ROOTING OF CUTTINGS IN RELATION TO THE PROPAGATION MEDIUM

KEITH LOACH

Glasshouse Crops Research Institute
Littlehampton, West Sussex

Abstract. Results relating the rooting of cuttings to the physical structure of the propagation medium are often inconsistent. Experiments reported here suggest that gaseous diffusion proceeds relatively freely through the bulk of conventional propagation media and also, that diffusion of oxygen down through the aerial portion of the cutting to its base could supply most of its needs. However, water films both within and around the base of the cutting can obstruct the free passage of oxygen to developing root initials. The subtlety of this influence precludes any obvious and consistent relationship between rooting and the volumetric air and water contents of the media. Practical guidelines for using media, based on consideration of the type of cutting, season, and propagation system are suggested.

INTRODUCTION

Our usage of propagation media for rooting cuttings is based on accumulated practical experience rather than on a sound understanding of the principles involved. Unfortunately, trials of different media often give varied or even opposed results because many other factors interact to determine whether cuttings will root satisfactorily.

Results from a useful trial comparing the rooting of five species in five different media are shown in Figure 1. It is evident that the influence of the rooting medium can be substantial but the best medium differs between species. Even with related cultivars in the same genus, divergent results can be obtained in different media (Figure 2).

It has frequently been supposed that the optimal requirements for rooting cuttings can be specified in terms of the physical characteristics of the medium. However, consistent guidelines have failed to emerge using this approach. Matkin (6) concluded that a rooting medium should have around 20% of its volume as air-filled pore space, which is consistent with Puustjarvi's (8) suggestion that a minimum air content of 15% is required. O'Dell and Stoltz (7) on the other hand found that three woody ornamental species gave an average of 91% rooting in media with only 1% air-filled porosity and Gislerod (3) found that 3.8 to 7.5% volume of air was necessary for rapid rooting of *Poinsettia* in small propagation blocks. Part of this discrepancy may originate from the disparate methods used to measure the physical chacteristics of the medium and also to the widely different propagation systems employed. Nevertheless, it also suggests that our understanding of the principles involved in use of propagation media is far from complete.

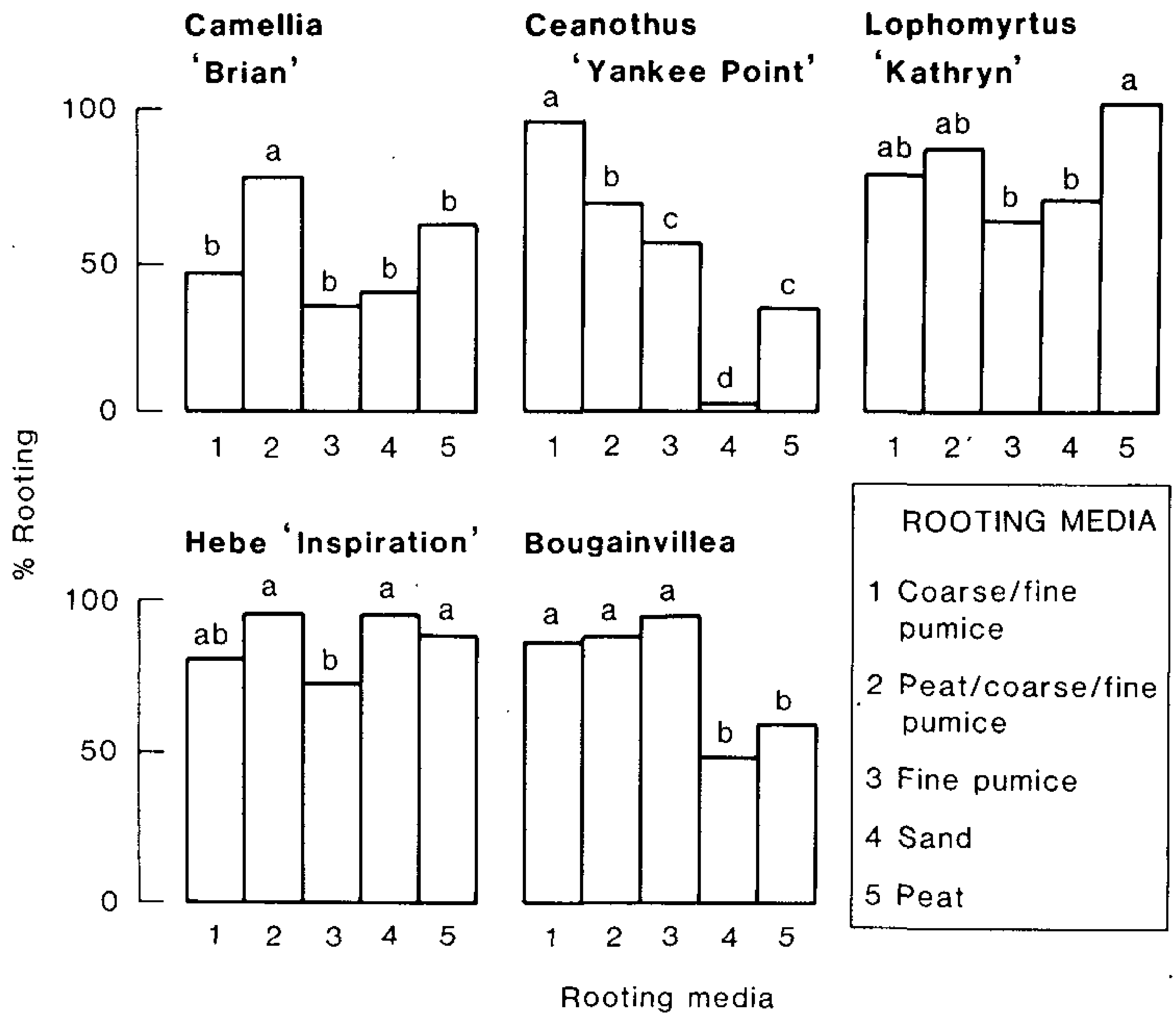

Figure 1. Rooting of cuttings of five different species in five media. Data from the Ann. Rep. New Zealand Nursery Research Centre. 1984.

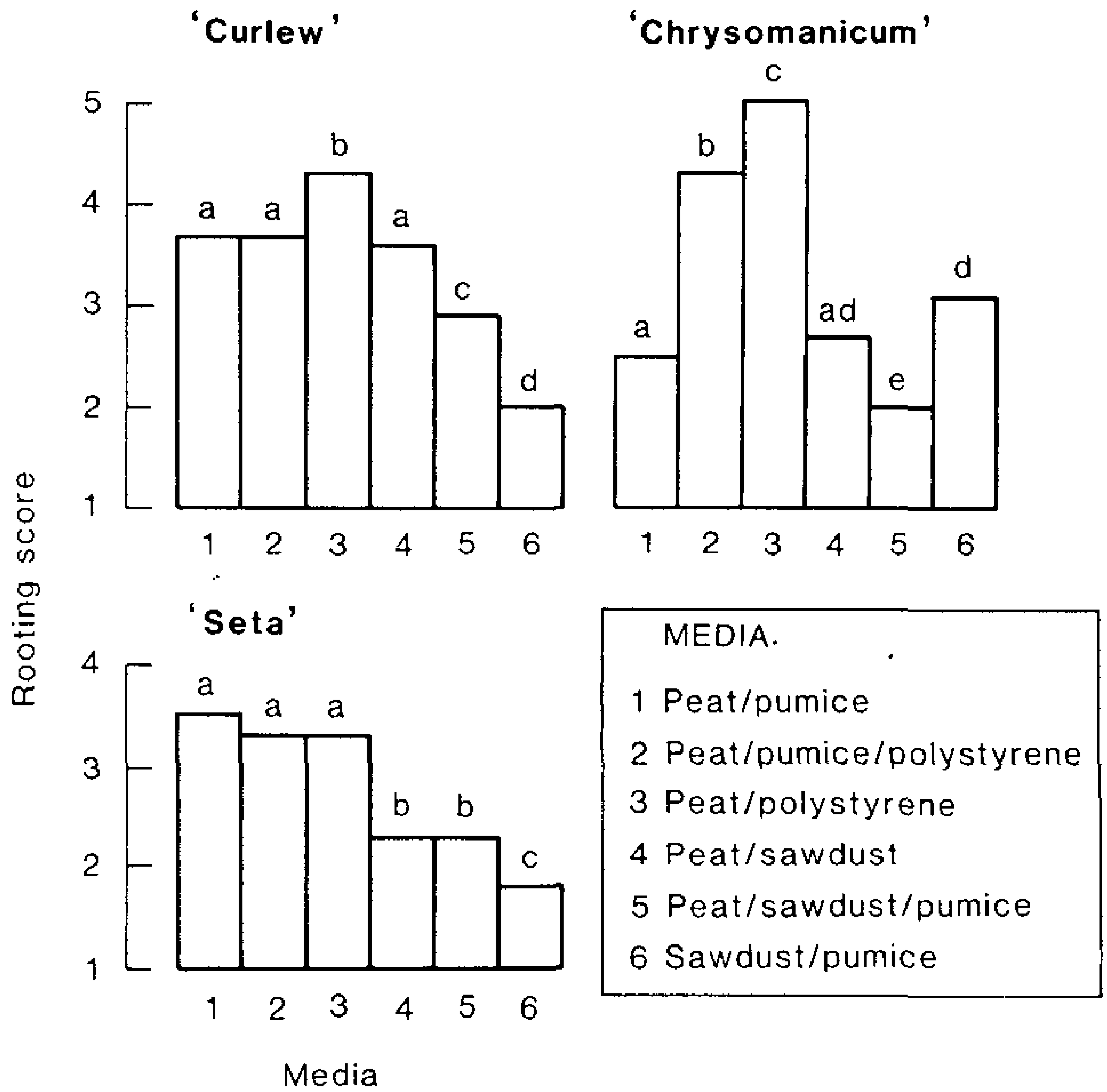

Figure 2. Rooting of three rhododendron cultivars in six media. Data from the Ann. Rep. New Zealand Nursery Research Centre. 1978.

PRINCIPLES

A rooting medium serves three essential functions: it provides, 1) support for the cutting, 2) water, and 3) aeration — i.e. oxygen to support the intensive metabolic processes in root formation. The provision of sufficient water to prevent wilting is a prime requirement. Measurements of the rates of water uptake by cuttings placed in media with successively increasing volumetric water contents showed a simple linear relationship between rate and percent water (4); i.e. from the point of view of supplying water to the cutting, the wetter the medium the better. However, the more water filling the pore space, the less air, and it is important to achieve a suitable balance between air and water contents.

The actual requirement for oxygen in the rooting process and the ability of the medium to provide it have seldom been studied except for attempts to relate rooting to measured air-filled porosities in different mixes. The discrepant results from such comparisons have already been referred to. In ecological and field-crop studies some detailed and quantitative treatments of aeration have been undertaken (2) and their application in our context will be discussed later.

Oxygen can reach the base of the cutting by two routes, i.e. through the medium, or by diffusion down through the tissues of the cutting itself. Quite a wide range of cuttings will root if placed with their bases in water and, since oxygen diffusion through water is 10,000 times slower than through a gaseous medium, we can assume that the latter route, through the cutting, is important in these cases. The Russian horticulturist, Komissarov (5) explored a system of rooting cuttings in water as a viable production method. Out of 30 species tested, 20 gave an almost equal percentage rooting in water as in sand.

This paper reviews the results of a series of experiments and measurements conducted over several years in an attempt to understand the relationship between root initiation and the air/water balance in the medium. Because of space limitations, full experimental details cannot be given in every instance.

OXYGEN SUPPLY

A conventional rooting medium has an open structure to give easy drainage and to facilitate gaseous diffusion. Rapid diffusion of oxygen through the bulk of a peat-grit (equal volumes) propagation mix was demonstrated by including oxygen-generating calcium peroxide (1% by volume) at mixing. The oxygen content of the medium was sampled at 8 min. intervals by withdrawing 0.5 ml samples by syringe, from a 1 ml porous chamber buried in the medium. This sample was then injected through a silicone rubber septum into a stream of nitrogen flowing through a Taylor Servomax, paramagnetic oxygen analyser, to give an instantaneous measure of oxygen concentration.

Results (Figure 3) showed that calcium peroxide released sufficient oxygen when in contact with the moist medium to raise the internal oxygen concentration to 27% by volume, within 8 min. of mixing. Thereafter, the concentration fell rapidly through diffusion, to reach normal atmospheric levels within an hour.

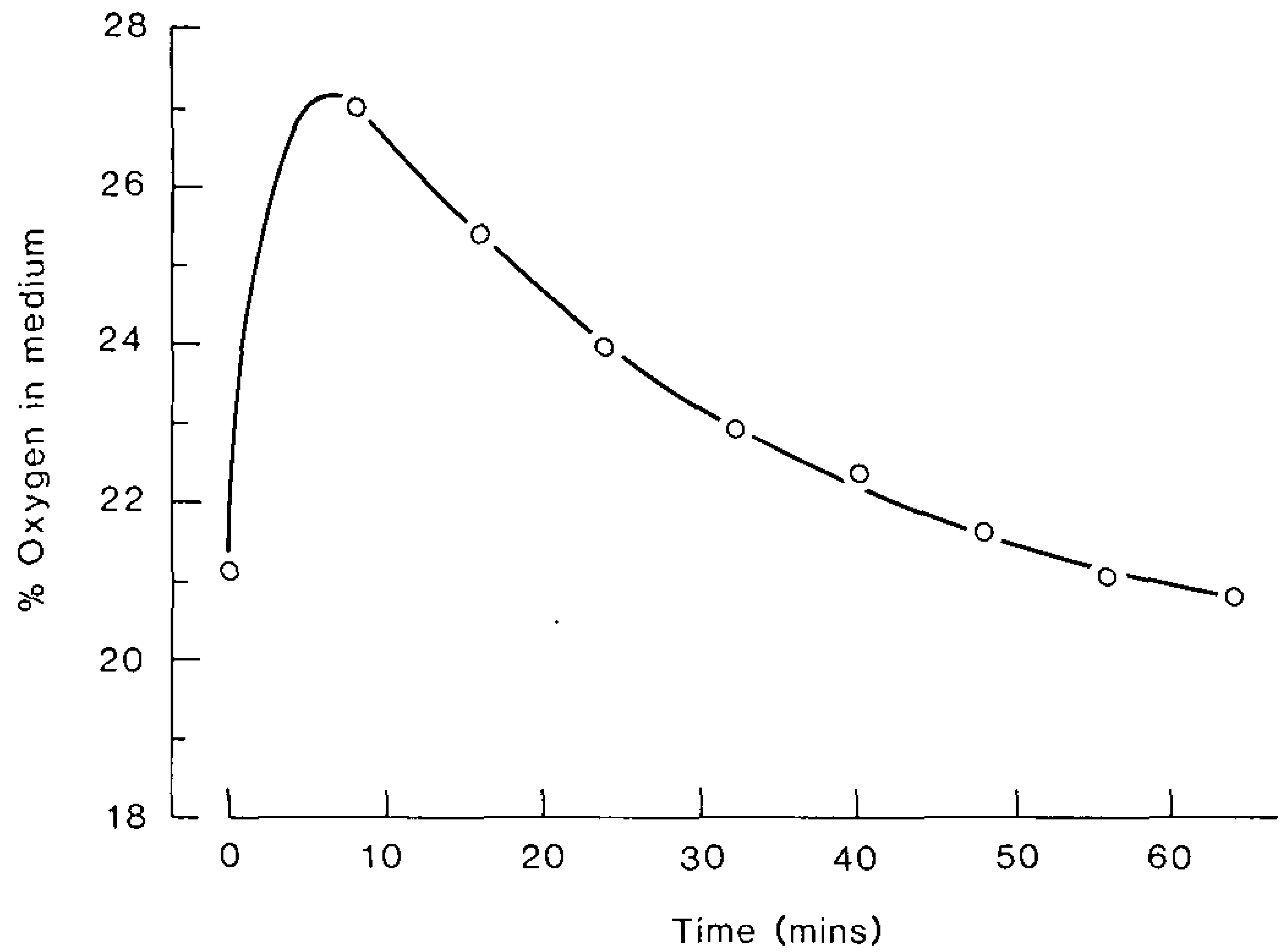

Figure 3. The time course of changes in the oxygen content of a 1/1 peat/grit medium containing 1% of oxygen-releasing calcium peroxide.

Similar methods were used to demonstrate oxygen diffusion from the atmosphere down through the tissues of the cutting to its base. Cuttings were inserted, "gas-tightly", through the rubber stopper of a glass specimen tube (75mm long × 25mm diameter) and the whole retained in an atmosphere of pure oxygen for up to 3 hours. The base of the cutting just touched a water surface in the tube. The stopper also contained a septum through which 0.5 ml samples of the internal atmosphere of the tube could be withdrawn for analysis. The oxygen concentration within the tube, after a set time, indicated the relative ease of oxygen diffusion through the tissues of the cutting. Seven replicate cuttings of each species were used and the measurements repeated on two days.

Table 1 shows close agreement between the duplicate daily measurements and significant differences among species.

Conifers were apparently more porous to diffusing oxygen than were broadleaf evergreens, though cutting bases of both groups were clearly able to receive oxygen by this route. Taken together with the demonstration of free oxygen movement through the medium it is, at first sight, difficult to see how short cuttings in an open mix can suffer serious oxygen deficiency. However, judged from practical experience, difficulties do arise and it is important to understand their origin.

Table 1. Oxygen diffusion through cuttings[1]. Listed in decreasing order.

Species	Percent oxygen	
Chamaecyparis thyoides 'Ericoides'	39.0	37.8
Chamaecyparis lawsoniana 'Pembury Blue'	36.2	33.8
Juniperus chinensis 'Plumosa Aurea'	37.3	35.8
Cupressocypariis leylandii	29.1	28.2
Ilex aquifolium 'Argentea Marginatum'	28.2	28.6
Nothofagus dombeyi	26.5	24.4
Garrya elliptica	21.3	23.6
SED	3.5	

[1] See text for description of method. A high value indicates rapid diffusion. Each figure is the mean for 7 cuttings, measured after 3 hours.

WATER SUPPLY

The importance of ensuring that tissues within the cutting remain turgid is evident when different propagation systems are compared and changes in water content are measured. Figure 4 illustrates a comparison of rooting in conventional open mist, polythene-enclosed mist, and a non-misted, shaded polythene tent. The change in water content of the cuttings

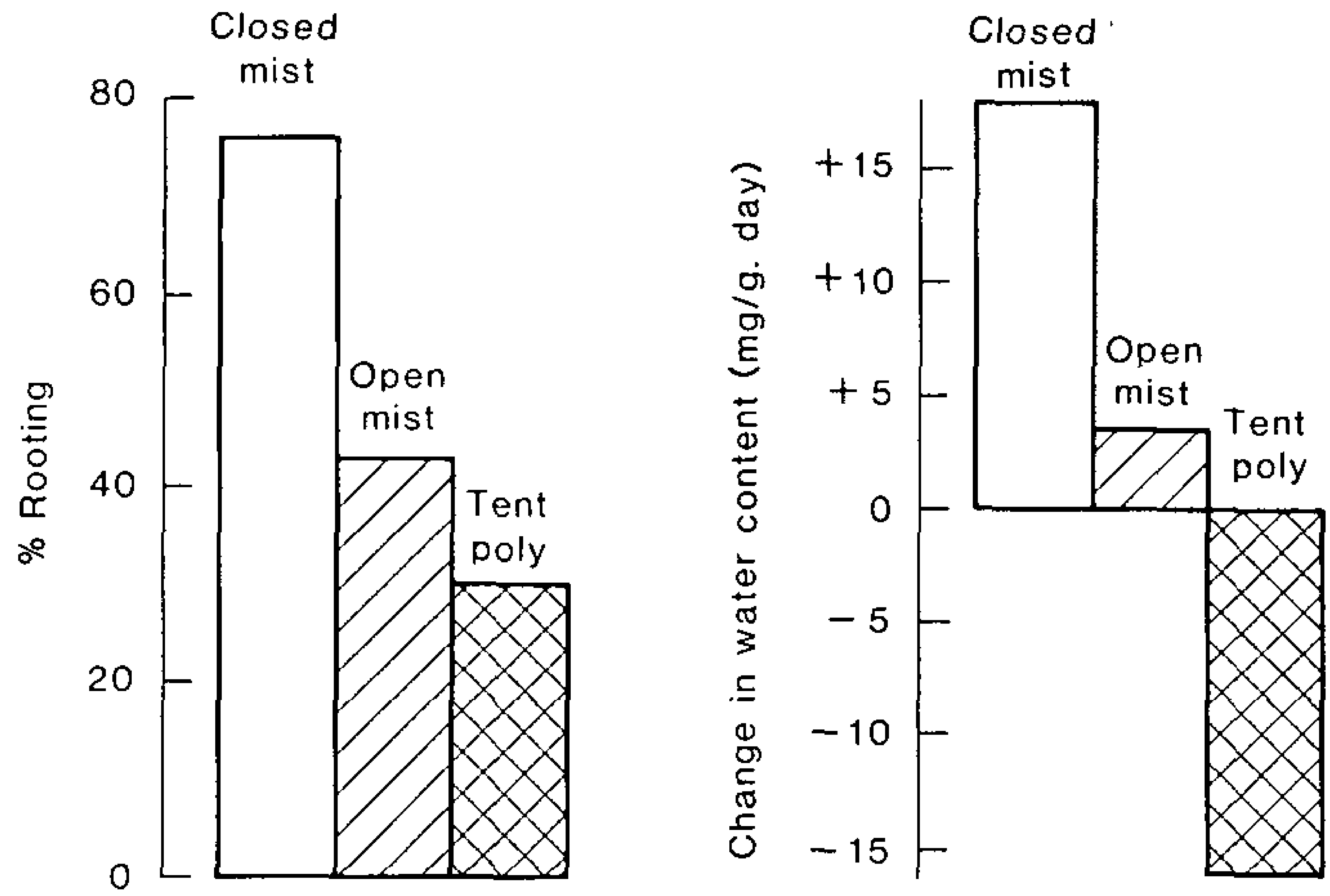

Figure 4. Mean rooting percentages for summer cuttings of six species in three different propagation systems, in relation to measured changes in cutting water content.

over a three week period following insertion (and before any rooting had occurred) was measured by appropriate sampling, drying, and weighing. Subsequently, rooting was scored as soon as it had occurred to a reasonable percentage in the best system — enclosed mist. Misted cuttings gained water from the time of insertion whereas non-misted cuttings lost water. The correspondence between rooting and the relative abilities of the three systems to conserve the water status of the cuttings is clear.

Tissue water content is determined by the balance between water loss from the leaves and water supply through the cutting base. As noted above, water uptake by cuttings is directly related to the volumetric water content of the medium. In summer conditions with soft cuttings, it is possible to demonstrate a positive relationship between rooting success and the water content of the medium. Figure 5a records the results of an experiment where cuttings of *Fuchsia magellanica* 'Nana Gracilis' were rooted in three media composed of peat (Irish, medium grade) and grit (Chichester, 5mm) in volumetric ratios of 1/3, 1/1, and 3/1. These were placed on sand beds with water tables held at 4 different depths below the pots (down to 100mm), to maintain 12 different water contents in the media. The soft cuttings clearly benefited from wet media. However, in winter conditions with harder cuttings, the reverse relationship can be shown and the importance of balancing the need for air and water is then most evident.

AERATION

It is only occasionally possible to demonstrate a positive relationship between the volumetric air content of the medium and rooting. Figure 5b presents such a result for cuttings of × *Cupressocyparis leylandii* 'Castlewellan' propagated in 1/1 peat (Irish, medium)/perlite (supercoarse), maintained over 6 water table treatments to achieve a range of air contents. The correlation is perhaps less than impressive and, in any case, since the percent air and percent water are inversely correlated for any one medium, it is not possible to say whether high air content or low water content promoted better rooting.

In a further experiment where cuttings of *Cryptomeria japonica* 'Elegans' were propagated in 5 different media under a non-misted polythene tent during winter, rooting was inversely related to the volumetric water content of the medium but showed little correlation with air content (Figure 6). This suggests that "poor aeration" may owe more to an excess of water at the base of the cutting than to the overall air-filled porosity. Water films at the base could perhaps restrict oxygen diffusion at this very localised level, even though the bulk of the medium is well aerated.

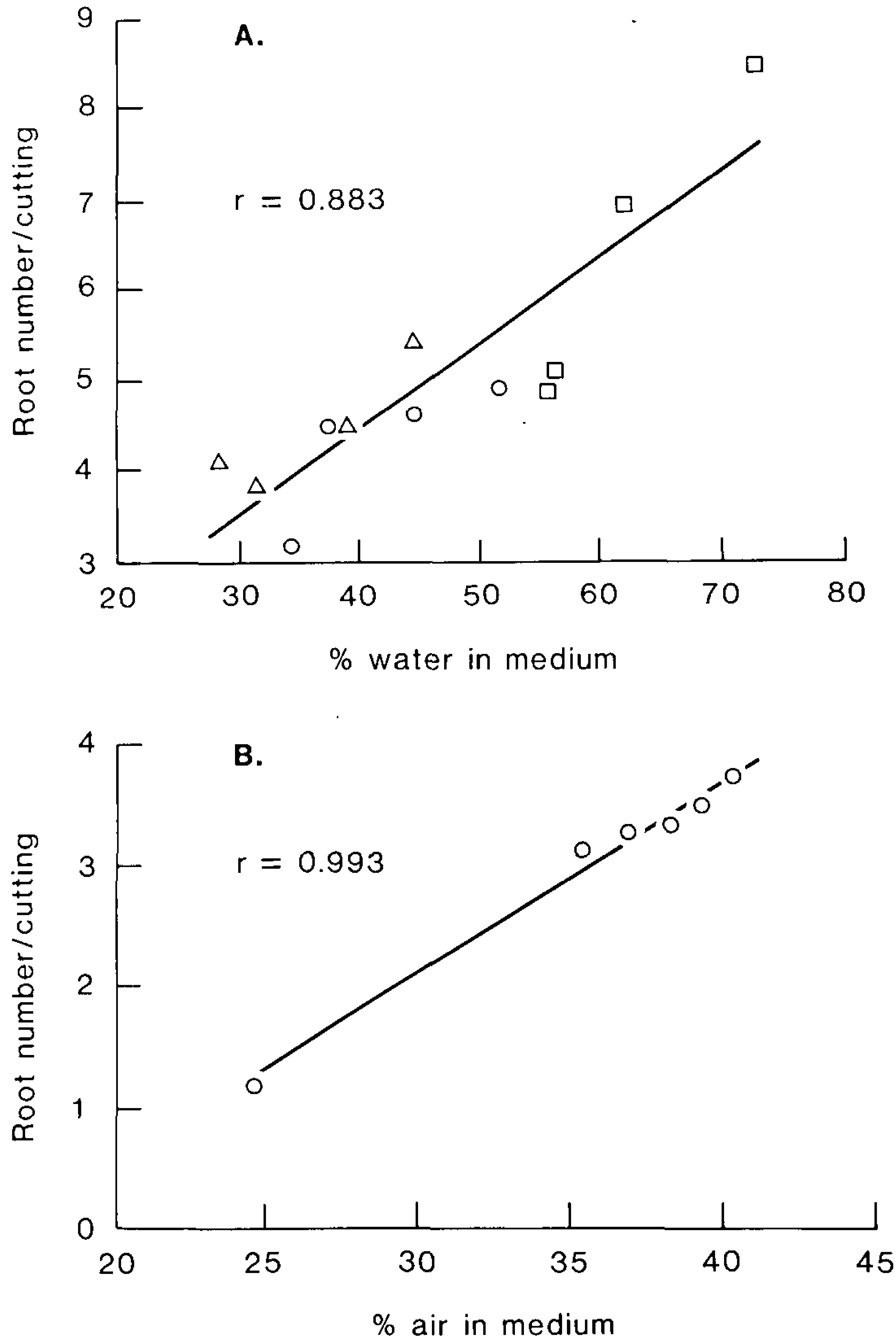

Figure 5. (A) The relationship between rooting cuttings of *Fuchsia magellanica* 'Nana Gracilis' and the volumetric water content of the medium. (△=1/3, ○=1/1, □=3/1 mixes of peat/grit over 0, 50, and 100 mm water tables or freely drained.)
(B) The relationship between rooting of cuttings of × *Cupressocyparis leylandii 'Castlewellan'* and the volumetric air content of a 1/1 peat/perlite medium, (differences again obtained by varying water table heights).

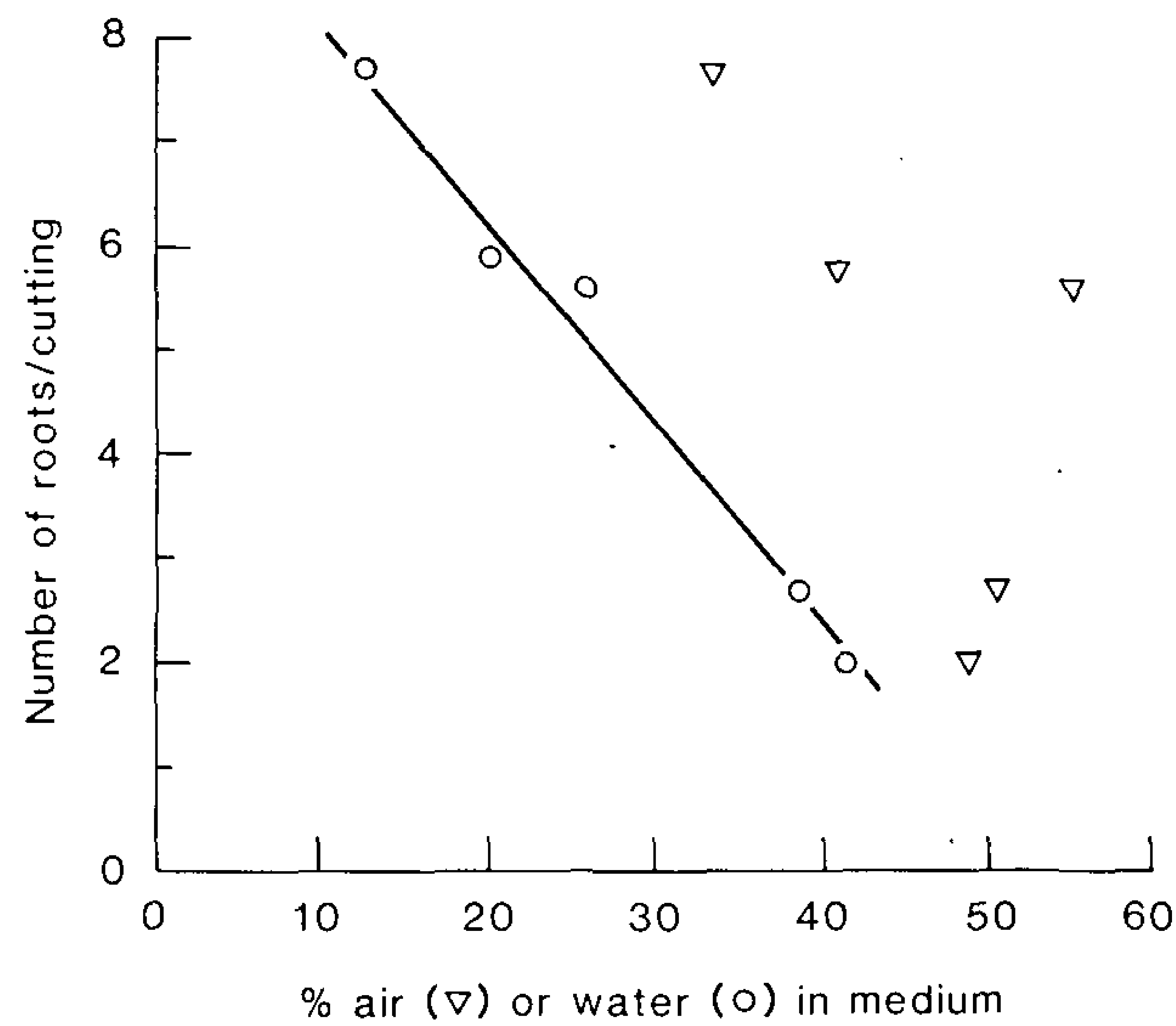

Figure 6. Rooting of cuttings of *Cryptomeria iaponica* 'Elegans' in relation to the volumetric water and air contents of five different media. r= −0.947 and −0.199, respectively.

Such observations are not entirely confined to conifer cuttings in winter conditions, though conifers do seem to be particularly sensitive to wet media. Cuttings of three broadleaf evergreen species, *Philadelphus* 'Burfordensis'. *Buxus sempervirens* and *Ulmus pumila* 'Hansen' propagated in a densely fogged polythene enclosure gave similar results. A pneumatic fogging nozzle (Sonicore 052H) was located at one end of a 8.5m × 1.7m × 0.9m (height) clear polythene enclosure constructed over the propagation bench. The operation of the nozzle was controlled by a timer operating for 60 sec. on and 75 sec. off in sequence to give a persistent, visible fog. The volumetric water content of a 1/1 peat/perlite rooting medium varied from 38% near the nozzle to 32% at the opposite end. Even this narrow range appeared to have a substantial effect on the rooting of the three species (Figure 7). Poor rooting close to the nozzle was associated with a greater gain in water by the cuttings over the first three weeks following insertion (see Figure 7).

However, when two coarse, well-drained media — pine bark and grit — were used, the variation in water content along the length of the enclosure was much reduced, but the positional effects on rooting still persisted (Figure 8). In these instances neither the volumetric water nor air contents of the bulk of the medium related to the rooting performance. Close to the nozzle, cuttings frequently showed damage and decay at

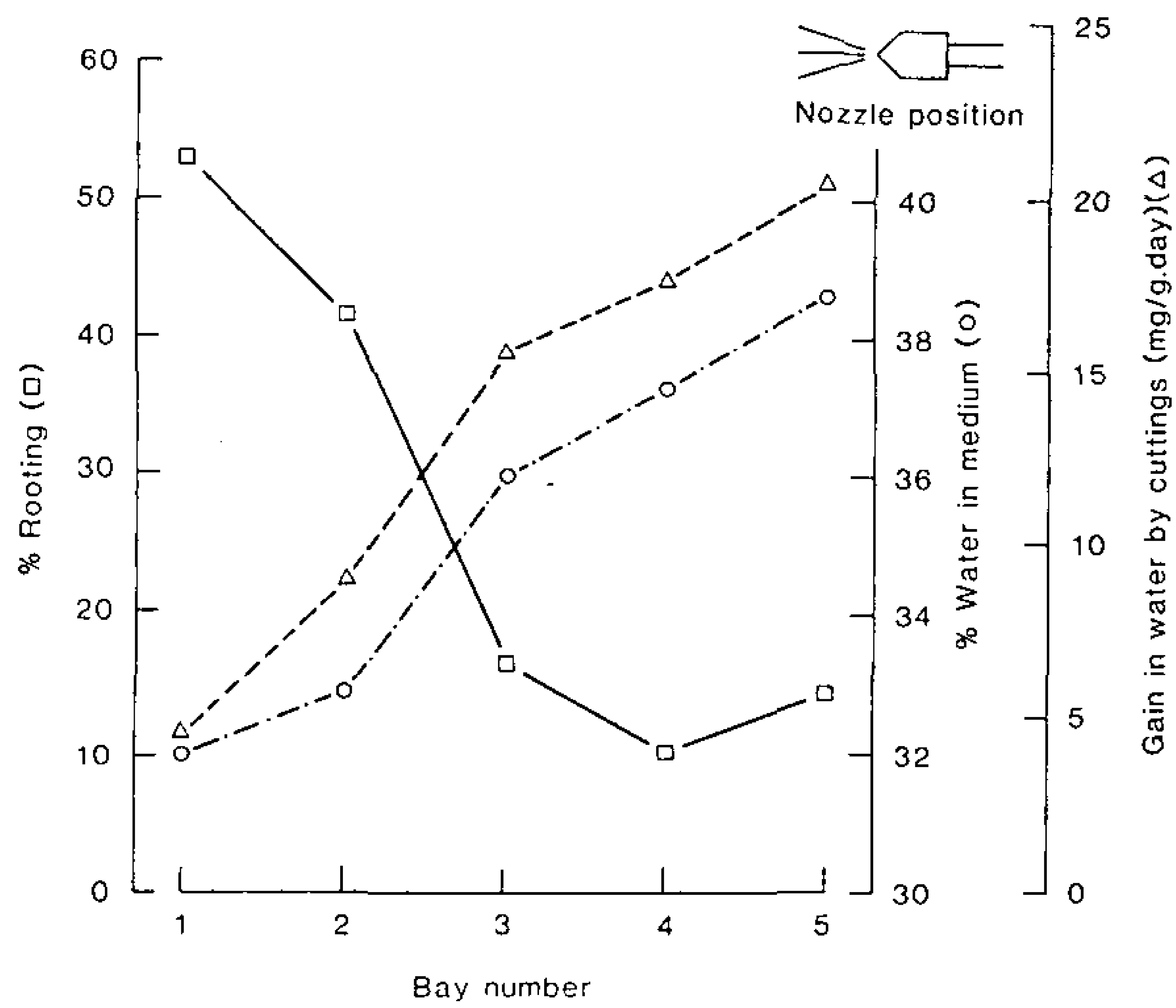

Figure 7. Variation in rooting in relation to distance from a fogging nozzle. (Each bay is 1.7m long). The volumetric water content of the medium and the water gain by the cuttings are also shown. Data are means for three species.

their bases (scored here on a 0 to 5 basis, for zero to most severe damage — Figure 8): weight changes in the cuttings were not measured in this experiment.

Finally, changes in the water content of cuttings inserted in a fine, pine bark medium and positioned along the fogged enclosure were measured (by weighing) over six weeks. Further cuttings were left in place until rooting had occurred. The species used was *Chamaecyparis lawsoniana* 'Ellwoodii'. Fresh and dry weight changes were followed in the basal 15 mm and in the remaining top portion of the cuttings. The pots of cuttings were either protected by an additional polythene "umbrella" supported 100 mm above them to prevent direct fall-out of fog droplets onto the cuttings and medium, or they were left uncovered. This achieved a range of "wetness" of the cuttings and media along the enclosure.

The rooting which occurred showed no clear relationship to either the volumetric water or air contents of the bark medium. However, a close inverse correlation was observed between the final root score and the water gain (i.e. change in fresh weight - change in dry weight) in the basal 15 mm of the cutting during the first six weeks from insertion (Figure 9). Calculations showed that this water gain amounted to as much as 29% of the total volume of the basal segment, sufficient to easily fill most of the intercellular spaces and reduce oxygen diffusion very substantially. Rooting was not related to water changes in the top of the cutting.

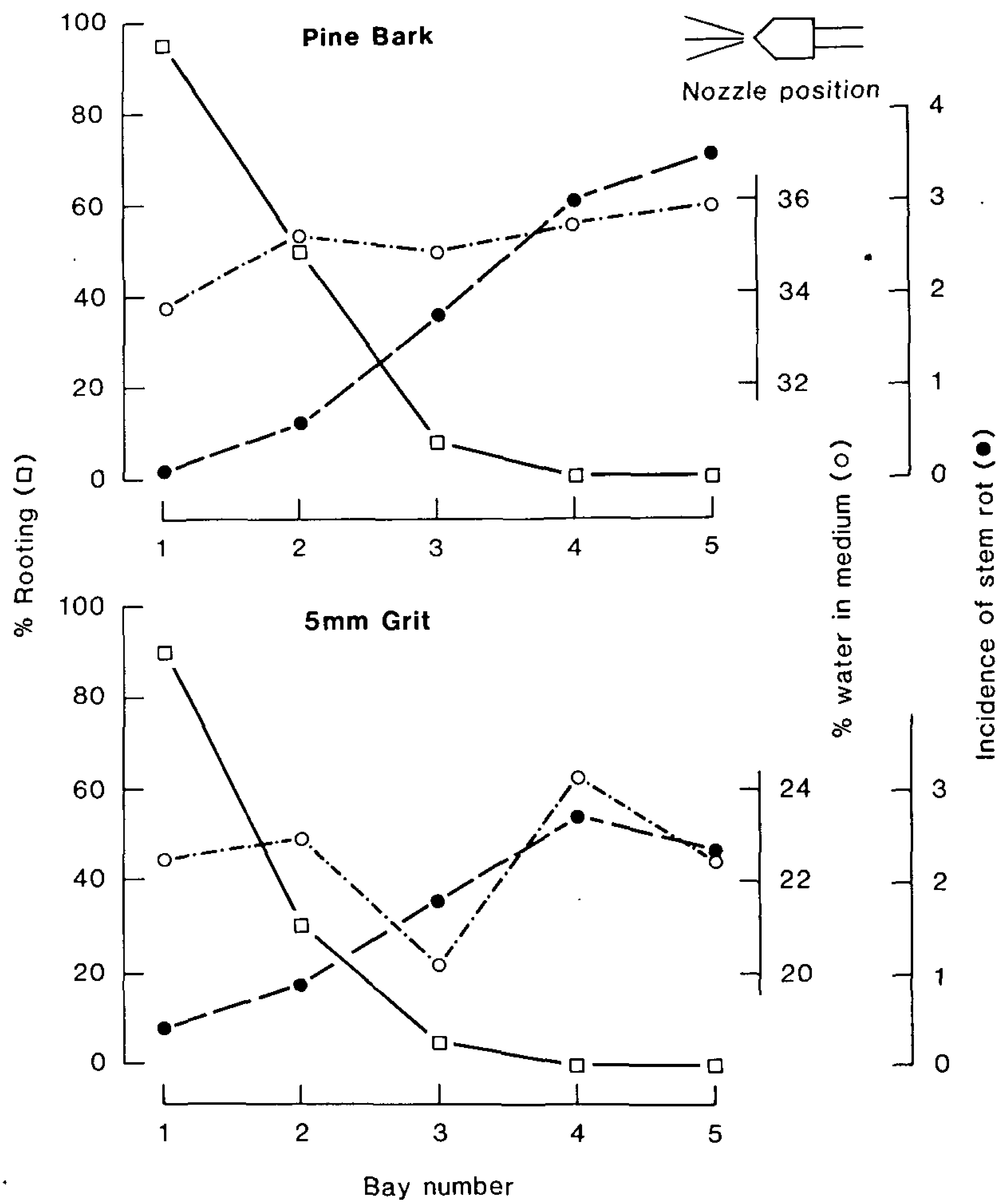

Figure 8. Rooting of cuttings of *Cryptomeria japonica* 'Elegans' in two coarse media, in relation to distance from a fogging nozzle. The volumetric water content of the medium and the incidence of basal stem rotting are also shown.

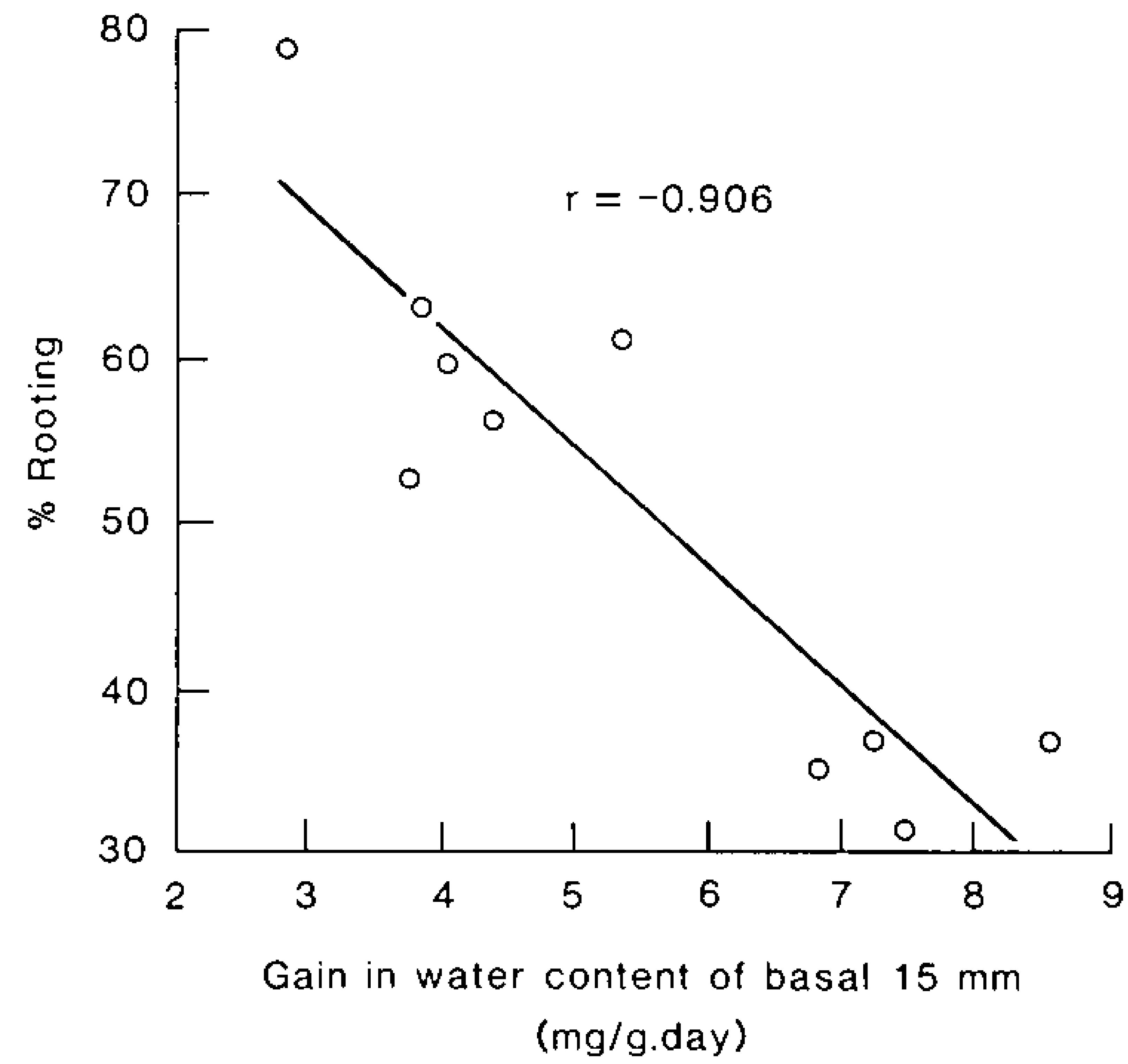

Figure 9. Rooting of *Chamaecyparis lawsoniana* 'Ellwoodii' in fog, in relation to the gain in water by the basal 15 mm of the cuttings.

DISCUSSION

In the foregoing experiments, evidence is presented that gaseous diffusion through the bulk of conventional propagation media proceeds relatively freely and that the base of a cutting can, at least initially, receive oxygen by internal diffusion downwards from the exposed top portion.

With reference to this diffusive pathway from the top, Armstrong (2), presents an equation for assessing the maximum length of stem (1, in cm) which could be supported entirely by longitudinal oxygen transport through the tissues, if it were inserted in an anaerobic medium:

$$1 = \sqrt{2\, D_e\, C_o / M}$$

1 depends on C_o, the oxygen concentration in the air (273 × 10 g cm^{-3} at 20°C). D_e the effective diffusivity of oxygen in air which consists of the diffusion coefficient (0.201 $cm^2\ s^{-1}$ at 20° C), multiplied by a fractional factor relating to the gas-filled porosity of the stem (e.g. 0.04), and M, the respiratory oxygen consumption within the tissues (e.g. 1×10^{-7}g $cm^{-3}\ s^{-1}$). With these values inserted, 1 is 6.6 cm. In practice, few cuttings are inserted more than about 3 cm deep so that on the basis of these speculative calculations, the aeration route through the cutting could normally provide much of the cutting's oxygen requirement.

The question of oxygen supply *via* the rooting medium is more complex. While equations have been formulated to describe this pathway in soils (2), the requisite biological data are lacking for our situation and this precludes any full quantitative assessment. For example, organically-based propagation media must present an active oxygen sink in themselves but quantitative information on respiration in peat or bark-based rooting media is sparse. Similarly the relative importance of diffusion through the cut stem base, the lenticels or the stem cuticle is unknown.

We have observed that whilst the propagation medium can have a marked effect on rooting, there is only occasionally any clear correlation between rooting and the volumetric air content of the medium (Figure 5b); the relationship between rooting and water content can be positive (Figure 5a), negative (Figures 6 and 7) or entirely absent (Figure 8). In cases where wetter media give poor rooting, it is striking that only a small change in the volumetric water content can have a large effect (Figure 7 and more specifically, Figure 8). Poor rooting is often associated with a large gain in water by the cuttings themselves (Figure 7), most notably in the basal portion (Figure 9).

The implication is that water, in both the rooting medium and within the base of the cutting itself, can present a major diffusion barrier, (remembering that oxygen undergoes a 29-fold drop in concentration at an air/water interface and diffusivity of oxygen through water is 10,000 times lower than in air). Waterlogged cutting bases in some species show evident damage (e.g. Figure 8), which may result from anoxia within the tissues. The time course of changes in hydration of the bases of cuttings have, surprisingly, seldom been studied.

Recognition of the possible significance of small changes in water film thicknesses within the cutting and medium, suggests a reason for the apparently disparate results which are common in the literature relating rooting to the physical structure of the medium.

PRACTICAL CONSIDERATIONS

The rooting media used on most nurseries consist of an organic and a mineral component. The organic component — commonly peat — is used because of its large total pore space and its ability to hold water. Bark, sawdust, leaf mould, sphagnum moss, or rice hulls have also been used. The mineral component is used to increase the proportion of large, air-filled pores: sand, grit, pumice, scoria, perlite, vermiculite, polystyrene, clay granules, or rockwool are commonly employed. The mineral component should be sufficiently coarse and used in sufficient quantity to ensure that it does more than fill in the pore spaces between the peat aggregates; e.g. the air-filled porosity of our peat/perlite mixes does not improve substantially until the proportion of perlite is increased to around 75%. Fine sand is inappropriate for a rooting mix and a coarser grit is desirable.

From the foregoing, it will be evident that there can be no single, "ideal" mix. It will depend upon the type of cutting, time of year, climate, other characteristics of the propagation system and unfortunately, even the weather. Practical suggestions are summarized in Table 2 and explained further below.

Table 2. Suitable rooting media

Good, all-purpose:	
1/1	Medium grade peat/coarse perlite (or 5 mm grit), (or fine (<8 mm) bark)
Better (same materials, varied proportions):	
1/3 for:	winter conditions, or mature cuttings, or "wet" systems
3/1 for:	summer conditions, or soft cuttings, or "dry" systems

A good, all-purpose medium is obtained using equal proportions of medium-grade peat and a coarser amendment such as coarse perlite, 5 mm grit, or bark. However, it is sensible to vary the proportions according to the type of cutting, season, and the propagation system involved.

Soft, immature cuttings with broad, actively transpiring leaves require a medium with a high water content, i.e. with a large proportion of peat, especially in summer conditions. Harder cuttings in winter transpire less and benefit from a fast-draining, more open structure. A "wet" propagation system calls for an open rooting medium: thus a polythene-enclosed mist system, a densely fogged house, propagation under "contact" polythene (where the sheet is wrapped directly over the trays of cuttings), and dull conditions, all require an open medium. Relatively "dry" systems, such as a polythene tent without mist, or open mist in summer, benefit from the use of a medium with more water, i.e. a greater proportion of peat. Sensible variations, within these almost self-evident guidelines, can be achieved through varying the proportion of peat from 75% down to 25% of the total volume of the mix (Table 2). It is unfortunate that our present level of knowledge precludes more specific recommendations.

MINERAL NUTRITION

Most cuttings contain sufficient reserves of nutrients to initiate roots. It is not generally necessary and indeed can sometimes be harmful (1) to add fertilisers to rooting media.

Once rooting has occurred, the provision of a dilute liquid feed maintains root and top growth and is often beneficial. Recently, the practice of incorporating controlled-release fertilisers (e.g. Osmocote, Ficote, Nutricote) in the medium has been recommended. Such coated fertilisers release their nutrients slowly and largely avoid damage to sensitive new root tips which standard chemical fertilisers can cause. For example, Efford Experimental Horticultural Station has recommended the incorporation of up to 1 kg/cubic m of an extended release, coated fertiliser into a medium containing equal proportions of peat and bark. With other mixes, lower levels may be safer.

Acknowledgements. Thanks are due to R.L. Jinks, Dr. R.I. Grange, and Dr. W. Armstrong for their helpful discussions. Technical assistance was provided by Mrs. C. Deans, Miss E.A. Solti, and Miss L. Holt.

LITERATURE CITED

1. *Ann. Rept. New Zealand Nursery Research Centre*, 1982. Nutrients in the propagation medium. 49-57.
2. Armstrong, W. 1979. Aeration in higher plants. *Adv. Botan. Res.* 7:225-332.
3. Gislerod, H.R. 1983. Physical conditions of propagation media and their influence on the rooting of cuttings. III. The effect of air content and temperature in different propagation media on the rooting of cuttings. *Plant and Soil* 75:1-14.
4. Grange, R.I. and K. Loach. 1983. The water economy of unrooted leafy cuttings. *Jour. Hort. Sci.* 58:9-17.
5. Komissarov, D.A. 1969. Biological basis for the propagation of woody plants by cuttings. Israel Program for Scientific Translations, Jerusalem.
6. Matkin, O.A. 1965. Physical properties of propagating media. The *Plant Prop.* 11:18.
7. O'Dell, G.A. and L.P. Stoltz. 1978. Media particle-size effects on rooting. *The Plant Prop.* 24:4-8.
8. Puustjarvi, V. 1969. Water-air relationships of peat in peat culture. *Peat and Plant News* 2:43-53.