in late 1980. First, a wide range of experimental papers, based on various combinations of natural and synthetic fibres plus resin binders, was prepared at ORF. These papers were screened by accelerated biodegradation tests with a mixed spore suspension of wood-destroying fungi, as well as by standard physical tests for paper. Three paper types were selected for further study and evaluation; a fourth type, the best from the first study (DFK), was included as a reference point.

Hand-made paper at ca 70 g/m^2 basis weight was made in sheets approximately 30 cm^2, using a Williams sheet mold. These sheets were pressed and dried under physical restraint prior to further treatment. The materials used to make the four paper types are listed in Table 1.

Table 1. Composition of four experimental paper types.

Type	Composition
DFK	65% unbleached softwood kraft 25% Fybrel 990 SWP 10% polyester 1/4 in. staple fibre
MF	50% unbleached softwood kraft 15% Fybrel 990 SWP 31% vinyon 1/4 in. staple fibre 4% melamine formaldehyde resin solids
VA	45% unbleached softwood kraft 20% Fybrel 990 SWP 20% vinyon 1/4 in. staple fibre 15% vinyl acetate resin solids
AC	50% unbleached softwood kraft 20% Fybrel 990 SWP 10% polyester 1/4 in. staple fibre 20% methyl methacrylate/acrylic resin solids

All four papers contained a 'synthetic wood pulp' made from polyethylene (Fybrel 990). The fybrids, incorporated into the paper, required heat bonding to create a network. Therefore, each type of paper was heat cured under pressure. Types VA and AC were subsequently impregnated with their respective resin additions and cured. Type MF incorporated melamine formaldehyde in its fibre furnish and required only heat treatment for curing.

The finished papers were cut to size and made up into cylindrical containers 3.7 cm in diameter and 7.5 cm long with a hot melt adhesive to form the seal. Approximately 1000

[3] A heavy unbleached kraft wrapping paper and a urea-formaldehyde impregnated paper with high wet-strength properties.

containers were made from each paper type, of which 960 were used for greenhouse testing.

In addition to the four experimental containers, the study included two commercial controls consisting of FH 408 Japanese paperpots. In one the paperpots were used in the matrix form (PP) -- the normal configuration in which this commercial container is used for seedling production. The second control (PPS) attempted to simulate the configuration of the handpacked experimental containers, and involved separating the filled paperpots, gently rolling them into a cylindrical form and repacking them into the holding tray. This created air spaces between the repacked paperpots, comparable with those between the experimental containers.

A further treatment was added to the greenhouse study to provide a comparison of seedling growth with no container present. Seeds were sown directly into holding trays filled with the same growing medium used for the containers and were grown as bare-root (BR) seedlings under otherwise identical experimental conditions.

All containers were filled by hand with a 50:50 peat:vermiculite growing medium, sown with black spruce or jack pine and set out in the greenhouse in blocks, replicated four times. Sowing dates for the spruce and pine were 9 March and 27 April, 1981, respectively. Fertilizer applications (100 ppm N of 10-52-10 Plant-Prod soluble fertilizer) were started at 24 days from sowing for both species. These were increased to 200 ppm N of 20-20-20 Plant-Prod water-soluble fertilizer at 38 days from sowing. This is a fairly typical nutrient schedule for containerized seedling production; fertilizers were applied continuously at each watering.

Two weeks after sowing and every two weeks thereafter, 10 containers per replicate were removed from each container type. This was continued for 18 weeks for spruce and 12 weeks for pine. The seedlings and growing medium were carefully removed from five of the containers and the paper was returned to ORF for testing; the other five containers were retained for seedling growth measurements. Regular observations were made to quantify foliage chlorosis (Munsell 1963). Shoot height, total dry weight, and root-collar diameter of seedlings were measured and quantitative observations of root egress through the container wall were made.

The five containers returned to ORF were washed to remove surplus growing medium, brought to equilibrium moisture content at 50% RH and 23 C, and weighed. Two specimens, 1.5 x 7.5 cm, were cut from each weighed container and their tensile strength was determined at a constant rate of elongation on an Instron tester. Average weights and tensile strengths were compared with those of unexposed paper specimens tested immediately after manufacture. Mass and tensile strength retentions were calculated and expressed as percentages.

RESULTS AND DISCUSSION

Container Paper Performance

The four experimental and two control containers performed differently in terms of mass and tensile strength retentions. Both the black spruce and the jack pine trials gave the same relative ranking of containers. With mass retention the containers were ranked, in descending order, MF > AC > VA PPS > PP > DFK (Fig. 1). With tensile strength retention the ranking, in descending order, was quite different: PPS > PP > MF AC > VA > DFK (Fig. 2).

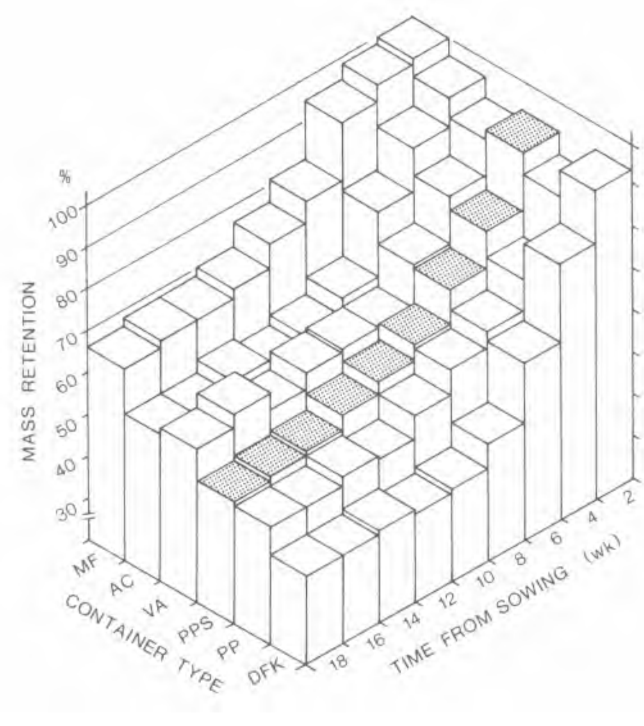

Figure 1. Mass retention in black spruce containers.

Mass and tensile strength retentions were compared for both species at equivalent exposure levels (i.e., time from sowing). The values for pine were generally lower than those for spruce, particularly in the PPS and PP containers, although the differences between the experimental containers were fairly small (Fig. 3). It is suggested that the

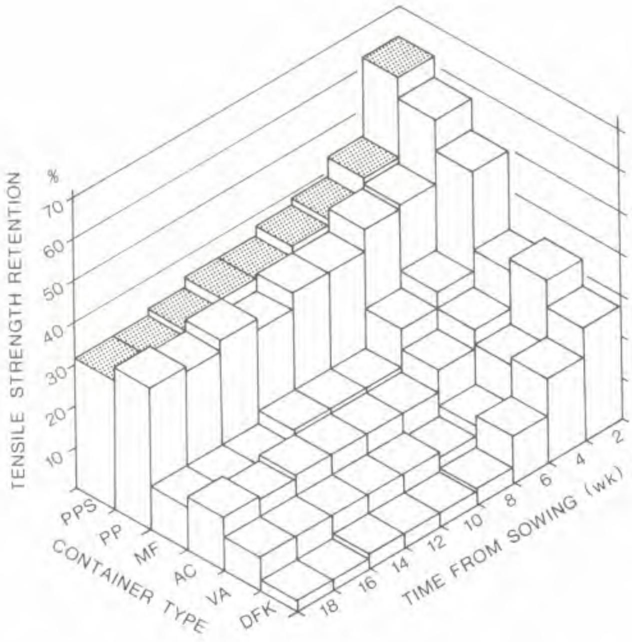

Figure 2. Tensile strength retention in black spruce containers.

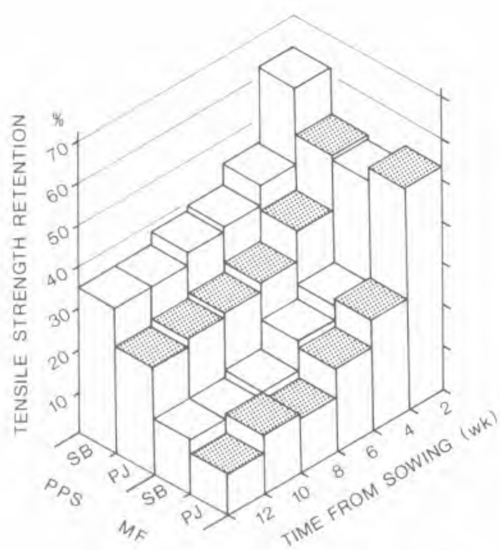

Figure 3. Comparative tensile strength retentions over time for Type PPS and MF containers.

difference between species was related to the 7-week difference in sowing dates and the concomitant higher average temperatures in the greenhouse during the pine trial. Higher ambient temperatures, because of increased solar insolation, would be expected to increase microbiological activity in and around the container, resulting in accelerated degradation of the paper. The difference in performance of the two containers illustrated in Figure 3 can perhaps be explained by the fact that the MF containers rapidly reached a point at which additional exposure caused very slight reductions in tensile strength retention. The PPS containers, being at higher retention levels (because of their binder content), still have the potential for further reductions in tensile strength.

When we compared the performance of papers from the four experimental containers at the end of the black spruce trial period (18 weeks), we found a wide range in mass retention values. Since the composition of these papers is known, and if it is assumed that only kraft pulp fibres are subject to biodegradation, it is possible to determine the residual biodegradable content. This can he expressed as the percentage by weight of kraft fibre remaining in the paper at the end of 18 weeks.

The residual biodegradable content ranged from a high of 17% for Type MF paper to a low of 3% for Type VA (Table 2). If we examine tensile strength retention it will be noted that a somewhat smaller range occurs, and that the maximum and minimum values do not coincide with those of residual biodegradable content. If the ratio of tensile strength retention to residual biodegradable content is calculated, the result can be described as the tensile index. On this basis, Types AC and VA appear to have performed better than either Type MF or Type DFK. In fact, the performance ranking for tensile index is VA > AC > MF > DFK, which does not coincide with the observed handling characteristics of the containers. In subjective handling tests we would rank the containers, in descending order of practical value, MF > AC = PP = PPS > VA > DFK.

To this point we have considered tensile strength retention rather than actual tensile strength. The former was selected because it is a sensitive and reproducible variable. It can he determined on the small samples dictated by the container dimensions. However, the one drawback to this parameter is that machine-made papers are anisotropic whereas handmade papers are almost always isotropic (Table 3).

From Table 3 we see that machine direction tensile strength of Type PPS paper is twice that of its cross-directional tensile strength. The differences between cross-directional tensile strength of Type PPS and

Table 2. Tensile strength retention and residual biodegradable content at 18 weeks in black spruce trial.

Container type	Mass retention (%)	Bio-resistant components content (%)	Residual biodegradable content (%)	Tensile strength retention (%)	Tensile index
MF	67	50	17	11	0.6
AC	55	50	5	14	2.8
VA	58	55	3	10	3.3
DFK	43	35	8	4	0.5

Table 3. Tensile strengths of container papers at 18 weeks in black spruce trial.

Container type	Tensile strength (g/15 mm width)	Percentage of PPS control
PPS (CD)[a]	1103	100
PPS (MD)	2210	200
PP (CD)	1198	109
PP (MD)	2397	217
AC	866	78
MF	482	44
VA	376	34
DFK	81	7

[a](CD) = cross direction (i.e., perpendicular to paper travel on machine)
(MD) = machine direction (i.e., parallel to paper direction on machine)

that of Types AC and MF are considerably less than the corresponding differences in tensile strength retention. This is due to the method used for calculating average tensile strength for the Type PP and PPS papers, *viz:*

$$\text{Average tensile strength} = \sqrt{\frac{MDts^2 + CDts^2}{2}}$$

where: MDts = machine direction tensile strength
CDts = cross-direction tensile strength

The weakest point in the fibre matrix is important in terms of resistance to root egress. Hence, the cross—directional tensile strength of Types PP and PPS is probably a more realistic parameter by which to compare them with the experimental papers.

The superior performance, in terms of tensile strength, of Type AC paper is partly explained by reference to Figure 4, which illustrates tensile energy absorption (TEA) versus incubation time in an accelerated biodegradation study. The differences in performance of Types AC and PP versus those of Types MF, VA and DFK indicate an interesting phenomenon. As the kraft pulp fibre is destroyed by microorganisms, the elastic nature of the bonding agent (methylmethacrylate/acrylic) in Type AC takes over and allows additional mechanical stress to be absorbed as elongation. With Types MF, VA and DFK the bonding agent is inelastic relative to the kraft—Fybrel matrix. As the kraft fibre is destroyed the bonding agents are unable to convert mechanical stress into elongation and therefore yield very low TEA values. The similarity between the curves for Types AC and PP suggests that the bonding system used in commercial paperpot material is similar to that incorporated into the Type AC experimental paper.

Seedling Growth

The performance of the seedlings in the different containers varied considerably. Progressions of average shoot heights and total dry weights in jack pine are illustrated in Figures 6 and 7, respectively; dry weight progressions in black spruce are illustrated in Figure 8. Root—collar diameters showed similar patterns of growth.

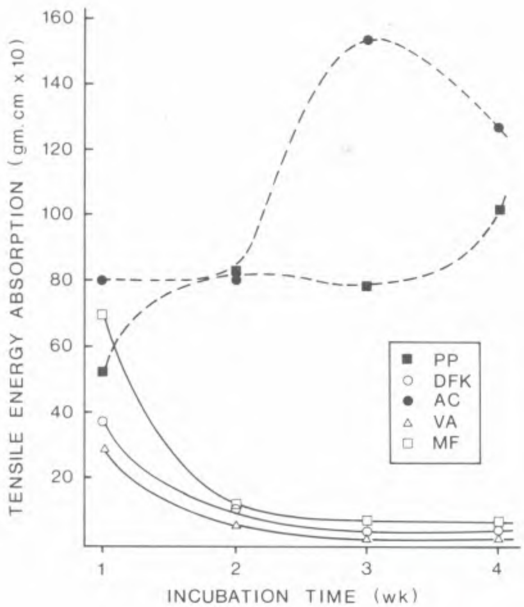

Figure 4. Tensile energy absorption over time in an accelerated biodegradation test.

Figure 5. Bare-root and containerized jack pine seedlings at 8 weeks from sowing.

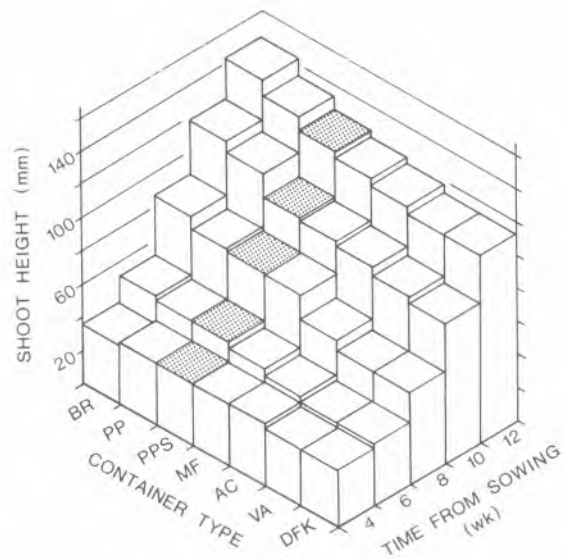

Figure 6. Progression of mean shoot height in jack pine seedlings.

In general, seedlings grown in the experimental containers were smaller on any given date than were those in the control containers or those grown bare-root (BR). Significant differences in shoot height and total dry weight between container types were evident as early as 8 weeks from sowing in both species, and, in jack pine especially (Fig. 5), were accompanied by some initial chlorosis of seedlings in the experimental containers. This chlorosis, and the associated depression in growth rates, undoubtedly resulted from utilization and depletion of available nitrogen in the growing medium by soil microorganisms during decomposition of the cellulose component of the container wall. Foliage chlorosis was most pronounced and persistent in Types VA and DFK (Munsell 5GY[7/6-7/8] compared with 5GY[6/6] in BR and Types PP and PPS), probably because of more severe nitrogen depletion resulting from the more accessible carbohydrate source (i.e., kraft pulp fibres) in these container types. It will be noted that seedlings grown in Types VA and DFK also suffered the most severe depression in dry matter accumulation.

Foliage chlorosis diminished after a few weeks, and all seedlings had recovered their color well before the end of their normal greenhouse production cycle. However, while relative differences in shoot height between container types also tended to diminish (Fig. 6), there were still significant residual differences in both species at the end of the greenhouse study. Shoot heights of black spruce seedlings in Types VA and AC, and of jack pine in Types VA, AC and DFK, were significantly lower than those of bare-root seedlings and those in the commercial container Types PP and PPS. The exception was Type MF, which occupied an intermediate position in both species throughout the study, and in which shoot heights were never significantly less than those of seedlings in Type PP. By the final sampling date no signifi-

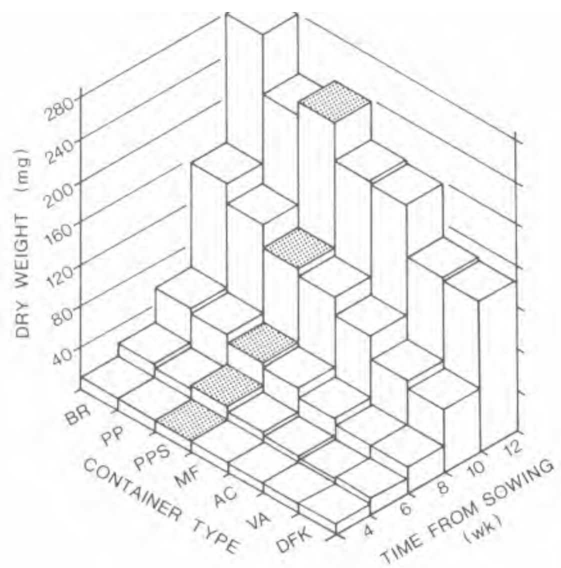

Figure 7. Progression of mean dry weight in jack pine seedlings.

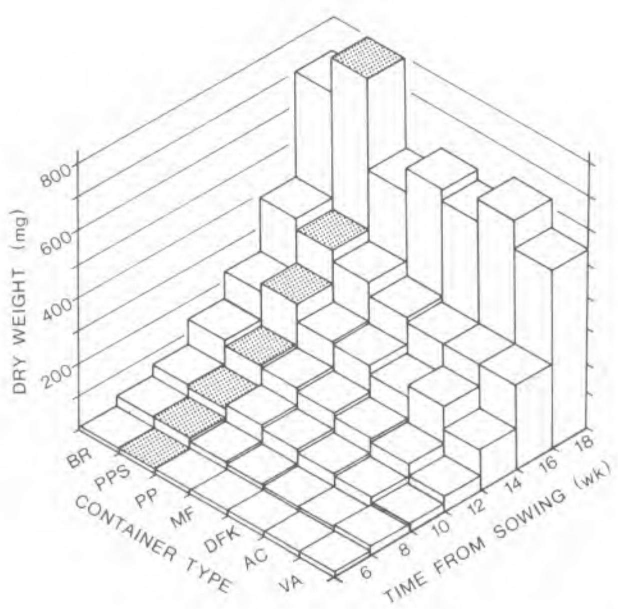

Figure 8. Progression of mean dry weight in black spruce seedlings.

cant height differences existed between seedlings from container Types MF, PP or PPS.

Seedling dry weights followed the same pattern as shoot height up to the final sampling date (Fig. 7 and 8), when anomalies attributed to inadequate watering of the larger seedlings began to obscure the relationships between BR, Type PP and Type PPS. Differences in seedling response in the experimental containers were most pronounced in jack pine. Types MF and AC yielded seedlings with the highest total dry weights in both species and, as with shoot height, Type MF seedlings were statistically equivalent to those in Type PP containers at all sampling dates. Type AC seedlings lagged behind somewhat early in the study, but final dry weights were not significantly different from those of Type MF or PP seedlings.

It is noteworthy that growth rates of bare-root seedlings and seedlings grown in matrix format paperpots (Type PP) were appreciably, though not significantly, superior to those of the separated paperpot control (Type PPS) for much of the greenhouse cycle. This is attributed to the more uniform moisture conditions prevailing in these treatments, resulting from improved lateral moisture movement and the absence of air spaces between individual containers. In Type PPS and the experimental containers, moisture conductivity between containers was presumably less because of a much lower contact area between container walls.

While significant differences in seedling growth occurred in the various types of container, in practice any loss in growth could be made up by extending the growing period in the greenhouse. Of greater importance, perhaps, than the loss of growth potential are the resistance of the container to root egress and its handling characteristics. It has already been noted that we subjectively ranked the handling characteristics of the containers in descending order of practical value: MF > AC = PP = PPS > VA >DFK. Data for root egress through the container wall, the extent of which determines ease of separation of containers and the amount of inter-rooting (themselves expressions of handling characteristics) matched this order closely (Table 4). There was less root egress from Type MF and Type AC containers at the end of the greenhouse cycle than from Types PP and PPS, and this suggests the likelihood of less root damage during handling and planting. However, while the Type MF container had excellent residual integrity, some tendency to root deformation was noted, an indication that the material used was perhaps too tough and might restrict initial root growth after outplanting. This could best be adjusted by reducing the resin content of the paper.

Table 4. Root egress through the container wall at end of greenhouse cycle.

Species	Number of roots emerging through container wall in Type: MF	AC	PP	PPS	VA	DFK
Black spruce (18 weeks)	0.3	0.7	1.2	2.3	5.4	24.9
Jack pine (12 weeks)	0.6	1.5	3.2	4.0	5.2	13.4

CONCLUSIONS

Two materials (Types MF and AC) have been developed which appear to have considerable potential for use in the manufacture of tree seedling containers. The important attributes of these container materials are high residual mass retention values, and relatively high residual tensile strengths brought about by bio-resistant resin bonds between their natural and synthetic fibre components. No adverse effects upon seedling growth rates in the greenhouse have been found, and the containers produced from these materials have excellent handling characteristics under the seedling production schedules currently employed in Ontario. A final conclusion on the suitability of these materials for container manufacture must await the results of current outplanting trials.

ACKNOWLEDGMENTS

The financial support of the Ontario Ministry of Natural Resources, Forest Resources Branch is gratefully acknowledged. The support and encouragement of Mr. K.H. Reese of the Forest Resources Branch has been of tremendous assistance to both principal investigators. We thank the Ministry for permission to make this contribution to the Symposium proceedings.

LITERATURE CITED

Anon.
1963. Munsell color charts for plant tissues; 2nd ed. Munsell Color Company Inc., Baltimore, Maryland.