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By

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Submitted in Partial Fulfilment
of the Requirements for the
Degree of Master of Science in Forestry

School of Forestry
Lakehead University
Thunder Bay, Ontario
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A Caution to the Reader

This M. Sc. F. thesis has been through a formal process of review and comment by several faculty members at the School of Forestry, Lakehead University, as well as an external examiner (Dr. Tom Landis, Westwide Nursery Specialist, U.S.D.A. Forest Service).

It is made available for loan by the school for the purpose of advancing the practice of professional and scientific forestry.

The reader should realize that the opinions expressed in this document are the opinions and conclusions of the student and do not reflect the opinions of either the major supervisor, the faculty or the university.

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ABSTRACT

Temesgen, H. 1992. Growing media, feeding schedules, and container coating for *Eucalyptus globulus* Labill. container stock production. 120 pp. Adviser: Prof. R. J. Day.

Key words: container stock, *Eucalyptus* Dill. spp., *Eucalyptus globulus* Labill., feeding schedules, media, root growth potential, *Sphagnum* L'Herit .

Present day container nursery systems for the production of *Eucalyptus* Dill. are reviewed and documented from the results of a comprehensive questionnaire distributed to 30 major *Eucalyptus* producing countries. The results of the survey showed that 41 *Eucalyptus* species were under production in 1990. Most of these species were grown in containers that varied in diameter, depth, diameter to depth ratio, and volume. The growing media, fertilizer types, fertilizer formulation, and the morphological standards used for the production of *Eucalyptus* stock for outplanting varied considerably.

Two separate experiments were conducted with *Eucalyptus globulus* nursery stock. 1) The media and feeding schedule study tested the merits of *Sphagnum* peat, Vermiculite, and Perlite in various proportions as growing media under the exponential and replacement feeding schedules. Seedling height (cm), root collar diameter (mm), top dry weight (mg) and root dry weight (mg) were measured to study growth of the seedlings. 2) The media and container coating study tested the merits of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in various proportions as growing media in coated and uncoated containers. It also evaluated the effects of container coating on root growth potential and root form. In addition to the morphological attributes measured in the media and feeding schedule study, root number, and root elongation were measured.

Both studies were subjected to Analyses of Variance to determine the significance of differences in growth attributes. Both studies showed that seedling height and root collar diameter are not appropriate morphological characteristics to determine or compare the size and quality of finished *Eucalyptus globulus* stock. A response surface showed that the highest seedling dry weight range lies between 60 to 67% *Sphagnum* peat, 33 to 40% Vermiculite and 0 to 3% Perlite in the experimental region. The highest predicted seedling dry weight was found at 62% *Sphagnum* peat and 38% Vermiculite. In each growing medium, seedlings grown under the exponential feeding schedule had a more rapid seedling dry weight gain and higher Dickson's Seedling Quality Index than those grown under the replacement feeding schedule. *Eucalyptus globulus* seedlings grown in coated Ventblock containers filled with various proportions of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite were physiologically and morphologically superior to their counter parts grown in uncoated containers.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table

Table

Page

Table

Page

Table

Page

Table

Page

LIST OF FIGURES

Figure

Page

Figure

Page

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INTRODUCTION

There is a significant lack of scientific and technical literature on the nursery practices used to produce *Eucalyptus* Dill. (eucalypts) nursery stock. This is especially true in regard to the growing media, feeding schedules, morphological and physiological standards, and root culturing.

It is hypothesized by the author that: 1) *Eucalyptus globulus* Labill. seedlings grown in various proportions of *Sphagnum* L'Herit peat, Vermiculite, and Perlite under the exponential and replacement feeding schedules will show a range of levels of morphological performance; and 2) *Eucalyptus globulus* seedlings grown in various proportions of *Sphagnum* peat, Vermiculite, Perlite, and composted radiata pine (*Pinus radiata* D. Don) bark in coated and uncoated containers under the exponential feeding schedule will show different levels of morphological and physiological performance.

In addition to documenting the present day container systems used for the production of *Eucalyptus*, this study evaluates the above hypotheses in terms of the following three objectives.

1) Review and document the present day container nursery systems for the production of *Eucalyptus* in general, and *Eucalyptus globulus* Labill. in particular through a comprehensive questionnaire distributed to 30 major *Eucalyptus* producing countries.

2) Determine the relative merits of *Sphagnum* peat, Vermiculite, and Perlite in various proportions as growing media for *Eucalyptus globulus* nursery stock under replacement and exponential feeding schedules.

3) Determine the relative merits of *Sphagnum* peat, Vermiculite, Perlite, and radiata pine bark in various proportions as growing media for *Eucalyptus globulus* nursery stock in coated and uncoated containers, and also evaluate the effects of container coating on root growth potential and root form.

LITERATURE REVIEW

CAVITY TYPE, VOLUME, SHAPE AND ARRANGEMENT

The quality of container stock is affected by the type, volume and shape of the cavities in which it is grown, and inter-plant spacing of the cavities in the trays or blocks. As the morphological and physiological characteristics of the seedlings of various tree species differ, the type, volume, shape and inter-plant spacing of the cavities must be varied to match the growth rates and spatial requirements of individual species. Researchers and/or nurserymen should consider the following points in designing or in selecting a cavity and tray or block type for a particular tree species.

1) The volume of the cavity should provide sufficient growing space for adequate biological development, but should also be small enough in size to be economical during nursery production and for transport to the outplanting sites.

2) The shape of the cavity should satisfy the root development requirements of the tree species without causing root deformity or root binding prior to shipping for outplanting.

3) The inter-plant spacing of the cavities in the trays of blocks should be sufficient for adequate shoot development. Cavities must be spaced wide enough to prevent the loss of lower foliage and to provide sufficient aeration for rapid drying after watering, and intum, to minimize fungal attack (e.g. attack by *Botritis cinerea* Pers., etc.).

4) The cavities should be supported in trays or blocks that are convenient and allow efficient nursery operations such as filling, seeding, handling, watering, fertilizing and transporting.

There are so many types of seedling container used in reforestation programs throughout the world, it is not possible to discuss them all here. Five common, but very different types of seedling containers presently used are: British Columbia/Canadian Forest Service (BC/CFS) Styroblocks and Ventblocks (molded in polystyrene); Japanese Paper Pots (pull-out paper folders); Multipots (molded in polyethylene); Polythene Tubes (thin flexible polyethylene tubes requiring support); and Spencer-Lemaire Book Planters (folded vacuum formed polystyrene). The containers differ according to the material they are made from. Each container is produced with a range of cavity volumes and shapes, and inter-plant spacing (Table 1).

Table 1. Ranges of volume and shape, plant spacing, number of cavities/m^2 and recycling capacity of the major container types (Day 1991).

Container Types	Volume Range (cm^3)	Shape Range (Diam to Depth Ratio)	Plant Spacing cm	No. of Cavities/m^2	Average Number of Reuses
BC/CFS Styroblocks	39-330	1:2-1:7.5	2.84-6.83	218-1162	4 to 5
Japanese Paper Pots	44-350	1:1.13-1:1.5	2.5-5.0	397-1617	0
Ropack Multipots	57-148	1:2.8-1:1.53	2.88-4.78	437-1204	10
Polythene Tubes	39-1260	1:2-1:7.5	n/a	n/a	0
Spencer-Lemaire Book Planters	40-1300	1:2-1:7.5	2.8 -8.3	147-1288	2-3

Of the container types in the above list, Polythene Tubes were the principal ones used for *Eucalyptus* production in the world up to 1980. Polythene Tubes are supplied in a range of widths either as individual tubes or in rolls which can be cut to any length (FAO 1979). A wide variety of Polythene Tube volumes and shapes are used in the various countries producing *Eucalyptus* seedlings (Table 2).

Table 2. Volume and shape ranges of polythene tubes used for *Eucalyptus* Dill. production (FAO 1980).

Country	Volume Range (cm^3)	Shape Range (Diam to Depth Ratio)
Australia	90 to 120	1 to 2 up to 1 to 1.75
New Zealand	1000	1 to 2
Nigeria	760 to 1260	15.5 to 25.8
South Africa	330	1 to 1.54
Zambia	39 to 330	1:2 to 1:7.5

Because of difficulties in growing uniform stock in Polythene Tubes and the very high cost of Japanese Paper Pots, these container types are now falling out of use and are being replaced by plastic containers with fixed (e.g. Ropack Multipots, and BC/CFS Styroblocks and Ventblocks) or removable cavities (e.g., Leach Tube, Starlite Tubes). Since 1980, other containers have been adopted by many countries because of their greater efficiency in both the nursery and shipping phases. The Queensland Forestry Department Tube (Q.F.D. Tube), Yates Bookplanter, Starlite Tube, Leach Tube, and LaBelle and Todd Planters are examples of these containers. They are now in use in Australia, Brazil and the United States. The containers that are replacing Polythene Tubes for *Eucalyptus* production are listed in Table 3.

Table 3. Volume and shape range of some containers used for *Eucalyptus* Dill. production (Day 1989a, 1991; Geary *et al.* 1983).

Country	Container Type	Volume Range (cm^3)	Shape Range (Diam:Depth Ratio)
Australia (Queensland)	Q.F.D. Tube	170	1:4.3
Australia	Jiffy Pots	22.5 to 102.0	1:1.7 to 1.8
	Kwik Pots	65.4 to 90.0	1:1.4 to 1:1.27
	Nally's-100	46.8	1:1.6
	Smith's	54.2	1:1.8
	Yates Bookplanter	216	1:3.4
Europe	Starlite Tube	50	1:4.3
S. America	Lannen Ecopots	137 to 166	no info.
United States	Leach Containers	49.1 to 163.9	1:4 to 1:6.5
	LaBelle Planter Blocks	47.0 to 78.0	1:2.80
	Todd Planter Blocks	75.0	no info.

Most of the seedling container cavities are long and narrow and have diameter to depth ratios of 1:3 to 1:5. The reasons for their low diameter to depth ratios are: 1) the block or trays occupy a small production area at the nursery; 2) the production of longer 'plugs' per unit volume of soil permits deeper outplanting in the field and the potential for greater access to soil moisture; and 3) they require simpler mechanization.

As Ropack Multipots, and BC/CFS Styroblocks and Ventblocks are well designed for efficiency in the greenhouse and shipping phases, and are made with cavities that have volumes and shapes that are suitable for *Eucalyptus* stock production, they were used in this study. There are various types of Ropack Multipots, and BC/CFS Styroblocks and Ventblocks under production (Tables 4 and 5).

Table 4. The characteristics of Ropack Multipots seedling containers under production (Day 1991).

Ventblock Type	Tray Size Length (cm)	Tray Size Width (cm)	No. of Cavities	Cylindrical Cavities Diam. (cm)	Cylindrical Cavities Depth (cm)	Dia/Depth Ratio	Volume (cm^3)	Plant Spacing(cm)	No.cavities per m^2
1. MP#1-67	36	22	67	3.2	8.9	1:2.80	57.4	3.43	846
2. MP#2-67	36	22	67	3.2	8.9	1:2.80	57.4	3.43	846
3. MP#3-96	61	36	96	3.8	12.2	1:3.20	98.3	4.78	437
4. MP#4-96	61	36	96	3.8	16.8	1:4.40	147.5	4.78	437
5. MP#6-45	36	22	45	3.8	12.1	1:3.80	98.3	4.19	568
6. PCA313A	61	36	198	2.5	13.3	1:5.30	57.4	3.33	901

Table 5. The characteristics of some BC/CFS Ventblocks seedling containers under production (Day 1991).

Ventblock Type	Tray Size Length (cm)	Tray Size Width (cm)	No. of Cavities	Cylindrical Cavities Diam. (cm)	Cylindrical Cavities Depth (cm)	Dia/Depth Ratio	Volume (cm^3)	Plant Spacing(cm)	No.cavities per m^2
1. 240/40	60	35	192	2.4	11.0	1:4.75	39.0	3.08	1130
2. 198/60	60	35	240	2.4	11.0	1:4.44	50.0	3.43	936
3. 180/75	60	35	160	3.0	12.5	1:4.60	62.0	3.25	936
4. 112/105	60	35	198	3.0	13.5	1:4.75	106.0	4.18	527
5. 77/170	60	112	3.0	14.9	15.0	1:7.50	172.0	3.62	366
6. 91/130	60	35	160	3.0	22.5	1:3.53	133.0	4.32	430
7. 45/330	60	35	80	3.8	15.0	1:2.53	336.0	6.83	215

Most seedling container trays or blocks have inter-plant spacings that range from 2.88 to 4.78 (Table 4 and 5). Such inter-planting spacing provides adequate growing space and permits sufficient ventilation to minimize fungal attack. The containers selected for use in this study were MP#3-96 and the Ventblock 102/115. The MP #3-96 has 437 cavities per m^2, a depth of 12.2 cm, a diameter to depth ratio of 1:3.2, and a volume of 98.3 cm^3. The Ventblock 102/115 has 542 cavities per m^2, a depth of 14.9 cm, a diameter to depth ratio of 1:4.75, and a volume of 106.0 cm^3. Both the MP#3-96 and Ventblock 102/115 provide sufficient growing space for *Eucalyptus* seedlings and prevent suffocation which could lead to fungal development and loss of the lower foliage. Of all the multipots listed, the MP#3-96 is the most economical block for *Eucalyptus* nursery operations. The Ventblock 102/115 is moderately economical and available with either coated (with root inhibitors) or uncoated container cavity walls.

John and Mark (1982) reported that a private nursery in Florida uses Leach Tube and Todd Planters to grow *Eucalyptus*. *Eucalyptus* seedlings at the Florida Department of Forestry nursery are also grown in Leach Tubes (Tinus and McDonald 1979), Todd Planter Blocks and LeBelle Planter Blocks (Geary *et al.* 1983). These containers range in volume from 47 to 78 cm^3. Geary *et al.* (1983) stressed the importance of cavity volume, and its effects on growth and root form of various tree species. However, they do not clearly indicate the best types of commercial container that are available for *Eucalyptus* production. As the containers used in Florida range in volume from 47 to 78 ml for the Leach tube and the LaBelle Styrofoam blocks, it is obvious *Eucalyptus* can be grown for outplanting in subtropical areas in containers of this size range. Research work in Western Australia with the Department of Conservation and Land Management by Day (1989a; 1989b) recommended that for outplanting in Mediterranean climates *Eucalyptus globulus* should be grown in a container with a minimum volume of 100 ml. The following commercially available containers were recommended by Day (1989a; 1989b) for testing in Western Australia:

1) BC/CFS Styroblocks	Cavity Vol (cm^3)	2) Ropack Multipots	Cavity Vol. (cm^3)
Styro # 4	65.0	MP #2-67	65.5
Styro # 6	106.0	MP #6-45	98.3
Styro # 8	133.0	MP #4-96	147.5

In the above study, the Styro # 4 and MP #2-67 containers were included to test containers smaller than 100 ml. As a result of this work, the Department of Conservation and Land Management has adopted a locally produced 98 ml container.

GROWTH MEDIA

Natural soils, biotic products, and modified minerals are used singly or in combination in preparing the growth media for container stock. The natural soils used in container media are generally 'top soil' or 'sand'.When natural soils are used in container media it is essential to indicate their textural, chemical, and biotic characteristics. The biotic products used are: 1) peats derived from *Sphagnum* peat, sedge (*Carex* (Dill.) L.) species, grass (*Graminae*) species and other peat forming species; 2) composted bark, sawdust, sugar cane waste; and 3) animal manures. The modified minerals used are either Vermiculite (expanded mica) or Perlite (expanded silica). The ingredients included in container growth media are often selected because of their local availability and cost.

The types of growing media used and their relative proportions have a significant influence on the growth and quality of the container seedlings produced (Day 1989b, Tinus and MacDonald 1979, Carlson 1983). Thus, the selection of a growing medium is a crucial step in container stock production. In selecting a medium or media for container stock production the following should be considered: 1) container type to be used; 2) components to be included in the medium; 3) physical and chemical characteristics of the medium for growing seedlings; 4) ease of loading the medium into the cavities; and 5) coherence of the medium when the seedlings are extracted from the cavities.

According to Nelson (1978) and Day (1991), an ideal growing medium should have the following physical and chemical characteristics: 1) suitable structure and drainage capacity; 2) water holding capacity and air content in suitable ranges (i.e. after watering a medium should have a water holding capacity of 35 to 50 % by volume and an air content of 10 to 20%); 3)bulk density from 0.643 to 1.22 g/ml; 4) Carbon:Nitrogen Ratio (C:N) >30; 5) suitable buffering capacity; 6) unfavourable environment for either pest or disease infestation; 7) pH from 4.5 to 5.8 for acidophilous plants and 6.2 to 6.8 for others; 8) Cation Exchange Capacity (CEC) in a range from 10 to 30 meq/100 g; and 9) electrical conductivity <0.30 ms/cm.

Development of Growing Media Preparation

The production of small container stock for outplanting was initiated by research carried out in Ontario and British Columbia in the 1950's (MacLean 1959, Walters 1961). The first large scale operational afforestation or reforestation program with small container stock was carried out in Ontario in 1966. In British Columbia, an operational scale reforestation program with container stock began in 1970 (Cayford 1972). The unique Canadian development of small container stock captured the imagination of foresters around the world and stimulated research, operational trials and reforestation programs in temperate, Mediterranean, subtropical and tropical climates. Over the three decades since the initiation of container stock use in Canada, the growing medium has changed from media based on natural soils to media based on *Sphagnum* peat, Vermiculite and/or Perlite mixtures. These are commonly called peat-lite mixtures. As *Sphagnum* peat, Vermiculite and/or Perlite may not be available or may be too expensive in some countries, composted bark and sawdust are used as substitutes for them.

Brix and Van Den Driessche (1974) recommended that natural soil not be used as a rooting medium for small container stock because peat-lite media have more desirable physical characteristics (i.e. superior water holding capacity, aeration, and bulk density). Both *Sphagnum* peat and Vermiculite have much higher CEC on a dry weight basis than either sandy-loam soil or ground bark (Buckman and Brady 1969). Owston (1972) gave figures for CEC in milliequivalents of 103, 72, and 13 per 100 g dry weight for 1:1 finely ground *Sphagnum* peat:Vermiculite, 1:1 Douglas-fir bark:Vermiculite, and sandy-loam soil, respectively.

Carlson (1983) and Tinus and MacDonald (1979) showed that the use of peat-lite media in Canada and the United States resulted in spruce and pine nursery stocks that were in better morphological and physiological condition and were more uniform in quality than similar stock grown in mineral soil. Since these publications, most nurseries in North America have changed their growing medium from natural soil and sand mixtures to peat-lite media.

The inavailability and high cost of imported *Sphagnum* peat and Vermiculite and/or Perlite have been and are still a major concern of growers producing *Eucalyptus* container stock in Mediterranean, sub-tropical and tropical countries. Because of this, substitutes for *Sphagnum* peat, Vermiculite and Perlite have been sought during the last fifteen years. Brown and Pokorny (1979) found ground bark has physical properties which makes it an alternative to *Sphagnum* peat. Ruehle and Marx (1977) reported that bark stimulates excellent mycorrhizal development and may inhibit disease organisms. Pine bark mixes have gained prominence in recent years and are also used for growing woody ornamentals (Pawuk 1981). A comprehensive review of the 'preparation and utilization of pine bark as a growing medium for plants' was made by Van Schoor *et al.* (1990).

Gartner (1979) recommended that until a way is developed to avoid the alkalinity problem of bark, it should only be used as a partial substitute for peat in media used to grow container stock. However, the use of *Pinus* L. and *Eucalyptus* species bark as a substitute for peat has increased rapidly since 1985. Currently many nurserymen are growing *Eucalyptus* container stock in pure *Pinus* bark or in media with high proportion of *Pinus* or *Eucalyptus* bark.

Container growth media have been modified and improved since 1966. These improvements were made in three overlapping periods. The three periods were: 1) 1966 to 1976 when soil based media were generally used; 2) 1976 to 1985 when peat-lite media were used; and 3) 1985 to present when peat-lite media began to be replaced with media containing *Pinus*, *Eucalyptus* and other bark especially in countries where *Sphagnum* peat and Vermiculite and/or Perlite were either lacking or expensive (Van Schoor *et al.* 1990).

Soil Based Media (1966 to 1976)

A number of workers have evaluated soil based media (Pawuk 1981, Goodwin 1976, Hellum 1975, Le Roux 1975, Mathews 1971). Pawuk (1981) argued that soil based media can produce stock of equal quality to those grown in soil-less media, provided that the soil has satisfactory physical and chemical properties. According to the United Nations Food and Agriculture Organization (FAO), the media selected for use in *Eucalyptus* nurseries between 1966 and 1976 were usually composed of locally available low cost components (FAO 1979). Table 6 shows several countries use soil based media.

Peat-lite Media (1976 to 1985)

Day (1989a) reported that in North America, almost all the media are now composed of Peat-lite Media.(a combination of *Sphagnum* peat and Vermiculite). "Peat moss" is used to describe many peats that are used for container media. This includes: 1) horticultural grade *Sphagnum* peat; 2) humified *Sphagnum* peat; 3) sedge peat; and 4) commercially available peat and soil mixes. Of these, horticultural grade *Sphagnum* peat has the best physical and chemical characteristics (Tinus and MacDonalds 1979). Because of this, horticultural grade *Sphagnum* peat was included in this study and it will be reviewed in detail.

Sphagnum Peat Moss provides good buffering capacity, appropriate Carbon-Nitrogen (C:N) balance, low pH and high CEC. It is unfavourable to disease and pest infestation. It has a water holding capacity of 56% water by volume in coarse grades to 84% in fine grades (Klougart and Olsen 1969). Moreover, *Sphagnum* peat has the ability to retain nutrients because of its unique hyaline cells. These cells assist in controlling the nutrition of container stock and ensure a reserve of water and nutrients. Phipps (1974) reported electrical resistance measurements of *Sphagnum* peat alone or with Vermiculite was near twice that of other media. Due to these characteristics, *Sphagnum* peat is a highly preferred medium when cost is not a limiting factor.

Table 6. Media used for *Eucalyptus* container stock production in some countries between 1966 and 1976 (FAO 1979).

Country	Site	Description
Australia	Australian Capital Territory	CSRIO Division of Forest Research uses 1 Part sandy loam: 1 part river sand:1 part organic matter.
	Queensland	Dept. of Forestry at Gympie uses sandy soil with clay soil and/or organic matter.
	Tasmania	AFH in northern Tasmania uses a local sifted soil mixed with slow-release fertilizer.
	Victoria	APM Forest uses fine weed-free sand with slow-release fertilizer.
Iran		Clay or silt soil. Sometimes rice bran mulch is added to prevent drying and cracking of the soil.
Israel	Ilanot	A sandy soil is used without fertilizer.
	Gaza	A 25% sandy loam soil with compost and fertilizer.
Italy		90% top soil with 10% cow manure.
Laos		Silt soil.
Nepal		A sandy loam soil without fertilizer.
New Zealand		60/40 peat and sandy loam soil.
Nigeria	Bukuru	5 parts river sand: 4 Parts composted town refuse fertilizer
	Samaru	2 parts river sand: 3 Parts rotted cow dung with fertilizer
Pakistan		3 parts fine river sand: 3 parts silt: 2 parts decomposed leaf mould
South Africa		50/50 sieved topsoil and partially decomposed sawdust.
Spain	Huelva	75 % forest humus: 25% fertilizers.
Sri Lanka		A fine sandy loam soil
Sudan		50 % sand: 50% river silt.
Tunisia		Forest top soil without fertilizer.
Zambia		Sandy humic topsoil from *Brachystegia* woodland.

Carlson (1983) evaluated five commercial brands of *Sphagnum* peat in the prairie provinces and found differences in seedling growth. He recommended that each peat brand be tested for pH and coarse to fine ratio, and then modified to meet set standards. Carlson (1983) gave standards for physical and chemical characteristics of peat quality (Tables 7 and 8).

Table 7. Standard physical characteristics of acceptable peat quality (Carlson 1983).

Physical Characteristics	Acceptable standards
Saturated weight (g/l)	600-900
Dry weight (g/l)	< 100
Ash content (%)	< 10
Bulk density (g/ml)	< 0.12
Water Capacity by volume (%)	> 50
Air capacity (%)	> 34

Table 8. Standard chemical characteristics of acceptable peat quality (Carlson 1983).

Chemical characteristics	Range required
pH (Hydrogen ion concentration)	4.5-5.5
Electrical conductivity	< 0.50 ms/cm
Cation exchange capacity	85-160 meq/100 gm
Exchangeable Sodium	<10

Klougart and Olsen (1969) recommended the addition of 30 gm of fine-ground limestone (97% $CaCO_3$) to 1 kg dry *Sphagnum* peat to change the pH one unit when the pH range of the media is low.

Vermiculite is a light, expandable, hydrated Magnesium-Aluminium-Iron silicate; it is a plate-like silicate mineral (Tinus and MacDonald 1979). Vermiculite is neutral in reaction with good buffering capacity, bulk density of 0.9-1.05 g/ml, weighs 100-140 kg/m^3 and is able to absorb 400-500 l/m^3 of water (Nelson 1978). Vermiculite is also insoluble in water and has high CEC and contains mineral nutrients, especially potassium (Tinus and MacDonald 1979).

After mining, Vermiculite is exposed to a temperature of 1000 ^0C in furnaces that force bound water out and its platy layers apart. This process causes the mineral to expand to form sharp irregular shaped granules which act as both 'spacers' to ensure good aeration for root growth, and particles that can absorb and retain nutrient solution.

Tinus and MacDonald (1979) classified horticultural Vermiculite in to four sizes: 1) No. 1 particles with a diameter of 5 to 8 mm; 2) No. 2 particle with a diameter of 2 to 3 mm; 3) No. 3 particles with a diameter of 1 to 2 mm; and 4) No. 4 particles with a diameter of 0.75 to 1 mm. Grades 1 and 2 are common for horticultural uses. Tinus and

MacDonald (1979) recommended horticultural grade No. 1 for containers with a cavity volume greater than 160 ml and No. 2 for small containers with a cavity volume less than 160 ml. They also argued that finer grades of Vermiculite (i.e. No. 3 and 4) pack too densely and do not provide sufficient space in the medium for adequate aeration. This is especially the case when Vermiculite begins to deteriorate.

Perlite is made by crushing a hydrated silicate mineral ($SiO_2 + H_2O$) found in lava. It is prepared by heating the crushed mineral to 760 ^{0}C. This process expands the SiO_2 particles and results in sharp granules of Perlite. The resulting sponge-like, sterile granules hold three to four times their weight in water. It is used as a granular bulking agent in growing media. Perlite has a pH of 6.0 to 8.0, bulk density of 0.12 g/ml and a particle size of 1 to 3 mm (Tinus and MacDonald 1979).

Unlike Vermiculite, Perlite lacks buffering capacity, CEC, and mineral nutrients. Perlite's usefulness is to increase aeration and moisture retention in growing media for container stock production. Tinus and MacDonald (1979) stressed that Perlite does not compress. This property makes it an important growing medium component in plug type containers.

Pawuk (1981) found that Peat-lite media resulted in best seedling growth. The proportions of *Sphagnum* peat and Vermiculite and/or Perlite in peat-lite media must be well regulated. Too much Vermiculite or Perlite leads to excessive drainage and allows the medium to fall through drainage holes. An excessive amount of Vermiculite and/or Perlite can cause seedling plugs to fall apart when they are removed from the containers (Carlson 1983).

Mixtures of *Sphagnum* peat and Vermiculite are most widely used as a rooting media in the Pacific Northwest (Brix and Driessche 1974). Phipps (1974) stressed that plugs composed of the *Sphagnum* peat-Vermiculite and *Sphagnum* peat alone had a greater tendency to remain intact than other mixes. A number of workers have evaluated media prepared with various ratios of *Sphagnum* peat to Vermiculite and/or Perlite (Day 1989a, Carlson 1983, Geary *et al.* 1983, Pawuk 1981, Goodwin 1975, Hellum 1975, Brix and Driessche 1974, Tinus *et al*. 1974, and Phipps 1974).

The ratio of peat to Vermiculite most often ranges from 1 to 1, up to 2 to 1 (Carlson 1983). Day (1989a) reported the common ratios of *Sphagnum* peat to Vermiculite or Perlite as 0 to 1, 1 to 1, 2 to 1, and 3 to 1. Both 3 to 2 and 1 to 2 are sometimes used (Tinus and MacDonald 1979). Carlson (1983) noted that some nurseries have successfully used peat without any Vermiculite or Perlite (i.e. 1 to 0 mixture). The 0 to 1 (pure Vermiculite) mixture is only used in nurseries producing *Eucalyptus* stock from cuttings by vegetative propagation (e.g. Aracruz in Brazil). Day (1989a) reported that a 1 to 2 mixture of *Sphagnum* peat to Vermiculite is used by the Queensland Forestry Department for a wide range of *Eucalyptus* species. He argued that a 1 to 1 or 2 to 1 mixture is the best growing media for *Eucalyptus* species, provided the *Sphagnum* peat is sufficiently pure (free from other plant materials) and fibrous. Table 9 presents the recommended proportions of *Sphagnum* peat, Vermiculite, and Perlite mixes in North America.

Table 9. Recommended *Sphagnum* peat, Vermiculite, and Perlite mixes for some tree species in North America.

Tree species	*Sphagnum* peat	Vermic-ulite	Perlite	Location	Source
	(%)	(%)	(%)		
Picea and *Pinus*	67.0	33.0	0.0	Eastern Canada	(Carlson 1983)
Psedotsuga menziessii	75.0	25.0	0.0	Western Canada	(Carlson 1983)
*Pinus resino*sa	50.0	50.0	0.0	Wisconsin	(Phipps 1974)
Pinus	50.0	50.0	0.0	Louisiana	(Barnett 1974)
Picea and *Pinus*	50.0	50.0	0.0	Rockies and Plains	(Tinus 1974)
Eucalyptus	50.0	25.0	25.0	Florida	(Geary *et al.* 1983)

Geary *et al.* (1983) argued that the addition of Perlite was based on proprietory information that Perlite increases the retention of nutrients. Phipps (1974) experimented various proportions of *Sphagnum* peat and vermiculite on red pine (*Pinus resinosa* Ait.) and found that the relative proportions these components in the medium significantly influenced seedling growth. The best red pine seedlings were produced in a 1 to 1 peat-Vermiculite medium.

Ligel and Ventor (1987) argued that 50% *Sphagnum* peat is usually sufficient for use in container media and a 1 to 1 mix of shredded *Sphagnum* peat to Vermiculite minimizes weight and facilitates container handling in most mechanized operations. A mixture of *Sphagnum* peat and Vermiculite is most widely used as a rooting media in the Pacific Northwest (PNW), but ground bark is the favourite with some growers in the PNW (Brix and Driessche 1974).

Perlite is made by crushing a hydrated silicate mineral ($SiO_2 + H_2O$) found in lava. It is prepared by heating the crushed mineral to 760 ^{0}C. This process expands the SiO_2 particles and results in sharp granules of Perlite. The resulting sponge-like, sterile granules hold three to four times their weight in water. It is used as a granular bulking agent in growing media. Perlite has a pH of 6.0 to 8.0, bulk density of 0.12 g/ml and a particle size of 1 to 3 mm (Tinus and MacDonald 1979).

Unlike Vermiculite, Perlite lacks buffering capacity, CEC, and mineral nutrients. Perlite's usefulness is to increase aeration and moisture retention in growing media for container stock production. Tinus and MacDonald (1979) stressed that Perlite does not compress. This property makes it an important growing medium component in plug type containers.

c) Peat-lite mixes

Pawuk (1981) showed that a combination of *Sphagnum* peat and Vermiculite resulted in the best seedling performance. The proportions of *Sphagnum* peat and Vermiculite and/or Perlite in peat-lite media must be well regulated. Too much Vermiculite or Perlite leads to excessive drainage and allows the medium to fall through drainage holes. An excessive amount of Vermiculite and/or Perlite can cause seedling plugs to fall apart when they are removed from the containers (Carlson 1983).

Mixtures of *Sphagnum* peat moss and Vermiculite are most widely used as a rooting media in the Pacific North west (Brix and Driessche 1974). Phipps (1974) stressed that plugs composed of the *Sphagnum* peat moss-Vermiculite and *Sphagnum* peat moss alone had a greater tendency to remain intact than other mixes.

A number of workers have evaluated media prepared with various ratios of *Sphagnum* peat:Vermiculite and/or Perlite (Day 1989a, Geary *et al.* 1983, Pawuk 1981, Goodwin 1976, Wellum 1975, Brix and Driessche 1974, Carlson 1983, Tinus and Balmer 1974, and Phipps 1974).

The ratio of peat to Vermiculite most often used ranges from 1 to 1 upto 2 to 1 (Carlson 1983). Day (1989a) reported the common ratios of *Sphagnum* peat to Vermiculite or perlite as 0 to 1, 1 to 1, 2 to 1, and 3 to 1. Both 3 to 2 and 1 to 2 are sometimes used (Tinus and MacDonald 1979). Carlson (1983) noted that some nurseries have successfully used straight peat without any Vermiculite or Perlite (i.e, 1 to 0 mixture).

of the secondary xylem including the vascular cambium are used. These organic sources are removed by the debarkers. During the composting process, it is essential to add sufficient nutrients (i.e. ammonium phosphate and calcium carbonate), and to ensure that the bark is moist and well aerated;

2) fertilization during the composting process aids in decomposition and ensures that the bark will be in an appropriate pH range and contain adequate nutrients for the growth of container stock.

Sandra and Smith (1990) found that the addition of lime to pine bark before sowing (enrichment) resulted in hardier seedlings of *Eucalyptus grandis* Hill ex Maid., and their study concluded that pine bark is capable of supplying the necessary trace elements to meet the needs of the seedlings. The research recommended that pre-enrichment treatment need not be necessary to supply the trace elements.

Gartner (1979) and Mason and Van Arsdel (1978) reported that composted bark has fewer growing problems than fresh bark. Hardwood bark can be used satisfactorily even though the pH increases from 5.2 for fresh bark to 7.5 to 8.0 in the composting process. Since the composted bark gets more alkaline (i.e. pH 8.0 to 8.5), ferrous sulphate and elemental sulphur must be added to bring it back to the desirable range of 5.0 to 6.0 (Gartner 1979).

Other Media

A wide variety of 'other media' have been used to grow container stock. Many of these media were listed in Table 6. Some additional media include soil amended with Perlite, crushed composted pine cones, sugar cane waste and sawdust. There is little consistent information on these media in the literature, so it is only possible to describe some of them in this section. For instance, nurseries in Haiti use a 2:1:1 mixture of bagass (pressed sugar- cane fibers), rice hulls and alluvial soils; the Monterey nursery in Puerto Rico uses a 2 to 1 alluvial soil and pressed cane fibers (FAO 1979).

Rimando (1987) reported on the use of Perlite in combination with clay soils and advocated the use of this medium. Pawuk (1981) found that media derived from composted pine cones held water better and produced larger seedlings than bark media. He suggested that rotten pine cone media could be substituted for bark media. Burdett and Martin (1982) used the following media in their experiment on chemical root pruning: 1) 3 parts *Sphagnum* peat to 1 part Vermiculite with the addition of 3 kg/m^3 of dolomitic lime;

2) 3 parts Vermiculite to 1 part *Sphagnum* peat; and 3) 1 part *Sphagnum* peat to 1 part Vermiculite and 1 part sand with an addition of 1.3 kg/m^3 of dolomitic lime.

A mixture of sand, *Sphagnum* peat, and Vermiculite was tested for the performance of *Eucalyptus grandis* Hill ex Maid., *Eucalyptus robusta* Sm., *Eucalyptus viminalis* Sm. and *Eucalyptus tereticornis* Sm. by the Florida Department of Forestry (FDF) (Geary *et al.* 1983). This study showed that sand increased the amount of watering required and did not produce seedlings with firm root plugs. With the exception of *Eucalyptus viminalis*, the growth of the other species was poorer when sand was included in the medium.

IRRIGATION AND FERTILIZATION

Irrigation and fertilization are important container nursery operations that influence the quality of stock. They play a major role in the: 1) germination (affected by irrigation only) and growth of stock in the nursery; 2) production of uniform quality stock with optimal morphological and physiological characteristics for outplanting; 3) production of two or more crops because of improved growth; and 4) minimizing the cost of container stock production by increasing growth rates.

The irrigation and fertilization system should provide an equal amount of water and fertilizer to each cavity. Systems that do not provide even coverage of water and fertilizer should be avoided. In modern container nurseries it is usual to use travelling irrigation booms to apply irrigation water and nutrient solutions (Day 1989a). Irrigation and fertilization regimes must be adjusted for the characteristics of the growing media, age of seedlings, the growing cycle of the tree species, the environmental conditions and the cultural practices at the nursery. These attributes either directly or indirectly determine the type of fertilizer required, and the rate of water and fertilizer applied for container stock production. Irrigation and fertilizer regimes must also be adjusted throughout the growing period to meet the exponentially increasing demands of the seedlings if vigorous seedlings are to be produced.

Quality and Quantity of Water and Concentration of Nutrients

The quality and quantity of water, the concentration of nutrients strongly affect the growth and quality of container stock. Thus, it is essential to provide an adequate supply of high quality water, containing nutrients in balanced concentrations.

Tinus and MacDonald (1979) reported the following positive and negative attributes to consider when judging water quality: 1) total dissolved salts (mg/l or ppms); 2) electrical conductivity (μomhs); 3) amount of nutrient ions present (mg/l or ppm) (e. g. nitrogen, phosphorous, potassium, calcium, magnesium, iron, etc.); 4) amount of other ions (mg/l or ppm) affecting nutrient availability (e. g. sodium, carbonate, bicarbonate, etc.); 5) heavy metal concentration (e. g. chromium, cadmium, arsenic, etc.); and 5) pH test

The amount of water and concentration of nutrients in it should be compatible with the rates of evapotranspiration and absorption. The rate of evapotranspiration is dependent on the temperature, humidity and turbulence of the air in which the seedlings are grown. According to Tinus and MacDonald (1979) the rate of absorption is dependent on the: 1) rate of evapotranspiration; 2) frequency of watering and fertilizing; 3) concentration of nutrients in solution; 4) cavity volume; and 5) physical and chemical characteristics of the growing medium. When the rate of evapotranspiration exceeds the rate of absorption, mineral nutrients (i.e. salts) increase in concentration in the medium. This necessitates periodic monitoring of conductivity and leaching of the medium with either water or nutrient solution to keep it in an appropriate range of salt concentration.

Leaching of excess fertilizer is an important operation in preventing the build up of salts in any fertilization scheme. Day (1989b) recommended that the conductivity of the medium used for *Eucalyptus* species should not exceed 500 μohms and excessive salts in the medium should be leached by applying an excess of nutrient solution. He suggested that if there is a severe concern for high salt content in the medium, it can be leached with water until water drips from the bottom of the containers. In British Columbia fertilizers are usually leached twice a week during the growing season (Brix and Van Den Driessche 1974).

Determination of Irrigation Needs

Carlson (1983) stated that there were no accurate methods to determine when irrigation is needed. He proposed the following direct and indirect methods of measuring the water retained in the medium.

Direct Methods involve the use of: 1) soil moisture tensiometers to measure soil suction; or 2) weighing the medium to measure percent moisture content and the loss or gain of water (Carlson 1983). As it is not possible to use tensiometers other than in mineral soils, the first direct method recommended by Carlson is not valid. Thus, it is only possible to use the second direct method to determine the change in the amount of water in most growing media (i.e. peat-lite). Carlson (1983) recommended the second direct method be used.

Indirect Methods involve the measurement of light energy and wind as a measure of the potential evapotranspiration (Carlson 1983). Such methods may become practical if the instrumentation required becomes cheap enough to be installed at container nurseries.

Nutrient Requirements

The response to specific irrigation and fertilizer regimes vary from nursery to nursery because of variation in local climate, water quality, growing media, and the species to be raised (Tinus and MacDonald 1979). The authors stated that these variations can be monitored and/or compensated for by adjusting the pH, the mineral and water content of the irrigation water, and the concentration of fertilizer in it.

Ingestad (1971) noted that the nutrient requirements of tree seedlings are satisfied when: 1) all the essential nutrients are present in the medium in optimum proportions; 2) the ratio of the nitrogen sources NH_4^+ and NO_3^- in the nutrient solution is at an optimum for the species to be grown; and 3) the total nutrient concentration in solution is at an optimum.

Swan (1972a, 1972b, and 1972c) conducted a comprehensive study on foliar nutrient concentration on red pine (*Pinus resinosa Ait.*), shore pine (*Pinus contorta* Dougl.), and lodgepole pine (*Pinus contorta* Dougl. var. latifolia Engelm.). The seedlings were used as an indicator of tree nutrient status and fertilizer requirement. He used a sand culture apparatus to grow these species for six months in the greenhouse. Five experiments for each of the above species were conducted. In each of these experiments, the supply of one of the five macro-nutrients (nitrogen, phosphorous, potassium, magnesium, and calcium) was varied from nil to 350 ppm. All other essential elements were supplied at known and satisfactory levels for the growth of each tree species. This study found a strong relationship between the seedling dry weight and foliar nutrient concentration. Swan noted that the lowest seedling dry weights were associated with acute deficiency of one or more nutrients. Conversely, the highest seedling dry weights were associated with well balanced nutrient solutions.

The source of nitrogen has a marked effect on the growth of some species of conifer seedlings. The ionic sources of nitrogen, ammonium (NH_4^+) and nitrate (NO_3^-) are usually recommended. For coniferous species, NH_4^+ generally results in greater growth than NO_3^- (Van Den Driessche 1971). In some instances, greater growth resulted from the use of NO_3^- (Radwan *et al.* 1971). A mixture of ammonium and nitrogen nitrate normally results in greater growth than a single source (Tinus and MacDonald 1979). The only non-ionic source of nitrogen is usually urea (NH_2CONH_2). As NH_2CONH_2 has to be broken down by bacteria to NH_3 and then converted by nitrobacteria to NH_4^+ and NO_3^- before it acts as a plant nutrient, it is not usually considered to be an effective fertilizer.

The Plant Products Co.® forestry fertilizers are formulated with an ideal balance of macro-nutrients (i.e. nitrogen, phosphorus, potassium, calcium and magnesium) for the optimum growth of forest tree seedlings in peat-lite medium. Day (1991) stressed that Plant Products Co.® forestry fertilizers are also well supplied with micro-nutrients (i.e. iron, copper, zinc, etc). These fertilizers are tailored for use in peat-lite medium so it is not necessary to add additional macro- or micro-nutrients as is the case for Plant Products Co.® horticultural fertilizers. Plant Products Co.® forestry fertilizers were recommended and used for growing black spruce (*Picea mariana* (Mill.) K. Koch) at the Ontario Ministry of Natural Resources Forest Stations. These fertilizers were also recommended for *Eucalyptus globulus* by Day (1989a): 11-41-8 for starter, 20-8-20 for grower, 8-20-30 for hardener.

Fertilization Methods

Fertilizer(s) for container nurseries can be applied either in the growing media or through irrigation water (Carlson 1983; Tinus and MacDonald 1979).

Fertilizer in growing medium

Slow release fertilizers are incorporated into the growing media or granular fertilizers are supplied after the cavities are filled as "top dressings" (Tinus and MacDonald 1979). Application of fertilizers in growing media is commonly used for container stock production. However, because of the rapid leaching of the soluble fertilizers included in the medium, this method can result in early starvation. Day (1991) argued that when fertilizer is incorporated into the growing medium, it is impossible to meet the exponentially increasing requirements of the seedlings (i.e. no nutrition during germination, high phosphorus and low nitrogen when starting, higher nitrogen during rapid growth, high phosphorous and potassium during hardening of the crop).

Fertilizer through irrigation water

Soluble fertilizers are dissolved in water and injected into the irrigation system of the greenhouse. Tinus and MacDonald (1979) recommended that soluble fertilizer at controlled concentrations be applied through irrigation water; they stressed that this method gives the best control of nutrition and the most flexibility, if a change is needed. Brix and Van Den Driessche (1974) reported that in the B.C. Styroblock system, only dolomite lime is added to the growing medium; all macro and micro nutrients are supplied with irrigation water.

Feeding Schedules

Nutrients are either applied intermittently or continuously. When liquid feeding schedules are used, the total nutrient concentration must be monitored to avoid detrimental or even toxic levels of nutrients (Ingestad 1971).

Intermittent Feeding Schedule

Tinus and MacDonald (1979) stated that intermittent feeding schedules are cheaper because of less man hours in fertilizer application, and less fertilizer applied. Some (OMNR) nurseries still use intermittent feeding schedules. An example of an intermittent feeding schedule that was recommended and used for growing black spruce in Japanese paper FH-408 containers at the OMNR Swastika Forest Station is presented in Table 10.

Table 10. Intermittent feeding schedule recommended and used for growing black spruce (*Picea mariana* (Mill.) K. Koch) in Japanese paper FH-408 containers at the OMNR Swastika Forest Station (Day 1991).

Period	Weeks after Germination	Soluble Fertilizer	Prescription g/m^2 of crop
Starting	1 to 3	10-52-10	8.5 every 2 days
Early Growth	4 to 6	20-20-20	8.5 every 2 days
Full Growth	7 to 12	20-20-20	10.0 every 2 days
Hardening	13 to 14 etc.	10-52-10	8.5 every 3 days

Geary *et al*. (1983) reported an intermittent feeding schedule used for *Eucalyptus* production in Florida. Fertilization of *Eucalyptus* container stock starts three weeks after sowing; the seedlings are fertilized three times per week with a special 15-25-20 liquid mix until they are ready for shipping.

Continuous Feeding Schedule

In a continuous feeding schedule the fertilizer is always included in the solution used for all irrigations. Day (1991) argued that continuous feeding schedules provide a flexible and favourable pH and nutrient environment for the seedlings. The continuous feeding schedule has been gradually replacing the intermittent feeding schedule. Day (1991) listed the advantages of continuous feeding as follows:

1) nutrient levels can be changed very quickly, to correct deficiencies or to harden-off seedlings;

2) nutrients are evenly distributed throughout the plug so that root growth does not concentrate in one zone, while being burned in another;

3) because there is no build-up of particular ions, there is little chance of an induced deficiency of one nutrient, caused by the excess of another;

4) regular flushing of growing media prevents the build-up of salts and eliminates burning of roots;

5) this method simplifies the actual fertilization process and eliminates the major sources of fertilization problems (i. e. salt build up);

6) problems with uneven soil moisture content or individual cell drying are reduced; and

7) Nutrient levels are returned to target specification with each fertilization.

Day (1989a) proposed a comprehensive replacement feeding schedule for *Eucalyptus globulus* in West Manjimup, Australia (Table 11). Generally, two types of continuous feeding schedules (i. e. replacement and exponential) are used for container stock fertilization. In both schedules, completely soluble fertilizers are used (Day 1991).

In the replacement feeding schedule complete nutrient solutions with specific concentrations of macro- and micro-nutrients are used for all irrigation needs. These solutions are varied to suit the needs of the seedlings during the starting, growing, and hardening processes. Various researchers have developed and/or reported several replacement feeding schedules with different kinds and rates of fertilizer for various tree species (Day 1989b, Geary 1983, Mullin and Hallet 1983, Brix and Van Den Driessche 1974). Mullin and Hallett (1983) indicated that the replacement feeding schedule is well adapted for the production of plug stock in peat-lite medium in solid wall plastic seedling containers. Day *et al.* (1989b) recommended that the replacement method of liquid fertilization and irrigation be tested for *Eucalyptus globulus* production.

Brix and Van Den Driessche (1974) gave an example of a replacement feeding schedule for conifer seedling production in BC/CFS Styroblock #2. After germination, Plant Products Co.® 10-52-10 horticultural fertilizer was applied to provide 62 ppm N, 141 ppm P, and 52 ppm K for 1-2 weeks. Plant Products Co.® 20-20-20 was then applied to provide 100 ppm N, 44 ppm P, and 82 ppm K for 6-8 weeks. Thereafter N was reduced from the nutrient solution and Plant Products Co.® 0-52-34 was substituted to supply 141 ppm P and 176 ppm K for 1-2 weeks.

In the exponential feeding schedule, complete nutrient solution containing a specific concentration of macro- and micro-nutrients is initially selected after studies to determine the optimum initial growth rates. The concentration of this solution is then increased exponentially to maintain an optimum exponential growth rate. The exponentially increased nutrient solution is applied for all irrigation needs and is used to replace the solution contained in the medium as the seedlings grow.

Timmer and Armstrong (1987) studied red pine (*Pinus resinosa* Ait.) seedlings and found that height growth, dry matter production, and root development at the end of the greenhouse phase were significantly higher for seedlings that were fed exponentially than those fed by the replacement feeding schedule. Ingested and Kahr (1985) reported that growth under exponential feeding was proportional to the rate of exponential increase in nitrogen during the period of growth. The maximum relative growth rates were about 6 to 7.5% dry weight increase per day. This is a much lower maximum than for broad-leaved species (about 20 to 30% per day) under similar growth conditions. To confirm the need for exponential feeding, Timmer and Armstrong (1987) found a constant addition rate of nitrogen results in a successive decline in the nitrogen content of plants.

Table 11. A proposed continuous liquid feeding schedule for Eucalyptus globulus container stock to be grown on the prototype nursery at west Manjimup (Day 1989b)

Time Scale in Days, Weeks and Growth Periods

Days		
0, 7, 14	Germination	1) Crop is sown, and placed under the travelling irrigation boom. It is then watered to keep the medium moist in the upper layer until germination is ensured. Fertilizer is not applied during the germination period because it is not necessary and may damage tender emerging roots. Germination should be complete 14 days after sowing.
21, 28, 35	Starting	2) The crop is started to promote root growth by continuously applying a solution of Starter mix [50-205-90] from the travelling irrigation boom. The starter mix is diluted to contain 50 ppm of N, 90 ppm of P, and 75 ppm of K (all elemental). The starting should be completed in 21 days.
42, 49, 56	Growing-low	3) The crop is INTIALLY GROWN while it is small by continuously applying a weak solution of growing mix [100-135-180]. The growing mix is diluted to conatin 100 ppm of N, 60 ppm P, and 150 ppm of K (all elemental). If the crop reaches 20 cm in height during this period, it should be top pruned to stimulate root growth and the formation of a sturdy top.
63, 70, 77	Growing-High	4) The crop is ACTIVELY GROWN when it is rapidly increasing in size by continuously applying a double strength solution of growing mix [100-135-180] . The growing mix is diluted to contain 200 ppm of N, 120 ppm of P, and 300 ppm of K (all elemental).
84, 91, 98	Cool Weather	5) The crop is FINALLY GROWN as it approaches maturity during cooler weather in April-May by again continuously applying a weak solution of growing mix [100-135-180]. The growing mix is diluted to contain 100 ppm of N, 60 ppm of P, and 150 ppm of K (all elemental).
105, 112, 119	Hardening	6) The crop is HARDENED when it reaches maximum size by reducing or eliminating the amount of nitrogen in the fertilizer and by increasing the amounts of phosphorous and potassium. This is done by continuously applying hardening mix (25-205-180). The hardening mix is diluted to contain 25 ppm N, 90 ppm P and 150 ppm of K (all elemental).

ROOT CULTURING

Initially it was hoped that the root form of container stock would not be modified by the limited size of the cavities in which they were grown. According to Kinghorn (1974), one of the principal objectives of container stock was to produce seedlings with natural root forms. It is now well known that almost all container cavities modify the root form of the seedlings grown in them (Van Eerden and Kinghorn 1978). Normal root extension is invariably severely limited by the very small diameter and short length of most cavities. As a result, the roots of container stock usually grow a few centimetres radially towards the cavity wall and then turn down its sides following the root-training bands and grooves (if present) to form a knot at the drainage hole where they are air pruned (Wiensczyk 1989).

Bergman and Haggstrom's (1976) historic review reported that root deformation has been a severe problem with many reforestation species since the 1920's and probably before that. The authors stated that root deformation is mainly caused by faulty nursery practice, although they indicate that it can also be the result of poor outplanting methods. In particular, the type of container selected to grow the stock can cause major root deformities. For instance, Bergman and Haggstrom (1976) showed that root deformation is severe in the Japanese 408 Paper Pot container. Salem (1978) suggested that stock produced in Can-Am #2 multipots regenerated roots more effectively than those grown in FH-408 paper pots as the paper is a barrier to root egress. Wiensczyk (1989) compared the root form of jack pine seedlings grown in FH-408 paper pots with that of seedlings grown in Can-Am #2 multipots. He found that both containers resulted in a significant modification of the natural root form, but that the modification induced by the the Can-Am #2 multipot was far less severe than that of the FH-408 paper pot. He also confirmed that seedlings grown in Can-Am #2 multipots regenerated roots far better after outplanting than seedlings grown in FH-408 paper pots.

Root deformation has been more actively researched in conifer species than in hardwood species and little is known about the root deformation of *Eucalyptus* species. The root deformation of pines, which is often acute, has been studied by Wiensczyk (1989), Sutherland and Day (1988), Dong and Burdette (1986), Burdette *et al.* (1983), Burdette (1978), Salem (1978), Carlson and Nairn (1977). Root deformation in spruce, which is often less severe, has been studied by Day and Sutherland (1986), Sutherland (1984), Sutton (1978), and Carlson and Endean (1976).

Poor root form and root deformation often result from root coiling or spiralling around the inside of the container and/or the sharp downward growth of the roots where the roots meet the container wall. These are common problems of seedlings grown in most containers (Burdett and Martin 1982, MacDonald *et al.* 1980, Carlson and Nairn 1977).

Carlson and Nairn (1977) studied the root form of jack pine planted from smooth-walled cylindrical containers and found a high degree of root coiling or spiralling, cavity compression due to root binding and large numbers of kinked roots. Various studies have been conducted to investigate, define and correct the problem of the abnormal root growth of container stock (Day *et al* 1989d, Burdett and Martin 1982, MacDonald *et al.* 1980, Grene 1978, Stefanson 1978, Carlson and Nairn 1977). To overcome the root coiling and spiralling problem, Carlson and Nairn (1977) recommended the use of vertically oriented ribs on the inside of smooth-walled containers to direct the roots downward. Long (1978) reported that seedlings grown in containers with ribs had fewer coiled roots than those grown in smooth-walled containers. Stefanson (1978) also found that ribs inside the containers reduced the degree of root spiralling and coiling.

Poor root form and root deformation often result from root coiling or spiralling around the inside of the container and/or the sharp downward growth of the roots where the roots meet the container wall (Burdett 1982; Carlson and Nairn 1977). Poor root form and deformation are common problems of seedlings grown in most containers and can be controlled by copper and copper salts. Copper and copper salts have been applied to the walls and bottoms of seedling containers to prune the roots by limiting and preventing the roots from growing through the bottom and sides containers (Day *et al.* 1989, MacDonald *et al.* 1984, and MacDonald *et al.* 1980). Burdett (1982) used styroblock containers coated with latex paint containing cupric carbonate and found that coating inhibited the growth of the lateral roots of the seedlings when they reached the container wall. He stated that after transplanting, chemically root-pruned pine seedlings produced more vigorous root growth than untreated control seedlings.

MacDonald *et al.* (1980) found that applying $CuCO_3$ mixed with latex paint to the inner walls of plastic containers stopped the growth of the lateral roots of ponderosa pine (*Pinus pondersa* Laws.) at the container wall. $CuCO_3$ coating also resulted in the proliferation of higher order lateral roots at the container wall. The rebranching of the lateral roots caused by $CuCO_3$ coating led to the production of more new active root tips than on seedlings grown in uncoated containers. These authors also studied Indole Buteric

Acid (IBA) as a coating chemical to limit the root growth of ponderosa pine. They found that IBA inhibited root growth at the container wall, but root growth was not as severely limited by IBA as it was with $CuCO_3$.

Burdett and Martin (1982) found the effectiveness of various chemical root pruning treatments varied with species, container size, growing medium, and the concentration of $CuCO_3$ in the coating. Burdett (1982) stated that the chemical root pruning technique is not universally applicable because of the lack of knowledge about the adequate amount for each type of container and each tree species.

Day *et al.* (1989d) found that $CuCO_3$ and latex paint coatings inhibited root development of *Eucalyptus globulus* after outplanting in Western Australia. They recommended that the practice of coating seedling containers with various thicknesses of $CuCO_3$ in latex paint be discontinued because the coatings were found to severely limit root growth in the containers and root egress from them after outplanting. They also recommended that coatings containers with $CuCO_3$ in latex paint be fully and carefully tested before it is used operationally.

STOCK QUALITY

Morphological Quality

The amount of information on the morphological and/or physiological characteristics of container stock is minimal. Day *et al.* (1985), and Armson and Sadreika (1979) described the attributes used to measure the morphological characteristics of bare root nursery stock and the methods used for measuring them are given in (Day *et al.* 1985; Harvey 1987).

The principal attributes used to describe the morphological characteristics of container stock are (Day 1991): 1) height (HT) in cm; 2) seedling dry weight (SDW) in mg; and 3) top dry weight to root dry weight ratio (T/R ratio). These morphological characteristics are commonly used to describe the container stock being produced by government or private nurseries in Ontario. Because of the small size of container stock and the difficulties in taking measurements, root collar diameter (RCD), root area index (RAI), and root volume (RV) stock are rarely measured except for research purposes.

Physiological Quality

The morphological attributes of bare root or container stock do not predict either the survival or growth of the stock, or its physiological condition (Wiensczyk 1989, Burdette 1987, Harvey 1987, Ritchie 1985 and Burdette *et al.* 1983). The physiological condition of the container stock is not often measured because most physiological tests are time consuming and dependent on the use of expensive laboratory equipment.

The following characteristics are measured to assess the physiological condition of bare root or container stock (Day *et al* 1985): 1) root growth potential (RGP); 2) plant moisture stress (PMS); 3) nutrient content; and 4) starch content. The principal measure of the physiological quality of container stock is RGP. This is because the RGP test provides satisfactory information on whether the stock will or will not initiate an adequate number or length of new roots after outplanting. Burdette (1987) rated RGP as the best single physiological quality determinant of a stock. As RGP was the only measure of the physiological quality of the stock studied in this thesis, it will be reviewed in detail.

Root Growth Potential Test

It is very important to correlate stock quality with field performance, since field performance is the most critical and definitive measure of stock quality (Burdette 1987, 1983). Burdette stressed that the performance of stock after outplanting is dependent on the interaction between the quality of the stock and the field environment after outplanting. As it is far easier to improve nursery practice to produce stock of optimum quality (e.g. by watering, fertilizing or sheltering, etc.) than to modify the field outplanting environment, it is essential to evaluate the RGP of stock before it is shipped from the nursery (Day and Koppikar 1987).

Failure to monitor RGP of seedlings may result in shipping stock of inferior quality that has low survival and growth potential. If poor stock is shipped, the investments in site preparation and planting will also be lost. Burdette (1987) emphasised that the RGP of nursery stock measured in the ideal conditions of growth chamber can not always be correlated with the RGP measured after outplanting. This is because RGP determined in a growth chamber is often greater than that measured in the field. The effectiveness of the correlation of $RGP_{field}/RGP_{laboratory}$ determines the usefulness of RGP as a predictor of outplanting performance (Ritchie 1985).

Burdette (1987) showed that survival and growth of nursery stock after outplanting are mainly related to its RGP. He found positive correlations that accounted for 70% of the variation between RGP test and post-planting performance results. Burdette (1987) asserted that the higher the RGP of stock, the higher was its potential for root extension after outplanting, and for absorption of moisture and nutrients. Thus, the RGP test result provides an indirect measure of seedling ability to absorb moisture and nutrients after outplanting.

The RGP of container stock can be described by measuring root number (RN), root elongation (RE) in cm, root area index (RAI) in cm^2, and root volume (RV) in cm^3. RGP can be estimated either from one or a combination of these attributes (Day and Harvey 1984). RN is determined by counting the number of new white root tips. Sometimes only the number of roots greater than a certain length, such as 5 or 10 mm, are counted and those less than these lengths are either ignored or their number are estimated. In estimating the latter, codes such as those proposed by Day and Harvey (1984) or Burdett (1979a; 1979b) can be used.

RGP can also be measured as the increment or decrement in RAI (Rietveld and Tinus 1989; Day *et al.* 1985). Changes in RV can also be used as a measure of seedling RGP (Day and Harvey 1982). The methods used for measuring the change in RAI and RV are given in (Day *et al.* 1985; Day and Harvey 1984). The authors also stated that RAI and RV measurements are not as accurate as RN and RE measurements because of the loss of up to 20% of the RAI or RV during RGP tests.

METHODS

The methods used in this research are presented in three major sections. These are the questionnaire, the media and feeding schedule study, and the media and container coating study.

THE QUESTIONNAIRE

A questionnaire was developed and distributed to 120 nurseries in 30 major *Eucalyptus* growing countries. These countries were Algeria, Argentina, Australia, Bolivia, Brazil, Brundi, Chile, Peoples Republic of China, Colombia, Ethiopia, Ecuador, France, Guyana, Haiti, Malaysia, New Zealand, Nigeria, India, Indonesia, Kenya, Peru, Portugal, South Africa, Spain, Sri lanka, Swaziland, Taiwan, Tanzania, United States of America, and Zambia.

The questionnaire (Appendix I) was designed to solicit general information on nursery practices that are used to produce a wide range of *Eucalyptus* species; it was also designed to solicit specific information on the nursery practices used to produce *E. globulus* container stock. The principal types of information requested in the questionnaire were the types of *Eucalyptus* L'Herit species grown, types of containers and growing media used, types and rates of fertilizer used, problems associated with growing media, and standards for *Eucalyptus* stock out-planting.

THE MEDIA AND FEEDING SCHEDULE STUDY

Two separate, yet identical, experiments were set up in the Lakehead University greenhouse on February 11th, 1991 to study the effects of exponential and replacement feeding schedules on the growth of *E. globulus* container stock.

Most peat-lite media for *Eucalyptus globulus* have ranges of *Sphagnum* peat from 0 to 67%, Vermiculite 17 to 67%, and Perlite 0 to 50% (Day 1990 pers. comm.).As the extreme vertices design considers the upper and lower bounds of the media components, it was used to define the combinations of *Sphagnum* Peat, Vermiculite, and Perlite in the study (Table 12) (Anderson and McLean 1974). The extreme vertices design was used so that the results obtained from *E. globulus* seedlings grown in the nine peat-lite media treatments would produce a response surface that would enable the selection of an optimum peat-lite medium. The experimental region selected for the media and feeding schedule is shown in Figure 1. The nine peat-lite media treatments listed in Table 12 were loaded into MP#3-96 seedling trays. An MP#3-96 tray has 96 cavities and a planting spacing of 4.78 cm. Each cavity in the tray has a volume of 98 cm^3 and a diameter to depth ratio of 1 to 3.2. The seed for each experiment was imported from Chile. It was then sent to the Ontario Ministry of Natural Resources seed plant at Angus Ontario for cleaning and testing and was found to have 98% purity and 85% viability at the time of sowing. The degrees of freedom for the media treatments and experimental error were 8 and 21, respectively.

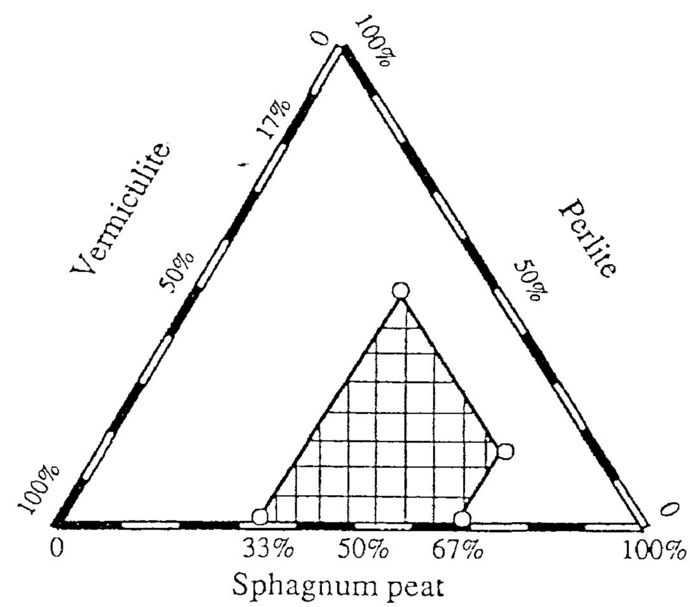


Figure 1. The experimental region in media and feeding schedule study.

Note: 0 = extreme vertex. The boundaries show the constraints for *Sphagnum* peat, Vermiculite, and Perlite in the experiment.

Table 12. Growing media composed of *Sphagnum* peat, Vermiculite, and Perlite in percent in media and feeding schedule study.

Treatment Number	Sphagnum (%)	Vermiculite (%)	Perlite (%)
1)	33.0	17.0	50.0
2)*	33.3	33.3	33.3
3)	33.0	42.0	25.0
4)*	33.0	67.0	0.0
5)	50.0	17.0	33.0
6)	50.0	33.0	17.0
7)	50.0	50.0	0.0
8)	67.0	17.0	16.0
9)	67.0	33.0	0.0

*Note: The second medium is used for *Eucalyptus* species by the U.S. Forest Service in Florida and Florida Department of Forestry (Geary *et al.* 1983); the fourth medium is used by the Queensland Forestry Department (Day 1989).

A Gleason filling line at the Ontario Ministry of Natural Resources, Thunder Bay Nursery was used to fill the MP#3-96 trays. The Gleason line ensures uniform loading and compaction of the growing media. Thirty trays were filled for each of the exponential and replacement feeding experiments. All media treatments were replicated three times. As there were three extra trays, three additional replications were made of three randomly selected media treatments. The trays were randomly distributed on the greenhouse benches (Appendix II). One seed was sown per cavity by hand on October 12, 1990. After sowing, the cavities were covered with a thin layer of silica grit mulch. The exponential and replacement experiments were set up on adjacent benches under an Andrpro travelling irrigation boom which has the capability of applying separate feeding schedules to each bench. The boom was used to apply the various concentrations of dilute fertilizer solution. A Dosatron soluble fertilizer injection pump (Model V 500 Voludoseur) was used to inject the fertilizer into the irrigation water for both feeding schedules.

Plant Products Co.® (P.P.) forestry fertilizers were used for the exponential feeding schedule. The Nitrogen level was increased at the rate of 5% per day for 75 days. The nitrogen level was changed at five day intervals as shown in Figure 2. P.P. forestry fertilizer 11-41-8 was applied from the 10^{th} to the 35^{th} day, 20-8-20 from the 36^{th} to the 75^{th} day (Figure 2). After 75 days, the nitrogen was reduced from 323.74 to 50 ppm with

P.P. 8-20-30 and the stock was subjected to periodic stressing to the temporary wilting point to ensure adequate lignification and hardiness (Appendix III).

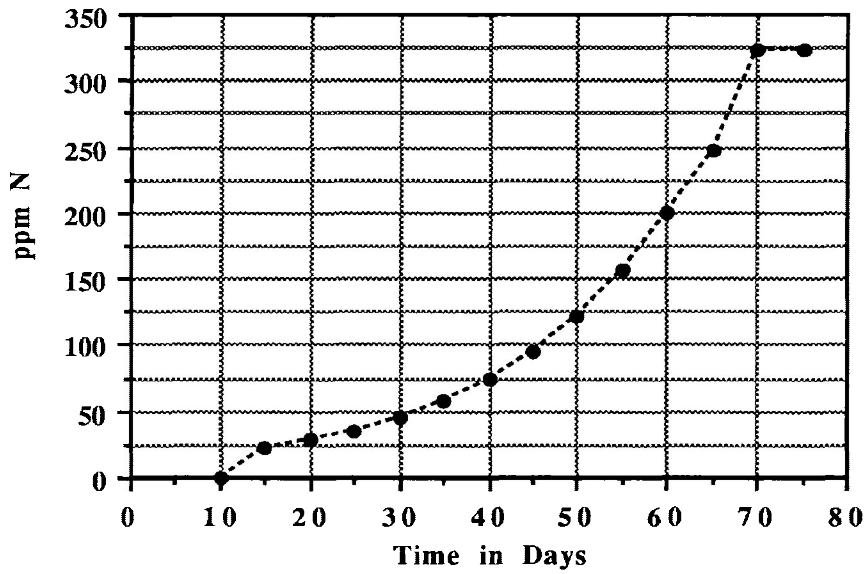


Figure 2. Nitrogen in ppm over days under exponential feeding schedule when N is increased exponentially at 5%.

The replacement feeding schedule which was developed for *Eucalyptus globulus* by Day (1989b) was used with minor modifications. P.P. forestry fertilizer 11-41-8 was applied at the rate of 50 ppm N for Starter from the 10th to the 30th day, 20-8-20 for Grower from the 31st to the 50th day, and 20-8-20 was applied at the rate of 100 ppm N for High Grower from the 51st to the 75th day (Figure 3). After 75 days, the nitrogen was reduced from 200 to 50 ppm with P.P. 8-20-30 and the stock was subjected to periodic stressing to the temporary wilting point to ensure adequate lignification and hardiness (Appendix IV). Under the replacement feeding schedule, the nitrogen level was completely changed at twenty-one days intervals by irrigating with nutrient solution at the levels of N shown in Figure 3.

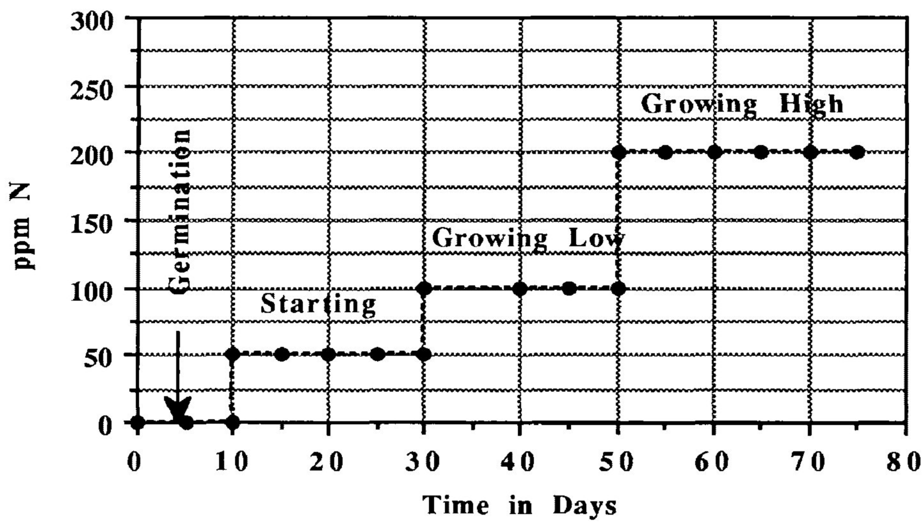


Figure 3. Nitrogen in ppm over days under replacement feeding schedule.

Ten seedlings were randomly removed from each experimental unit at 30 day intervals for measurements of RCD, HT, TDW and RDW. The tops and roots of the ten seedlings from each media treatment were dried separately for 48 hours in a large laboratory oven set at 70 ^{0}C. Dickson's Seedling Quality Index (DSQI) (Dickson *et al.* 1960) was calculated at the end of the experiment (i.e. 120 days after germination). The data for each experiment was entered, verified, compiled and subjected to statistical analysis on the Vax 780 Mainframe computer using the SPSSX package.

The exponential and replacement feeding experiments were treated separately for statistical analysis. The data for each experiment were entered, verified, compiled and subjected to statistical analysis on the Vax 780 Mainframe computer using the SPSSX package. The data were tested for non-homogeneity of variance using Bartlett's test (Steele and Torrie 1980) before it was subjected to Analysis of Variance (ANOVA). In both the exponential and replacement feeding experiments, the means of the morphological attribute were plotted over time to show the growth progression of the seedlings in each of the nine growing media treatments. Emphasis was given to the significance of results at the end of the greenhouse production phase. In both the exponential and replacement feeding experiments, ANOVA was conducted on TDW and RDW to determine if there were any significant differences between or among seedlings grown in each media treatment.

THE MEDIA AND CONTAINER COATING STUDY

An exponential feeding schedule experiment was set up in a completely randomized design with three replications in the Lakehead University greenhouse on Jan 16, 1991. The experiment was designed to test the effects of: 1) Ventblock 112/105 trays with coated (with patented chemical coating) and uncoated (chemically untreated) cavities; and 2) eight growing media on the morphological qualities of *Eucalyptus globulus* seedlings. The Ventblock 112/105 trays are 59 x 35 cm in length and width and have 112 cavities and a planting spacing of 4.84 cm. Each cavity in the tray has a volume of 106 cm^3 and a diameter to depth ratio of 1 to 4.75. The eight media treatments were filled into 24 coated and 24 uncoated Ventblock 112/105 trays (Table 13). The degrees of freedom for the media-coating treatments and experimental error were 15 and 32, respectively.

Table 13. Growing media composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in media and container coating study.

Media Number	Radiata Pine bark (%)	*Sphagnum* peat (%)	Vermiculite (%)	Perlite (%)
1)	100.0	0.0	0.0	0.0
2)	50.0	0.0	50.0	0.0
3)	37.5	37.5	25.0	0.0
4)	0.0	100.0	0.0	0.0
5)	0.0	33.0	33.0	33.0
6)	0.0	67.0	33.0	0.0
7)	0.0	50.0	50.0	0.0
8)	0.0	50.0	33.0	17.0

Note: Growing media No. 6, 7, and 8 were selected from the media and feeding schedules study.

A Gleason filling line at the Ontario Ministry of Natural Resources, Thunder Bay Nursery was used to fill the 48 Ventblock 112/105 trays with the eight growing media listed in Table 13. The trays which were 59 X 35 cm in length and width were randomly distributed on the bench, under a travelling irrigation boom, and covered an area of 8.65 m^2 in the Lakehead University greenhouse (Appendix VI). One seed was sown per cavity by hand on January 16, 1991. After sowing, the cavities were covered with a thin layer of silica grit mulch. The liquid fertilization schedule used was identical to that used in the media feeding schedule study (Appendix V). The total amount of nitrogen ppm applied under the exponential feeding schedule over 75 days was the same as the total amount of nitrogen applied in the media and feeding schedule studies.

Ten seedlings were randomly removed from each experimental unit at 30 day intervals for measurements of root collar diameter, height, top dry weight (TDW) and root dry weight (RDW). The tops and roots of the ten seedlings from each media treatment were dried separately for 48 hours in a large laboratory oven set at 70 ^{0}C. Dickson's Seedling Quality Index (DSQI) (Dickson *et al.* 1960) was calculated at the end of the experiment (i.e. 120 days after germination). The data for each experiment was entered, verified, compiled and subjected to statistical analysis on the Vax 780 Mainframe computer using the SPSSX package.

The seedling dry weight results at the end of the experiment were used to select four media treatments to study the root growth potential of seedlings grown in coated and uncoated cavities. These media were 100% radiata pine bark, 50% radiata pine bark -50% Vermiculite, 37.5% *Sphagnum* peat - 37.5% radiata pine bark - 25% Vermiculite, and 50% *Sphagnum* peat - 50% Vermiculite.

Twenty seedlings were randomly selected from coated and uncoated containers of each of the four media listed above. They were potted separately in 75% Vermiculite - 25% *Sphagnum* peat media in two litre container with drainage holes. The pots were placed on a rooting bed in a growth chamber in a completely randomized design. The growth chamber root growth potential test was conducted for 14 days at 25 ^{0}C during day time and 20 ^{0}C at night. The natural photoperiod was extended to 16 hours with incandescent lightening.

Another set of 20 seedlings were randomly selected from coated and uncoated containers of each of the four media listed above and were placed in hydroponic system designed for root growth potential testing for 21 days. A small compressor fitted with lines to submerged air stone in the water was used to aerate and stir the water. This ensured that there were adequate levels of dissolved oxygen during the root growth potential test.

A computer program developed by Day and Koppikar (1987) was used with a Hipad Digitizer® to count root number (RN) and to measure root elongation (RE). After 14 days, the effective root growth potential of all the seedlings grown in the growth chamber was determined from the seedlings' RN and RE. The RN and RE of all seedlings grown in the hydroponic test were measured at five days interval for 21 days. The RN and RE were determined by counting the number of newly developed white root tips greater than 1 cm and by measuring the length of the same roots. The computer program classified root tips in to three categories: 1) small (root tips 0.0 to 0.49 cm); 2) medium (0.5 to 1 cm in length); and 3) long (>1 cm). The small, medium, and long RE were summed to calculate total RE. ANOVA was carried out on RN and RE for both the growth chamber and hydroponic RGP tests. ANOVAs were also conducted on the hydroponic test at five day intervals.

RESULTS

THE QUESTIONNAIRE

The questionnaire (Appendix I) was sent to 120 nurseries in 30 countries in November 1990. Some nurseries in Brundi, Guyana, Malaysia, and Zambia acknowledged the receipt of the questionnaire but did not provide detailed answers. Only 24 nurseries in nine countries answered it (Table 14).

Table 14. Number of bare root and container stock produced by country (state) and nursery.

Country (State)	Nursery	Stock type and Number Produced		
		Bare root	Container	Total
Australia (Victoria)	Aust. paper Manuf.		1,000,000	1,000,000
Australia (Victoria)	Dept. Conserv.& Environ.		2,380,000	2,380,000
Australia (W.A)	Alcoa		2,800,000	2,800,000
Australia (W.A)	APPM Forests	1,570,000	1,650,000	3,220,000
Australia (N.S.Wales)	Coffs Harbour		80,000	80,000
Cyprus	Natural Resources		16,000	16,000
Ecuador	Casilla		75,000	75,000
Indonesia	RIAU	1,566,590		1,566,590
Indonesia	Way Kawat		48,000	48,000
Indonesia	Kebaro		485,000	485,000
Kenya	Karuri	80,000	500	80,500
New Zealand	Appletons	48,500		48,500
New Zealand	Taradale		830,000	830,000
South Africa	Sunshine seedling services		9,000,000	9,000,000
South Africa	Sappi forest nursery		24,402	24,402
South Africa	Timber growers assoc.		36,000	36,000
Taiwan	Taipei		100,000	100,000
USA (California)	Zappa		3,500	3,500
USA (California)	Valley Crest		7,300	7,300
USA (California)	Lewis A. Moran		93,000	93,000
USA (California)	Corn flower farm		64,000	64,000
USA (California)	Austra-flora		9,000	9,000
USA (California)	Monterey Bay		13,300	13,300
USA (California)	Lyon tree farm		47,000	47,000
Total		3,265,090	18,762,002	22,027,092

Forty-five *Eucalyptus* species were grown by the 24 nurseries. Fifteen percent of the seedlings were bare root (Table 15).

Table 15. Number of bare root and container stock by *Eucalyptus* species grown by 24 nurseries.

Eucalyptus species	Number Produced		
	Bare root	Container	Total
botroides		250,000	250,000
camaldulensis	69,485	370,200	439,685
citrodora		1,700	1,700
dalrympleana		5,500	5,500
delglupta	230,450	437,000	667,450
delegatensis		100,000	100,000
dunnii		6856	6856
elata		410,000	410,000
erythrocorys		5,000	5,000
europhylla		81,000	81,000
fastigata	772,312	21,000	793,312
fraxinoides	2,000	2,000	4,000
globulus	160,000	769,500	929,500
gomphocephala		5,000	5,000
grandis	113,545	6,123,618	6,237,163
gunnii		17,500	17,500
laevopinza		1,500	1,500
leucoxylon		20,000	20,000
lesouefi		1,000	1,000
levoxion		250	250
linearis		1,000	1,000
macarthurii		614,152	614,152
meliodora		1,000	1,000
microcorys		30,000	30,000
nicholi		7,450	7,450
nitens	1,440,000	3,165,320	4,605,320
obliqua	11,500	320,000	331,500
ovalta		20,000	20,000
pauciflora		1,000	1,000
pellita	384,254		384,254
pilularis		30,000	30,000
polyanthemos		9050	9,050
pulverulenta		1,100	1,100
regnans	2,000	1,512,414	1,514,414
rudis		3,100	3,100
saligna	40,000	503,000	543,000
siderophloia		17,000	17,000
sideroxylon		15,500	15,500
smithii		1,003,542	1,003,542
spathulate		1,000	1,000
tereticornis	39,544	10,000	49,544
torquata		3,500	3,500
viminalis		113,000	113,000
woodwordii		1,000	1,000
Others		2,750,250	2,750,250

Table 16 presents the characteristics of the principal containers used for the production of *Eucalyptus* species. The containers used for *Eucalyptus* production are listed in five generic groups for ease of presentation: plastic pots; paper pots; peat pots; plastic tubes; and book planters.

Table 16. Diameter, depth, diameter to depth ratio, and volume of plastic pots, paper pots, peat pots, plastic tubes, and book planters used for *Eucalyptus* production.

Types	Diameter (cm)	Depth (cm)	Diam:Depth ratio	Volume (ml)	No. of nurseries that used the container
1) Plastic Pots					
Plastic	4.0	9.0	1:2.27	80.0	8
Kwik	3.5	7.0	1:20	56.0	1
Jiffy	5.0	7.0	1:1.41	175.0	1
2) Paper pots					
FH-308	3.0	7.5	1:2.5	44.0	2
FH-315	3.0	15.0	1:5.0	88.0	2
FH-408	4.0	8.0	1:2.0	70.0	2
3)Peat pots					
541 Fertil-peat	4.0	5.0	1:1.3	33.0	1
545 Fertil-peat	5.0	5.0	1:1.0	33.0	1
548 Fertil-peat	6.0	6.0	1:1.0	80.0	1
4) Plastic Tubes					
Polythene	3.0	12.2	1:4.4	50.0	1
Dibbling	3.0	12.5	1:4.2	100.0	1
Polythene	3.4	13.7	1:4.0	100.0	1
Leach Superstuby	3.8	14.0	1:3.7	114.7	1
Leach Super Cell	3.8	21.0	1:5.6	164.0	1
Dibbling	4.0	17.7	1:4.3	155.0	1
Polythene	4.5	12.0	1:2.7	175.0	2
Viciflora	5.0	12.5	1:2.5	N/A	2
Polythene	9.0	14.0	1:1.6	89.0	3
Polythene	10.0	15.0	1:1.5	117.7	1
5) Book planters					
Tinus (4)	3.8	20.3	1:5.6	350.0	1
Hilson (4)	3.8	12.0	1:3.1	173.0	4

Note: N/A indicates the information was not available.

The containers used for *Eucalyptus* seedling production ranged in: diameter from 3.0 to 10.0 cm; depth from 5.0 to 21.0 cm; diameter to depth ratio from 1: 1.0 up to 1: 5.6; and volume from 33 to 350 ml. Table 17 lists the proportions of growing medium and methods of media preparation for *Eucalyptus* production.

Table 17. Proportions of growing medium and their method of preparation by 21 nurseries.

Soil	Composted bark	Saw-dust	*Sphagnum* peat	Vermi-culite	Perlite	Method used to prepare	Country	Nursery
%	%	%	%	%	%			
1) Soil based media								
100	-	-	-	-	-	N/A	Ecuador	Casilla
90	10	-	-	-	-	Screened and manually mixed.	Indonesia	Way Kawat
87.5	12.5	-	-	-	-	Manually mixed.	Kenya	Karuri
80	20	-	-	-	-	Screened and mechanically mixed.	Cyprus	Nat. Resour.
80	-	-	-	20	-	Screened and mechanically mixed.	Australia	APPM Forests
50	50	-	-	-	-	Bark composted 1 month.	Cyprus	Dept. Cons.
50	-	50	-	-	-	Fertilizer is premixed.	United States	Valley Crest
2) Bark based media								
-	100	-	-	-	-	Bark is composted.	South Africa	Sunshine
-	100	-	-	-	-	Bark is composted.	South Africa	Sappi
-	100	-	-	-	-	Bark is composted.	South Africa	Timber growers
-	80	-	-	20	-	N/A	United States	Zappa
30	70	-	-	-	-	Bark is composted for 3 months.	Australia	Alcoa
20	60	--	20-	-	--	Sterilized for 3/4 hours.	Australia	Coffs Harbour
50	50	--	-	-	-	Mixed in cement mixer.	United States	Austra-Flora
50	50	--	--	-	--	Bark is composted for 1 month.	Australia	Dept. Conserv.
20	50	--	30	-	--	Screened soil is used.	United States	APPM Forests
-	50	-	-	37.5	12.5	Bark is composted for 3 months.	United States	Corn flower
	38	34	28	-	-	Mixed in a gleason mixer.	United States	Lewis.A. Moran
3) Peat-lite mixes								
-	-	-	50	-	50	Media are manually mixed.	United States	Lyon tree farm
10	20	-	40	30	-	N/A	Taiwan	Taipei
4) Others								
25	-	-	75-	20	-	Redwood sawdust is used.	United States	Monterey Bay
33	-	-	67*	-	-	Media are manually mixed.	Indonesia	RIAU
-	-	-	100*	-	-	Media are manually mixed.	Indonesia	RIAU

Note* indicates sedge-*Sphagnum* peat.

Table 18 lists the types of fertilizer, formulation, and time of incorporation. The types of fertilizer, formulation, and time of incorporation varied from nursery to nursery.

Table 18. Fertilizer types, formulation, and time of incorporation for *Eucalyptus* production at 24 nurseries.

Fertilizer type	Fertilizer Formulation	Time of Incorporation	Nursery
Ammonical nitrogen	Liquid	After sowing	Corn Flower
Ammonium nitrate	Liquid	After sowing	Karuri
Ammonium nitrate, Ammonium phosphate and Potassium nitrate	Liquid	After sowing	Austra-Flora
Aquasol	Liquid	After sowing	Coffs Harbour
Osmocote, Dolomite, and Magamp	Granular	Before sowing	Coffs Harbour
Magamp and Triple Super Phosphate	Granular	Before sowing	RIAU
Ferrous sulphate, Gypsum, Dolomite lime, and Micro max.	Granular	Before sowing	Lyon tree Farm
Ferrous sulphate, Super phosphate, Magnesium sulphate,Potassium nitrate,	Granular	Before sowing	Alcoa
Gypsum and Oscomote	Granular	Before sowing	Lewis A. Moran
Plant Products 17-11-11	Liquid	After sowing	Sappi
Plant Products 11-17-11	Liquid	After sowing	Sappi
Plant Products 20-20-20	Liquid	After sowing	Appletons
Plant Products 15-15-15	Liquid	After sowing	Way Kawat
No fertilizer is applied	N/A	N/A	Taradale
No fertilizer is applied	N/A	N/A	Casilla
Osmocote and Magamp	Granular	Before sowing	APPM Forest
Osmocote, Dolomite and Aquasol	Granular	Before sowing	Dept. Conserv
Osmocote coated Phosphorous	Granular	Before sowing	C. S. I. R. O
Oscomote	Granular	Before sowing	Zappa
Oscomote	Granular	Before sowing	Corn Flower
Prokote	Granular	Before sowing	Monterey Bay
Potassium nitrate	Liquid	After sowing	Monterey Bay
Potassium nitrate, Super phosphate, and Single super phosphate	Liquid	After sowing	Sunshine
Triple super phosphate	Granular	Before sowing	Kebaro
Ammonium nitrate and Triple super phosphate	Liquid	After sowing	Karuri
Plant Products 15-15-15	Liquid	After sowing	Kebaro
Plant Products 20-20-20 or 30-10-10	Liquid	After sowing	Taipei
Plant Products 24-5-12	Liquid	After sowing	Valleycrest

Note: N/A = not applicable.

Table 19 lists the problems associated with growing media. Excessive drying, water logging, and insects pests are the prominent problems associated with growing media.

Table 19. Problems associated with growing media used for *Eucalyptus* production at some nurseries.

Problems associated with growing media	Country	Nursery
Excessive drying, cut worms, and *Botrytis* rot	South Africa	Timber growers
Excessive drying	Ecuador	Casilla
Excessive drying, root rot, and water logging	Australia	Alcoa
Excessive drying and insect pests	Indonesia	Way Kawat
Excessive drying and water logging	Australia	APPM Forest
Excessive drying and water logging	Australia	C. S. I. R. O.
Excessive drying, insect pests, fungi and water logging	Indonesia	RIAU
Fungus	United States	Zappa
Fungus, cutworms, and ants	Kenya	Karuri
Insect pest	Taiwan	Taipei
Insect pest, water logging, and excessive drying	Australia	Coffs Harbour
Meally bugs and ear wigs	United States	Austra-Flora
Psyllids, water logging and drying	Australia	Taradale
Water logging	South Africa	Sappi forest
Weeds	Cyprus	Nat. resources

Questions 7 and 8 of the questionnaire have similar responses and are summarized as follows. Several nurseries reported that *Sphagnum* peat is expensive and unavailable. Thus, peat-lite media were not widely used. Almost all the nurseries did not have research on growing media, and fertilizer regimes and fertilization schedule; nurseries that have a fertilization schedule did not give details. The RIAU nursery of Indonesia is studying coconut fiber as a substitute for peat moss. Table 20 lists the standards for height, root collar diameter, and shoot to root ratio.

Table 20. Height, root collar diameter (RCD), and top to root ratio (T/R ratio) standards used for outplanting of *Eucalyptus* species in some countries.

Height (cm)	RCD (mm)	T/R ratio	Country	Nursery
12.7 to 14.0	1.3	N/A	United States	Valley crest
15.0	5.0	N/A	South Africa	Sappi Forest
18 to 20	>3.0	N/A	United States	Lewis A. Moran
20.0	5.0	3:1	Australia	C. S. I. R. O
20.0	5.0	N/A	Australia	Alcoa
20 to 25	2.5	3:1	South Africa	Timber Grower
20 to 31	5.0	N/A	United States	Lyon Tree Farm
20 to 40	>1.25	N/A	Australia	APPM Forests
25.0	2.5 to 5.0	2:1	Australia	Coffs Harbour
25.0	N/A	N/A	Indonesia	Kebaro
25 to 35	2.5 to 3.0	N/A	Australia	Taradale
30.0	3.0	2:1	Ecuador	Casilla
30.0	3 to 4	N/A	Taiwan	Taipei
30 to 40	N/A	N/A	Indonesia	Way Kawat
30 to 60	N/A	N/A	Kenya	Karuri
30 to 60	N/A	2:1 to 4:1	New Zealand	Appleton
39.4	2.0	N/A	United States	Corn flower farm
50.0	5	N/A	Cyprus	Natural Resources
60 to 90	<5.0	N/A	South Africa	Zappa

Note: N/A indicates no information is given.

THE MEDIA AND FEEDING SCHEDULE STUDY

The results of the exponential and replacement feeding schedule studies are presented together for ease of comparison of each attribute on the same sampling dates. The statistical significance of the results of ANOVA (SPSS 1986) are presented in Table 21.

Table 21. A comparison of the significance of differences in height (HT), root collar diameter (RCD), top dry weight (TDW), root dry weight (RDW), and seedling dry weight (SDW) of *Eucalyptus globulus* stock grown in nine media treatments 30, 60, 90, and 120 days after germination under exponential and replacement feeding schedules.

Source of Variation	Measurement Attribute / No. of Days After Germination																			
	HT (cm)				RCD (mm)				TDW (mg)				RDW (mg)				SDW (mg)			
	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120
	I. Exponential feeding schedule																			
Treatments	S	S	NS	NS	S	S	NS	NS	NS	NS	S	S	NS	NS	NS	NS	NS	NS	S	S
	II. Replacement feeding schedule																			
Treatments	S	S	NS	NS	S	S	NS	NS	NS	NS	S	S	NS	NS	S	NS	NS	NS	S	S

Note: S = Significant difference; NS= Non significant difference ($p < 0.05$).

Where significant differences occur, the results for each attribute are presented in the sections that follow.

Height 30 and 60 Days After Germination

Table 21 shows significant differences in HT 30 and 60 days after germination under both the exponential and replacement feeding schedules. The significant differences in HT were lost after 90 days. The mean height of seedlings grown in the nine media 30 and 60 days after germination are presented in Table 22.

Table 22. Mean heights of *Eucalyptus globulus* seedlings grown in nine media under exponential and replacement feeding schedules 30 and 60 days after germination.

Proportions of media			Exponential Feeding		Replacement Feeding	
Sphagnum Peat (%)	Vermiculite (%)	Perlite (%)	No. of days after germ. 30 (cm)	60 (cm)	No. of days after germ. 30 (cm)	60 (cm)
33.0	17.0	50.0	3.49c	6.80d	4.13c	7.65b
33.3	33.3	33.3	3.78c	7.97c	4.51bc	7.74b
33.0	42.0	24.0	3.88c	7.78c	4.31c	7.88ab
33.0	67.0	0.0	4.58b	8.35bc	5.30a	7.17c
50.0	17.0	0.0	4.36bc	7.97c	4.30c	7.47b
50.0	33.0	17.0	4.52b	7.90c	5.0ab	8.15a
50.0	50.0	0.0	4.60b	8.18bc	5.0ab	8.15a
67.0	17.0	16.0	4.76b	9.01a	4.76bc	7.51b
67.0	33.0	0.0	5.45a	8.72a	5.45a	7.62b

Note: Mean HTs with the same letter were not significantly different from each other.

Seedlings grown in 33% *Sphagnum* peat were significantly shorter than those grown in either 50 or 67% *Sphagnum* peat under the exponential and replacement feeding schedules for the first 30 to 60 days. After 60 days there were no significant differences in height between the growing media.

Root Collar Diameter 30 and 60 Days After Germination

Table 21 shows significant differences in RCD 30 days after germination under both the exponential and replacement feeding schedules. The significance of differences in RCD was lost after 60 days from germination under the exponential feeding schedule and after 30 days under the replacement feeding schedule. The mean RCD of seedlings grown in the nine media 30 and 60 days after germination under the exponential and 30 days after germination under the replacement feeding schedules are presented in Table 23.

Table 23. Mean root collar diameters of *Eucalyptus globulus* seedlings grown in nine media under exponential and replacement feeding schedules 30 and 60 days after germination.

Proportions of media			Exponential Feeding		Replacement Feeding
Sphagnum Peat	Vermicu-lite	Perlite	No. of days after germination		days after germ.
			30	60	30
(%)	(%)	(%)	(mm)	(mm)	(mm)
33.0	17.0	50.0	9.1b	12.6c	9.1c
33.3	33.3	33.3	9.5b	12.5c	9.0c
33.0	42.0	24.0	8.9b	12.5c	9.8bc
33.0	67.0	0.0	10.0b	13.8a	11.0a
50.0	17.0	33.0	9.9b	13.5ab	9.5bc
50.0	33.0	17.0	9.8b	13.5ab	9.9bc
50.0	50.0	0.0	9.9b	14.1a	9.1c
67.0	17.0	16.0	9.9b	13.5ab	11.3a
67.0	33.0	0.0	11.0a	14.0a	10.4ab

Note: Mean RCDs with same letter were not significantly different from each other.

Seedlings grown in 33% *Sphagnum* peat were significantly thinner than those grown in either 50 or 67% *Sphagnum* peat for the first 30 days in both feeding schedules, and 60 days for exponential feeding schedule.

Seedling Dry Weight 90 Days After Germination

As seedling dry weight was the only significantly different attribute of morphological quality at the end of the study (Table 21, Figures 4, 5, 6, and 7), seedling dry weight results will be presented in detail.

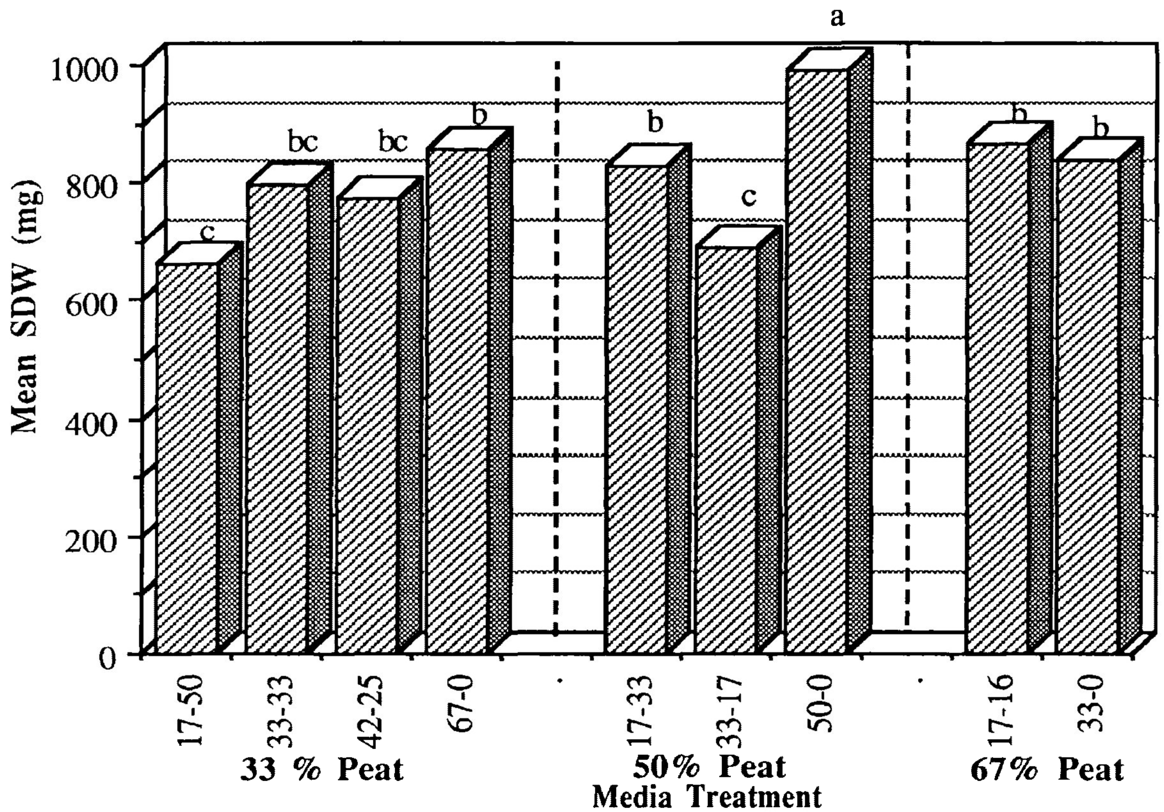


Figure 4. Mean seedling dry weights of *Eucalyptus globulus* stock grown in nine media under the exponential feeding schedule 90 days after germination.

Note: Media were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent respectively; media with same letter were not significantly different.

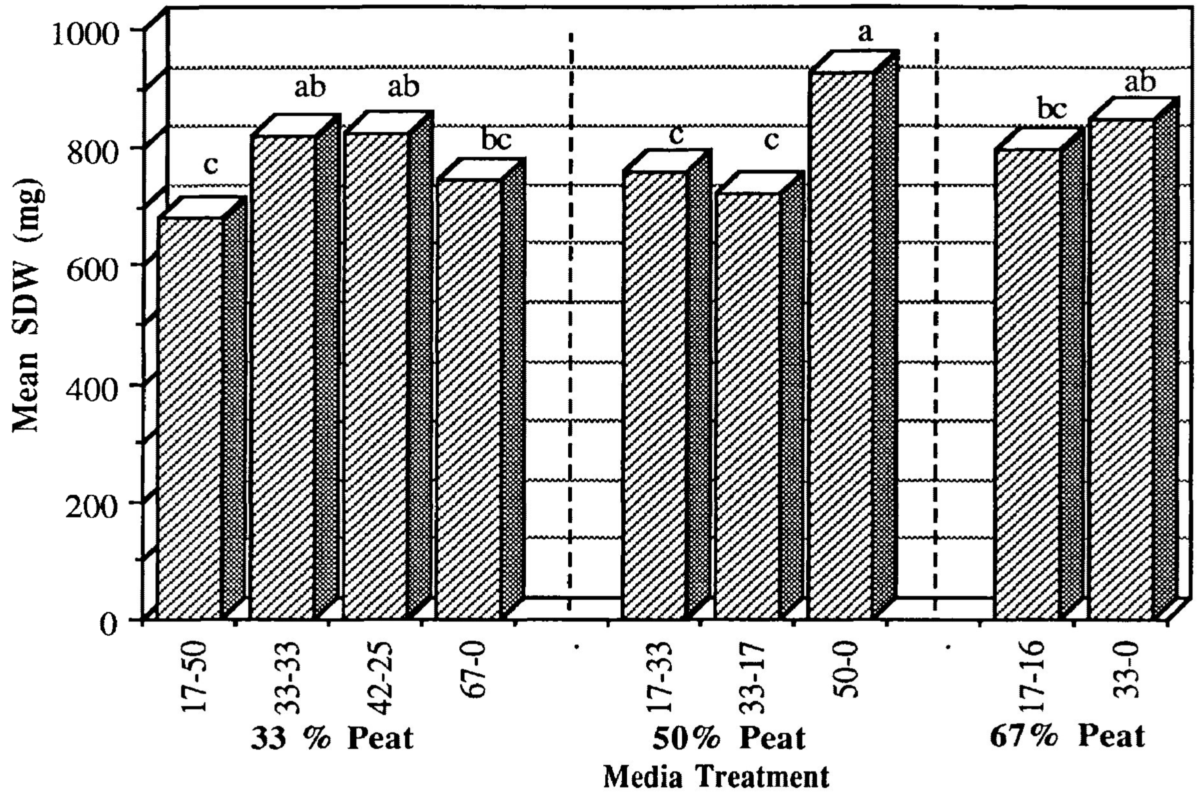


Figure 5. Mean seedling dry weights of *Eucalyptus globulus* stock grown in nine media under replacement feeding schedule 90 days after germination.

Note: Media were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent respectively; media with same letter were not significantly different.

Figures 4 and 5 did not show definite trend towards higher or lower seedling dry weight as the proportion of Vermiculite in the medium was increased (i.e. from 17 to 67%) in each *Sphagnum* peat level. Seedlings grown in 50% *Sphagnum* peat and 50% Vermiculite had the highest seedling dry weight under both feeding schedules.

Seedling Dry Weight 120 Days After Germination

Figure 6 presents the mean seedling dry weight under the exponential feeding schedule 120 days after germination.

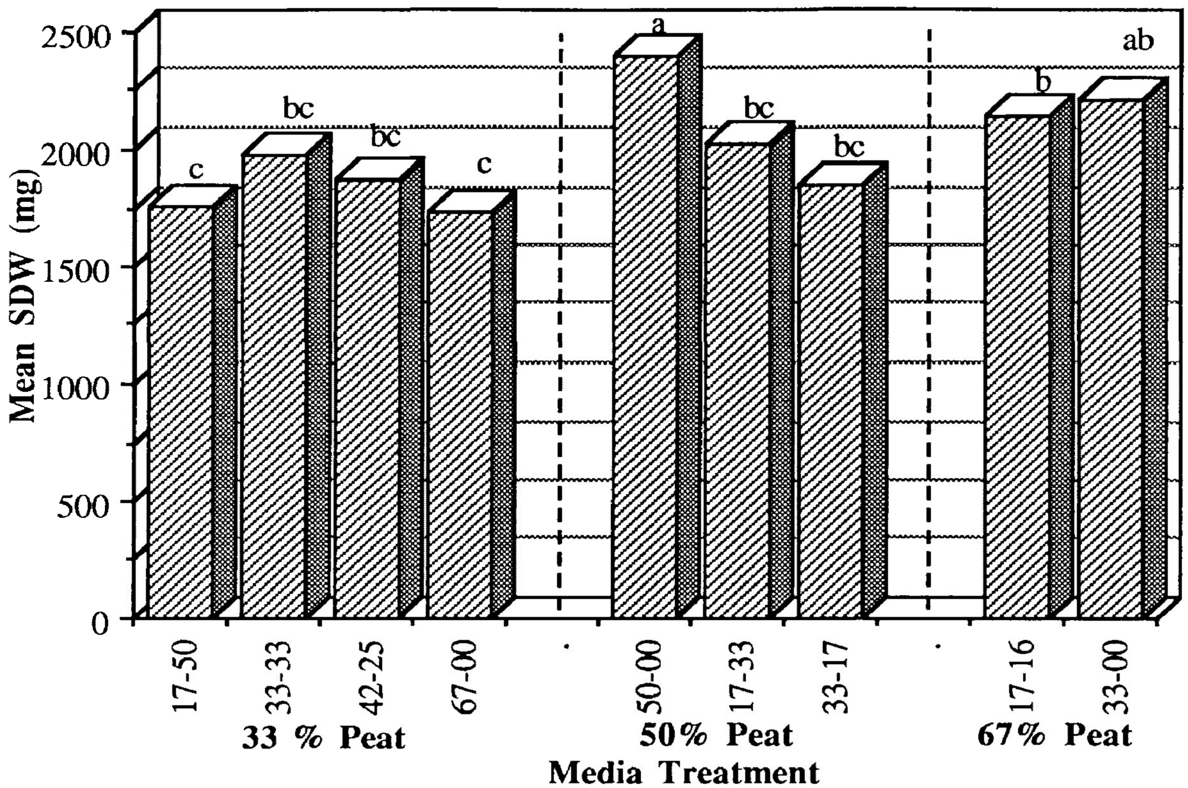


Figure 6. Mean seedling dry weights of *Eucalyptus globulus* stock grown in nine media under exponential feeding schedule 120 days after germination.

Note: Media were composed of *Sphagnum* peat level, Vermiculite, and Perlite in percent respectively; media with same letter were not significantly different.

Figure 7 presents the mean seedling dry weight under the replacement feeding schedule 120 days after germination. Figures 6 and 7 again did not show a definite trend towards higher or lower seedling dry weight as the proportion of Vermiculite in the medium was increased (i.e. from 17 to 67%) in each *Sphagnum* peat class. Seedlings grown in 50% *Sphagnum* peat and 50% Vermiculite again had the highest seedling dry weight under both feeding schedules.

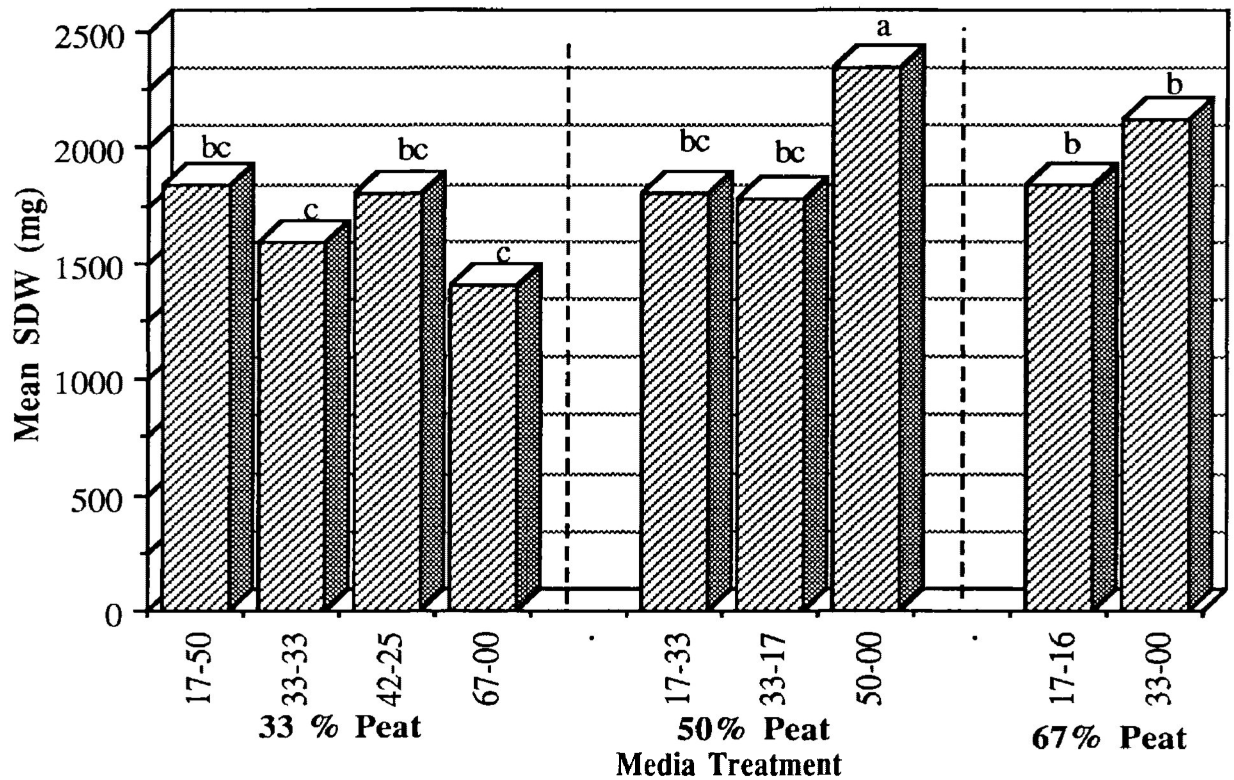


Figure 7. Mean seedling dry weights of *Eucalyptus globulus* grown in nine media under replacement feeding schedule 120 days after germination.

Note: Media were composed of *Sphagnum* peat level, Vermiculite, and Perlite in percent respectively; media with same letter were not significantly different.

Table 24 presents the mean seedling dry weight of *Eucalyptus globulus* stock grown in 33-, 50- and 67% of *Sphagnum* peat levels 90 and 120 days after germination.

Table 24. Mean seedling dry weights of *Eucalyptus globulus* stock grown in 33-, 50-, and 67% *Sphagnum* peat classes under exponential and replacement feeding schedules 90 and 120 days after germination.

Sphagnum peat class (%)	Exponential Feeding		Replacement Feeding	
	Number of days after germ.		Number of days after germ.	
	90	120	90	120
	(mg)	(mg)	(mg)	(mg)
33	771.8	1835.5	751.7	1632.0
50	836.4	2090.7	813.3	1974.7
67	853.5	2175.0	822.2	1835.6
Grand Mean	820.6	2033.7	795.7	1862.1

Note: Mean seedling dry weights linked by a line were not significantly different.

A students t tests showed significant differences between seedlings grown in the three *Sphagnum* peat classes (Table 25).

Table 25. Students t values for comparison of mean seedling dry weights of *Eucalyptus globulus* stock grown in 33-, 50-, and 67% *Sphagnum* peat classes under exponential and replacement feeding schedules 90 and 120 days after germination.

Comparisons of *Sphagnum* peat class (%)	Exponential Feeding Number of days after germ.		Replacement Feeding Number of days after germ.	
	90	120	90	120
33 to 50	2.82*	4.17**	2.82*	4.88**
33 to 67	2.20*	2.28**	2.18*	2.30*
50 to 67	< 1	< 1	< 1	< 1

* - significant at the 0.05% level.

** - significant at the 0.01% level.

Seedlings grown in 33% *Sphagnum* peat were significantly lighter than those grown in either 50- or 67% *Sphagnum* peat (Tables 24 and 25). Table 26 presents the mean seedling dry weight and its significant differences ($p < 0.05$) between stock grown in the nine media under both feeding schedules 120 days after germination.

Table 26. Mean seedling dry weights of *Eucalyptus globulus* stock and its significance ($p < 0.05$) for nine media treatments under exponential and replacement feeding schedules 120 days after germination.

Growing Media No.	Exponential Feeding Schedule Growing Medium	(mg)	Signif-icance	Replacement Feeding Schedule Treat. No.	Growing Medium	(mg)	Signif-icance
7	50-50-00	2399.0		7	50-50-00	2342.3	
9	67-33-00	2208.0		9	67-33-00	2117.9	
8	67-17-16	2137.7		8	67-17-16	1841.3	
5	50-17-33	2023.0		3	33-42-25	1825.0	
2	33-33-33	1979.0		5	50-17-33	1803.0	
3	33-42-25	1871.6		6	50-33-17	1779.0	
6	50-33-17	1850.2		1	33-17-50	1703.7	
1	33-17-50	1757.7		2	33-33-33	1596.7	
4	33-67-00	1733.5		4	33-67-00	1404.0	

Notes: Media were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; growing medium number as described in table 12. Media linked by a line were not significantly different from each other.

Dickson's Seedling Quality Index

There was no definite trend towards higher or lower DSQI (Dickson *et al* 1960) values as the proportion of *Sphagnum* peat in the medium was increased from 33 to 67%, but seedlings grown in 50% and 67% *Sphagnum* peat had higher DSQI than those grown in 33% peat (Table 27).

Table 27. Dickson's Seedling Quality Indices (DSQI) for *Eucalyptus globulus* stock grown in nine media under exponential and replacement feeding schedules 120 days after germination.

Medium No.	Growing Medium	Exponential feeding	Replacement feeding
1	33-17-50	0.365	0.359
2	33-33-33	0.386	0.368
3	33-42-25	0.364	0.355
4	33-67-00	0.337	0.322
5	50-17-33	0.379	0.345
6	50-33-17	0.372	0.33
7	50-50-00	0.445	0.415
8	67-17-16	0.390	0.371
9	67-33-00	0.405	0.391
	Mean	0.383	0.362

Note: Growing media were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent respectively.

Response Surface for Seedling Dry Weight

The standard least squares techniques (Anderson and McLean 1974) were used on the seedling dry weight data to obtain the complete quadratic model (EQ 1). The coefficient of determination (R^2) for the model was 0.99.

$$Y = 1515.35X_1 + 94.02X_2 + 1481.86X_3 + 5628.8X_1X_2 + 1367.56X_1X_3 + 662.85X_2X_3 \quad \text{[EQ 1]}$$

Where Y = seedling dry weight in mg,
X_1 = *Sphagnum* peat %,
X_2 = Vermiculite %,
X_3 = Perlite %

The quadratic model was used to develop the response surface presented in Figure 8 and to determine proportions of a *Sphagnum* peat, Vermiculite, and Perlite medium that would produce seedlings of maximum dry weight in the experimental region. Seedling dry weight increased with *Sphagnum* peat, but decreased with the increase of Perlite.

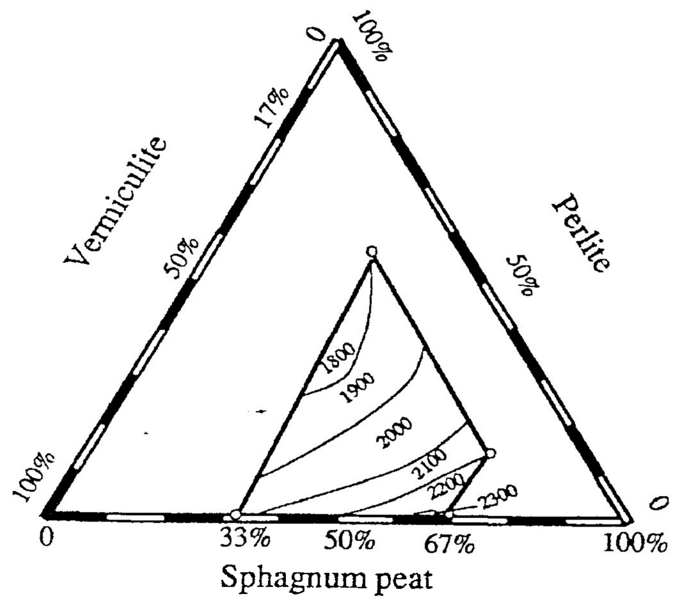


Figure 8. Response surface for the effects of various proportions of *Sphagnum* peat, Vermiculite, and Perlite on seedling dry weight of *Eucalyptus globulus* stock.

Note: The contours in the figure show the predicted seedling dry weight (mg) at 100 mg step in the experimental region. The lowest and highest predicted seedling dry weights were 1840 and 2302 mg.

The highest seedling dry weight range (i.e. 2290 - 2302 mg) lies between 60 to 67% *Sphagnum* peat, 33 to 40% Vermiculite, and 0 to 3% Perlite in the experimental region. The highest predicted seedling dry weight value was found at 62% *Sphagnum* peat and 38% Vermiculite.

THE MEDIA AND CONTAINER COATING STUDY

The significant results of each attribute in the media and container coating study are presented in the sections that follow. Table 28 summarizes the significance of HT, RCD, TDW, RDW, and SDW results after statistical analysis by ANOVA.

Table 28. A comparison of the significance of differences in height (HT), root collar diameter (RCD), top dry weight (TDW), root dry weight (RDW), and seedling dry weight (SDW) of *Eucalyptus globulus* stock at 30, 60, 90, and 120 days after germination in the media and container coating study.

Source of Variation	Measurement Attribute / No. of Days After Germination																			
	HT (cm)				RCD (mm)				TDW (mg)				RDW (mg)				SDW (mg)			
	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120	30	60	90	120
Treatments	S	S	NS	NS	NS	S	NS	NS	NS	NS	S	S	NS	NS	S	S	NS	NS	S	S

Note: S = Significant difference; NS= Non significant difference ($p< 0.05$).

Height 30 and 60 days after germination.

The significance of difference in HT was lost after 90 days (Table 28). Mean height of seedlings grown in the eight media in both coated and uncoated containers 30 and 60 days after germination are presented in Table 29.

Table 29. Mean heights of *Eucalyptus globulus* seedlings grown in eight media in both coated and uncoated containers 30 and 60 days after germination.

Medium No.	Growing medium	Coated containers No. of days after germ 30	Coated containers No. of days after germ 60	Uncoated containers No. of days after germ 30	Uncoated containers No. of days after germ 60
	Pb-S-V-P*	(cm)	(cm)	(cm)	(cm)
1	100-0-0-0	10.1bc	22.5ab	10.2bc	20.7bc
2	50-0-50-0	9.8bc	19.9c	11.3ab	18.1d
3	37-37-25-0	7.6d	24.8a	9.5bc	23.2ab
4	0-100-0-0	9.3bc	17.1d	11.8a	21.4ab
5	0-33-33-33	7.6d	24.8a	9.5bc	23.2ab
6	0-67-33-0	7.4d	16.9d	8.2cd	21.1bc
7	0-50-50-0	8.1d	19.1cd	8.6cd	21.3b
8	0-50-33-17	7.4d	16.7d	8.2cd	22.1ab

Note*: Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively. Mean heights with same letter were not significantly different at $p< 0.05$.

There was no definite trend towards taller or shorter height as the proportion of radiata pine bark in the medium was increased from 0 to 100% either in coated or uncoated containers (Table 29).

Root Collar Diameter 60 days after germination.

Root collar diameter of the seedlings grown in the eight media in both coated and uncoated containers were significantly different only at 60 days after germination (Tables 28 and 30).

Table 30. Mean root collar diameters of *Eucalyptus globulus* seedlings grown in eight media in both coated and uncoated containers 60 days after germination.

Medium No.	Growing Medium	Coated	Uncoated
	Pb-S-V-P*	(mm)	(mm)
1	100-0-0-0	18.0a	18.2a
2	50-0-50-0	15.0b	18.1a
3	37-37-25-0	19.8a	18.8a
4	0-100-0-0	15.6b	18.5a
5	0-33-33-33	15.9b	15.5b
6	0-67-33-0	14.3b	15.9b
7	0-50-50-0	18.8a	19.6a
8	0-50-33-17	14.5b	15.3b

Note*: Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively. Mean root collar diameters with same letter were not significantly different at $p< 0.05$.

Root Dry Weight

Root dry weight of seedlings grown in the eight media in both coated and uncoated containers were not significantly different 30 and 60 days after germination, but became significantly different after 90 days (Table 28). The mean RDW of seedlings grown in the eight media 90 and 120 days after germination are presented in Table 31.

Table 31. Mean root dry weights of *Eucalyptus globulus* seedlings grown in eight media in both coated and uncoated containers 90 and 120 days after germination.

Medium No.	Growing medium	Coated containers No. of days after germ 90	Coated containers No. of days after germ 120	Uncoated containers No. of days after germ 90	Uncoated containers No. of days after germ 120
	Pb-S-V-P*	(mg)	(mg)	(mg)	(mg)
1	100-0-0-0	217.8ab	286.7a	191.83b	287.3a
2	50-0-50-0	209.3ab	312.9a	223.2a	276.0ab
3	37-37-25-0	238.7a	303.6a	135.0c	253.1ab
4	0-100-0-0	216.5ab	278.1ab	234.8a	273.5ab
5	0-33-33-33	146.7c	240.8ab	169.5bc	175.1b
6	0-67-33-0	161.3bc	271.8ab	142.5c	242.9ab
7	0-50-50-0	159.0bc	245.7ab	217.6ab	283.0a
8	0-50-33-17	183.3bc	284.2a	217.2ab	195.4ab
	Mean	191.1	277.9	191.5	248.3

Note*: Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively. Mean root dry weights with same letter were not significantly different at $p < 0.05$.

Seedlings grown in the eight media in both coated and uncoated containers showed considerable variation in RDW. Seedlings grown in uncoated containers filled with 100% *Sphagnum* peat and 67% *Sphagnum* peat and 33% Vermiculite had the lowest root dry weight 120 days after germination (Table 31). A students t test showed significant differences between the RDW of seedlings grown in coated and uncoated containers 120 days after germination. Seedlings grown in coated containers averaged higher root dry weight than those grown in uncoated containers.

Seedling Dry Weight

There were no significant differences in SDW 30 and 60 days after germination. However, significant differences occurred after 90 days (Table 28). As seedling dry weight is a good descriptor of the quality of stock and as it was significant at the end of this study, its results will be presented in detail.

Seedling Dry Weight 90 Days After Germination

Figure 9 presents the mean seedling dry weight of *Eucalyptus globulus* stock grown in the eight media in both coated and uncoated containers 90 days after germination.

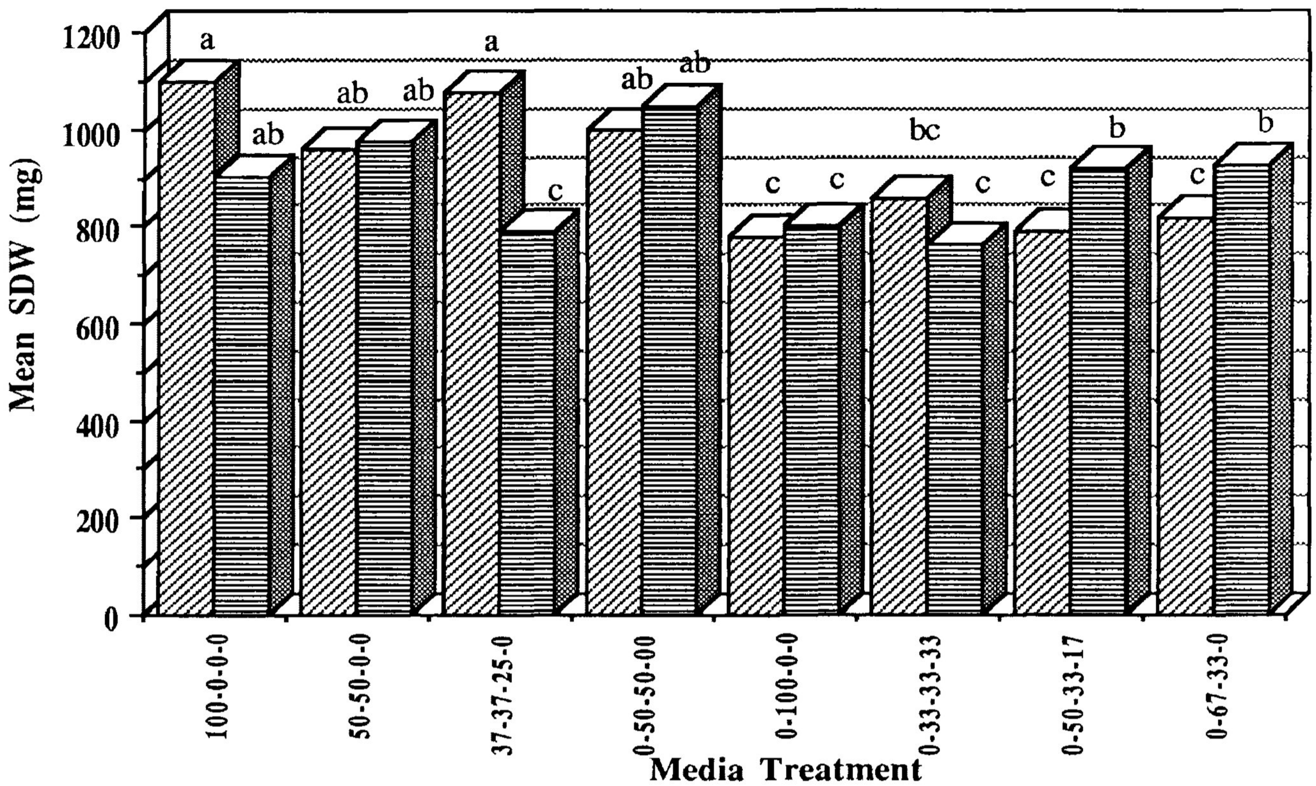


Figure 9. Mean seedling dry weights of *Eucalyptus globulus* stock grown in eight media in coated and uncoated containers 90 days after germination.

Note: Diagonally hatched bars indicate coated container; cross hatched bars indicate uncoated containers. Media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; significant difference between the media are indicated by different letters.

Seedlings grown in 37.5% radiata pine bark, 37.5% *Sphagnum* peat and 25% Vermiculite had significantly higher seedling dry weight in coated containers than their counter part grown in uncoated containers (Figure 9).

Seedling Dry Weight 120 Days After Germination

There were no significant differences in SDW 30- and 60-days after germination, the differences became significant after 90-days. In coated containers *Eucalyptus globulus* seedlings grown in 100% radiata pine bark which was best medium for SDW were 33.4% heavier than those grown in 50% *Sphagnum* peat, 33% radiata pine bark and 17% Vermiculite which was the worst medium. In uncoated containers seedlings grown in 37.5 radiata pine bark, 37.5% *Sphagnum* peat, and 25% Vermiculite which was the best medium for SDW were 42.5% heavier than those grown in 100% *Sphagnum* peat which was the worst medium (Table 3).

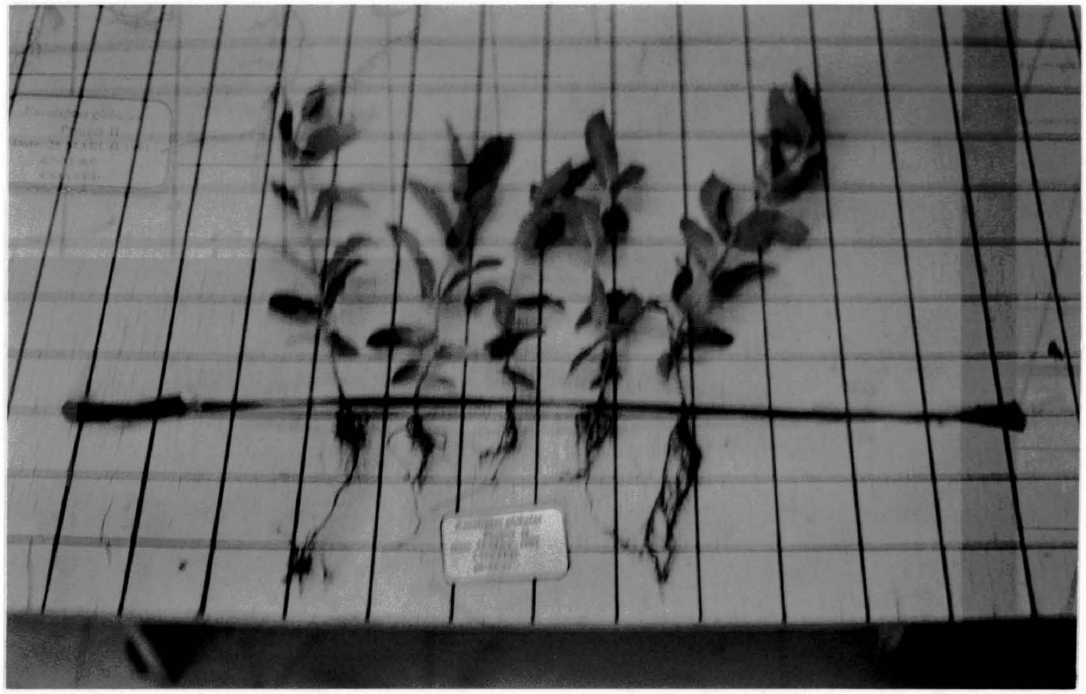
Table 32. Mean seedling dry weights and their significance ($p < 0.05$) for *Eucalyptus globulus* seedlings grown in eight media in coated containers 120 days after germination.

Medium No.	Growing Medium	Coated	Uncoated
	Pb-S-V-P*	(mg)	(mg)
1	100-0-0-0	1493.2a	1311.9ab
2	50-0-50-0	1457.0a	1411.6ab
3	37-37-25-0	1432.0ab	1481.2a
4	0-100-0-0	1422.0ab	1039.0b
5	0-33-33-33	1329.8ab	1410.0ab
6	0-67-33-0	1283.5ab	1074.0b
7	0-50-50-0	1244.5ab	1303.0ab
8	0-50-33-17	1119.0ab	1145.0ab
	Mean	1347.0	1272.0

Note*: Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively. Mean seedling dry weights with same letter were not significantly different at $p < 0.05$.

The SDW of the stock grown in the eight media in coated and uncoated containers ranged from 1119 to 1493 mg and from 1039 to 1481 mg, respectively. Seedlings grown in 67% *Sphagnum* peat and 33% Vermiculite, and in 50% *Sphagnum* peat, 33% Vermiculite and 17% Perlite had the lightest seedling dry weights in both coated and uncoated containers (Table 32). A students t test (Milliken and Johnson 1984) showed significant differences in seedling dry weight between the seedlings grown in coated and uncoated containers. Seedlings grown in coated containers averaged 6% higher in seedling dry weight than those grown in uncoated containers.

Figure 10 depicts the roots of *Eucalyptus globulus* seedlings grown in coated and uncoated containers at the end of the experiment.



a.

b.

Figure 10. Roots of *Eucalyptus globulus* seedlings grown in a) coated containers and b) uncoated containers at the end of the experiment.

The DSQI values did not show a definite trend towards higher or lower values as the proportion of radiata pine bark in the medium was increased from 0 to 100%. Seedlings grown in coated containers had higher DSQI value than those grown in uncoated containers, but seedlings grown in 0-50-50-0 showed the opposite (Table 33).

Table 33. Average Dickson's Seedling Quality Indices (DSQI) of *Eucalyptus globulus* seedlings grown in eight media in both coated and uncoated containers 120 days after germination.

Medium No.	Growing Medium	Coated	Uncoated
	Pb-S-V-P*		
1	100-0-0-0	0.28	0.24
2	50-0-50-0	0.30	0.27
3	37-37-25-0	0.29	0.17
4	0-100-0-0	0.30	0.27
5	0-33-33-33	0.27	0.23
6	0-67-33-0	0.22	0.19
7	0-50-50-0	0.25	0.29
8	0-50-33-17	0.25	0.24
	Mean	0.27	0.24

Note*: Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively.

Table 34 presents the top to root dry weight ratios of seedlings grown in the eight media in both coated and uncoated containers 120 days after germination.

Table 34. Top dry weight to root dry weight ratio of *Eucalyptus globulus* seedlings grown in eight media in both coated and uncoated containers 120 days after germination.

Medium No.	Growing Medium	Coated	Uncoated
	Pb-S-V-P*		
1	100-0-0-0	4.21	3.57
2	50-0-50-0	3.66	4.14
3	37-37-25-0	3.72	4.85
4	0-100-0-0	4.91	4.93
5	0-33-33-33	3.89	4.813
6	0-67-33-0	3.52	4.49
7	0-50-50-0	3.50	3.76
8	0-50-33-17	3.55	3.05
	Mean	3.87	4.2

Pb-S-V-P indicates radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent in a growing medium, respectively.

There was no definite trend in top to root dry weight ratio between the seedlings grown in coated and uncoated containers. However, seedlings grown in uncoated containers averaged a higher top to root dry weight ratio than those grown in coated containers (Table 34).

Root Growth Potential (RGP) Test

Growth Chamber RGP Test

The ANOVA of root number (RN) and root elongation (RE), at the end of the test period, showed significant differences in RE between the seedlings tested. However, there was no statistically significant difference in RN. Table 35 summarizes the RN and RE results of the growth chamber test after 14 days.

Table 35. Root number and root elongation of *Eucalyptus globulus* seedlings in growth chamber test after 14 days.

Growing medium	Container type	Average RN				Average RE (cm)			
		<0.5	.5-1	>1	Total	<0.5	0.5-1	>1	Total
100-0-0-0	Coated	2	3	287	292	0.02	0.07	91.1	91.19
100-0-0-0	Uncoated	5	3	279	287	0.08	0.12	81.3	81.5
50-0-50-0	Coated	4	4	250	258	0.08	0.12	86.7	86.9
50-0-50-0	Uncoated	1	5	268	274	0.02	0.19	84.4	84.61
37-37-25-0	Coated	0	5	268	273	0.00	0.21	91.1	91.31
37-37-25-0	Uncoated	3	1	213	217	0.04	0.03	57.2	57.27
0-50-50-0	Coated	0	2	191	193	0.00	0.08	66.5	66.58
0-50-50-0	Uncoated	2	1	205	208	0.00	0.05	56.2	56.25

Note: Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively.

Seedlings grown in coated containers had higher root elongation than those grown in uncoated containers, even though they were grown in the same media (Table 35; Figure 11). Figure 11 presents root elongation in the growth chamber test after 14 days.

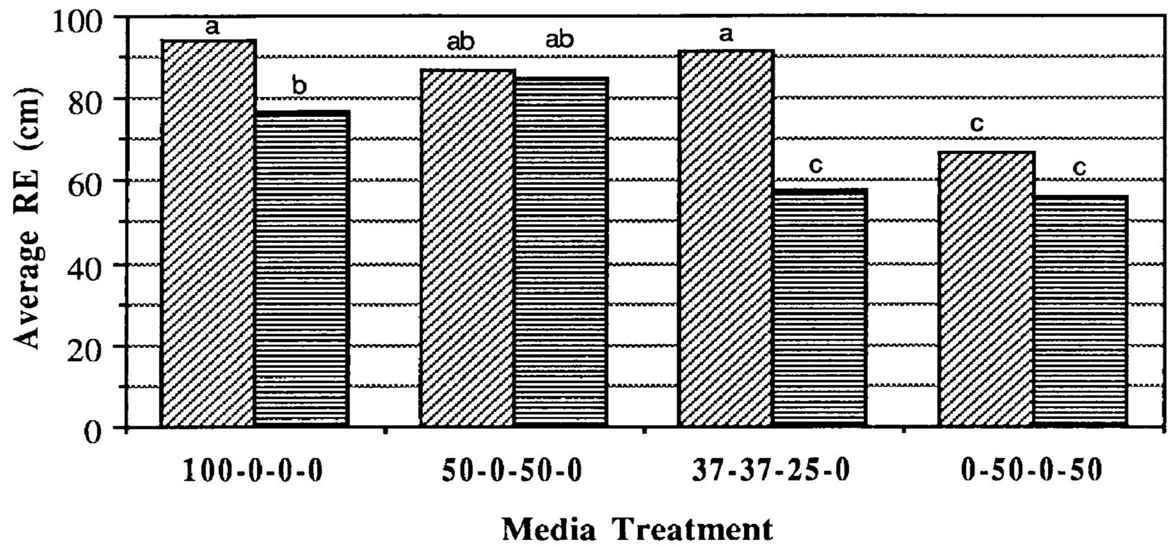


Figure 11. Root elongation of *Eucalyptus globulus* seedlings in growth chamber root growth potential test after 14 days

Notes: 1. Diagonally hatched bars = coated containers; Cross hatched bars = uncoated containers.

2. Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; root elongation (RN) with same letters were not significantly different from each other.

Seedlings grown in 50 % *Sphagnum* peat with 50% Vermiculite and 50 % radiata pine bark with 50% Vermiculite, did not show significant differences in RE; seedlings grown in 100% radiata pine bark, and 37.5 % *Sphagnum* peat, 37.5 radiata pine bark and 25% Vermiculite had the highest root elongation (Figure 11).

The Hydroponic RGP Test Results

Table 36 summarizes the hydroponic test results and compares the statistical significance. There were significant differences in RN and RE after the 15^{th} day.

Table 36. Comparison of the significance of differences in root number and root elongation of *Eucalyptus globulus* seedlings in hydroponic root growth potential test after 5, 10, 15, and 20 days.

Source of Variation	RN and RE / no. of days after the start of the hydroponic test							
	RN				RE(cm)			
	5	10	15	20	5	10	15	20
Treatments	NS	NS	S	S	NS	NS	S	S

Note: S = Significant difference; NS= Non-significant difference at $p<0.05$.

Figures 12 and 13 present the average root elongation and root number in the hydroponic RGP test after 15 days.

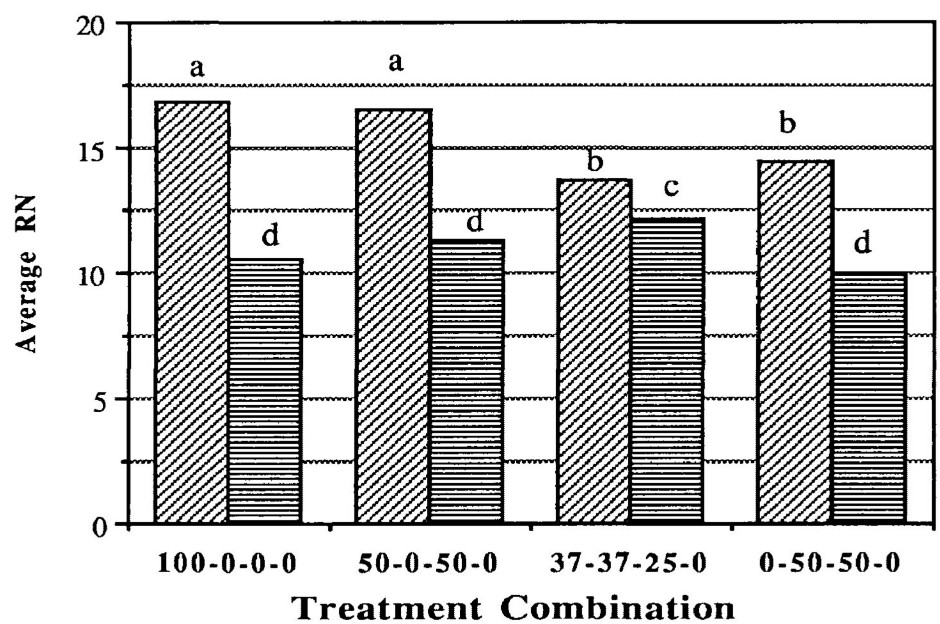


Figure 12. Average root numbers of *Eucalyptus globulus* seedlings in hydroponic root growth potential test after 15 days.

Notes: 1. Diagonally hatched bars = coated containers; Cross hatched bars = uncoated containers.

2. Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; root number (RN) with same letters were not significantly different from each other.

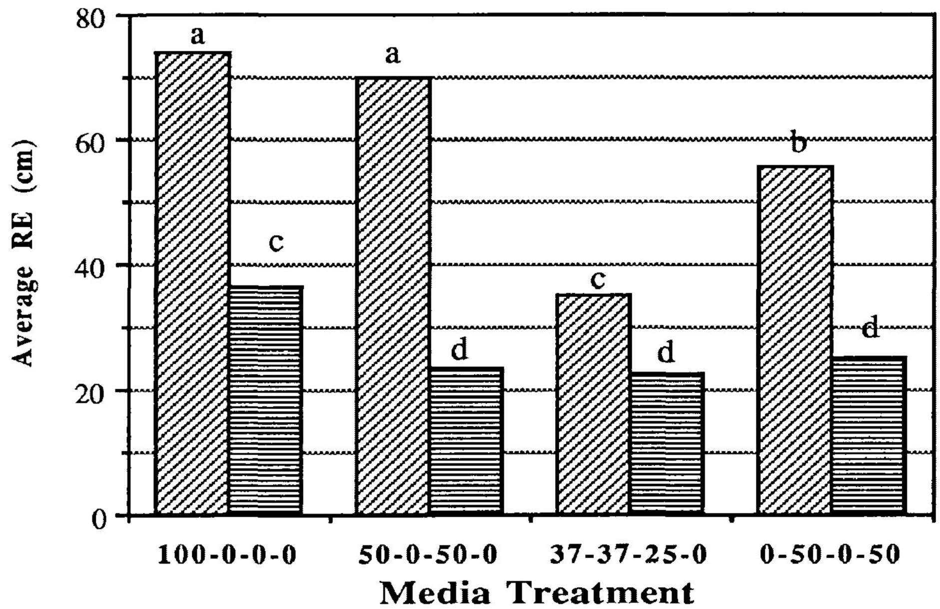


Figure 13. Average root elongation of *Eucalyptus globulus* seedlings in hydroponic root growth potential test after 15 days.

Notes: 1. Diagonally hatched bars = coated containers; Cross hatched bars = uncoated containers.

2. Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; root elongation (RE) with same letter were not significantly different from each other.

Figures 12 and 13 show that seedlings grown in coated containers had significantly higher root elongation than those grown in uncoated containers.

Figure 14 presents the average root number in the hydroponic RGP test after 21 days.

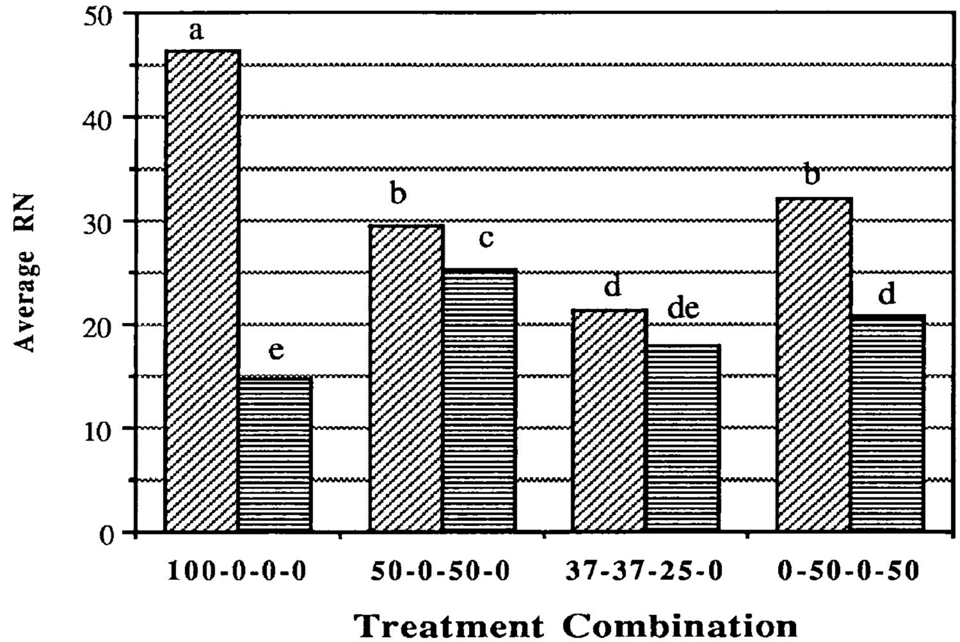


Figure 14. Average root numbers of *Eucalyptus globulus* seedlings in hydroponic root growth potential test after 21 days.

Notes: 1. Diagonally hatched bars = coated containers; Cross hatched bars = uncoated containers.

2. Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; root number (RN) with same letter were not significantly different from each other.

Seedlings grown in coated containers filled with 100% radiata pine bark had the highest root number. The differences in root number between seedlings grown in coated and uncoated containers were highly significant in 100% radiata bark, and 50% *Sphagnum* peat with 50% Vermiculite (Figure 14).

Figure 15 presents the average root elongation in the hydroponic RGP test after 21 days.

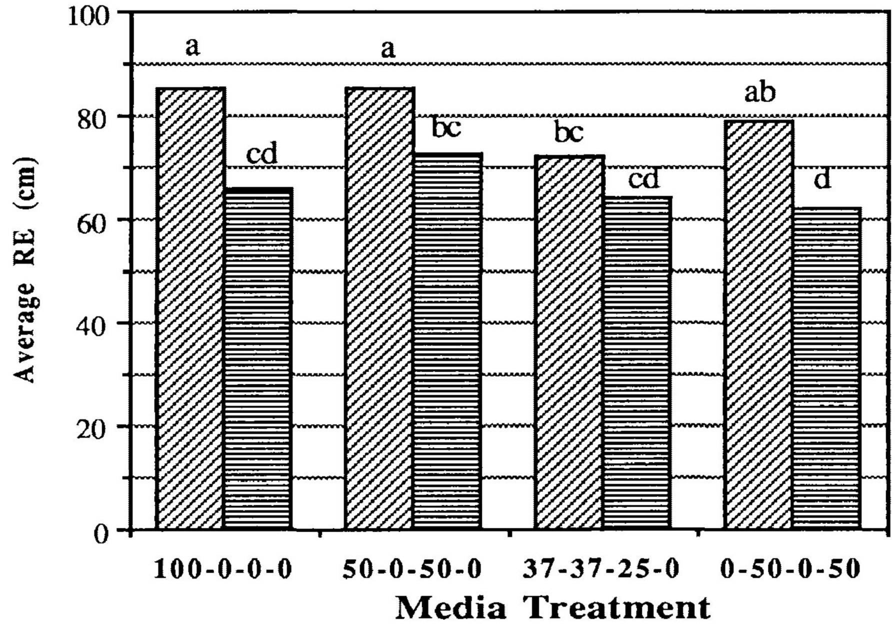


Figure 15. Average root elongation of *Eucalyptus globulus* seedlings in hydroponic root growth potential test after 21 days.

Note: 1. Diagonally hatched bars = coated containers; Cross hatched bars = uncoated containers.

2. Growth media were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively; root elongation (RE) with same letter were not significantly different from each other.

Seedlings grown in coated containers had shorter root elongation than those grown in uncoated containers (Figure 15). There was a strong positive correlation (r = 0.83) between RN and RE.

DISCUSSION

THE QUESTIONNAIRE

The reader should be aware that this discussion is based on the responses derived from the 24 nurseries in nine countries. The number of seedlings produced by individual nurseries ranged from 3500 to 9 million (Table 14). The five most commonly grown *Eucalyptus* species were *grandis*, *nitens*, *regnans*, *smithii*, and *globulus* in descending order. These species were grown by 4, 8, 4, 3, and 9 nurseries respectively. *E. globulus* was the fifth most widely grown species. Eighty four percent of the *Eucalyptus* seedlings were grown in containers. The APPM Forest nursery of Australia, Karuri nursery of Kenya, and Taradale nursery of New Zealand grew both bare root and container stock; the remaining nurseries grew only container stock. *E. camaldulensis, E. fastigata, E. fraxinoides, E. globulus, E. grandis, E. nitens, E. obliqua, E. regnans, and E. saligna* were grown both as bare root and container stock. The remaining *Eucalyptus* species were grown only as container stock. *E. nitens,* followed by *E. globulus*, had the highest number of bare root stock.

The results of the questionnaire showed that the five generic groups of containers used for *Eucalyptus* production were very variable in diameter, depth, diameter to depth ratio, and volume. These variations show considerable differences in the container configurations which can affect growth and development of seedlings. The containers used for *Eucalyptus* production averaged 4.8 cm in diameter, 11.9 cm in depth, 1:2.6 in diameter to depth ratio, and 112.4 ml in volume. It is interesting to note that book planters had the greatest average volume of 262.0 ml, followed by plastic tubes with 130.3 ml and peat pots with 103.3 ml. The smallest containers were paper pots with 67.3 ml and peat pots with 48.7 ml (Table 37).

As the paper and peat pots used for *Eucalyptus* production in tropical and subtropical areas ranged in volume from 33 to 88 ml and the Leach and LaBelle styrofoam blocks used in Florida ranged in volume from 47 to 78 ml, *Eucalyptus* can be grown for outplanting in tropical and subtropical areas in containers of this size range. Nurseries in the tropical climates use both high and low volume containers. For instance, the

Queensland Forestry Department (QFD) tubes have a diameter of 4.0 cm, depth of 7.0 cm, diameter to depth ratio of 1 to 4.3, and volume of 170 ml. Forestry companies in Portugal (e. g. Celby and Afocel) use FS 510 and PS 510 Ecopots with a diameter of 5 cm, depth of 8 cm, diameter to depth of 1 to 1.6 and volume of 121 ml (Day 1989). On the other hand, the Starlite tube is widely used in Brazil and has diameter of 2.9 cm, depth of 12.5 cm, diameter to depth ratio of 1 to 4.3, and volume of 50 ml. Even though the Ropack multi pots, BC/CFS Styroblocks and Ventblocks are well designed for efficiency in the greenhouse and shipping phases, none of the 21 nurseries used them. This might be attributed to their cost and/or lack of knowledge about their existence.

Table 37. Ranges and means of diameter, depth, diameter to depth ratio, and volume of major containers types used for *Eucalyptus* production.

Container Types	Diameter		Depth		Diam./Depth	Volume	
	Range (cm)	Mean (cm)	Range (cm)	Mean (cm)	Ratio Range	Range (ml)	Mean (ml)
Plastic pots	3.5 - 5.0	4.2	7.0-9.0	7.7	1:1.4-1:2.3	56.0-175	103.7
Paper pots	3.0 - 4.0	3.7	7.5-15.0	10.2	1:1.5-1:2.5	44.0-80	67.3
Peat pots	4.0 - 6.0	5.0	5.0-6.0	5.3	1:1.0-1:1.3	33.0-80	48.7
Plastic tubes	2.8 -10.0	5.0	12.2-21.0	14.5	1:1.5-1:5.6	89.0-175	118.2
Book planters	-	3.8	12.0-20.3	16.2	1:3.1-1:5.6	173.0-350	262.0
Average		4.3		10.8			128.0

Day (1989b) recommended that container cavity used for *Eucalyptus globulus* production at West Manjimup nursery in western Australia should be increased to an absolute minimum of 100 ml. It is very probable that *E. globulus* seedlings grown in low volume containers will have restricted root growth.

The major components of the growing media used for *Eucalyptus* production were soil, composted bark, sawdust, *Sphagnum* peat, Vermiculite, and Perlite. Pine bark was the most widely used medium; 100% pine bark was widely used by the nurseries in South Africa. Only the small Cornflower and Lyon Tree Farm nurseries of California, and Taipei nursery of Taiwan used peat-lite mixes (Table 17). Most of the nurseries used bark-based media. This can be attributed to the following bark attributes: 1) it is cheap and easily available; 2) it provides a light, well aerated and well drained medium; and 3) it contains most minor elements. As fresh bark has alkalinity problems, only composted bark is used. Almost all 24 nurseries prepared the growing media manually (Table 17).

The following nurseries use both granular and liquid fertilizers before and after sowing, respectively: Karuri of Kenya; Timber growers of South Africa; Kebaro of

Indonesia; and Corn flower and Monterey Bay of California. The Austra-Flora and Valleycrest nurseries of California, the Sunshine nursery of South Africa, and the Taipei nursery of Taiwan use liquid fertilizers. The Casilla nursery of Ecuador does not use fertilizer at all and the Taradale nursery of New Zealand did not give information about the types of fertilizers they used. The remaining 13 nurseries used granular fertilizers and put the fertilizer in the medium before sowing; most of the nurseries used granular fertilizer (Table 18).

Osmocote, Magamp, Urea, and Prokote are either plastic prill coated or granular, slow release fertilizers and are added to the growing media before sowing. These slow release fertilizers cannot be regulated throughout the growing period to meet the changing needs of the seedlings. Ammonical nitrogen, ammonium phosphate, ammonium nitrate, potassium nitrate, monoammonium phosphate and diammonium phosphate are liquid fertilizers that are applied after sowing. These liquid fertilizers can be regulated throughout the growing season to control the growth of the stock at the nursery.

Excessive drying, water logging and insects pests were the prominent problems associated with growing media. Problems associated with growing media were reported by nurseries that use either soil-based or bark-based media. Most nurseries used preventive methods (i.e. soil screening and sterilization) (Table 19).

The standards which must be met before outplanting of *Eucalyptus* species varied from nursery to nursery. For instance, height ranged from 20 to 60 cm, root collar diameter ranged from 1.3 to 5 mm, and shoot to root ratio ranged from 1 to 1 up to 4 to 1 (Table 20). The average height, diameter, and top to root ratio used by these nurseries were 30 cm, 3.5 mm, and 2.7 to 1, respectively. Only the Sappi forest nursery of South Africa uses shoot (800 gm) and root dry weight (250 gm) as standards for outplanting of *Eucalyptus* seedlings. Lewis A. Moran nursery in California used the number of leaves (seven pairs of leaves) as a standard for outplanting of *Eucalyptus* seedlings. The Zappa nursery of South Africa outplanted the tallest seedlings (i. e. 60 to 90 cm) and the Valleycrest nursery of the USA outplanted the shortest and thinnest seedlings. The Sappi forest nursery of South Africa outplanted the shortest and thickest seedlings (Table 20). Day (1989) recommended the following seedling morphological attributes before outplanting of *Eucalyptus* seedlings: 1) seedling dry weight of 1.5 g; 2) top dry weight of 1.07 g; and 3) root dry weight of 0.43 g. None of the nurseries responding to the questionnaire used any of the above morphological attributes as standards for outplanting.

THE MEDIA AND FEEDING SCHEDULE STUDY

Height and Root Collar Diameter

There were significant differences in HT between the seedlings grown in the nine media in both the exponential and replacement feeding schedules 30 and 60 days after germination, but these differences were lost after 60 days (Table 21). This loss of significance may be related to the seedlings attaining a maximum height in the 98 ml MP # 3-96 containers. More over, there were significant differences in RCD between the seedlings grown in the nine media under both feeding schedules 30 days after germination and 60 days after germination under the exponential feeding schedule. The HT and RCD results were not significant after 60 days of germination (at the end of the experiment), therefore, height and root collar diameter results are not useful in determining or comparing the size and quality of finished *E. globulus* stock in MP#3-96 containers.

Top and Root Dry Weight

There were no significant differences in TDW between the seedlings grown in the nine media under either the exponential or replacement feeding schedules 30 and 60 days after germination, but there were significant differences after 90 days (Table 21). There were no significant differences in RDW between the seedlings grown in the nine media under the exponential feeding schedule. However, significant differences in RDW occurred 90 days after germination under the replacement feeding schedule.This significant difference in root dry weight can be attributed to sampling error (Table 21).

Seedling Dry Weight

There were no significant differences in SDW between the nine media either under the exponential or the replacement feeding schedule 30 or 60 days after germination. However, there were significant differences in SDW after 90 days under both feeding schedules. The change from non-significant differences to significance after 60 days is attributed to increased difference in TDW because top dry weight was significantly different after 60 days while RDW remained non-significant for 120 days.

Figures 16 and 17 show the mean seedling dry weight produced in the nine media 30, 60, 90, and 120 days after germination under the exponential and replacement feeding schedules.

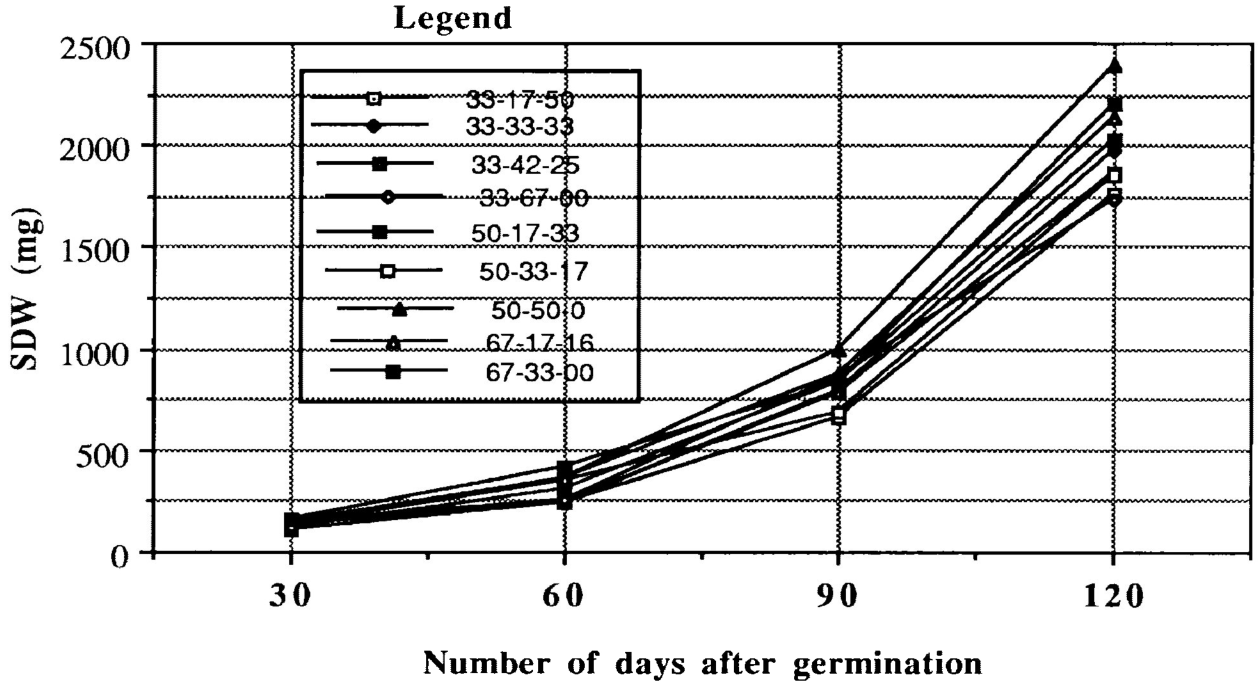


Figure 16. Mean seedling dry weights of *Eucalyptus globulus* stock grown in nine media 30, 60, 90, and 120 days after germination under exponential feeding schedule.

Note: Media in the legend were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively.

Significant divergence between the seedling dry weight growth progressions in the nine media in both feeding schedules began at 90 days after germination. Seedlings grown in 50% *Sphagnum* peat and 50% Vermiculite exhibited faster growth rate (Figures 16 and 17). Seedlings grown in 50%- or 67%-*Sphagnum* peat had higher SDW than those grown in 33% *Sphagnum* peat under both the exponential and replacement feeding schedules (Figures 4, 5, 6, and 7). The relative growth rates were about 14.45 to 19.91% and 11.7 to 19.52% increase in dry weight per day under the exponential feeding and the replacement feeding schedules, respectively.

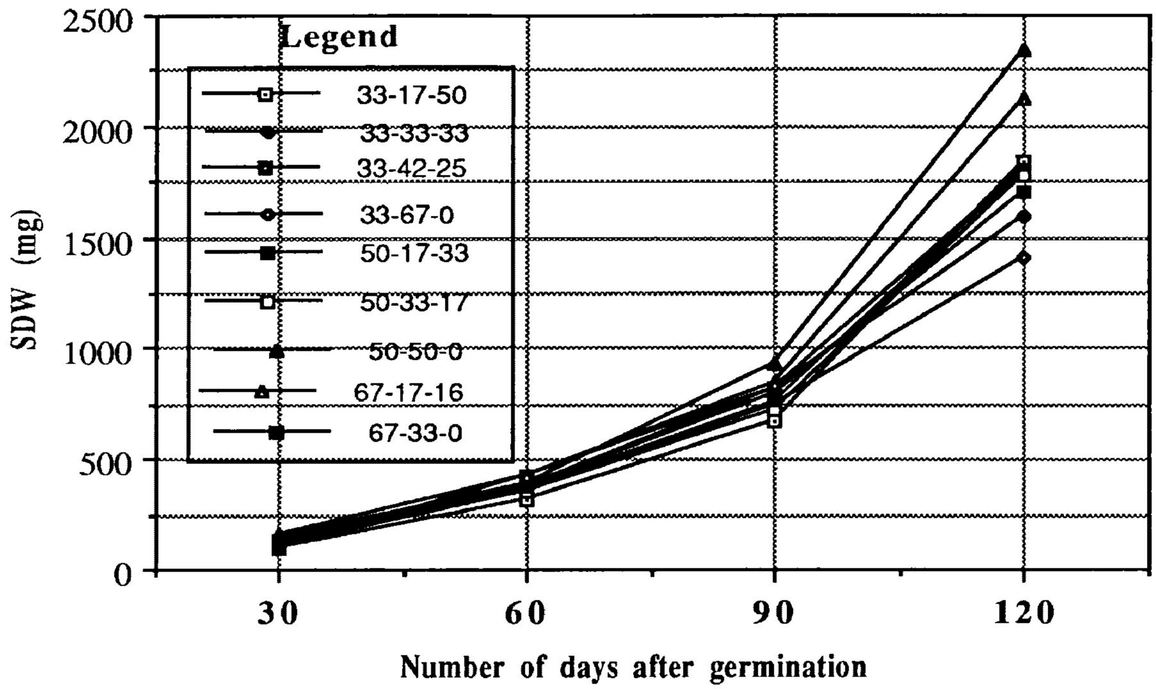


Figure 17. Mean seedling dry weights of *Eucalyptus globulus* stock grown in nine media at 30, 60, 90, and 120 days after germination under replacement feeding schedule.

Note: Media in the legend were composed of *Sphagnum* peat level, Vermiculite, and Perlite in percent, respectively.

Top Dry Weight to Root Dry Weight Ratio

The analysis for TDW and RDW showed a considerably high variation in TDW and low variation in RDW during the 120 day growing period. Seedlings grown in the nine media under the exponential feeding schedule ranged in TDW from 1386 to 1978 mg, in RDW from 347 to 421 mg, and top to root ratio from 3.5 to 4.2. Seedlings grown under the replacement feeding schedule ranged in TDW from 1087 to 1921 mg, in RDW from 318 to 421 mg, and top to root dry weight ratio from 3.5 to 4.3. Figure 18 shows the mean top dry weight, root dry weight, and top to root dry weight ratios of the seedlings grown in the nine media under the exponential feeding schedule.

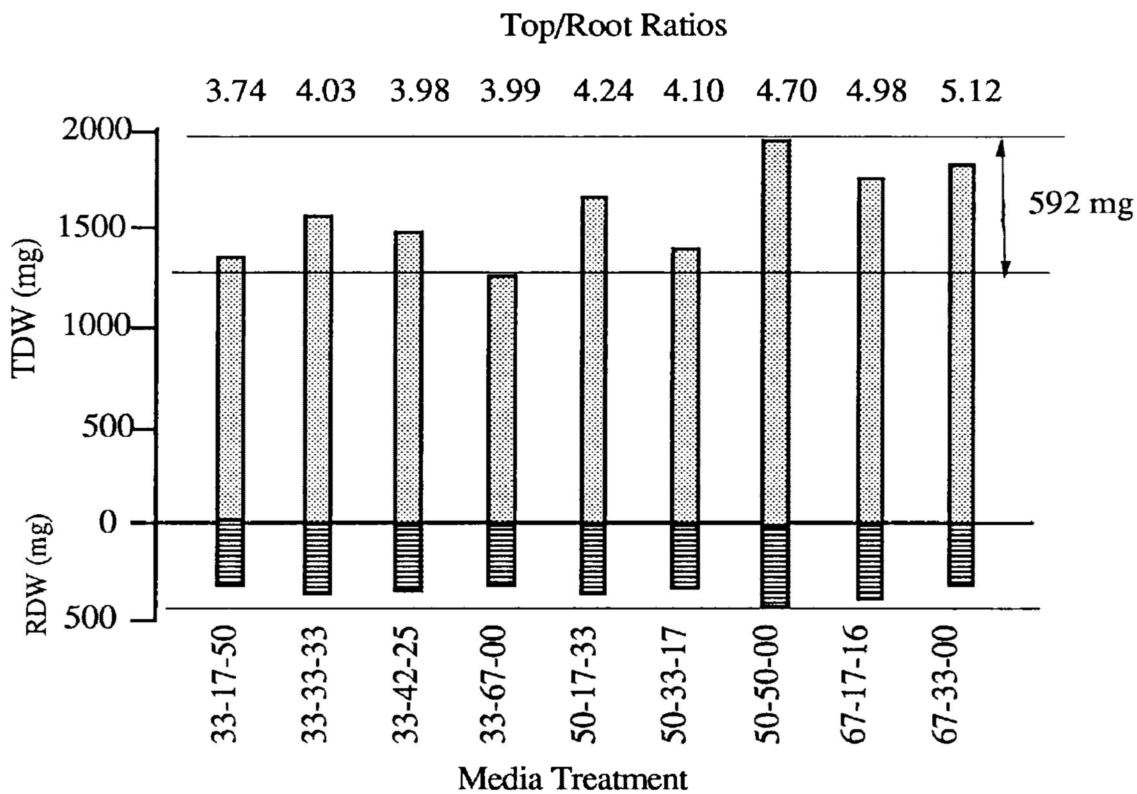


Figure 18. Mean top dry weights, root dry weights and top dry weight to root dry weight ratios of *Eucalyptus globulus* seedlings grown in nine media under exponential feeding schedule 120 days after germination.

Note: Media treatments were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively.

The top to root dry weight ratios of seedlings grown under the exponential feeding schedule show the two best media for SDW (i.e. 50% *Sphagnum* peat and 50% Vermiculite, and 67% *Sphagnum* peat and 33% Vermiculite) had high top to root dry weight ratios (4.7 and 5.12). The poorest media for SDW (i.e. 33% *Sphagnum* peat, 17% Vermiculite and 50% Perlite) had the lowest top to root dry weight ratio (3.74). The remaining media had a top to root dry weight ratio between these extremes (Figure 18).

Figure 19 shows the mean top dry weight, root dry weight, and top to root dry weight ratios of the seedlings grown in the nine media under the replacement feeding schedule.

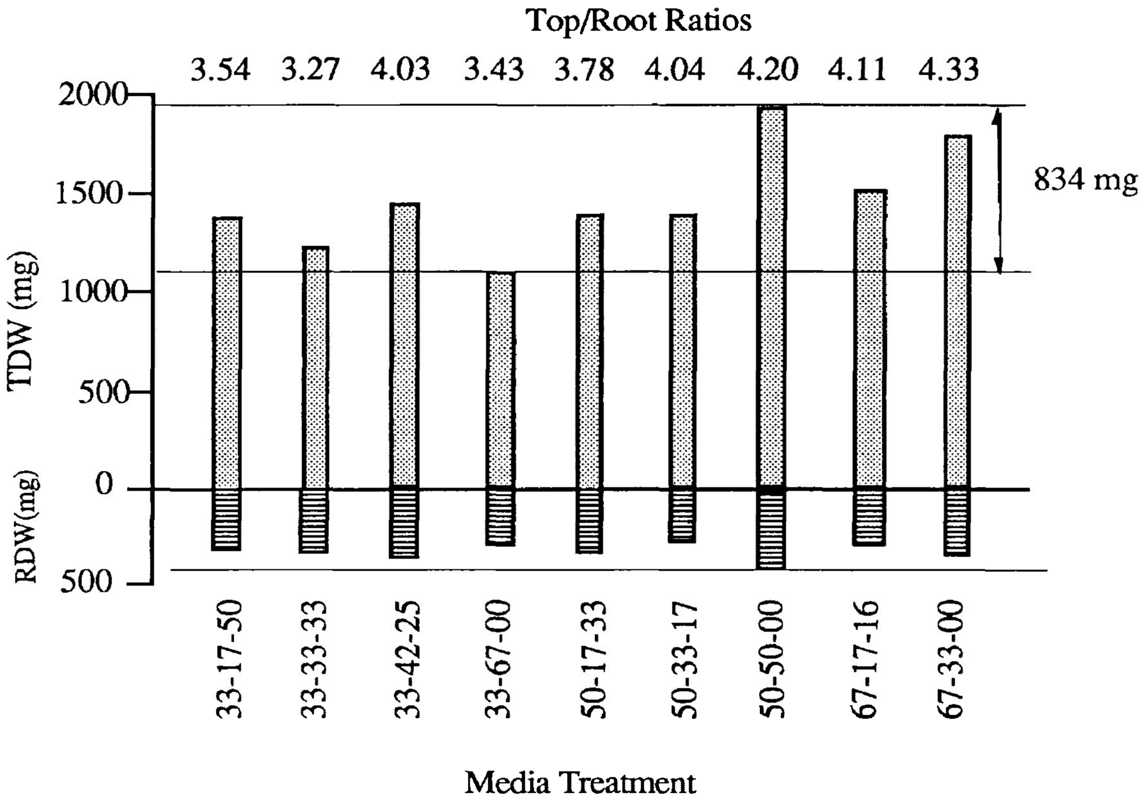


Figure 19. Mean top dry weights, root dry weights and top dry weight to root dry weight ratios of *Eucalyptus globulus* seedlings grown in nine media under replacement feeding schedule 120 days after germination.

Note: Media treatments were composed of *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively.

The top to root dry weight ratios of seedlings grown under the replacement feeding schedule show the two best media for SDW (i.e. 50% *Sphagnum* peat and 50% Vermiculite, and 67% *Sphagnum* peat and 33% Vermiculite) again had the highest top to root dry weight ratios (4.2 and 4.33). The poorest media for SDW (i.e. 33% *Sphagnum* peat and 67% Vermiculite) had the third lowest top to root ratio (3.54) (Figure 19).

Seedlings grown in 50%- or 67%-*Sphagnum* peat had higher top to root dry weight ratios, while those grown in media that contained Perlite had lower top to root dry weight ratios under both feeding schedules (Figures 18 and 19). Seedlings with low top to root dry weight ratios are prefered in moisture-deficit areas.

Dickson's Seedling Quality Index (DSQI)

The DSQI increased with an increase of *Sphagnum* peat class in the medium (Table 38). The media and feeding schedule study results support Phipps' (1974) argument that stated increasing the percentage of *Sphagnum* peat in a medium increases seedling height and biomass production per unit of time.

Table 38. Mean Dickson's Seedling Quality Indices of *Eucalyptus globulus* stock grown in 33-, 50-, and 67% *Sphagnum* peat classes under exponential and replacement feeding schedules 120 days after germination.

Sphagnum peat class (%)	Exponential Feeding	Replacement Feeding
33	0.365	0.351
50	0.40	0.365
67	0.40	0.381
Grand Mean	0.388	0.366

Sphagnum peat, Perlite, and Vermiculite proportions

Seedlings grown in media with lower proportions of Perlite (ranging from 0 to 50%) had higher seedling dry weight than those grown in media with a higher proportion of Perlite (Figures 4, 5, 6, and 7). The low seedling dry weight gain of the stock can be attributed to the lack of buffering capacity, poor C.E.C, and poor mineral nutrients retention of Perlite.

Increasing the *Sphagnum* peat in the medium increased the top dry weight. Unfortunately, it did not increase the root dry weight in equal proportion and resulted in higher top to root ratios. The heaviest seedlings which were grown in 50% *Sphagnum* peat and 50% Vermiculite medium had 73% higher seedling dry weight than the lightest seedlings grown in 33% *Sphagnum* peat and 67% Vermiculite. This difference was highly significant ($p < 0.01$) (Table 26). However, the 50% *Sphagnum* peat and 50% Vermiculite medium had the highest top to root ratios.

Pawuk (1981) compared twelve growing media for growing long leaf pine (*Pinus palustris* Mill.) and short leaf pine (*P. echinata* Mill.) and found that seedlings grew best in equal parts of *Sphagnum* peat and Vermiculite with low pH. Phipps (1974) compared nine growing media for red pine (*Pinus resinosa* Ait.) and found that seedlings grew best in 50% *Sphagnum* peat and 50% Vermiculite. Both Pawuk (1981) and Phipps (1974) attributed this response to high C.E.C., long moisture retention, and low pH of the 50% *Sphagnum* peat and 50% Vermiculite media.

The highest seedling dry weight range (i.e. 2290 - 2301 mg) in the response surface lies between 60 to 67% *Sphagnum* peat and 33 to 40% Vermiculite (Figure 8). The highest predicted seedling dry weight value was found at 62% *Sphagnum* peat and 38% Vermiculite in the experimental region. This media combination could be higher or lower under different experimental region.

The selection of a growing media for the production of quality stock should not be based on top dry weight or root dry weight alone, as top to root dry weight ratio also influences seedling quality. It is imperative to give due consideration to the top to root dry weight ratio, physiological characteristics (especially RGP), and moisture regime of the plantation sites in selecting a growing medium.

The Exponential and Replacement Feeding Schedules

A students t test for independent samples and unequal variances (Steel and Torrie 1980) did not show significant differences in seedling dry weight between the seedlings grown under the exponential and replacement feeding schedules. However, the relative maximum growth rates were 19.91 and 19.52% dry weight increase per day under the exponential and replacement feeding schedules, respectively. In each of the nine growing media, seedlings grown under the exponential feeding schedule had higher seedling dry weight and Dickson's Seedling Quality Index than those grown under the replacement feeding schedule (Tables 24, 26, and 27). There was no uniform trend in top to root dry weight ratios between the two feeding schedules.

THE MEDIA AND CONTAINER COATING STUDY

Height and Root Collar Diameter

There were significant differences in height between the seedlings grown in the eight media in both coated and uncoated containers 30 and 60 days after germination. However, these differences were lost after 60 days (Table 28). The loss of significance appears to be related to the seedlings' attaining a maximum height in the 112 ml Ventblock 102/115 containers. Furthermore, there were significant differences in root collar diameter between the seedlings grown in the eight media in both coated and uncoated containers only at 60 days after germination. The HT and RCD results were not significantly different after 60 days. Therefore, it is not possible to use height and root collar diameter results to determine or compare the size and quality of finished *E. globulus* stock.

Top and Root Dry Weight

There were no significant differences in TDW and RDW between the seedlings grown in the eight media in both coated and uncoated containers 30 and 60 days after germination, but there were significant differences after 90 days (Table 28).

Seedling Dry Weight

There were no significant differences in SDW between the seedlings grown in the eight media in both coated and uncoated containers 30 and 60 days after germination, but there were significant differences after 60 days. The change from non-significant to significant differences after 60 days is attributed to increased differences in top dry weight and root dry weight (Tables 28 and 31).

Significant divergence between the seedling dry weights of seedlings grown in the eight media in both coated and uncoated containers began 90 days after germination. Seedling grown in coated containers averaged significantly higher seedling dry weight than those grown in uncoated containers. The relative growth rates were 9.33 to 12.34% dry weight increase per day in coated containers and 8.66 to 12.34% in uncoated containers. Seedlings grown in the media and feeding schedule study averaged higher seedling dry weights and growth rates than those grown in the media and container coating study. This can be attributed partly to the severe winter weather which resulted in short days and cooler temperatures in the greenhouse.

Figures 20 and 21 show the mean seedling dry weight in coated and uncoated containers 30, 60, 90, and 120 days after germination.

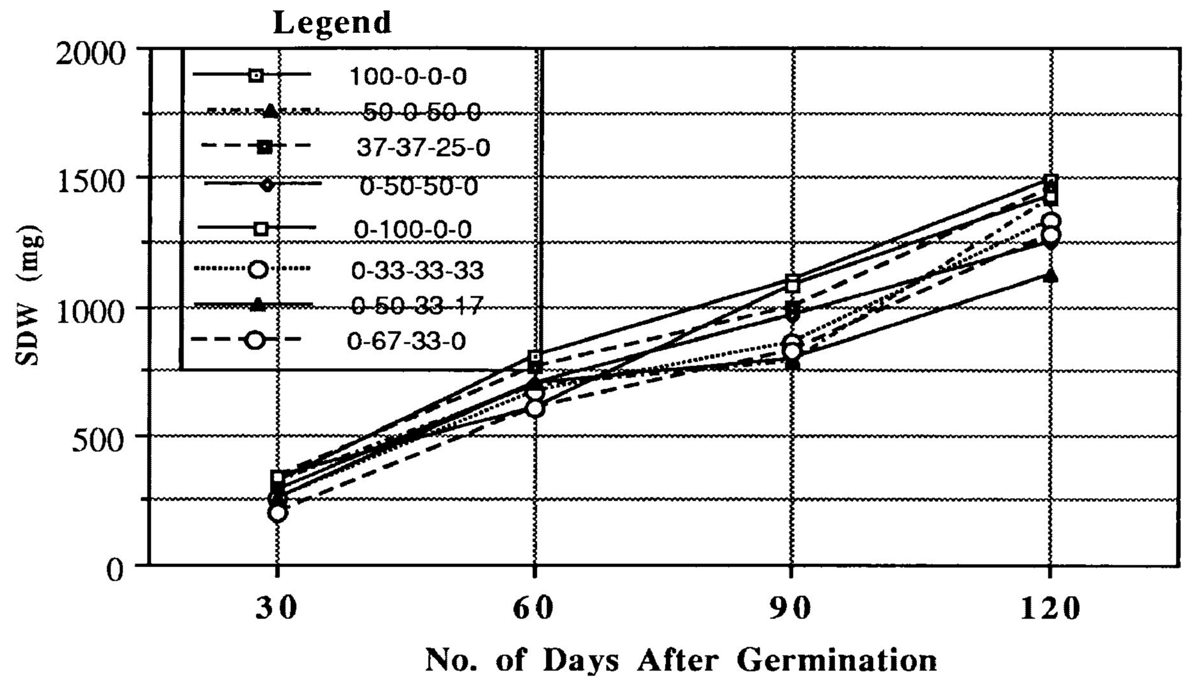


Figure 20. Mean seedling dry weights of *Eucalyptus globulus* seedlings grown in eight media in coated containers 30, 60, 90, and 120 days after germination.

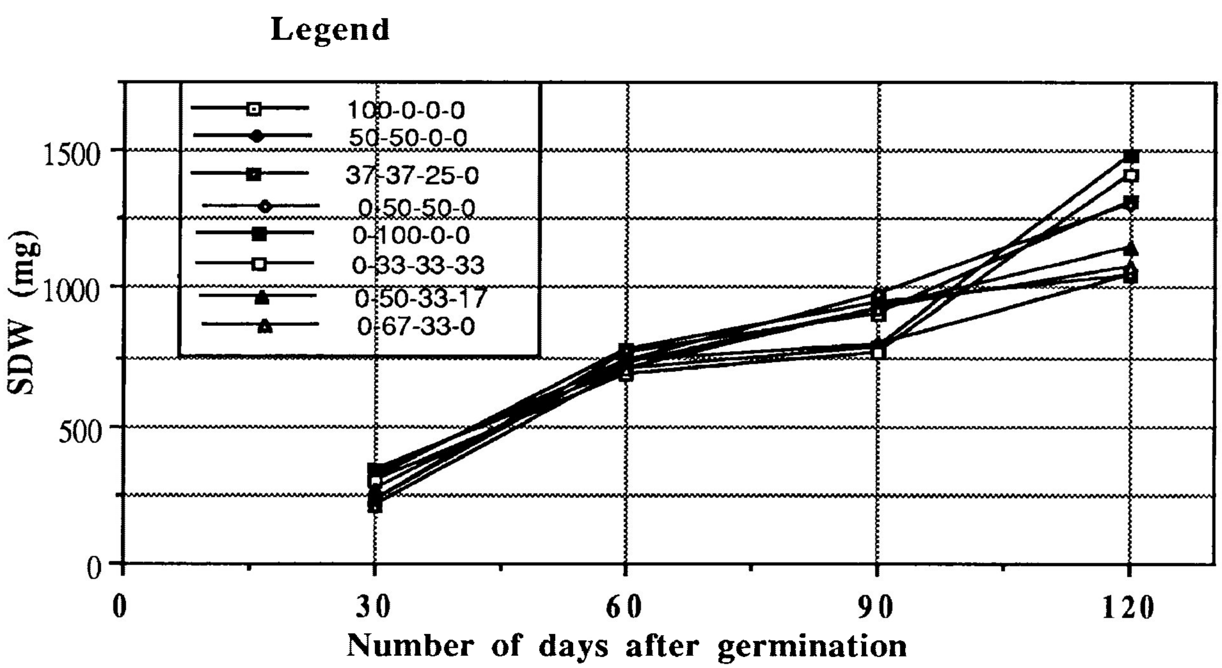


Figure 21. Mean seedling dry weights of *Eucalyptus globulus* seedlings grown in eight media in uncoated containers 30, 60, 90, and 120 days after germination.

Note: In Figures 20 and 21 media in the legend were composed of radiata pine bark, *Sphagnum* peat, Vermiculite, and Perlite in percent, respectively.

Top Dry Weight to Root Dry Weight Ratio

Seedlings grown in the eight growing media ranged in top to root dry weight ratio from 3.5 to 4.9. Increasing the proportions of either *Sphagnum* peat or radiata pine bark from 0 to 100% did not show either an increasing or decreasing trend of the top to root dry weight ratios (Table 34).

Dickson's Seedling Quality Index

Increasing the proportions of either *Sphagnum* peat or radiata pine bark from 0 to 100% did not show a definite trend toward either increasing or decreasing the DSQI values. Seedlings grown in coated containers had higher Dickson's Seedling Quality Index than those grown in uncoated containers, but seedlings grown in 50% *Sphagnum* peat and 50% Vermiculite showed the reverse (Table 33).

Root Growth Potential Test

The results of the growth chamber RGP test did not show significant differences in RN between the seedlings tested, but there were significant differences in RE (Figure 11). Seedlings grown in coated containers exhibited significantly higher root elongation than those grown in uncoated containers, but seedlings grown in 50% radiata pine bark and 50% Vermiculite did not a show significant difference (Figure 11). In the hydroponic test, seedlings grown in coated containers had significantly higher root number and root elongation than those grown in uncoated containers, even though they were grown in identical media (Figures 12, 13, 14 and 15). Burdett (1987) asserted that the higher the root growth potential of the stock, the higher the potential for root extension after outplanting, and for absorption of moisture and nutrients. Based on Burdett's assertion and the results of this research, the use of coated container for *Eucalyptus globulus* production is recommended.

The root number in the growth chamber test was significantly higher than in the hydroponic test. The growth chamber and the hydroponic tests were similar except for the difference in their test periods, but the difference in RN was remarkable. The RN in the growth chamber test ranged from 193 to 292 while in the hydroponic test it ranged from 15 to 46. The RE in growth chamber test ranged from 56 to 94 cm, while in the hydroponic test it ranged from 62 to 85 cm. Typically, bare-root or balled *Eucalyptus* seedlings in Australia exhibit a minimum of 50 new roots per seedling (Day 1991 pers. comm.). Seedlings in the growth chamber test grew a minimum of 190 new roots and an average RE of 55 cm per seedling. The roots of seedlings grown in coated containers were visually shorter and thicker than those grown in uncoated containers (Figure 10). Seedlings grown in both coated and uncoated containers had vertical roots and evenly distributed lateral roots.

The poor rate of root growth in the hydroponic test concede the results reported by Rietveld (1989). Rietveld stated that the reason for the slow root growth in hydroponic test is vague, but it may be due to inadequate levels of dissolved oxygen even in stirred water (i.e. gas exchange may be inhibited by a boundary layer around the roots that results from a lack of circulation). Conversely, the reason for more vigorous root growth in the growth chamber test can be attributed to the well aerated growing medium (33% *Sphagnum* peat and 67% Vermiculite). There was a strong correlation between RN and RE under both the growth chamber and hydroponic tests.

The results of the root growth potential test: 1) showed that container coating hinders the lateral root growth and their rebranching; 2) supports Ritveld's (1989) findings that root number and root elongation are different in RGP tests conducted in soil and hydroponic culture (i.e. the growth chamber test promoted faster and more uniform root growth than the hydroponic test); and 3) showed that a 21 day test period is required for hydroponic root growth potential test, instead of the 14 day test period as it is used for many tree species.

CONCLUSIONS AND RECOMMENDATIONS

A multitude of *Eucalyptus* species are grown in various afforestation and/or reforestation programs around the world. Most of these species are grown in containers that vary in diameter, depth, diameter to depth ratio, and volume. The types and proportions of growing media, the types and formulation of fertilizers, and the morphological standards used to classify outplanting stock of *Eucalyptus* species vary greatly. Since the morphological and physiological qualities of *Eucalyptus* stock are dependent on the above characteristics, close investigation and improvement of the containers, growth media and fertilizer that are being used to produce *Eucalyptus* stock, are invaluable. These can lead to the improvement of stock quality and performance after outplanting.

Nurseries growing *Eucalyptus* species could use either the exponential or replacement feeding schedules to improve stock quality. The results of this research showed that seedlings grown under the exponential feeding schedule had a rapid seedling dry weight gain and higher seedling quality indices than those grown under the replacement feeding schedule. This can be attributed to the exponential feeding schedule's match to the growth rate of *Eucalyptus globulus* seedlings.

Seedling quality is affected by media, feeding schedules and container coating. There were significant differences between and/or among the seedlings grown in the nine media tested under the media and feeding schedule study. These differences were apparent under both the exponential and replacement feeding schedules. Seedlings grown in 50% or 67% *Sphagnum* peat had higher seedling dry weight than those grown in 33% *Sphagnum* peat. Similarly, seedlings grown in media filled with 37%-, 50%-, and 100% radiata pine bark had higher seedling dry weight than those grown in media without radiata pine bark. Seedlings grown in 50% *Sphagnum* peat and 50% Vermiculite had the highest seedling dry weight in the media and feeding schedule study, and seedlings grown in 50% radiata pine bark and 50% Vermiculite had the second highest seedling dry weight in the media and container coating study. These results indicate that it is possible to substitute radiata pine bark for *Sphagnum* peat.

The highest predicted seedling dry weight was found at 62% *Sphagnum* peat and 38% Vermiculite. The response surface showed that seedling dry weight increased with increase in *Sphagnum* peat, but decreased with increase of Perlite in the experimental region. The level of *Sphagnum* peat should increase and that of Perlite decrease to provide a broader experimental region in future research.

This research does not single out one or two types of the media tested as ideal media for growing *Eucalyptus globulus* stock. As planting sites vary widely, it is probable that stock of several morphological configurations will be required. This research shows that nurseries that want to grow light seedlings with low top to root dry weight ratios (preferred in moisture-deficit areas) are advised to use freely draining media filled with higher proportions of Vermiculite or Perlite. Conversely, nurseries that want to grow heavy seedlings with high top to root ratios are advised to use media with higher proportions of *Sphagnum* peat. It is hoped that the results of this research will prompt nurserymen to consider seedling dry weight, and Dickson's Seedling Quality Indices when growing *Eucalyptus* stock for outplanting on various sites.

Root morphology and physiology are important for the establishment of vigorous *Eucalyptus* stock. Container systems that train lateral root, inhibit root deformity, and promote short root development with high RGP ensure successful seedling establishment and rapid growth. *Eucalyptus globulus* seedlings grown in coated Ventblock 102/115 were superior morphologically and physiologically to those grown in identical uncoated containers especially in RGP (as expressed by higher RE and RN) and root form. Similar results were obtained in both the growth chamber and hydroponic root growth potential tests. The results: 1) showed that coating of the Ventblock 102/115 trains and limits the lateral root growth and the rebranching of lateral roots; 2) supported the alternate hypothesis that stated RN and RE are significantly different in coated and uncoated containers; 3) showed that coated containers result in higher RE and RN than uncoated containers. Coated containers are recommended for future *E. globulus* production as seedling stability increases with the number of lateral roots and their elongation.

It is necessary to widen the understanding horizon of the physical and chemical characteristics of the growing media and the physiology of seedlings grown in coated and uncoated containers in order to establish vigorous plantations. The following areas are recommended for further research:

1) calibration of fertilization rate with the rate of seedling growth under the exponential feeding schedule;

2) study of the influence of seedling dry weight, root dry weight and top to root dry weight ratio on field establishment and growth after outplanting;

3) study of the RGP (root egress) of seedlings grown in coated container in the field and determination of the effect of RGP on establishment success and growth after outplanting.

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APPENDICES

APPENDIX I

QUESTIONNAIRE FOR ASSESSING EXISTING CONTAINER NURSERY SYSTEMS OF *Eucalyptus* Dill.

Questionnaire On *Eucalyptus* spp Nursery Stock Production

by
Temesgen H. and Robert J. Day[1]

FOREWORD

We do hope that you will read this questionnaire and will take a few minutes to complete it. The reason for the questionnaire is the significant lack of information on the nursery practices used to produce eucalypt (*Eucalyptus* Dill.) nursery stock in the scientific and technical literature.

As soon as the data solicited in the questionnaire is returned and compiled we will send you a summary of the results and hope that this will be of interest to you.

The objective of this questionnaire is to compile information on the nursery practices that are used for the production of eucalypt nursery stock in the principal countries of the world that are establishing eucalypt plantations. The questionnaire is designed to solicit general information on the nursery practices that are used to produce a wide range of eucalypt species; it is also designed to solicit specific information on the nursery practices used to produce Tasmanian blue gum (*Eucalyptus globulus* Labill.) container stock.

The results of the questionnaire will be presented as the first part of a Master of Science thesis being undertaken by Temesgen Hailemariam under the supervision of Prof. Robert Day at the School of Forestry at Lakehead University in Canada. The second part of the thesis research is entitled "Feeding schedules, growing media, and container coating for *Eucalyptus globulus* Labill. container stock production".

The questionnaire is being mailed to the principal agencies producing eucalypt nursery stock in the following countries : Algeria, Argentina, Australia, Bolivia, Brazil, Brundi, Chile, Peoples Republic of China, Colombia, Ethiopia, Ecuador, France, Guyana, Hawaii, New Zealand, Nigeria, India, Indonesia, Italy, Kenya, Peru, Portugal, South Africa, Spain, Srilanka, Swaziland, Tanzania, United States of America, Uganda, and Zambia.

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GENERAL QUESTIONS ON EUCALYPT STOCK PRODUCTION

Question 1. What number of each species and what types of eucalypt (*Eucalyptus* L'Herit) nursery stock did your organization grow in 1989-90?

(Please tabulate by the number produced in 1989-90.)

No.	Species	Bare- or Open-Root Stock	Container or Balled Stock
1)			
2)			
3)			
4)			
5e)			
6)			

Others) Please attach a list.

Comments on Question 1.

Question 2. If you grow container stock:

Question 2a What types of container(s) do you use?

(Please tabulate the size characteristics of the containers below.)

	Container Type (Name)	Diameter or Side (cm)	Depth (cm)	Volume (cm^3)
1)				
2)				
3)				
4)				
5)				

Comments on Question 2a

Question 2b What kind of material(s) do you use to fill the container(s)? Please list the percentages of the materials you use in your medium?

(Please tabulate the percentages of the materials used in the medium below.)

Material Type	Percentage (%)
1) Soil (please specify type below)	________
2) Sand (please specify type below)	________
3) *Sphagnum* peat moss	________
4) Other peats (please specify type below)	________
5) Compost (leaf and plant residues)	________
6) Compost (bark)	________
7) Manure (please specify type below)	________
8) Perlite	________
9) Vermiculite	________
10) Other Materials (please specify)	________

Comments on Question 2b

Question 2c What method(s) do you use to prepare your growing medium(ia)?

(Please describe the methods you use to prepare the growing media below)

Comments on Question 2c

Question 3. **If you apply fertilizer:**

Question 3a **What type(s) of fertilizer do you use? List them by Name (e.g. Ammonium Nitrate, Manure etc.) and Formulation e.g. (33-0-0, 10-10-10 etc.). Please indicate by checking the box whether the fertilizer is applied in granular or liquid form.**

(Please list the fertilizers and indicate whether they are granular or liquid below.)

No.	Fertilizer Name	Fertilizer Formulation	Granular	Liquid
1)	________	________	☐	☐
2)	________	________	☐	☐
3)	________	________	☐	☐
4)	________	________	☐	☐
5)	________	________	☐	☐
6)	________	________	☐	☐

Others) Please attach a list.

Comments on Question 3a

Question 3b **Is (Are) the fertilizer(s) incorporated in the growing medium before sowing or pricking out, or applied after sowing or pricking out or both?**

i) The fertilizer is incorporated in the medium before sowing or pricking out .... ☐

ii) The fertilizer is applied to the medium form after sowing or pricking out .... ☐

ii) The fertilizer is applied both before and after sowing or pricking out (both i and ii above) .... ☐

Comments on Question 3b

Question 4 **If fertilizer(s) is (are) incorporated in the medium please list the type(s) and amount(s) of fertilizer(s) incorporated in the medium in grams per cubic metre.**

	Fertilizer Name	Formulation	Quantity Per Cubic Metre (grams/m^3)
a)	______	______	______
b)	______	______	______
c)	______	______	______
d)	______	______	______
e)	______	______	______
f)	______	______	______
g)	______	______	______
Others)	Please attach a list.		

Comments on Question 4

Question 5 **If fertilizer(s) is (are) applied to the medium after germination or pricking out (usually in liquid form) please list the type(s) of fertilizer(s) applied and provide an approximate schedule of application.**

	Fertilizer	
	Name	**Formulation**
1)	____________________	______________
2)	____________________	______________
3)	____________________	______________
4)	____________________	______________
5)	____________________	______________
6)	____________________	______________
7)	____________________	______________
Others)	Please attach a list.	

Application Schedule (in 10 Day Units) from Germination (Question 4)

Time in Days Comments	Fertilizer Applied	Amount Applied (g/m2)m and
0-10		
11-20		
21-30		
31-40		
41-50		
51-60		
61-70		
71-80		
81-90		
91-100		

Note: If you have a schedule please attach it and send it to us. (Please describe comments on the next page)

Comments on Question 5

Question 6 Have you ever encountered any of the following problems associated with your growing medium?

1) Insect pest(s)....... ☐ **2) Water logging......** ☐

3) Excessive Drying... ☐ **4) Other(s)............** ☐

Comments on Question 6

Question 7 **Have you ever carried out research on the growing medium(ia) and fertilizer regime(s) for the production of *Eucalyptus globulus* Labill. nursery stock? If you have done so, please send any information (papers, reports etc.) on the research you have completed.**

Comments on Question 7

Question 8 **If you are not currently using 'Peat-Lite' mixtures as a growing medium (i.e. *Sphagnum* spp peat moss in combination with either or both Vermiculite and/or Perlite), please indicate why you rejected this medium in the Comments.**

Comments on Question 8

Question 9 What is the optimum size of the eucalypt stock for out-planting in your locality?

(Please tabulate the optimum size below.)

No.	Morphological character	Value of Attribute
1)	Height (m)	______
2)	Root collar diameter (cm)	______
3)	Top dry weight (mg)	______
4)	Root dry weight (mg)	______
5)	Top/Root ratio	______
6)	Others	______

Comments on Question 9

APPENDIX II

THE LAYOUT OF THE MP# 3-96 TRAYS UNDER THE ANDRPRO TRAVELLING IRRIGATION BOOM WITH EXPONENTIAL AND REPLACEMENT FEEDING SCHEDULES.

The layout of the MP#3-96 trays with the exponential and replacement feeding schedule experiments under the Andrpro travelling irrigation boom.

Exponential			**Replacement**		
8	7	9	3	4	9
4	5	3	8	8	3
3	6	4	2	7	4
6	5	2	6	3	2
9	1	7	9	5	1
8	6	4	7	6	9
7	2	8	1	7	5
2	3	1	4	6	2
6	4	2	7	5	7
1	5	7	3	8	2

Note: The treatments are listed numerically in Table 12.

APPENDIX III

EXPONENTIAL FEEDING SCHEDULE FOR *Eucalyptus globulus* Labill. IN THE MEDIA AND FEEDING SCHEDULE STUDY.

Exponential feeding schedule for *Eucalyptus globulus* in the media and feeding schedule study.

Days	Date	Amount of N applied (ppm)	Fertilizer Type	Amount of Fertilizer (kg)/100 lt.
0-14	____	____	____	____
15-20	Nov.4 to Nov.8	22.10	11-41-8	0.400
21-25	Nov.9 to Nov.13	28.22	11-41-8	0.512
26-30	Nov.14 to Nov.18	36.02	11-41-8	0.656
31-35	Nov.19 to Nov. 23	45.97	11-41-8	0.835
35-40	Nov 24 to Nov.28	58.67	20-8-20	0.587
41-45	Nov.29 to Dec.	74.89	20-8-20	0.785
46-50	Dec.3 to Dec.7	95.58	20-8-20	0.856
51-55	Dec.8 to Dec.12	121.98	20-8-20	1.220
56-60	Dec.13 to Dec.17	155.73	20-8-20	1.558
61-65	Dec.18 to Dec.22	198.75	20-8-20	1.998
66-70	Dec.23 to Dec.27	246.17	20-8-20	2.460
71-75	Dec 28 to Jan.3	323.74	20-8-20	3.240
76-85	Jan. 6 to Jan.10	50.0	8-20-30	0.759
86-95	Jan. to Jan.15	25.0	8-20-30	0.360

APPENDIX IV

REPLACEMENT FEEDING SCHEDULE FOR *Eucalyptus globulus* IN THE MEDIA AND FEEDING SCHEDULE STUDY.

Replacement feeding schedule for *Eucalyptus globulus* in the media and feeding schedule study.

Days	Date	Activity	Fertilizer	N-P-K	ppm/100lt
0 to 14	Oct.20 to Nov.3	Germination	None	___	___
15 to 35	Nov.4 to Nov.24	Starting	50-205-90	11-41-8	0.9
36 to 56	Nov.25 to Dec.15	Growing - low	100-136-300	20-8-20	1.0
57 to 77	Dec.16 to Jan.3	Growing - high	200-120-300	20-8-20	5.0
78 to 90	Jan.3 to Jan 7	Hardening	25-205-180	8-20-30	1.0

APPENDIX V

EXPONENTIAL FEEDING SCHEDULE FOR *Eucalyptus globulus* IN THE MEDIA AND CONTAINER COATING STUDY.

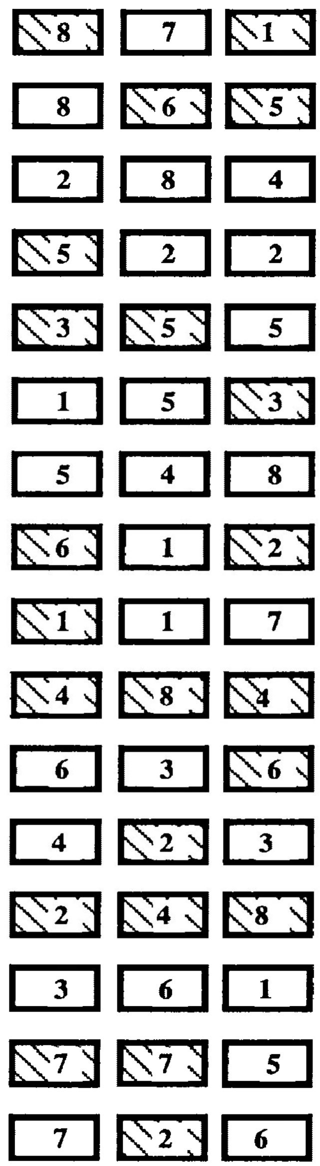
Exponential feeding schedule for *Eucalyptus globulus* in the media and container coating study.

Days	Date	Amount of N applied (ppm)	Fertilizer Type	Amount of fertilizer (kg)/100 lt.
0-14				
15-20	Feb.5 to Feb.9	22.10	10-52-10	0.364
21-25	Feb.10 to Feb.14	28.22	11-41-8	0.512
26-30	Feb.15 to Feb.19	36.02	11-41-8	0.656
31-35	Feb.20 to Feb.24	45. 97	11-41-8	0.835
35-40	Feb.25 to March 1	58.67	20-8-20	0.587
41-45	March 2 to March 6	74.89	20-8-20	0.785
46-50	March 7 to March 11	95.58	20-8-20	0.856
51-55	March 12 to March 16	121.98	20-8-20	1.220
56-60	March 17 to March 21	155.73	20-8-20	1.558
61-65	March 22 to March 26	198.75	20-8-20	1.988
66-70	March 27 to March 31	246.17	20-8-20	2.460
71-75	April 1 to April 5	323.74	20-8-20	3.240
72-85	April 6 to April 10	50.0	8-20-30	0.759
86-95	April 11 to April 15	25.0	8-20-30	0.360

APPENDIX VI

THE LAYOUT OF THE VENTBLOCK 112/105 TRAYS UNDER THE ANDRPRO TRAVELLING IRRIGATION BOOM UNDER THE EXPONENTIAL FEEDING SCHEDULE IN THE LAKEHEAD UNIVERSITY GREENHOUSE.

The layout of the Ventblock 112/105 trays under the Andrpro travelling irrigation boom under the exponential feeding schedule in the Lakehead University greenhouse.



Note: Coated containers are designated by diagonal lines; boxes without diagonal lines designate uncoated containers. The numbers refer to growing media explained in Table 13 of the text.

APPENDIX VII

ANOVA TABLES FOR THE MEDIA AND FEEDING SCHEDULE STUDY

ANOVA table for height under the exponential feeding schedule 30-days after germination

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	10.58	1.32	10.2	0.000
Error	21	2.78	0.13		

ANOVA table for height under the exponential feeding schedule 60-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	111.4	1.42	3.8	0.015
Error	21	7.7	.37		

ANOVA table for height under the replacement feeding schedule 60-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	3.92	0.49	6.3	0.000
Error	21	1.67	0.08		

ANOVA table for the root collar diameter under the exponential feeding schedule 30-days after germination

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	1258.3	157.3	3.26	0.005
Error	21	1012.4	48.21		

ANOVA table for root collar diameter under replacement feeding schedule 30-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	2051.9	256.49	3.7	0.007
Error	21	1458.1	69.44		

ANOVA table for root collar diameter under exponential feeding schedule 60-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	2051.9	256.5	3.7	0.007
Error	21	1458.2	69.4		

ANOVA table for seedling dry weight under the exponential feeding schedule 90-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	287717.0	35964.0	4.6	0.003
Error	21	167057.3	7955.0		

ANOVA table for seedling dry weight under the replacement feeding schedule 90-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	165598.1	20699.1	4.2	0.003
Error	21	101077.2	4813.3		

ANOVA table for seedling dry weight under the exponential feeding schedule 120-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	1313807.7	164225.9	4.4	0.003
Error	21	781182.8	37199.8		

ANOVA table for seedling dry weight under the replacement feeding schedule 120-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	8	208173.74	260190.0	3.77	0.007
Error	21	1448141.6	68959.1		

APPENDIX VIII

ANOVA TABLES FOR THE MEDIA AND CONTAINER COATING STUDY

ANOVA table for height under the exponential feeding schedule 30-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	82.9	5.5	5.1	0.000
Error	32	35.2	1.1		

ANOVA table for height under the exponential feeding schedule 60-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	124.2	8.3	3.8	0.001
Error	32	70.0	2.2		

ANOVA table for root collar diameter under the exponential feeding schedule 60-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	16222.5	1081.5	4.42	0.000
Error	32	7828.2	244.6		

ANOVA table for root dry weight under the exponential feeding schedule 90-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	97487.2	6499.1	4.5	0.000
Error	32	46238.6	1445.0		

ANOVA table for seedling dry weight under the exponential feeding schedule 90-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	563873.1	37591.5	5.03	0.000
Error	32	239237.3	7476.2		

ANOVA table for root dry weight under the exponential feeding schedule 120-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	73410.7	4894.1	2.33	0.004
Error	32	54556.1	2097.55		

ANOVA table for seedling dry weight under the exponential feeding schedule 120-days after germination.

Source of Variation	Df	SS	MS	F	Sig. of F
Treatment	15	991289.3	66085.95	3.03	0.006
Error	32	698638.9	21832.5		