The second method we use is cold frame production. This is the main method used on the nursery and the species of *Berberis* propagated with this method include: *Berberis* × *stenophylla*, *B. darwinii*, *B.* × *ottawensis* 'Purpurea', *B. thunbergii*, *B. verruculosa* and *B. candidula*.

The rooting medium in the frames consists of an equal mixture by volume of grit, peat and parent soil. This mixture is well forked through and then raked to remove any large lumps of soil.

There are two types of *Berberis* propagated in the frames, deciduous and evergreen. The deciduous types are propagated from mid-September to early October. The type of cuttings are nodal or of a mallet type. Those that lend themselves to a nodal type are the *B. thunbergii* and *B.* × *ottawensis* cultivars. The cuttings are 4 to 5" long of the current year's growth. The minimum thickness of the cuttings is just below pencil width. The lower three leaf joints and spines are removed and the cutting is then dipped in Seradix No. 3. The cutting is then inserted in the cold frame at a spacing of 1½" square. These are well watered in and covered with a shaded Dutch light. Rooting of the deciduous types sometimes takes place before the winter, but if not they root by the spring.

Evergreen cultivars are taken next from early October to early November. Mallet cuttings are used with the exception of *Berberis* × *stenophylla* where nodal cuttings are used. The length and treatment of the cuttings are the same as with the deciduous types.

The shading on the Dutch lights is removed during December as maximum light is required. Shading, consisting of emulsion paint and water, is put on again during March so as to reduce scorch on the cuttings. Once rooted the cuttings are potted up in 3" polythene pots.

MIST PROPAGATION — PAST, PRESENT AND FUTURE

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Past and Present. The International Plant Propagators' Society was founded at a time when mist propagation was in its infancy as a commercial system in the United States, and the founding members played a significant role in its development. The early history of the method has been outlined by Snyder (16). Mist propagation has frequently been viewed as a mechanized version of older frame methods which involved manually-applied overhead watering of the cuttings. The most appropriate comparison is with the old "sun-frame" method which used a closed, unshaded frame, with cuttings watered laboriously every half-hour.

The first recorded use of mist (3) by G.E.L. Spencer in 1936 was for propagation of cacao cuttings and was apparently unsuccessful. It attracted little attention at the time but at the end of that decade Rains, Gardner, and Fisher in the United States independently used mist systems for a wide range of species with considerable success. Through the 1940s mist was tried by an increasing number of researchers and nurserymen but its widespread commercial acceptance came in the 1950s in the United States and somewhat later elsewhere.

At the 14th International Horticultural Congress in 1955, papers relating to mist propagation were read by Snyder and Hess (8,17) and by Floor (5) from Holland. These attracted considerable attention and furthered the adoption of the method in many countries. Early developments were comprehensively reviewed by Rowe-Dutton (14) in 1959 and more recently, abstracts of 400 papers dealing with mist have been collected (2).

Initially, mist was applied continuously over the cuttings but the weaknesses of this system were soon apparent. Cuttings were heavily leached and the rooting medium was cold and readily waterlogged. To counter this, mist was applied intermittently, with the aim of maintaining a film of water on the leaf surfaces but applying a minimum amount to the medium. Also, base heat provided by electrical soil-warming cables proved beneficial and the adage, "warm feet and cool heads" was coined as describing the "ideal" conditions for cuttings.

There are, in fact, few direct comparisons of continuous and intermittent mist in the literature. Snyder and Hess's data (17) show that intermittent mist gave appreciably better percentage rooting than continuous mist in only one out of the six species compared, though they remarked that comparisons of root number and length showed intermittent mist to be superior. When Sharpe (15) compared the two systems simultaneously for peach cuttings, he reported that, "neither one appeared to have a clear advantage." However, general experience appeared to confirm the superiority of intermittent mist and brought about a switch from continous application.

Intermittent mist was first controlled by time clocks but more sophisticated alternatives soon appeared. The first "artificial leaf" controller was constructed at Cornell University at the instigation of H. Templeton, a Tennessee nurseryman (19). This incorporated the now well-known principle of using twin electrodes, separated by insulating material; when wetted a small current flowed between them, when dry the circuit was broken and a relay opened a solenoid valve, restarting mist application. Thus the sensor simulated a real leaf and operated to maintain a film of water over the cuttings. Numerous variations in construction and even in terminology for this sensor have been described (14,20).

A variety of solar control mechanisms have been devised. In these, a light integration mechanism induces misting at a predetermined accumulation of solar radiation by the light sensor. Another controller commonly used is the "sensitive balance" system, first introduced in Britain by H.J. Welch in 1957 and with counterparts in other countries (20). When the mist film evaporates from a screen mounted on one arm of a small balance, the balance tips and so actuates the solenoid. Other controllers were devised (14) though few have survived until today.

In comparing different control systems, attention must be paid to their effectiveness, and their adjustment and maintenance requirements. Ideally, the sensor should match evaporation from the cuttings and integrate all the factors which control this, viz. temperature, humidity and ventilation. With a timer the onus is on the operator to adjust the settings in accordance with the weather, whilst the leaf and balance systems automatically cope with environmental changes. Solar controllers rely on natural correlations between the pertinent factors, e.g. in high light conditions temperatures are high, humidities low and the glasshouse vents open, all of which increase evaporation. Ranking controllers in terms of their theoretical effectiveness, the artificial leaf and balance outperform the solar controller and timer but for trouble-free operation the order is reversed. Each system has its adherents, depending on the individual's relative valuation of efficiency and ease of maintenance.

Physiological Principles. The success of mist propagation relies on its ability to maintain cuttings turgid until roots form. Water loss from a cutting is determined mainly by the vapor pressure gradient between leaf and air. Losses can therefore be reduced by keeping the leaf cool to minimize leaf vapor pressure and/or by ensuring a high ambient vapor pressure in the air. Snyder and Hess (17) clearly differentiated between propagation techniques involving humidification, designed primarily to maintain a high air vapor pressure, and mist, where the main aim is to cool the leaves.

The principles behind mist as outlined by Hess and Snyder

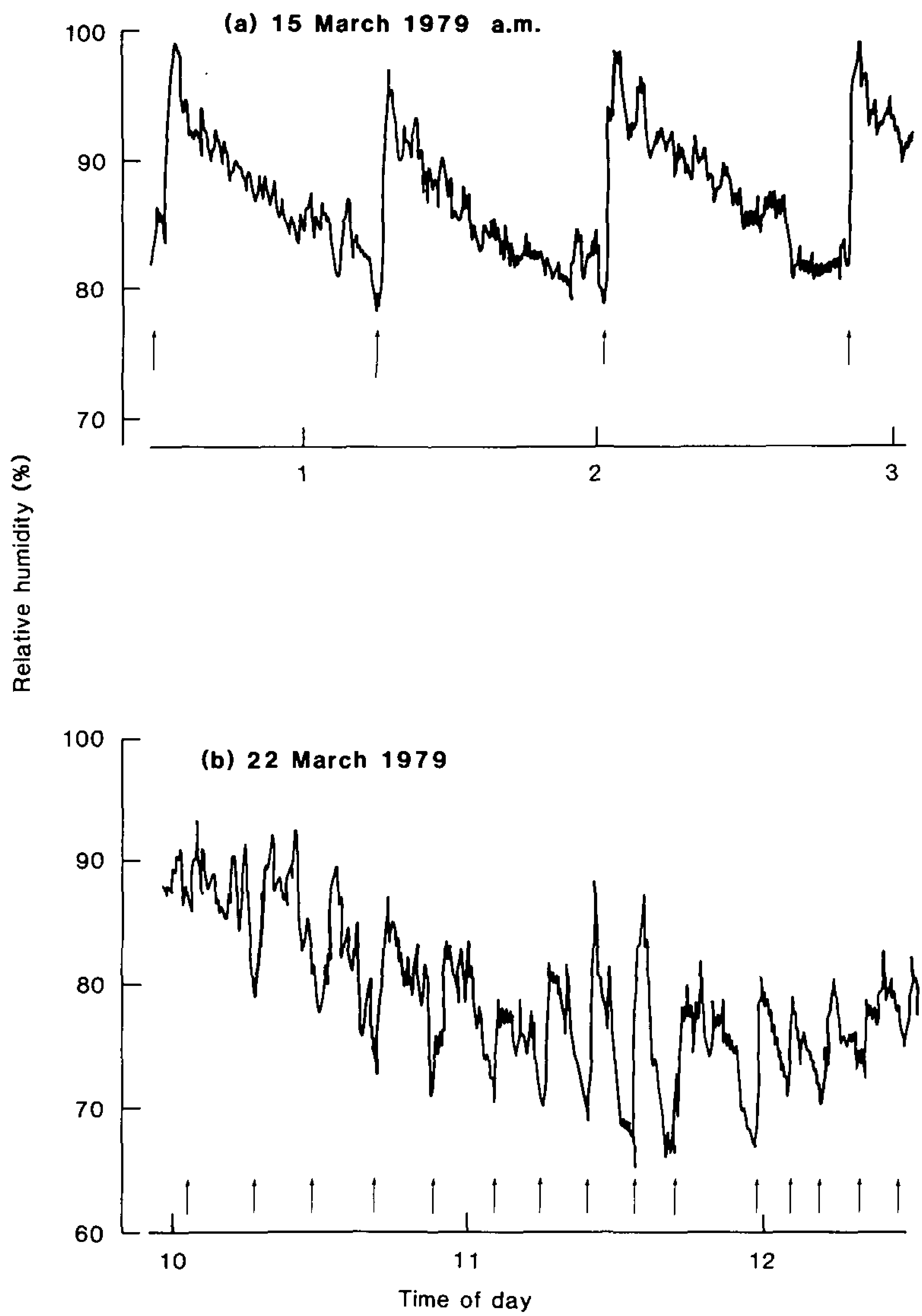

Figure 1. Relative humidity measured on a misted bench using an aspirated thermocouple psychrometer with a fast response time, (a) at night and (b) during the daytime. Arrows indicate mist bursts.

(8) are:

1. Evaporation from the water film covering the leaves cools the leaves and so restricts water vapor loss.
2. Because water losses are small, cuttings can be rooted at high light intensities and this facilitates the photosynthetic accumulation of carbohydrates required for root growth.

Side benefits accrue from controlling the water loss, e.g. more juvenile cuttings, with inherently greater water loss but greater rooting ability can be used.

These principles, based on relatively little data, bear reexamination in the light of subsequent studies. Recent measurements of ambient humidities on a mist bench (Grange and Loach, unpublished) illustrate a problem inherent with mist; between bursts the humidity falls toward ambient glasshouse levels (Figure 1a and 1b) and, if the water film covering the foliar surfaces is less than complete, then water loss must occur from the cuttings. The water cover is inevitably imperfect because falling mist cannot fully reach the leaf undersurfaces where most stomata occur and the cuticle is often thinnest. Increasing the ambient humidity by raising the misting frequency is self-defeating, in the sense that evaporative cooling of the leaves is then reduced and leaf vapor pressure is increased.

Simultaneous measurements of leaf temperatures on misted and non-misted benches showed the effectiveness of mist in cooling the leaves (Figure 2). Leaf temperature of the misted cuttings averaged 7.2°C lower than for non-misted cuttings (Table 1). Air temperatures were also appreciably lower under mist, presumably because the falling droplets cool the air through evaporation. It is clear that, in addition to direct evaporative cooling of the leaves, advective cooling through movement of cooled air over the cuttings on the open bench must make a significant contribution in moderating the leaf temperatures. (Advection is a term describing the transfer of air and air characteristics by horizontal motion.)

Misted cuttings were only 0.3°C cooler than the adjacent air but dry leaves were 2.1°C above adjacent air temperature. The

Table 1. Average temperatures during the day on misted and non-misted benches.[1]

	Mist	No Mist	Difference
Leaf temperature	21.7°C	28.9°C	7.2°C
Air temperature	22.0	26.8	4.8
Leaf/air temp. difference	−0.3	+2.1	+2.4

[1] Measured by 10 differential leaf/air thermocouples and a single aspirated air temperature sensor per bench (1 m^2)

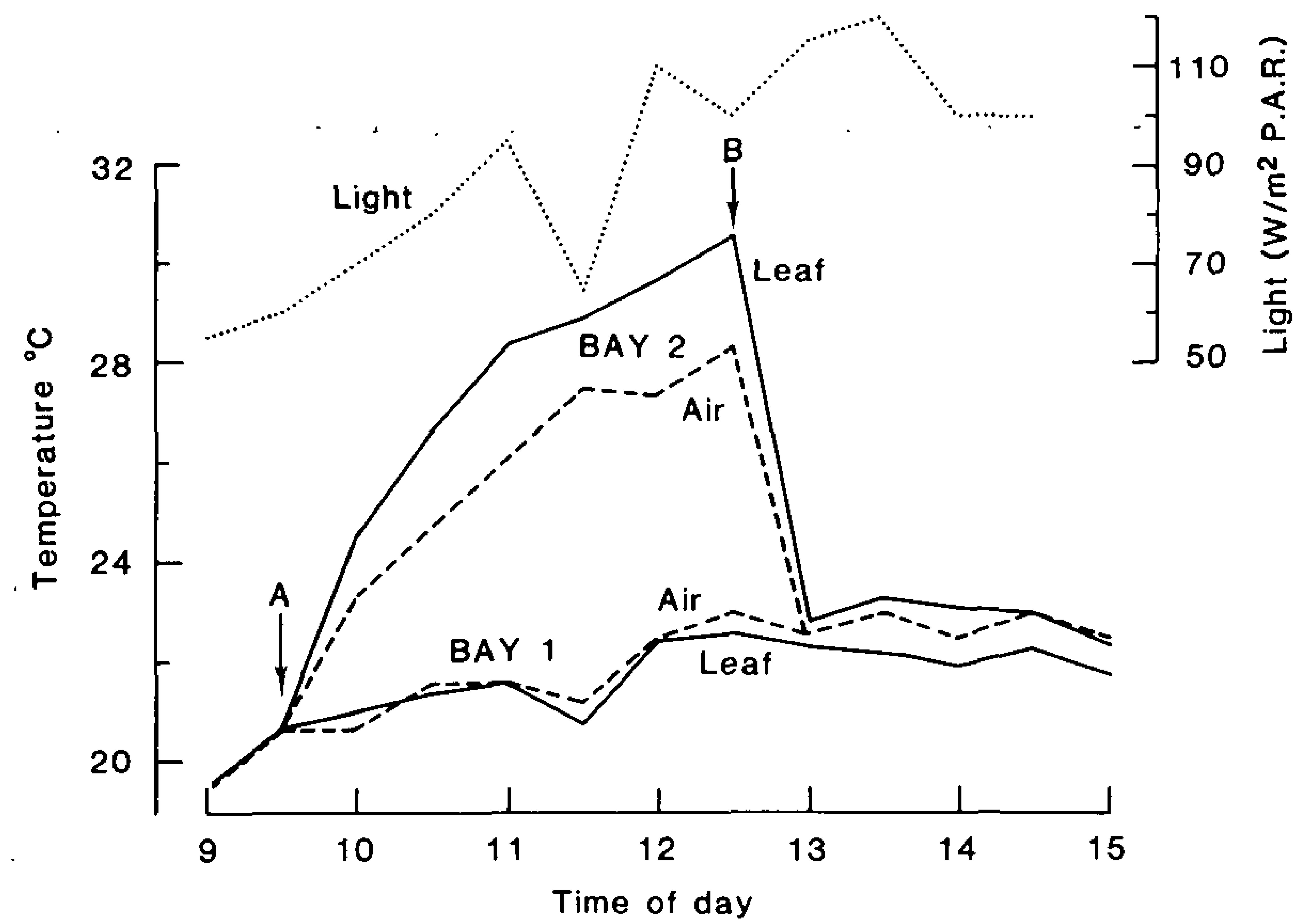

Figure 2. Leaf and air temperatures on misted (Bay 1) and non-misted (Bay 2) propagation benches. The mist on Bay 2 was switched off at time A and on again at B.

consequences in terms of leaf-air vapour pressure gradients are noted in Table 2. Dry cuttings faced three times the leaf-air vapor pressure gradient compared with mist cuttings and would thus lose water three times as fast (assuming leaf resistances to water loss were identical in both cases). Moreover, the water loss from dry cuttings comes from within the leaf, whereas that from misted cuttings is mainly from the externally-deposited water film.

Table 2. Leaf-air vapor pressure gradients during the day for cuttings on misted and non-misted benches.[1]

	Mist	No Mist
Leaf vapor pressure (kPa)	2.6	4.0
Air vapor pressure (kPa)	2.0	2.2
Gradient, leaf to air	0.6	1.8

[1] Assuming internal leaf air is saturated at leaf temperature.

It should be noted that in this experiment, the measurements were made on adjacent bays separated by a polythene divider and shielded above and on the south side to reduce direct sunlight and ensure an even mist spray pattern. Air movement over the bench was, therefore, considerably restricted and in a more open bench situation, the advective cooling would be greater relative to the direct evaporative cooling of the leaves.

In summary, vapor pressure gradients from leaf to air are inevitable even with mist, but the externally-deposited water film constitutes much of the water loss. The importance of advective cooling via mist-cooled air appears to have been overlooked in comparison to direct evaporative cooling of the leaves.

Turning to the second principle; our knowledge of the relationship between light, carbohydrates and rooting has been shown to be inadequate in recent years. While positive relationships between light levels and rooting have been demonstrated (4,9), a number of cases where high light was found to be detrimental to rooting have also been reported (see reviews 1,6,7). Many of the latter examples refer to somewhat artificial circumstances but there is evidence that in routine propagation, high light may be harmful to rooting. For example, when cuttings of *Hebe rakaiensis* were rooted under mist or under polythene sheeting (lightly shaded) in February, the misted cuttings accumulated more dry weight over five weeks but rooted less well, probably because they had a lower water content than those under polythene (Figure 3) — Loach and Whalley, unpublished.

Cuttings under high light usually have a lower water content than those under lower light levels and this frequently confounds interpretation of experiments designed to show the effects of light *per se* on rooting. For this reason we experimented in controlled environmental chambers, where precise temperature control should minimize light-induced leaf temperature (and hence leaf vapor pressure) differences. Propagation of cuttings of *Weigela florida* 'Variegata' and *Forsythia* × *intermedia* 'Lynwood' at 20, 40, 60 and 80 W m^{-2} photosynthetical active radiation (PAR) indicated that an irradiation of about 30 W m^{-2} was optimal for rooting (11). Rooting was negatively related to the sugar content of the cuttings but unfortunately, cuttings at lower light levels again had a higher moisture content (Figures 4a and b), thus preventing interpretation solely in terms of light.

Subsequently, measurements under shaded mist benches showed that leaf temperatures were not greatly influenced by the degree of shading. Presumably the cooling capacity generated by evaporation and advection copes adequately with different radiation loads. Under mist then, light effects can perhaps be examined independently of cutting water status. To test this, we propagated *Viburnum* × *bodnantense* 'Dawn' and *Hibiscus syriacus* 'Blue Bird' under mist at four different levels of shade, and used psychrometric techniques to measure cutting turgor (Grange and Loach, unpublished). Results are shown in

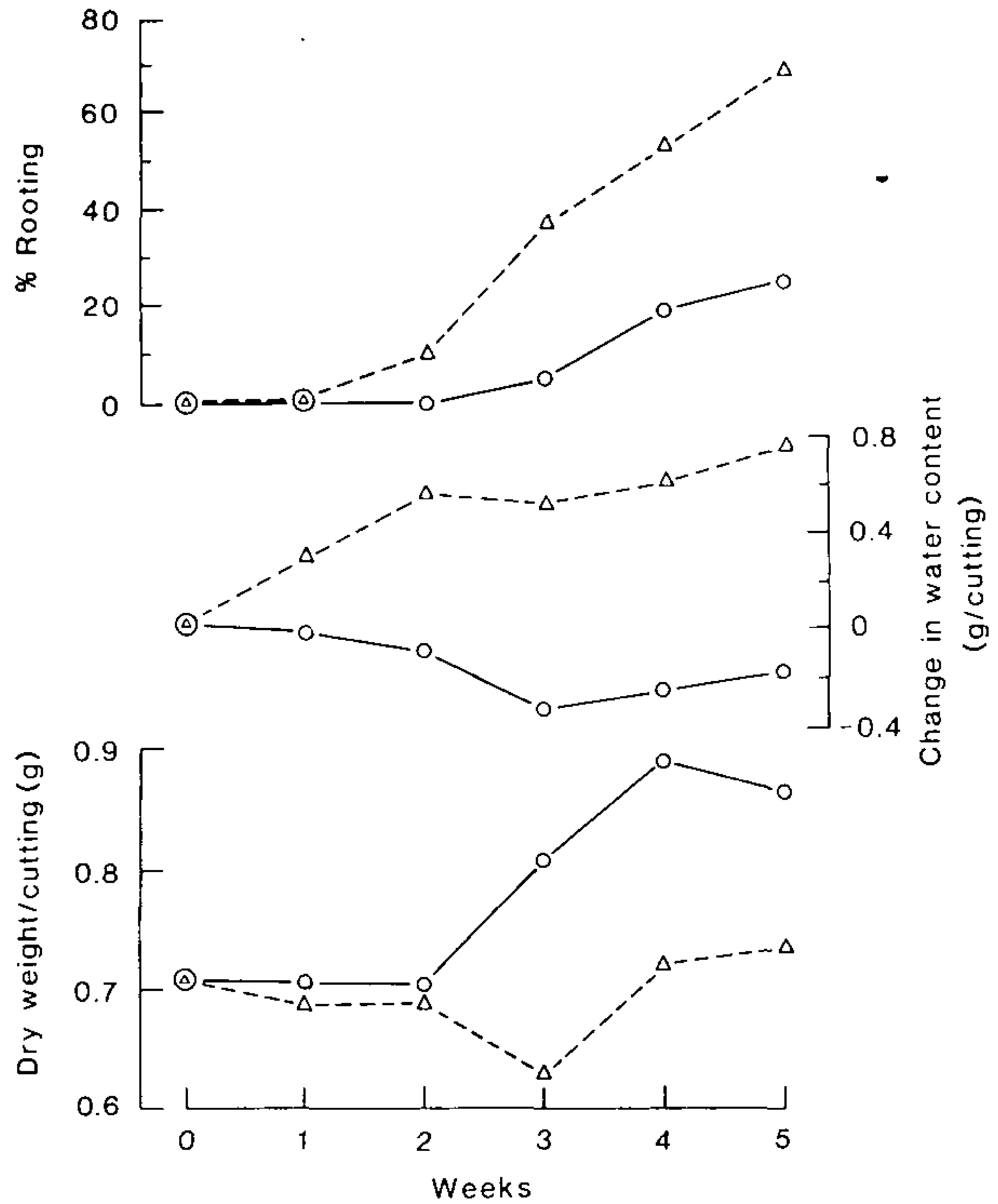

Figure 3. Changes in water content and dry weight during rooting of cuttings of *Hebe rakaiensis* under mist (O—O) and polythene (Δ---Δ).

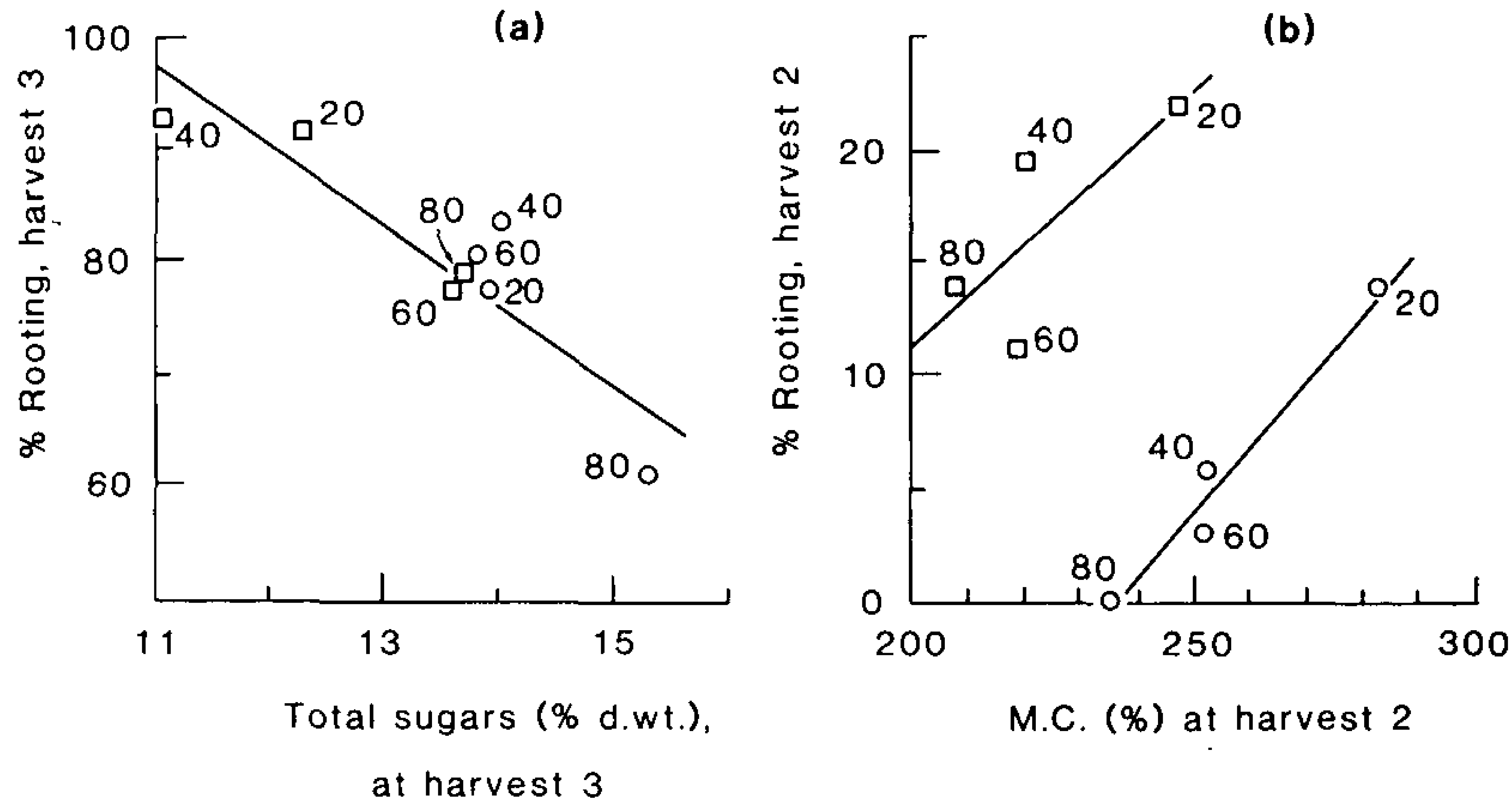

Figure 4. Relationship between percentage rooting after 3 weeks and sugar content (a), and percentage rooting after 2 weeks and moisture content (b) for cuttings of *Weigela florida* 'Variegata' (O) and *Forsythia* × *intermedia* 'Lynwood' (□) propagated at irradiances of 20, 40, 60 and 80 W m^{-2} PAR.

Figures 5 and 6. In general rooting decreased with increasing light but in *Hibiscus*, rooting was less good at the very lowest light level. This corresponds to the "minimum" light requirement observed for a range of hardy ornamentals by Loach and Whalley (12), i.e. 1.5 MJ m^{-2} day^{-1} of total shortwave radiation or 0.7 MJ m^{-2} day^{-1} PAR.

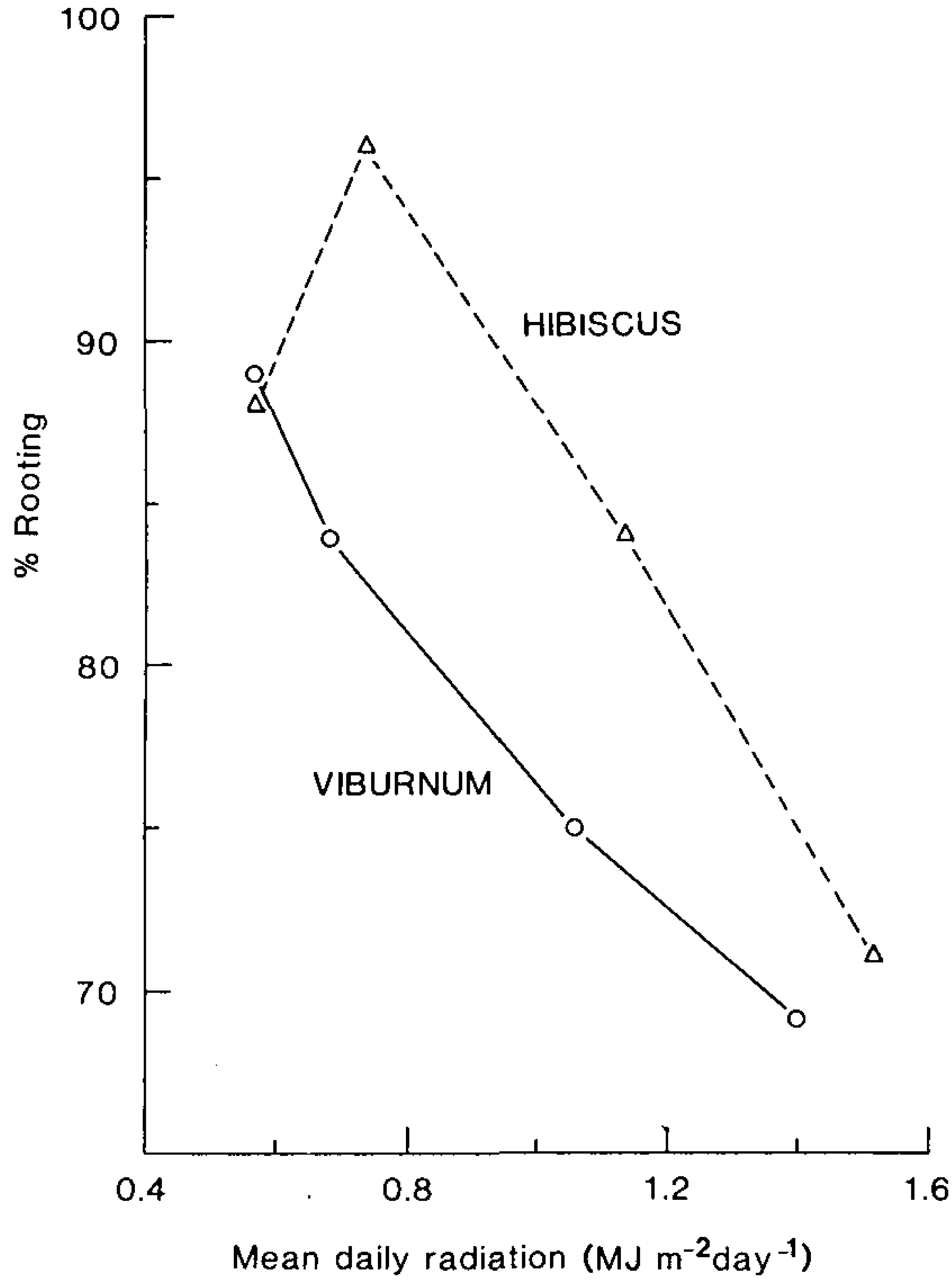

Figure 5. Percentage rooting of *Viburnum* × *bodnantense* 'Dawn' and *Hibiscus syriacus* 'Blue Bird' under mist shaded to give four different radiation regimes.

The osmotic potential of the leaf tissue was measured psychrometrically and as expected, decreased with increasing light, probably because more sugars are produced by photosynthesis at high light (cf. Figure 4a). In *Viburnum*, leaf turgor (estimated as the difference between the measured leaf water potentials and osmotic potentials) was similar in all light treatments, indicating that differences in leaf water status could not have accounted for the poorer rooting at high light. In *Hibiscus*, the leaves curled inwards in the high light treatment and were less effective at intercepting the mist, so that leaf turgor was reduced in this particular treatment (Figure 6). In the other three treatments turgor decreased at low light and again, could not have determined the order of rooting. A direct negative influence of high light on rooting is indicated.

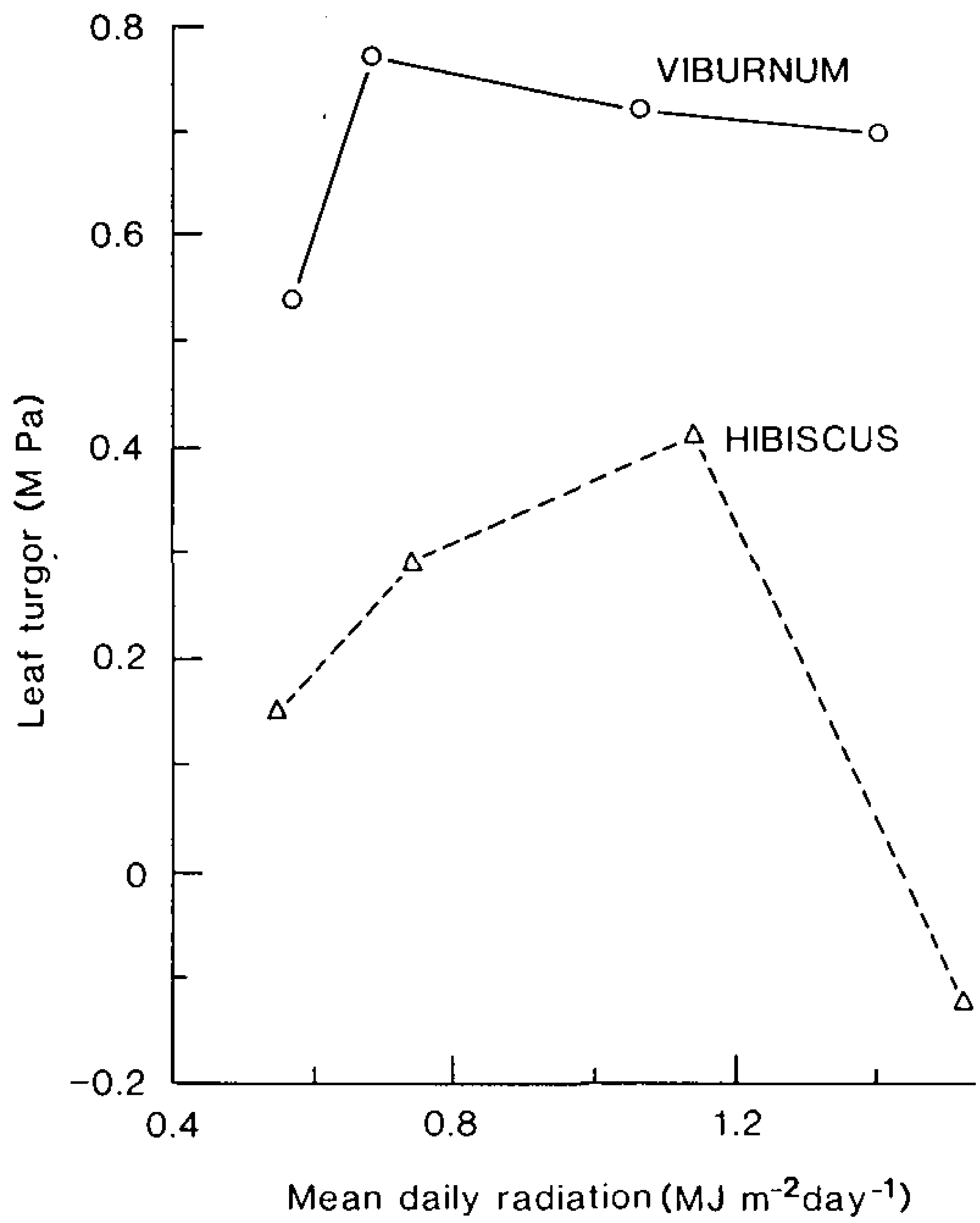

Figure 6. Leaf turgor in relation to radiation for cuttings of *Viburnum* × *bodnantense* 'Dawn' and *Hibiscus syriacus* 'Blue Bird' under mist.

Thus both cabinet and shaded mist experiments support doubts that high light and rapid accumulation of carbohydrates promote rooting in the way suggested by earlier studies. Further experiments to be reported elsewhere have shown that relationship between light and rooting is complex, but the conventional wisdom that mist is successful because it permits maximum photosynthesis, remains suspect.

Future developments. There are four conceivable ways in which mist propagation might be further improved:

1) by improving the distribution of the mist spray,
2) through better leaf cooling to reduce further the internal vapor pressure,
3) by increasing ambient vapor pressure (humidity) to offset the fall that occurs between mist bursts and,
4) through use of "hybrid" systems (see below).

It has already been noted that to minimize water losses (inevitable even under mist) an even spray coverage of all cutting surfaces is desirable. The relative efficiencies of different misting nozzles have recently been compared (18) but new designs promise further improvements over conventional types. In one of these, the water is broken into very small droplets by an ultrasonic resonator energized by compressed air. Use of compressed air makes the spray very directional, so that an array of these nozzles aimed tangentially into the canopy of cuttings should give better coverage than the conventional downwards-drifting spray. Trial layouts are needed to assess their value.

Conventional mist cools the leaves effectively through evaporation and advection and it is difficult to visualize any simple improvements in this direction. Shading, as we have seen, has little effect and increasing the ambient humidity reduces evaporative cooling and is counterproductive in this sense. However, in dull weather when mist bursts are infrequent and the effects of any imperfections in mist coverage are particularly evident, then humidification may be helpful.

Dutch workers in 1957 (14) trialled a hybrid system combining humidification on dull days with mist at other times (i.e. the humidifier was run more continuously on warm days to ensure that the cutting surfaces were wetted). A plastic-lined glasshouse was used to maintain high humidities but on warm days, air and compost temperatures were excessive. This is an inevitable problem with a sealed, humidified chamber. Ideally a means of sealing the house tightly for humidification, yet allowing occasional ventilation on warm days is required. Continuous ventilation would give uneven distribution of the "mist" from the humidifier. Difficulties were also encountered in devising a suitable controller for the humidifier; presumably this would be less difficult nowadays with the advent of microprocessors. A modified system incorporating ventilation and a superior controller would merit re-examination. Results in 1957 were comparable with conventional mist.

More recently, Milbocker and Wilson (13) have described a humidification system incorporating ventilation. Air is drawn through a ventilated enclosure and humidified at its point of entry. Evaporation of the fine water droplets dispensed by the humidifier, cools the inlet air, so moderating temperatures within the enclosure. In this way, temperatures were maintained below 38°C (100°F) in the enclosure (in Virginia) except on extremely hot, humid days. Provision of sufficient humidification on hot, drier days may present problems. Moreover, even in relative humidities approaching 100%, if leaf temperatures exceed air temperatures, then net loss of water will occur from the leaves. As already noted, where water loss is inevitable then wetted leaf surfaces are advantageous.

Simple outdoor frames, covered with polythene and incorporating timer-controlled mist nozzles, were used at Wageningen in the 1950s. Better results were obtained than in conventional glasshouses or with frame propagation but in cool summers it was not always possible to maintain a sufficiently high temperature. Conversely, in the hottest weather, extreme temperatures were again inevitable in these unventilated structures.

Another simple modification of conventional mist that has given improved results in the few test comparisons we have made, is the "mist plus mesh" method (10). Polythene or muslin mesh is placed over the cuttings and holds water droplets to increase the ambient humidity beneath. Some leaves are nevertheless wetted and a degree of advective cooling occurs through the open mesh. Further trials are necessary to test its effectiveness and to determine the best mesh size and material.

To test these various modified and hybrid systems against each other would require extensive experimentation. The first approach should be to make appropriate physical measurements (leaf temperatures and ambient humidities) on a small scale, to determine their relative efficiencies in minimizing leaf-air vapor pressure gradients, in a range of external conditions. Extensive trialling of the best systems should follow.

The polythene alternative. With simplicity in mind, we have tested propagation under polythene sheeting as an alternative to mist. The advantages in terms of capital cost are obvious but the disadvantages of propagating in a sealed enclosure in bright weather have already been noted. Can shading alone provide adequate protection in U.K. conditions? Nurserymen need guidelines to ensure that an appropriate level of shade is used.

Results of experiments to determine the minimum light requirement for propagation in a range of conditions (12) indicated that rooting is not severely curtailed until the daily radiation level falls below about 0.7 MJ m^{-2} PAR. From this and other experiments we devised shading regimes calculated to give an appropriate level of light for each month of the year. Some provision for diurnal light variation is made (insofar as shades are changed twice daily) and for weather variations (with a choice between "dull" and "bright" shade levels as judged appropriate). Experiments covering the period June to August 1979, the most testing time of the year, have given encouraging results (Table 3). In the three species where less than 95% of the cuttings rooted, polythene gave significantly better results than mist. In these cases root quality, as judged from the number of roots per rooted cutting was also superior under polythene. More extensive testing is needed but the possibility is attractive for satisfactory, year-round propagation under polythene, using a simple, prescribed shading regime.

Table 3. Rooting of cuttings under lightly shaded mist and under shaded polythene[1] in summer.

Species and date	Days in bench	Percent rooting		Root number/ rooted cutting	
		Mist	Poly	Mist	Poly
June/July					
Weigela florida 'Variegata'	19	100	100	41	21
Forsythia × *intermedia* 'Lynwood	20	96	100	16	12
Philadelphus 'Burfordensis'	26	59	95	14	25
Potentilla 'Red Ace'	14	100	100	23	26
July/August					
Callicarpa bodinieri	21	97	95	26	24
Hydrangea 'Altona'	17	95	98	2.6	3.6*
Corylus maxima 'Purpurea'	27	10	25	1.5	3.6*
Cornus alba 'Sibirica'	28	47	73	2.8	3.1*

[1] Polythene was shaded according to the calculated shading regime noted in the text.
* Root numbers scored on a 0 to 5 basis; others are actual counts.

LITERATURE CITED

1. Blazich, F.A. and C.W. Heuser. 1979. The mung bean rooting bioassay: a re-examination. *J. Amer. Soc. Hort. Sci.* 104: 117-120.
2. Cox, J.E.K. 1974. Annotated bibliography on mist propagation of cuttings. *Comm. Bur. Hort. and Plant. Crops, Tech. Commun.* No. 33.
3. Evans, H. 1951. Investigations on the propagation of cacao. *Trop. Agric.* 28: 147-203.
4. Fischer, P. and J. Hansen. 1977. Rooting of chrysanthemum cuttings. Influence of irradiance during stock plant growth and of decapitation and disbudding of cuttings. *Scientia Hortic.* 7: 171-178.
5. Floor, J. 1955. Moisture as a factor in the rooting of cuttings. *Rep. 14th Inter. Hort. Cong.*, 1955. Scheveningen. pp. 1140-1148.
6. Hansen, J. and E.N. Eriksen. 1974. Root formation of pea cuttings in relation to the irradiance of the stock plants. *Physiol. Plant.* 32: 170-173.
7. Hansen, J., L. Stromquist and A. Ericsson. 1978. Influence of the irradiance on carbohydrate content and rooting of cuttings of pine seedlings (*Pinus sylvestris* L.). *Plant Physiol.* 61: 975-979.
8. Hess, C.E. and W.E. Snyder. 1955. A physiological comparison of the use of mist with other propagation procedures used in rooting cuttings. *Rep. 14th Inter. Hort. Cong.*, 1955. Scheveningen. pp. 1133-1139.
9. Howard, B.H. and J.T. Sykes. 1966. Regeneration of the hop plant (*Humulus lupulus* L.) from softwood cuttings. II. Modification of the carbohydrate resources within the cutting. *J. Hort. Sci.* 41: 155-163.
10. Loach, K. 1977. Leaf winter potential and the rooting of cuttings under mist and polythene. *Physiol. Plant.* 40: 191-197.
11. Loach, K. and A.P. Gay. 1979. The light requirement for propagating hardy ornamental species from leafy cuttings. *Scientia Hortic.* 10: 217-230.
12. Loach, K. and D.N. Whalley. 1978. Water and carbohydrate relationships during the rooting of cuttings. Acta Hortic. 79:161-168.
13. Milbocker, D.C. and R. Wilson. 1979. Temperature control during high humidity propagation. *J. Amer. Soc. Hort. Sci.* 104: 123-126.

14. Rowe-Dutton, P. 1959. Mist propagation of cuttings. *Comm. Bur. Hort. and Plant. Crops, Digest No. 2.*

15. Sharpe, R.H. 1956. Observations on rooting softwood cuttings of peach. *Proc. Amer. Soc. Hort. Sci.* 67: 102-106.

16. Snyder, W.E. 1965. A history of mist propagation. *Proc. Inter. Plant Prop. Soc.* 15: 63-67.

17. Snyder, W.E. and C.E. Hess. 1955. An evaluation of the mist technique for the rooting of cuttings as used experimentally and commercially in America. *Rep. 14th Inter. Hort. Cong.*, 1955. Scheveningen. pp. 1125-1132.

18. Stoltz, L.P., J.N. Walker and G.A. Duncan. 1977. Mist nozzles. *Proc. Inter. Plant Prop. Soc.* 27: 449-454.

19. Templeton, H. 1965. Mist systems and their controls. *Proc. Inter. Plant Prop. Soc.* 15: 67-71.

20. Welch, H.J. 1973. Mist propagation and automatic watering. Faber and Faber, London.

PLANNING PROPAGATION FACILITIES FOR THE 1980S

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Ivan Dickings, Propagation Manager for Notcutts and myself, have had a once in a lifetime opportunity of planning and constructing a new propagation and liner facility which will take Notcutts into the 80s.

While the time scale for the operation could be simplified into one year planning, one year construction, one year debugging, the decision, in principle, to build a new propagation facility had been made a few years earlier — in fact, at least 28 years ago, according to the oldest member of the propagation staff. In preparation for the new unit, Ivan has been building up a team of staff capable of exploiting the new facilities for the past four years. We had also reappraised the propagation systems we were using including rooting media, direct rooting systems, types of liner pots, etc.

Objectives in planning a new propagation and liner unit:

1. Provide near optimum growing environment facilities for the wide range of plants propagated and techniques used. Maximize use of space in this controlled environment.

2. Plan for economical labor utilization, with an integrated materials handling system, including:

a) maximize use of skilled labor on skilled jobs.
b) keep heavy, dirty and monotonous jobs to a minimum.